Radioactive Waste Management

Solutions for a Sustainable Future

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RADIOACTIVE WASTE MANAGEMENT

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PROCEEDINGS SERIES

RADIOACTIVE WASTE MANAGEMENT

SOLUTIONS FOR A SUSTAINABLE FUTURE

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THE EUROPEAN COMMISSION AND THE
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FOREWORD

Radioactive waste is a by product of nuclear technologies used in medicine, industry, agriculture, research and power generation. Nuclear technologies play a vital role in diagnosing and treating various diseases, identifying and assessing material properties, measuring pollution levels, providing safe and effective means of disinfecting and sterilizing tools and equipment, diagnosing technical issues in industrial equipment, confirming weld integrities or enhancing crop yields and resilience. Nuclear power accounts for 10% of the world's low carbon electricity supply.

Users of nuclear technologies acknowledge the importance of managing the radioactive waste generated by these applications. Based on decades of experience and research and development, Member States are able to implement solutions for this important aspect of nuclear technologies effectively and safely. Furthermore, they strive for continuous optimization of the processes and activities involved, as exemplified in this conference. Sharing this progress and exchanging ideas on lessons learned are essential activities that enable operators, regulators, and governments to further strengthen their plans and programmes.

The radioactive waste management community acknowledges and embraces this responsibility and continues to make good progress. As science and technologies evolve, further optimizations in radioactive waste management can be foreseen in the near term and medium term. Continuing this trend is important to society and is supportive of the Sustainable Development Goals.

The International Conference on Radioactive Waste Management: Solutions for a Sustainable Future served as a platform to demonstrate and share the progress made in this field. Participants exchanged lessons learned and how they have been incorporated into waste management strategies at a fundamental programmatic level.

It was clear from the presentations and discussions that techniques for the safe management of the various types of waste arising from different applications are well established, and extensive experience has been obtained in most areas. Nevertheless, radioactive waste remains an important item on the agenda of many Member States and specifically those with the need to increase their capabilities and capacities to manage waste safely and securely. For this reason, and because of existing misperceptions concerning radioactive waste and its management, conference participants noted the importance of early engagement with all stakeholders to increase understanding and address concerns.

The participants also shared valuable examples of best practices in establishing effective national programmatic frameworks for waste management and in demonstrating how these continue to be successfully implemented. Concurrently, they highlighted the importance of keeping abreast of the latest scientific innovations, in continually questioning ideas, concepts and assumptions and integrating designs into realistic safety evaluations.

As highlighted at the conference, Member States are adapting and introducing successful strategies and approaches to further minimize or avoid waste production. For example, integrated waste management incorporates considerations and requirements into nuclear programmes from inception. These approaches employ circular economic strategies to reduce radioactive waste generation to a minimum by avoidance, reuse, and recycling, wherever possible.

Importantly, the conference recognized work in the field of radioactive waste management does not stop at national borders and can be most successful when conducted in partnership and through international cooperation and collaboration. Only in this way can radioactive waste management solutions fully contribute to a sustainable future.

This publication provides a summary of the conference sessions, including the full text of papers from the oral sessions and both the opening and closing speeches delivered during the conference. The papers associated with the poster presented at the conference are also included as supplementary files available on-line.

The IAEA is grateful to its cooperating partners, the Nuclear Energy Agency of the Organisation for Economic Co-Operation and Development, the World Nuclear Association and the European Commission. The IAEA would also like to express its appreciation to the members of the International Scientific Programme Committee and to the Secretariat of the Conference for their commitment, professionalism and engagement. The IAEA officers responsible for this publication were G.H. Nieder Westermann and F.N. Dragolici of the Division of Nuclear Fuel Cycle and Waste Technology, and D. Bennett and A. Guskov of the Division of Radiation, Transport and Waste Safety.

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The application of nuclear technologies in cancer therapy, generating low-carbon electricity, improving crop yields and many other applications is dependent upon the responsible and sustainable management of the wastes arising. These technologies are used to greater or lesser extent by all countries, hence the safe and responsible management of radioactive waste is something that affects us all.

Users of nuclear technologies acknowledge this responsibility and produce detailed plans and programmes setting out how the safe management of wastes will be achieved. Many Member States are now implementing these plans: some at an advanced stage and some just setting out on the journey. Sharing this progress, exchanging ideas on lessons learned and identifying key areas of progress for the future are essential components which enable operators, regulators, and governments to further strengthen these plans and programmes.

In earlier times radioactive waste management programmes tended to follow the linear pattern of take, make, use, dispose; however, times are changing. Operators and developers are increasingly adopting the principles of the circular economy into their programmes, jettisoning the linear model in favour of a more sophisticated and sustainable approach. This new thinking is epitomized by the 'waste hierarchy' where disposal is only considered after other options such as avoid, minimize, recycle, and reuse have been investigated. This not only promotes the circular economy and sustainability but also enables an integrated approach across different projects and programmes.

It is in this context that the IAEA organized the International Conference on Radioactive Waste Management: Solutions for a Sustainable Future, held in Vienna from 1 to 5 November 2021. Aspects of sustainability were showcased by presentations from 56 speakers and 169 e-posters, at this conference which was successfully held bringing together both in-person and virtual attendees. Special attention was given to young professionals in recognition that sustainability is also an important factor for the continuity of the workforce and its capability. The main objective of this Conference was to bring together practitioners, regulators, and decision makers in the field of waste management to facilitate the sharing of experiences and best-practice approaches and solutions.

The broad scope of the Conference covered all aspects of waste management ranging from planning through to implementation and operation, from Member States with advanced and mature nuclear programmes through to those with little nuclear infrastructure, and from those with significant inventories of Spent Fuel and HLW through to those with a small inventory of disused sealed radioactive sources (DSRS).

It is often said that the problem of radioactive waste is the issue preventing the wide-scale adoption of nuclear energy. The Director General of the IAEA, Mr Rafael Grossi, addressed this issue at the CoP26 where he highlighted the progress being made in radioactive waste management and the fact that there are now demonstrated to be implementable, safe, and sustainable solutions. The IAEA has a key role to play as the conduit for international collaboration and sharing, which can deliver these solutions together with the learning to allow the solutions to be tailored for individual circumstances.

One of the solutions referred to by Mr Grossi is the deep geological repository ONKALO being developed by Posiva Oy for disposal of the spent fuel that has powered Finland's nuclear power plants for more than 40 years. It is noted that in Finland spent fuel has been declared as waste by government policy. This disposal facility is at an advanced stage of construction and the first spent fuel is planned to be disposed of in 2025, demonstrating at last that nuclear power and allied technologies have a workable waste management solution.

Developing a disposal facility is a lengthy and complex business with many strands to be coordinated including research, siting, geological investigations, safety studies, and construction. Importantly it requires the consent of a supportive community, and this is now becoming widely accepted within the waste management community. Communication and engagement with stakeholders and partners, is now recognized as a prerequisite to successful radioactive waste management.

Although Finland is the most advanced country in progressing its spent fuel disposal programme, several other Member States are following in their footsteps, and many other Member States have implemented or are implementing, other aspects of waste management successfully. The waste management community has a long history of international collaboration and sharing of experiences so that there is now a wide catalogue of technologies and approaches that can be used and adapted to suit national and local circumstances. International organizations such as IAEA, WNA, OECD NEA and EC, also contribute through provision of international standards, guidance, and best practices, which serves to build stakeholder confidence in waste management programmes and organizations.

Building confidence and societal and political acceptance is increasingly recognized within the waste management community as being just as important as the science and engineering used to deliver the safe solution. A waste management organization may be very happy with their safety case, but this will count for nothing if they do not involve stakeholders in decisions that could affect them and cannot progress or build the facility.

The safety case is the key vehicle setting out the safety arguments as to why the operator believes that a practice or operation can be undertaken safely. In the case of radioactive waste disposal, the safety case presents the operator's understanding of the behaviour of the waste and performance and evolution of the disposal system into the long term.

This is not a one-off activity. The safety case will be developed and updated in line with the key design, construction and operational phases and is assessed and approved by regulators as part of the process for authorizing the disposal programme to progress to the next stage. Periodic safety reviews are necessary (usually every 10 years or so) where the safety case is reviewed and updated to take account of operational experience and learning, new data coming from site characterization or research or to take account of changing legislation or requirements. This is also an opportunity to revisit the supporting research programme to incorporate any new knowledge and developments. A successful safety case will demonstrate that the operator understands the disposal system and its evolution and provides confidence to regulators, workers and stakeholders.

Historically, the safety case was a technical document written almost exclusively for a regulatory audience but given that its purpose is to promote understanding and confidence, it's recognized now that the audience for the safety case is much wider and will include all the stakeholders in the project, including politicians, decision makers, and the local and wider community. Successful waste management programmes then are those that build confidence, work in partnership with stakeholders and engender trust. The Conference discussed this topic at length noting that societal and political acceptance can often be a deciding factor in the success or otherwise of waste management plans and that waste management organizations are increasingly drawing upon expertise from the social and political science fields.

The previous IAEA Conference on Radioactive Waste Management was held in 2016 and it is interesting to revisit the discussions and to see how the deliberations on stakeholder engagement and involvement have progressed and matured over the intervening period. Interestingly,in 2016 the topic of sustainability was hardly mentioned at all. In the intervening five years, concern about climate change and the need to move towards net-zero carbon technologies has led the IAEA and others to highlight the role which nuclear technologies play in a sustainable future. A consequence of this of course is the greater emphasis now placed on sustainability and the appearance of circular economy principles as drivers within radioactive waste projects and programmes.

Application of the waste hierarchy can lead waste management organizations to innovative solutions, finding value in material that hitherto was 'waste' and reducing the demand for valuable disposal space. Allied to this approach is the concept of integrated waste management, which has been successfully adopted by several Member States. Not only does it incorporate the principles of the waste hierarchy, but also encourages the operator to take a holistic view on all parts of the waste life cycle, looking for opportunities to maximize the use of existing facilities and resources, and hence to extract maximum value for money while still protecting people and the environment. Success in applying this concept involves a deep understanding and knowledge of the wastes and an ability to identify and address the central issues, not just the symptoms, as more traditional bottom-up approaches have done.

The IAEA has a key role in facilitating collaboration, including stakeholder interactions. Sharing knowledge, experiences and lessons learned, providing peer reviews, benchmarking and development of standards and guides are core IAEA functions. One of the speakers, Mr Ewoud Verhoef of the Netherlands, summed it up thus "Alone you may go faster, together we go further". And that is important because the road to develop sustainable radioactive waste solutions often is long. It is better and easier not to walk it alone.

MAIN CONCLUSIONS

1. Safe solutions exist and are available today for managing all types of radioactive waste including disposal, which remains the internationally recognized sustainable endpoint for waste management. Progress with the spent fuel disposal facility in Finland and in other countries clearly demonstrates that effective waste disposal solutions are available.

2. Waste management is not a 'bolt-on' end-of-life activity. It is an integral part of the Justification and early planning of any project or programme before any waste is generated.

3. Sustainable radioactive waste management needs to embrace the principles of the circular economy as embodied by the waste hierarchy — avoid, minimize, recycle, reuse — with disposal as the last resort option.

4. It is necessary to strive for open, transparent dialogue with all stakeholders, addressing societal, cultural, political, safety, security, environmental and economic factors. It is also necessary to recognize that approaches that have been already successfully implemented elsewhere will need to be adapted and tailored to suit national and local circumstances.

5. Innovation is a necessary component part of the scientific and engineering process underpinning radioactive waste management and needs to be embraced if nuclear technologies are to be used in a truly sustainable way in a net-zero world.

6. The safety case is the key vehicle for demonstrating understanding and evaluating safety, and for recording and discussing safety arguments with the often wide range of stakeholders: it needs to be open, transparent, and accessible to all. The intent is to promote understanding and build confidence. The safety case will be developed in an iterative fashion throughout the lifetime of the facility and used as necessary to direct design, operations, and research.

7. The successful waste management organizations are those that have a good safety culture and take time to question and apply the principles of continuous improvement: why do it this way? Is there another way, a better way? What can be learnt from successes and failures?

8. The concept of integrated waste management encourages a holistic, big picture top-down view to be taken of the waste life cycle, looking for opportunities to maximize the use of existing facilities and resource, and hence to extract maximum value for money, while still protecting people and the environment.

9. International cooperation and collaboration facilitates the sharing of experiences and learning from others. Progress is achieved together with well tested, understood, and viable solutions. Working together, following common standards and approaches, builds confidence in methods and outcomes.

10. Radioactive waste management has an intergenerational aspect: knowledge management and succession planning are key requirements. The aim is to protect people and the environment, not just today but also into the future.

2. OPENING SESSION

2.1. INTERNATIONAL ATOMIC ENERGY AGENCY DIRECTOR GENERAL OPENING STATEMENT

(As prepared for delivery)

Rafael Mariano Grossi
Director General of the International Atomic Energy Agency

I am pleased to open the International Conference on Radioactive Waste Management Solutions for a Sustainable Future. As you begin your discussions in Vienna, I am in Glasgow at the United Nations Climate Change Conference, so called COP26. My mission is simple, to remind leaders that nuclear energy has to be a part of the solution to our climate crisis. I am confident that nuclear energy can address the world's most pressing challenges, in part, because the industry has addressed one of its most pressing challenges. When it comes to nuclear waste, we have found solutions for a sustainable future, just like the title of this Conference says.

Not only are these solutions being implemented today, but the nuclear industry has successfully managed waste processing and disposal for more than half a century. Careful design and operation of nuclear power plants minimizes the amount of waste arising. Innovative technologies improve processing and recycling. Today dozens of facilities for low level and intermediate level radioactive waste are in operation throughout the world.

As far as high level radioactive waste from nuclear power plants is concerned, significant progress has been made in Sweden, France and several other countries. They are developing deep geological repositories for safe and effective disposal. And in Finland this kind of solution has already been built. Almost a year ago I travelled to the country's West coast and saw for myself what will soon become the world's first deep geological repository to start operations. What I said then remains true now. Onkalo as it's called, is a game changer for the long term sustainability of nuclear energy. It is an example of the ground breaking developments happening in waste management and a promising precursor to other innovative future solutions. Existing and future solutions for managing all classes of waste underpin the use of nuclear energy and all its applications whether for producing electricity, treating cancer, detecting covid, cutting plastic pollution or boosting crops

Ladies and Gentlemen, even as we forge ahead with solutions, we have to stay vigilant in dealing with legacy waste. This is an area in which the IAEA works closely and tirelessly with its Member States. Society places its confidence in the global expertise of the people attending this Conference, you. I am confident that you will continue to push forward in addressing our present and future responsibilities. For it is only when nuclear waste is managed successfully can nuclear science and technology contribute to a sustainable future for everyone.

2.2. DIVISION OF NUCLEAR FUEL CYCLE AND WASTE TECHNOLOGY DIRECTOR OPENING REMARKS

(As prepared for delivery)

Christophe Xerri
Director Division of Nuclear Fuel Cycle and Waste Technology,
International Atomic Energy Agency

Good morning, good afternoon and good evening. And welcome to what is I think is the first full hybrid conference. We are happy to see many people in the room and happy to know many of you are connected to this conference.

I do not want to add too much to what has been said by the Director General of the IAEA but certainly waste management is something that is happening in all 172 member states of the Agency. Whether you have a huge nuclear power programme or whether you are only using nuclear technologies for cancer treatment or other applications, everyone has something to manage. And it is clearly part of the sustainable approach that is expected today insofar as anything going with higher benefits will generate wastes that have to be managed.

The second key phrase that we have as we open today is ‘circular economy’, and I also think that we may discuss as integrated waste management, where at the end it is possible to avoid having the waste altogether.

So, innovation is important, solutions exist and there is a wealth already of experience in many countries. So, whatever your current step on the policy development, technical implementation and safety and security, and whatever and wherever you are on this journey, we trust you to move on this journey.

And through this International Conference, through the Agency, through the network of professionals, you can also share, learn and convey your experiences, so that networking is also part of your future work.

So, thank you again for being here today and we’re looking forward to exciting and interesting discussions and sharing of experience.

And in any case the knowledge is with you and we’re happy to help you share the knowledge.

Thank you. Thank you very much.

2.3. DIVISION OF RADIATION, TRANSPORT AND WASTE SAFETY DIRECTOR OPENING REMARKS

(As prepared for delivery)

Peter Johnston
Director Division of Radiation, Transport and Waste Safety,
International Atomic Energy Agency

Ladies and Gentlemen, dear colleagues.

As Director of the Division of Radiation, Transport and Waste Safety of the IAEA, I'm very pleased to add my welcome to you all at this International Conference on Radioactive Waste Management Solutions for a Sustainable Future.

As the DG indicated in his opening remarks, nuclear power and nuclear technologies are an essential part of providing a sustainable, low carbon future and it is essential that these are implemented safely and supported by the safe management of radioactive waste.

Past experiences have shown us the vital importance of developing and fostering a good safety culture within all our organizations. It is essential that we consider and address safety at all stages of our work. The IAEA safety standards provide the international reference point for ensuring safety.

Work on radioactive waste management, your work, is vitally important to all our futures. Based on the agenda for this week's conference it's evident and wonderful to see so many people, particularly young professionals, active in this field.

International cooperation is highly important, as we all work together towards this common goal. Your attendance here, whether it's in person or virtually, and your participation in this international conference is a very encouraging sign for the future.

I would like to conclude therefor by thanking you for your participation and wishing you all an interesting and fruitful conference.

Thank you very much.

2.4. SUMMARY OF THE CONFERENCE CHAIR OPENING STATEMENT

Ms Karen Wheeler
CEO of Radioactive Waste Management, United Kingdom

Ms Karen Wheeler, CEO of Radioactive Waste Management, the UK's national waste management organization with responsibility for all higher activity radioactive wastes, welcomed delegates both those attending in person and those participating via the remote web-app. One of the positive outcomes of participating is the realization that there are others grappling with the same problems as you and the opportunity for sharing experiences and networking. The aim of the conference is to focus on lessons learned and practical experience: things she said that you can take away and use to demonstrate progress and take concrete action on in your own country.

Participants in the conference will also be aware of the important role of nuclear technologies in many areas, but we as an industry historically have not taken the role of radioactive waste management seriously enough. This is now changing. We know that we have to communicate the message that nuclear waste can be managed in a safe and sustainable manner. Mr Grossi has started this with his message to the CoP26 leaders and we now need to continue and communicate and engage with our own stakeholders.

She noted that many Member States are now building new facilities for low and intermediate waste, planning and constructing deep geological facilities for HLW and SF, whilst others are taking new steps to implement nuclear power. This week the ambition is to share information, build relationships and networks and promote communication between specialists and decision makers. Vaccine development is a good example of what international collaboration can achieve. It is necessary build on this new-found recognition of the importance of science and leverage this to promote the successes in the world of radioactive waste management.

In planning the format of the conference, the Programme Committee identified seven key themes that are important for radioactive waste management and solutions for a sustainable future. Papers and posters as well as a number of side events, will be aligned with these key themes.

Ms Wheeler gave a brief overview of the seven themes: national programmatic perspectives, implementation of waste management strategies, solutions for specific wastes, role of the safety case, socioeconomic aspects, integrated waste management, multinational cooperation. She noted that the Co-Chair Mr Naeem would shortly say more about the purpose and content of these.

Ms Wheeler noted that the Programme Committee had determined that the essential role of young professionals to the sustainability of the global nuclear industry needs to be recognized and promoted within the delivery of the Conference. To this end seven young professionals had been selected to present papers and seven will be acting as session co-chairs.

Radioactive waste, she concluded, remains a topic of concern and even a fear for the public. It is necessary to find and implement safe, effective, and sustainable solutions and to communicate the science to support this and the ability to do this safely and securely. An important part of is the conference was to emphasize the important role of engaging with stakeholders and communicating with communities.

2.5. SUMMARY OF THE CONFERENCE CO-CHAIR OPENING STATEMENT

Mr Muhammed Naeem
Chairman of the Pakistan Atomic Energy Commission, Pakistan

Mr Muhammed Naeem Chairman of the Pakistan Atomic Energy Commission welcomed attendees and web-participants and thanked the Programme Committee for giving him the opportunity to work with IAEA and act as co-chair of this important and valuable conference.

Mr Naeem noted that the application of nuclear technologies in cancer therapy, generating low-carbon electricity, improving crop yields and many other applications, hinges on the responsible management of wastes arising from these activities. Users of nuclear technologies acknowledge and embrace this responsibility and as this Conference will demonstrate, considerable progress is being made world-wide in the safe and effective management of radioactive waste. Effective solutions are either available or are in an advanced stage of development for the full range of different waste types and activities. Even more progress is foreseen in the near- and medium term futures.

Mr Naeem said we need to learn from the past and look with confidence to the future. Every problem has a solution, true not only in mathematics, but also in radioactive waste management. Mr Naeem highlighted sessions and side events devoted to solutions for specific waste streams, progress in management of disused sealed radioactive sources, safeguards, and the role of safety cases in radioactive waste management, where participants will hear about other's progress, experience, learning and best practice.

Mr Naeem then went on to address another key theme of the conference, noting that within the technical community, as well as within most waste management organizations, there is a growing awareness that public and political acceptance is crucial to the work we do. The conference recognizes this and consequently has dedicated a full session and side event on the topic of socioeconomic aspects of radioactive waste management programmes. Selected speakers will present experiences, including tools and methodologies, that have shown themselves to be effective in engaging with the public. These strategies will focus on communicating challenges including but not limited to: factual and objective information sharing, creating opportunities for dialogue, local culture, local or national heritage.

Lastly, Mr Naeem introduced the important role that multinational collaboration plays within the radioactive waste management community. Research, development, and demonstration have advanced our understanding of the waste system, which includes treatment and conditioning of waste, optimizing of engineered barriers, as well as characterization of natural barriers. Building on this work various formal and informal networks have been established within and between countries. Several international agencies and organizations have come together to facilitate work in these areas and various case studies will be explored in the session and associated side events.

Nr Naeem finally highlighted the initiatives included within the conference programme to assist and raise the profile of young professionals attending the event. Young professionals will be taking part in all aspects of the programme including presenting papers and co-chairing sessions: such opportunities will help support and develop the expertise that will in the future be taking forward sustainable radioactive waste management programmes.

In conclusion, Mr Naeem offered the important take away that learning about the experiences of other Member States and the solutions that they have found to be successful will help all improve radioactive waste management in their home programmes. An outcome which is of course in line with the mandate of the IAEA.

2.6. MULTILATERAL COLLABORATION IN RADIOACTIVE WASTE MANAGEMENT – PANEL SESSION

Moderator	Rebecca Robbins, Division of Nuclear Fuel Cycle and Waste Technology, IAEA
Panel	Vincenzo Rondinella, European Commission, Joint Research Centre (EC JRC)
	Rebecca Tadesse, Organisation for Economic Cooperation and Development/ Nuclear Energy Agency (OECD/NEA)
	Bilbao y León, World Nuclear Association (WNA)

Ms Robbins introduced the panel session, noting that whilst the conference is hosted by IAEA, in actuality its a collaborative effort involving several international partners, and this session is an opportunity to learn more about three organizations in particular: the European Commission JRC, OECD NEA and WNA and specifically their involvement in, and contribution to, radioactive waste management.

The Joint Research Centre (JRC) is the European Commission's science and knowledge service. Mr Rondinella said that the JRC role is to make information available to support policy makers within the EC. The JRC has its own laboratories and hence is in a position to undertake research and generate its own data and information through direct and indirect actions. Research is currently being undertaken on various waste management topics to support implementation of the Waste Directive in EU Member States.

The OECD/NEA is an intergovernmental agency that facilitates cooperation between among countries to seek excellence in nuclear safety, technology, science, environment, and law. In the area of radioactive waste management, Ms Tadesse described two standing committees – the Integration Group for the Safety Case (IGSC) and Working Party on Information, Data and Knowledge Management. In addition radioactive waste management issues are also addressed via the agency's Regulators' Forum and Forum on Stakeholder Confidence.

The World Nuclear Association (WNA) is an international body with 180 members from 44 countries representing the nuclear industry across the entire fuel cycle from ore extraction through fuel manufacture and power generation to decommissioning and waste management. Ms Bilbao y León said the Association's mission is to promote a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions and contributing to the energy debate.

Can you describe how radioactive waste management is covered within your organization?

Ms Bilbao y León: The WNA has established a number of working groups to allow sharing of best practice, conduct investigations and development of consolidated positions to feed into policy at national and international levels. One such working group is the Waste Management and Decommissioning Working Group (WMDWG).

Mr Rondinella: The EC via JRC is undertaking and coordinating research in a number of areas related to waste management using both direct action and indirect action programmes. Programmes specific to waste management include waste characterization, waste package long term evolution and performance under accident conditions.

Ms Tadesse: The OECD/NEA standing committees are supported by a number of subgroups which bring together experts from member organizations to address lessons learned, share best practice and produce state-of-the-art publications. On the safety case as an example, the IGSC is now using HLW safety case lessons to develop best practice guides for ILW and LLW safety cases. The NEA also has cross cutting groups and can investigate best practices in regulation, radiological protection, competences, and stakeholder interaction.

In what capacity do you collaborate? How do you ensure the interactions are complementary?

Ms Tadesse: The NEA holds a yearly coordination meeting with IAEA at which the planned work programme is presented and where potential areas of duplication can be identified and appropriate changes made. In addition, NEA and IAEA participate in each other's key meetings as observers. Similar coordination arrangements apply to work with EC and WNA, and great efforts are devoted to coordination so as to avoid duplication.

Ms Bilbao y León: The WMDWG actively participates with international partners such as UN, IAEA, NEA and EC. For instance, the working group participates as a member or observer in many of the international working groups and is able to bring industry knowledge and perspectives into policy development and discussions.

Mr Rondinella: EC and, in particular, Euratom interacts institutionally with the IAEA and NEA on policy matters such as standards and inventory and also on research matters. The JRC was established by the Euratom Treaty and coordination of research programmes is part of its constitution and coordination is carried out routinely to promote integration and avoid overlap. JRC is unique in so far as it is able to generate its own information from the laboratories and makes available results and findings to all its partners.

What future challenges do you envisage and how do you intend to address them? How do you envisage further collaborating with other international organizations?

Mr Rondinella: As we heard from DG Grossi, spent fuel disposal in a geological repository will be implemented shortly and this will bring focus onto the importance of transfer and retention of knowledge. Another important aspect is going to be our ability to demonstrate our confidence in the science base to non-expert stakeholders. To do this effectively we need to be planning to maintain expertise and skills within the research community and to work together with international partners to improve communication of scientific matters to our public and communities.

Ms Tadesse: Optimization of radioactive waste management is a key issue that we need to address and. as new technologies arise, we need to ensure we continue to address this from the initial design through to eventual closure of facilities. Another key issue concerns stakeholders. Rather than thinking of them as a group to be informed of our decisions, we need to think of them as being part of our decision making processes. This way of thinking needs to become firmly established and needs further work to develop the strategies and methodologies for implementation. A third issue that we are facing is an ageing workforce. We are working with international partners to think more about competence management, training and skills so that we can bring on the younger generation.

Ms Bilbao y León: We agree with the above and are collaborating with our international partners. Also on our radar is making sure that when we adopt new technologies such as SMRs or advanced reactors, we do so in an integrated fashion and address the whole life cycle, not just the reactor but the support infrastructure such as fuel manufacture, waste management and fuel disposal. Some stakeholders have used waste as a reason not to progress with nuclear energy: perhaps by withholding consent, or closing reactors, or excluding nuclear energy from the sustainable finance frameworks. The nuclear industry has a good story to tell and we need to change the paradigm. Nuclear is the only energy source where waste management is already factored into the unit cost of electricity. We are working to improve communication and engagement, not only with the public but also decision makers, politicians and economists. In this we are adopting best practices from social science and looking to expand our interactions with stakeholders and engage with those outside of our traditional network.

Ms Robbins thanked the panel for their contributions making an interesting and informative session. Three themes; communication, knowledge management and capacity building, were common to the responses from all three organizations and these are topics that would be discussed again during the rest of the week.

2.7. INTEGRATED WASTE STREAM MANAGEMENT IN A SMALL INVENTORY COUNTRY

Wolfgang Neckel
Team Lead for Documentation, Instrumentation and Radiation Protection,
Nuclear Engineering Seibersdorf GmbH, Austria

Austria is typical of many small waste inventory nations; it has no nuclear power plants, a single research reactor and small routine waste arisings from industrial, research and medical nuclear applications. Mr Neckel of Austria's waste management organization, Nuclear Engineering Seibersdorf (NES), described arrangements for radioactive waste management.

The NES was established in 2003 and is responsible for all aspects of radioactive waste management in Austria including the decommissioning of the Seibersdorf research reactor. Austria's Radiation Protection Act is based on the 'polluter pays principle' and NES is contracted and licensed to operate the centralized waste management facilities, services which are funded by the various waste producers. The NES services include collection of wastes, sorting, characterization and conditioning prior to interim storage. The Seibersdorf site has modern waste management facilities and in addition to the processing of current waste arisings is also undertaking a programme of characterization and re-conditioning of older waste drums dating from the 1980s. Through this process NES is able to sort and characterize the contents using the latest technology enabling suitable items to be recycled or free-released with the remainder being conditioned and packaged for continued interim storage.

Mr Neckel advised that the Austrian government intends to develop a final repository for these wastes, but the form of disposal has not yet been decided. An expert group has been convened to advise on the options to be considered. Waste life cycle information and data are collected, recorded and held by NES on the national waste management database thereby facilitating waste package records to be assessed against Waste Acceptance Criteria for storage and ultimately for disposal.

Mr. Neckel's paper – ID290 Reconditioning of historic radioactive waste in Austria - Experiences with and status of the project – is provided next.

Paper ID#290

RECONDITIONING OF HISTORIC RADIOACTIVE WASTE IN AUSTRIA

Experiences with and status of the project

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Abstract

To comply with regulations and to ensure state of the art treatment of historical conditioned radioactive waste in Austria, as well as to guarantee safe interim storage until 2045, historic conditioned radioactive waste is being reconditioned in an ongoing project. Drums with waste forms of all three main conditioning types (drums with super-compacted pellets, homogenously cemented and in-homogenously cemented drums) found in Austria have already been reconditioned. Experiences from the reconditioning of all three types of drums and information regarding the status of the project is being shared. Steps of special importance proved to be the pre-sorting of the different waste types derived from existing documentation, the use of a specialized modular machinery for the dismantling of the drums layer by layer to limit cross-contamination, and the characterization of the waste performed in tandem and afterwards. As a last step, documentation of the original drum is consolidated with the information from the reconditioning processes and from radiological and chemical assays.

1. INTRODUCTION

At Nuclear Engineering Seibersdorf GmbH (NES) all radioactive waste produced in Austria is, on behalf of the Republic of Austria, collected, safely treated and temporarily stored until its final disposal.

The agreement with the Republic of Austria has been expanded until 2045, leading to investments in new buildings and technical equipment to ensure the stability of the waste until final disposal. Main projects to achieve this goal have included the construction of a New Treatment Center (NHZ) for radioactive waste, the construction of new interim storage halls (“Transfer Storage”) and the reconditioning of the old waste drums. Of these three projects the first two have been completed while the reconditioning project is ongoing.

The project has been implemented in three phases, corresponding to the three main types of drums to recondition:

(a) The first phase concerned 200-Liter drums with super-compacted pellets.
(b) The second phase concerns homogenously cemented sludges, salts and ashes.
(c) The third phase concerns 100-Liter drums with raw radioactive waste that has been formerly cemented into 200-Liter drums. We call this type in-homogenously cemented.

Lastly, there are also special waste packages which need to be reconditioned on a case-by-case basis.

Repackaging has to be done in all cases not only because of the new storage concept (see below) but also to guarantee the integrity of the drums till 2045 as internal and external corrosion was observed on some drums with historic waste. External corrosion because the — at its time state of the art — old interim storage warehouses were not climate controlled and internal as the — then state of the art — conditioning processes didn’t involve drying the waste drums.

In all cases the drums first had to be extracted from the old storage warehouses (where they have been densely packed) and then sorted. Figure 1 shows one of the two old interim storage facilities with the different types of drums at the start of the project. For ease of visualization the cylindrical drums have been depicted as cubes. Figure 2 left also shows the tightly stacked drums in the old interim storage facility. For the new interim storage warehouses the drums are horizontally stored in racks in such a way that inspections of each drum are possible (see Fig. 2 right) [1]. The new storage concept was also one of the many reasons why the reconditioning project was implemented. In preparation of the physical sorting process of the drums, depending on their waste form, historic information as well as information from the in-house waste management database (Dokurad) is being used.

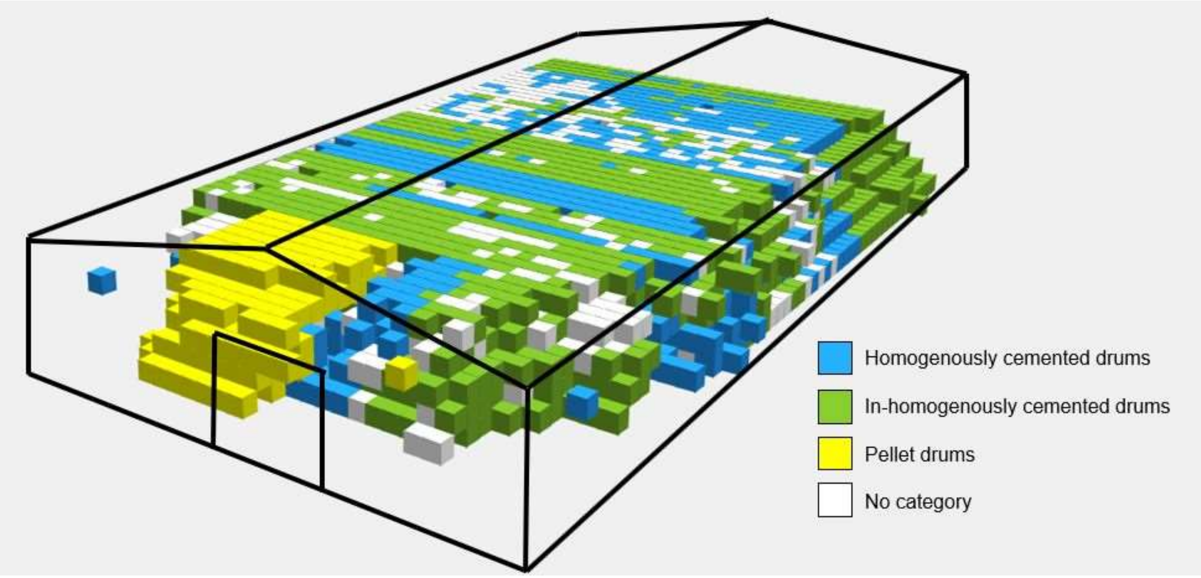

FIG. 1. Original storage configuration in LH12 by conditioning type.

FIG. 2. Left: old storage concept of tightly stacked drums [1]; Right: new storage concept.

2. PHASE 1 – REPACKAGING OF PELLET DRUMS

Since the 1990s a Fakir type super-compactor was available on site. Waste from before that time was conditioned using the other types of waste forms mentioned. Compacted pellets were packaged in 200-litre drums and — in some cases — filled with silica sand. For this type of waste only repackaging was necessary. The repackaging was done in a sorting box with personnel in force-ventilated suits (Fig. 3).

FIG. 3. Repackaging of pellet pellets in the "sorting box" at NES.

After repackaging into new 200-litre drums, (which have a glass fibre strengthened polyester liner to protect the coating as well as to halt oxidation processes between the contents of the drum and the drum itself), the repackaged drums were dried in a drum drying facility and then measured on a gamma scanner [2]. Before the drums were stored in storage racks in the new interim storage halls, the documentation was assembled (both in physical and digital form) and checked upholding the four-eyes principle.

In case of drums filled with silica-sand the sand was extracted during repackaging. Interestingly, most of the sand used could be cleared showing that the integrity of the encapsulation in the pellets is quite good.

About 1500 drums have been treated this way and this phase of the project is finished. The experiences during the project were all positive. The only waste minimization possible was the clearance of most of the silica sand used for filling in void spaces between the pellets and the original drums. Also, the original — now empty — drums were sent to an external recycling plant for melting. In some cases of pellets with filter material or PVC a long term spring-back effect was observed so that two new drums were created with pellets from this type. In a handful of cases, following the checking of the documentation, pellets had to be opened manually in the sorting box to extract combustible material.

3. PHASE 2 – HOMOGENOUSLY CEMENTED DRUMS

Homogenously cemented sludges, ashes and salts are being repackaged during phase 2 of the reconditioning project. The cemented waste had previously been covered by a layer of inactive cement. This phase is ongoing and the repackaging has required much more effort compared to phase 1. Two caissons (sorting/manipulation boxes made of stainless steel) in the aforementioned NHZ are being used for the repackaging and reconditioning of drums in phase 2 and phase 3.

First the old drum casing has to be removed, in a second step the inactive concrete segment on the top of the active concrete matrix (cylinder) needs also to be removed before the diameter of the cemented waste can be reduced (to fit the slightly smaller diameter of the new 200-litre drums). Only then can the repackaging take place. For these processes specialized machinery, that has been installed into one of the Caissons, was developed using a modular approach, dry techniques and remote semi-automatic operation [3]. Using this "drum-dismantling facility" (FZA = Fasszerlegeanlage), first the sheet metal drum mantle is cut into different segments (one for the top and the bottom, and three for the mantle). These then can be easily manually removed by the Caisson team in force-ventilated suits (see Fig. 4 left). In a second step, the inactive concrete segment is manually separated from the homogenously cemented waste block. This works quite well, because formerly the block of cemented waste had time to set before the inactive lid was cemented on. In a third step the FZA is further used to mill off about two centimetres of the diameter of the drum (see Fig. 4 middle). A cyclotron precipitator is the used and from there a sample is automatically gathered. This sample is then used for radiological and chemical characterization of the waste. The resulting cemented matrix (Fig. 4 right, for an example) is then repackaged into new 200-litre drums, which are then also sent to a gamma assay system.

FIG. 4. Left: dismantling of a drum after cutting in the FZA; middle: milling; right: homogenously cemented waste matrix after milling.

It was found that most of the original drum parts could be cleared. Those metal parts that couldn't get clearance are sent to an external metal recycling facility. The returned slag is conditioned just like other non-combustible radioactive waste. Also, most inactive-concrete top fillings could get cleared for conventional disposal. The same goes for some of the milling dust. Due to this, some reduction of the waste volume is being achieved. NES, together with the regulators, is further working on a way to possibly release some of the remaining waste matrixes for which, due to the 20+ years of interim storage, the activity of the radiological content has decayed enough.. This would greatly reduce the volume of waste that needs to go to a future final repository. So far over 1000 drums have been reconditioned this way.

The dismantling is being well documented using a QR-code based material-flow system in concert with the beforementioned waste management database Dokurad [4].

4. PHASE 3 – IN-HOMOGENOUSLY CEMENTED DRUMS

Austria has a special type of in-homogenously cemented waste drums: 100-litre drums with raw radioactive waste were historically cemented into 200-litre drums. Most of this type of waste is from the time before a high-force-compactor for super-compaction was available and before recycling of metal was an option and, in some cases, also before our incinerator facility was in operation. For this type of waste, a high percentage of volume reduction of the waste is possible using state-of-the art facilities including our super-compactor and incineration facility.

In a first step the same dismantling facility (FZA) is being used as for phase 2 type waste matrixes. The drums are being dismantled by cutting the sheet metal drum mantle. In this case also the concrete lining of the cemented 100-litre drums is being cut without damaging the drum itself (Fig. 5). In this way the drum – once transferred to the second Caisson – can be more easily manually dismantled (Fig. 6).

FIG. 5. Dismantling of a in-homogenous waste drum with the cutting tool of the FZA

FIG. 6. Removal of the pre-cut concrete liner to gain access to the inner drum.

After the concrete liner is cut away (see Fig. 5 right), the 100-litre drum is inspected. Sampling can be done in this step. Depending on the result of the inspection the raw radioactive waste is then either — alongside the 100-litre drum — inserted into cartridges for super-compaction (in case of non-combustible waste) or some raw waste is sorted out (in case there is combustible waste or metal, that could be sent to a recycling facility, inside), as shown in Fig. 7.

The samples are used for radiological and chemical characterization of the waste. The cartridges — before compaction — are also sent to the gamma scanner. After compaction the resulting pellets are sorted into new 200-litre drums (see Fig. 6) which are then being dried and afterwards prepared for interim storage.

FIG. 7. Inspection of the contents of the 100-litre drum (left), before put into cartridges for super-compaction (middle and right).

For this phase, documentation of the steps involved as well as of all the resulting parts of the original drum is also done using the same system mentioned in phase 2. Also, there are different types of raw waste in those 100-litre drums so that beforehand the drums are sorted regarding these types, using the information stored in the waste management database Dokurad, as well as additional physical documentation that is being digitalized into Dokurad. Examples of waste types are: waste from decommissioning projects; glass waste (mostly in-drum pressed see Fig. 8); metal and empty lead containers; mixed raw waste. Waste from different decommissioning projects is also pre-sorted by project. In addition to these types there will also be drums containing purely combustible waste.

FIG. 8. Example of raw waste found inside. glass waste (in some cases in-drum compacted).

In summary a subtle system is being used to carefully dismantle the drums one layer at a time, with cleaning steps after each layer. This is especially important for phase 3 type drums. This is done to forestall cross-contamination of the different layers, maximizing potentially clearable volumes.

As for the rest of the parts from the original drum, the sheet metal mantle has so been able to be cleared (even more so than the ones from phase 2). The rubble from the inactive concrete lining can, in most cases, be cleared for conventional disposal.

This phase is ongoing. So far over 400 drums of this phase have been dismantled. The process leads to a large minimization of the original waste volume. Starting with a about 800cm tall 200-litre drum and ending with a super-compacted pellet. On average so far about 60% of the volume was reduced. The worst case was the glass waste matrixes – already with a 100 t in-drum press compacted. With these only a 40% volume reduction could be achieved. Also, it was found that the in-drum press did damage the 100-litre drum.

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3. SUMMARY OF THE TECHNICAL SESSIONS

3.1. SESSION 1 – RADIOACTIVE WASTE MANAGEMENT – NATIONAL PROGRAMMATIC PERSPECTIVES

Radioactive waste management is an important issue for all Member States no matter how big or small. Whether it's host to a huge nuclear power programme or a small country only using radioactive materials for medical or industrial applications, there will be waste products to deal with and manage in a way that protects people and the environment. In this Session there are speakers from across this spectrum from States with advanced nuclear power programmes such as Canada and UK, through nations such as Türkiye just setting out to construct their first nuclear plant, to Norway with a small inventory from now closed research reactors and disused sealed radioactive sources (DSRS).

Of course, in a sense none of these programmes are being implemented in isolation. Implementers and operators will be following international standards and often best practices learnt as a result of international collaboration. Furthermore, they can ask the question, has a programme like mine been implemented or is one being implemented currently elsewhere? If so, what challenges were thrown up and how were they overcome? Are there implementable solutions available within the international community?

If the answer to the above questioning suggests that a solution already exists and has been implemented elsewhere, then this can be a big confidence booster, but the next question is to consider how the solution would need to be tailored to suit national and local circumstances and how it could be taken forward with stakeholders.

The speakers in this Session provided updates on current practices and perspectives in managing radioactive waste within the context of their national circumstances and described waste management strategies and policies, regulatory frameworks and challenges that have presented themselves. Two common themes emerged: the importance and benefits to be accrued from international collaboration and secondly, the benefits of step-by-step, or iterative development.

International collaboration, providing the opportunity for sharing of ideas, experiences and best practice is demonstrated in a number of presentations to be a major factor in improving and accelerating Member State's national programmes. However, the need to question and tailor solutions for local purposes was emphasized. Step-by-step or iterative development was mentioned several times, sometimes in connection with technical topics such as site characterization, safety case or design development and in connection with softer issues such as stakeholder engagement or communications. In each case, it's clear that working in an iterative way allows the developer to take account of feedback received, redirect or shape the direction of travel, and embrace continual improvement.

The Session also heard that radioactive waste management is not necessarily the problem that some think it is and that we can take confidence from the fact that long term solutions for all waste types are now being implemented. However, as the Keynote Speaker noted this doesn't mean that the industry can rest on its laurels as these are not 'one size fits all solutions' but ones that need to be tailored to take account of what might be different circumstances or societal expectations.

Social acceptance is now widely recognized as the remaining major challenge in radioactive waste management and successful waste management organizations are those that are taking it much more seriously than hitherto has been the case. Rather than viewing stakeholders and communities as the group to inform of our plans, the more enlightened approach is now considering them as partners that are involved throughout the process.

The Session included presentations from Member States at the early stages of implementing radioactive waste management structures and how they had collaborated with international partners who were willing to share lessons learned and best practices. The IAEA was mentioned several times in connection with helpful interventions, whether through peer-review or Technical Cooperation programmes.

The Session also heard from organizations that are further along this journey and have more mature and well-established organizational structures. Even here we heard about organizations taking stock and asking the question, are our structures allowing us to work in the most efficient way? Where are the bottlenecks, what aren't we doing so well, how can we improve communication, how can we better engage with our stakeholders? And examples were given of how this process of continual improvement is being implemented in practice.

Overall, three main conclusions can be drawn. Advanced waste management programmes have demonstrated that all types of radioactive waste can be managed through to disposal safely and in different geological settings. Social acceptance is recognized as the major challenge for implementing organizations and needs to be afforded appropriate priority. Radioactive waste management programmes at all levels of advancement, for small and large inventories and various waste forms, are achieving successful outcomes by using similar legal frameworks and applying international standards.

Session Chairs: S. Utkin (Russian Federation) and Z. Kamara (Sierra Leone)

Session 1 comprised seven papers from Canada, Argentina, Lithuania, Australia, Türkiye and the United Kingdom with an additional paper from one of the conference's Young Professionals Showcase Leads (Norway).

- **Paper ID#300 by L. Swami (Canada)** overviewed Canadian experience of finding a site to host a geological disposal facility for spent nuclear fuel and presented a number of learning points that will be applicable to similar programmes. First and most important, Canada followed a consent-based process engaging with communities that wanted to find out more about geological disposal. Investigating whether the community would have suitable geology for such an enterprise would follow but only after a relationship had been established between the two parties. Canada is also following an adaptive phased approach so that decisions are taken in a step-wise manner, with time to take stock and adapt future steps as necessary. Geological disposal is now recognized internationally as the solution for long term safe management of high level waste (HLW) and spent fuel but this is not a one-size-fits-all solution. Thankfully there are international standards and best practices and an international waste management community sharing ideas and providing mutual assistance.
- **Paper ID#297 by A. Bevilacqua (Argentina)** presented an overview of the status of radioactive waste management activities in Argentina, with particular focus on the Collaborative Strategic Plan 2021–23. This has been initiated to review the status of current activities, to define objectives for the management of spent fuel, disused sources and radioactive wastes, and to formulate an optimized plan with necessary actions to achieve the desired objectives. The paper describes the analysis of external and internal factors seen to affect the plan and the scoring technique used to identify the preferred approach.
- **Paper ID#92 by V. Jakimaviciute-Maseliene (Lithuania)** described plans for siting a geological disposal facility for spent nuclear fuel. At the present stage, the project is focussed on geological screening of potentially suitable host rock areas, of which there appear to be several suitable formations available. Selection of sites for detailed investigation is expected so that borehole characterization can commence in 2024. This is expected to be followed by construction of a URL and operation of a DGR about 2070.
- **Paper ID#151 by J. Shatwell (Australia)** described the steps being taken in Australia to improve radioactive waste management arrangements and facilities. There are currently no

centralized radioactive waste management facilities in Australia, nor an integrated strategy for treatment or packaging of low level waste (LLW) and intermediate level waste (ILW), and no disposal facilities. Organizational responsibilities have recently been redefined, with the creation of the Australian Radioactive Waste Agency which has been given the task to establish a National Radioactive Waste Management Facility for disposal of LLW and interim storage of ILW. A site in South Australia at Napandee is currently being considered and consulted on. Conceptual designs for a near surface facility and associated preliminary safety studies have been conducted.

- **Paper ID#294 by K. Sengul (Türkiye)** presented an overview of waste management plans in Türkiye. The country's first NPP is currently under construction and hence the National Radioactive Waste Management Plan has recently been updated to reflect the need to extend waste management facilities to accommodate the additional operational wastes and spent fuel arisings. Spent fuel is planned to be transferred to dry casks for storage after initial pool cooling. A new waste management organization (TENMAK) was established in 2020 and is charged with developing new near surface disposal facilities and ultimately disposal facilities for spent fuel.
- **Paper ID#310 by C. Parr (United Kingdom)** presented recent innovations in the UK to achieve the benefits of an integrated waste management approach. This has required significant organizational changes but will deliver, based on experience to date, enhanced waste management services, a stronger workforce, a more sustainable supply chain and better value for money for the taxpayer.
- **Paper ID#99 by H. Kristiansen (Norway)** presented a perspective from a small-inventory nation where a small inventory is defined as one not large enough to permit waste producers to generate sufficient funds to finance waste management through to final disposal. Norway has four reactors in decommissioning and hence has the full spectrum of wastes to manage, including some 17 te of spent fuel. Analysis of waste management costs has been undertaken for both mined and borehole type geological disposal. A mined facility will have significant fixed costs making it unattractive for a small inventory. A borehole solution on the other hand is more adaptable for small inventories and having lower fixed costs could be an attractive option, particularly if pursued as an international collaborative project.

Paper ID#300

TOWARD A NEW GLOBAL STANDARD: CANADA'S OUTLOOK FOR THE FUTURE OF RADIOACTIVE WASTE MANAGEMENT

Keynote Remarks
(As prepared for delivery)

L. SWAMI
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Abstract

Radioactive waste is a global challenge with a global solution. We all have to work together towards implementing our respective plans and ensuring that deep geological repositories go from being best practice, to accepted practice, to commonplace, around the world. Canada, like nations around the world, has benefitted from nuclear power generation for more than six decades. However, like all those countries, we now have to implement a safe, long term solution for used nuclear fuel. Implementing that solution is our job at the Nuclear Waste Management Organization (NWMO), a non-profit organization created in 2002 by the Canadian government. In 2007, the federal government selected Adaptive Phased Management as Canada's plan for used nuclear fuel. Canada's plan will see used nuclear fuel managed in a purpose-built deep geological repository – a series of naturally occurring and engineered barriers which, working in concert, can safely manage used nuclear fuel while protecting both people and the environment over the very long term. We are not alone in pursuing this option. We are both building upon and contributing to work underway in other countries as well as helping to lead the way for those who are following in our footsteps. Ongoing collaboration with international counterparts is essential for all of radioactive waste management organizations. Sharing information, conducting joint research, learning from shared experiences and lending supportive voices will ensure we can all reach our collective goals. Canada's Plan is approaching a critical juncture. The site selection process that the NWMO initiated in 2010 is drawing to a close. Initially, 22 communities stepped forward to learn more about this project and explore their potential to host it. By 2023, the NWMO plans to have selected a single, preferred site. Canada's Plan will only proceed with interested communities, First Nation and Métis communities, and surrounding municipalities, working together to implement it. The NWMO is proud of its progress to date and is monitoring other nations as they advance the implementation of their projects. In 2020, the NWMO also received a new responsibility: we were asked by the Minister of Natural Resources Canada to lead a separate and parallel engagement process with Canadians and Indigenous people to inform the development of a comprehensive integrated radioactive waste management strategy. This is part of the Government of Canada's Radioactive Waste Policy Review and leverages the NWMO's 20 years of recognized expertise in engaging Canadians and Indigenous people on plans for the safe long term management of used nuclear fuel.

The paper is presented verbatim as delivered by L. Swami as the keynote address for Session 1 – Radioactive Waste Management – National Programmatic Perspectives.

1. INTRODUCTION

All countries with inventories of spent fuel and radioactive waste require strong policies and effective management strategies that meet their particular requirements and are suited to their unique environmental and social realities.

Today, countries with mature nuclear programmes are at various stages of implementing a range of radioactive waste management solutions, from spent fuel disposal and handling of Design Safety Review Services, through to decommissioning and legacy waste management. At the same time, non-nuclear countries, and those with emerging industries, are following different pathways to reach viable and sustainable solutions for establishing waste management infrastructure and regulatory frameworks that are right-sized to a much different scale.

While there isn't a one-size-fits-all solution, there are most certainly best practices and innovative approaches that we can all learn from and adapt to our work and experience in our home countries.

This first session — on National Programmatic Perspectives — highlights the approaches being pursued by a diverse group of nations for implementing waste-dedicated strategies and projects, and building the public and stakeholder confidence required for success.

Radioactive waste management experts representing eight countries will share information, insights and perspectives related to their national radioactive waste management programmes.

We will hear an update on Australia's plans and progress in establishing a national waste management facility, and about Argentina's radioactive waste management strategy, which has evolved over decades of work.

We will learn about Lithuania's path in implementing a deep geological repository programme, and we will learn about Türkiye's planning process for a radioactive waste management system – at a crucial time when that country's first nuclear power facility will soon be in operation.

The United Kingdom will discuss an integrated waste management model that has been shaped by a deep understanding of needs and challenges.

I'm excited to say, our Young Professional award winner from Norway will close the session and discuss potential solutions for developing a nuclear waste management programme in a small-inventory state.

2. GENERAL CONTEXT

While today's session sets out to explore individual national programmes, we should never lose sight that every national effort is working towards the same common end.

And that is to build a future where the safe disposal of nuclear waste is no longer viewed as a problem in need of a solution, but instead as a proven model of responsible stewardship. Because, only in that future can the full potential of nuclear technologies be unlocked to meet the world's energy needs and protect our air, land, and water.

People the world over have benefited tremendously from nuclear power over our lifetimes, and we continue to rely on it to solve the challenges of today and tomorrow.

Last year alone, the world's nuclear plants supplied more than 2500 terra watt hours of electricity to power our lives. Beyond helping to meet energy needs, nuclear technology is also essential for life-saving modern medicine, with more than 40 million diagnostic and therapeutic procedures performed each year using nuclear isotopes.

But in the wake of these benefits, there are more than two million tonnes of used nuclear fuel worldwide, and millions more low and intermediate level radioactive waste – from contaminated soil and personal protective equipment to medical waste.

All of it requires safe and effective long term management solutions, which we need to move forward to realize – now, perhaps more than ever.

Today, governments in every corner of the planet are looking to nuclear energy as part of their climate change strategies and the transition to low-carbon economies.

The urgency of the climate crisis is real, and nuclear energy represents one of the most potent tools we have to fight it. If it were not for nuclear-generated electricity, some estimates suggest an additional 470 million tonnes of carbon dioxide emissions would be generated from fossil fuels every year. That's roughly the equivalent of adding 100 million passenger vehicles to our roadways.

3. CANADIAN OUTLOOK FOR THE FUTURE OF RADIOACTIVE WASTE MANAGEMENT

Recognizing this, the Government of Canada has stated in no uncertain terms that there is no path to meeting its 2050 target of net-zero carbon emissions without nuclear power. And, while global nuclear investment has remained consistent in recent years, between 33 and 39 billion dollars annually, some 30 countries are actively considering, planning, or initiating new nuclear power programmes.

Regardless of what the future holds, there is a mounting global imperative to implement solutions for the safe and effective long term management of the radioactive waste of today and tomorrow.

Fortunately, we have an accepted global solution, and no country is going it alone.

Today, after three decades of international cooperation, research and development, there is a resounding agreement that purpose-built deep geological repositories represent the best way to protect people and the environment over the very long term.

Last year, the OECD's Nuclear Energy Agency issued a report on the management and disposal of highlevel waste, which, among other things, observed that there is scientific consensus on the effectiveness of deep geological repositories, noting they are being designed to be intrinsically safe and permanent.

Canada is proud to be among a number of countries advancing similar repository projects and helping to set a new global standard.

While deep disposal is the globally accepted solution, all countries will necessarily have slightly different technical and implementation approaches depending on the nature of their used fuel, their geology, their legal and regulatory frameworks, and their social context.

To this point, it is worth highlighting that Canadians have a long and proud nuclear history. Canada is a Tier 1 nuclear nation, and a robust nuclear sector extending the full length of the fuel cycle, a proven safety record, and a comprehensive management approach for used fuel and all other waste streams.

Canada is a nuclear nation to be sure. Some 60 000 Canadians are directly or indirectly employed in the industry. We are the world's second largest producer of uranium. And our unique CANDU nuclear reactor technology is a point of national pride that regularly appears on lists of the country's top innovations and engineering achievements.

Furthermore, we have a robust and centralized legal and policy framework that facilitates the success of our nuclear power and radioactive waste management programmes.

In Canada, all matters that relate to nuclear activities and substances fall under the jurisdiction of the federal government, with the department of Natural Resources Canada responsible for determining the country's nuclear energy policies, including those related to radioactive waste. At the same time, the Canadian Nuclear Safety Commission is responsible for the regulatory oversight of the management of radioactive waste and is internationally recognized as a leading regulatory body.

The need for a permanent solution for our used nuclear fuel was studied and discussed in Canada for decades. In 1989, the government struck an independent environmental assessment commission — the Seaborn Panel — which worked over the next ten years, studying every facet of long term storage of nuclear fuel.

The outcomes of this work ultimately led to the Canadian Parliament passing the Nuclear Fuel Waste Act in 2002, which required the major owners and stewards of used nuclear fuel in Canada to establish the organization I have the privilege to lead – the Nuclear Waste Management Organization (NWMO).

When the NWMO was created that same year, we started by talking to Canadians and Indigenous peoples about how they wanted to see used fuel managed. A plan emerged with an implementation approach that is adaptive to change and ensures that the repository is built in an area that is safe and has informed and willing hosts.

And, in 2007, the Government of Canada selected this approach, known as Adaptive Phased Management, as Canada's plan for the long term management of used nuclear fuel.

Adaptive Phased Management is not just a technical approach, it is a principled commitment to Canadians and Indigenous peoples that we will work with them, and that Canada's plan will adapt as needed.

In fact, the NWMO has only worked in regions where a community voluntarily expressed interest in exploring their potential to host the project. We launched the site selection process in 2010 and 22 communities raised their hands. It was nothing short of extraordinary.

Today, after progressively more intensive social and technical studies, we're focused on two potential siting areas both in the central province of Ontario – South Bruce in Southern Ontario and the Ignace area in

Northwestern Ontario. We continue working in close cooperation with municipal and Indigenous communities toward our goal of selecting a site in 2023.

Which brings me to another distinguishing feature of Canada's approach – a deep commitment to reconciliation with indigenous peoples and interweaving indigenous knowledge into everything we do.

Indigenous inclusion is key. We work closely with First Nation and Métis communities and knowledge holders in both our engagement and technical work to ensure the project delivers meaningful benefits, incorporates their insights and their worldviews, and fully respects indigenous and treaty rights.

After a site is selected, Canada's plan will be implemented over many decades.

And because of the timelines involved, each step in the implementation process provides an opportunity to take stock and make any adjustments before proceeding. So, anticipating and adapting to new and emerging technologies are fundamental to the NWMO's approach.

For example, in Canada our storage containers are optimized specifically for CANDU reactor fuel, but we are also actively working with small modular reactor (SMR) developers to anticipate any changes in fuel types we may need to accommodate in the future.

Recognizing that SMRs may result in different types of used fuel, we encourage organizations developing these concepts to work with us early on, so we can build shared understanding and ensure the highest standards for safety and environmental protection are achieved.

At this early stage, much remains to be determined about how SMRs will take shape and their impact on the fuel cycle. However, I can tell you that no matter the source of the fuel that's used, safety will always be the NWMO's top priority, and any fuel waste will need to meet our safety criteria.

We have already had many productive discussions with industry players focused on SMR research and development, and we look forward to more collaboration in this rapidly developing segment of the industry.

As you can likely tell, at the NWMO, we're proud of the approach we are implementing on behalf of Canadians, and the benefits it stands to deliver for local communities, for Canada and for the world.

Based on our experience developing and implementing Canada's plan for used nuclear fuel, last year the federal Minister of Natural Resources asked the NWMO to lead development of an integrated strategy that addresses any remaining gaps in long term plans for other waste streams – and specifically some of Canada's low and intermediate level radioactive waste. While it is all safely managed today, some of it still requires plans for the very long term.

To this end, we've been engaged in an inclusive dialogue on the subject with waste producers and owners, government, indigenous peoples, civil society organizations, and interested Canadians. We are working towards developing a proposal that will take in to account all that public dialogue, along with international best practices, indigenous traditional knowledge and what is technically feasible in Canada.

I should also acknowledge that there a number of low level radioactive waste disposal projects underway in Canada that are being led by other organizations.

These projects include work by Canadian Nuclear Laboratories to advance development of a Near Surface Disposal Facility, in Chalk River, Ontario. The engineered containment mound will hold one million cubic metres of waste and feature 10 waste disposal cells.

Elsewhere, the federal government is undertaking an initiative responding to community-recommended solutions for cleanup and long term management of historic low level radioactive waste in Port Hope and Port Granby, Ontario.

In Port Hope, a long term waste management facility will be constructed to store approximately 1.2 million cubic metres of waste. The Port Granby project involves the relocation of approximately 450 000 cubic metres of waste and marginally contaminated soils to a new, engineered above-ground mound.

These projects could not move forward without the strong regulatory and legislative oversight of the Canadian government and our national regulator, the CNSC.

As we approach the 20th anniversary of the NWMO's establishment next year, we are looking forward to building on the strong momentum we've made to date and to achieving the next important milestones for implementing Canada's plan.

I don't have to tell you the daunting number of factors that are critical to bringing a project through development and into construction and operation. From established funding and government support – both of which we are fortunate to have in place – to community willingness, a strong safety case, and the technical expertise and capabilities to design and implement. Not to mention, licensing, permitting and the need to adapt to inevitable change along the way.

It is incredibly encouraging to know that the progress we are making is shared with our international counterparts and vice versa. With every step each of us takes, we are all moving forward together, ever closer to solving the global challenge of radioactive waste.

Our world depends on our collective success, and I am a firm believer that success in one jurisdiction can help drive success in others.

4. CONCLUDING REMARKS

The NWMO is proud to be working with our international counterparts, sharing information, leveraging research and development, and learning from each other. We have a number of bi-lateral cooperation agreements with our international partner organizations. We are also proud members of the International Association for Environmentally Safe Disposal of Radioactive Materials, EDRAM for short. I am happy to see several my colleagues from the association in the room today. Together, we are supporting the successful implementation of each individual nation's programme.

That's why it's so inspiring to be working on this endeavor at this particular moment in time. Make no mistake, we are embarking upon an exciting new era of nuclear waste management that is decades in the making.

In Finland, the world's first deep geological repository is anticipated to move into operations within the next few years. In France, an application for a repository construction license was submitted in 2019, with construction expected to start as early as next year. And in the UK, RWM is moving forward with its nationwide search in England and Wales for a suitable site and willing host community.

These are just a few notable examples, and I have no doubt we will hear more positive developments later in this session and over the course of the conference.

In closing, I want to thank the IAEA for convening this tremendously important event again this year, and for inviting me to lead off this first session.

International collaboration has always been key to every advancement and accomplishment in our field.

I will leave you with some key ingredients for success.

- We must earn public trust and acceptance.
- We must continue to hold one another accountable to progressively higher standards.
- And we must continue to collaborate on the science of tomorrow.

Thank you.

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SPENT FUEL, DISUSED SOURCES AND RADIOACTIVE WASTE MANAGEMENT STRATEGY IN ARGENTINA

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Abstract

The management of spent fuel, disused sources, and radioactive waste in Argentina is accomplished within a legal framework including the National Constitution, the Joint Convention, two National Laws, and a National Decree. In 1998, National Law Nr. 25018 appointed the National Atomic Energy Commission as the enforcement authority and established the National Radioactive Waste Management Program, which was assigned the responsibility for issuing and updating every three years a Strategic Plan to be sent through the official channels for approval by the National Parliament. The last update of the plan, the Collaborative Strategic Plan (CSP), was jointly composed by the National Program staff, issued in December 2020, sent for review in January 2021, and updated after being reviewed by the higher management officers of the National Atomic Energy Commission in July 2021. The CSP reviews the Mission and Vision statements. The former expresses the reason for the National Program, it is a lasting statement of its purpose and allows guidance for establishing objectives, formulating strategies, and carrying out tasks coherently and organized by highlighting the need for sustainability as follows:

"Accomplish the effective management of spent fuel, disused sources and radioactive waste exclusively arisen from the nuclear activities performed in Argentine territory to ensure people and environmental protection at present time and in the future. "

The latter indicates where the National Program is heading and allows focusing the efforts toward a defined direction as follows:

"Safely confine radioactive waste in repositories."

The CSP also points out National Program activities contributing to Sustainable Development Goals highlighting goals 7, Grow Affordable and Clean Energy; 9, Increase Industry, Innovation, and Infrastructure; 13, Organize Climate Action; and 17, Build Partnerships for the Goals; among others.

1. OBJECTIVES AND SCOPE

The aim of the Collaborative Strategic Plan (CSP) [1] is to define the objectives for the management of spent fuel, disused sources, and radioactive waste, as well as to settle the best actions which need to be carried out to reach such objectives. This plan eases the organizational management by conferring transparency, assigning well-defined goals and objectives to the involved areas, and allowing evaluations based on compliance with specified actions. It also ensures consistency between the actions being carried out, the requirements of National Law Nr. 25018 [2], and the organizational capacities by placing the National Radioactive Waste Management Program in relation to the environment.

This strategic plan encompasses 2021–2023 triennium activities.

2. RESPONSIBILITY

The authorities of the National Atomic Energy Commission, namely the enforcement authority established by Article 4 of National Law Nr. 25018 [2], are responsible for the compliance of its provisions. This law also creates the National Program within the scope of the National Atomic Energy Commission to carry out the activities required by its Article 10.

3. NATIONAL RADIOACTIVE WASTE MANAGEMENT PROGRAM

The National Radioactive Waste Management Program—hereinafter the National Program—performs the activities to fulfil the responsibility of the National Atomic Energy Commission for the safe management of spent fuel, disused sources, and radioactive waste exclusively arisen from the nuclear activities carried out in Argentine territory [2].

The aim of managing these materials is their confinement and isolation for a certain period and under such conditions that it does not entail an unacceptable radiological risk to people or the environment, both for present and future generations [1].

All management activities are carried out according to the regulatory framework, as well as national and international requirements and recommendations. The National Program has appropriate facilities to implement diverse stages of management and to undertake research, development, and innovation activities for introducing technologies to increase efficiency.

The National Program provides official information on its activities and projects to the Argentine Congress, the national and international scientific community, and the public.

3.1. Mission statement

The following mission statement expresses the reason the National Program exists. It is a lasting statement of the purpose of the National Program and allows guidance for establishing objectives, formulating strategies, and carrying out tasks in a coherent and organized manner by highlighting the need for sustainability.

"Accomplish the effective management of spent fuel, disused sources and radioactive waste exclusively arisen from the nuclear activities performed in Argentine territory to ensure people and environmental protection at present time and in the future."

3.2. Vision statement

The following vision statement indicates where the National Program is heading and allows to focus the efforts toward a defined direction.

"Safely confine radioactive waste in repositories."

3.3. Organizational values statement

Organizational values guide the decisions, actions, and behaviours of National Program workmates and they are a source of inspiration and motivation conferring identity and personality to the team as a basis for the organizational culture. The values of the National Program are safety, transparency, innovation, sense of membership, professionalism, interaction, and commitment.

4. EXTERNAL ANALYSIS

The National Program based its external analysis on the macro-environmental analysis for identifying external factors that are mainly out of the control of the National Program but impact on the organizational environment in which it has to be developed and on the analysis of the interested parties (i.e. individuals, groups and entities who have interests of any kind in the National Program and are affected by its activities and decisions).

4.1. Macro-environmental factors (PESTLE)

The National Program assessed a complete set of documents based on the collection and segregation of representative data and information related to management of spent fuel, disused sources, and radioactive waste. For each Political, Economic, Sociological, Technological, Legal and Environmental (PESTLE) factor, the

National Program identified those aspects that characterize its current national environment, as well as issues that could evolve into a certain risk for its performance. This analysis focuses on identifying those issues rather than trying to solve them.

4.1.1. Political factors

The most relevant political issues include the uncertain date for the signature of the contracts to build a fourth and fifth nuclear power plant, the deferred decision on spent fuel reprocessing, the loss of qualified personnel from the National Program to better paid sectors within the National Atomic Energy Commission, as well as companies within or outside the nuclear sector initiated several years ago, and the prohibition of new employment in the national public sector since 2018.

4.1.2. Economic factors

The most important economic factors include the fact that the trust fund for the management and disposal of radioactive waste created in 1998 by Article 13 of National Law Nr. 25018 [2] has never been established, the consequently insufficient budget the National Atomic Energy Commission can allocate to the National Program, the National Law Nr. 25160 [3] that created and established in 1999 the trust fund for financing the CAREM project to develop and build a low power innovative reactor prototype, the high inflation and interest rates, as well as the devaluation of the Argentine currency and the depreciation of salaries by a factor of about 2 since 2005.

4.1.3. Social factors

The most relevant social factors include the ongoing tradition of very little public participation in decision making processes (although in recent decades, national and provincial laws have explicitly incorporated mechanisms of transparency and participation, e.g. public hearings), the lack of public participation in matters related to waste of any kind (e.g. landfills or sewage treatment plants) resulting in controversies that often hinder the realization of projects, and the deep geological repository project run in the early 80s near the town of Gastre, Sierra del Medio, Province of Chubut and cancelled in the 90s due to a major controversy and public opposition.

4.1.4. Technological factors

Relevant technological factors include the cooperation agreement on radioactive waste management between ENRESA (Spain) and the National Atomic Energy Commission, the IAEA Technical Cooperation Project ARG9016 “Building capacities to select and characterize potentially suitable sites for the geological disposal of radioactive waste and spent nuclear fuel” and technologies under development (e.g. deep borehole).

4.1.5. Legal factors

The most important legal factors include the legal framework directly applicable to the National Program that includes the National Constitution [4], the Constitution of the Province of Buenos Aires [5], National Laws Nr. 24804 [6], 25018 [2], and 25279 [7] and Decree Nr. 1390/1998 [8]; the regulatory framework set by the Nuclear Regulatory Authority [9–10]; and the study for the siting of a nuclear power plant issued in 2016, which identified legal constraints to nuclear activities like the siting of radioactive waste repositories [11].

4.1.6. Environmental factors

Relevant environmental factors include the Environmental Policy formally declared by the National Atomic Energy Commission in 2003 [12] that reaffirms its responsible attitude in protecting the environment, preserving natural resources, and preventing environmental pollution within the framework of environmental legislation in force at the national, provincial, and municipal levels; the radiological monitoring plan and the environmental monitoring of air, surface water and groundwater carried out by the National Atomic Energy

Commission at its facilities and sites; and the Sustainable Development Goals (SGD) announced by The 2030 Agenda for Sustainable Development [13] to which the National Program activities contribute (in particular, SGD 7, Ensure access to affordable, reliable, sustainable, and modern energy for all; SGD 9, Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; SGD 13, Take urgent action to combat climate change and its impacts; and SGD 17, Strengthen the means of implementation and revitalize the global partnership for sustainable development).

4.2. Interested parties

The interested party concept refers to people, groups, and entities who have an interest in the National Program and are (or feel) affected by its activities and decisions. Interested parties were assessed based on their degree of interest and their power as opinion makers at the time of devising specific communications strategic actions.

The National Program identified 19 interested parties and their power, value or relationship with the National Program, as well as the relevance in terms of what it offers; demands were assessed for each. The complete set of interested parties includes the National Atomic Energy Commission, the utility Nucleoeléctrica Argentina (NA-SA), the Nuclear Regulatory Authority, Ministries and Secretaries, international organizations, universities, media, and contractors, among others. Table 1 shows the example for the first interested party identified and assessed.

TABLE 1. INTERESTED PARTIES ASSESSMENT

Interested party	Power, value, or relationship	Relevance	
		It offers	It demands
National Atomic Energy Commission	It is the host organization for the National Program within the National Public Administration. It employs specialists on nuclear energy and spent fuel, disused sources, and radioactive waste management matters.	Organizational umbrella. Budget. Visibility for communication, training, and outreach actions. Negotiating power with S&T, as well as governmental organizations and sectors.	Absence of public conflicts that may question the organization's reputation. Management of spent fuel, disused sources, and radioactive waste as prescribed by National Law Nr. 25018 [2].

5. INTERNAL ANALYSIS

The internal analysis was based on the Internal Factor Evaluation (IFE) matrix to identify and assess major strengths and weaknesses of the functional areas of the National Program, as well as the relationships among them.

Nine co-authors of the present paper weighted each factor between 1 (major weakness) and 4 (major strength), performed the analysis, and subsequently averaged their answers. Lastly, they sorted the IFE matrix in descending order to identify the strengths (average greater than 3) and weaknesses (average less than 2). Table 2 shows the example for the first and last out of 36 rows of the IFE matrix.

TABLE 2. INTERNAL FACTOR EVALUATION MATRIX

Internal factor	Why? (Brief description)	Average
Continuous management of spent fuel, disused sources, and radioactive waste as prescribed by national laws and decrees	It is reported regularly since 1950 (date of creation of the National Atomic Energy Commission).	4.00
Lack of independence between the National Program and the nuclear activities	On one hand, the legal framework appoints the National Atomic Energy Commission to perform nuclear activities and as shareholder of companies performing nuclear activities. On the other hand, National Law Nr. 25018 appoints the National Atomic Energy Commission as the enforcement authority for the management of spent fuel, disused sources and radioactive waste and creates the National Program.	1.00

6. STRATEGIC PILLARS SELECTION

Fifteen general objectives for the management of spent fuel, disused sources and radioactive waste were determined as actions of the National Program defined by the National Atomic Energy Commission Presidency Resolution Nr. 474 published in 2012 [14]. In line with these actions the following strategic pillars for the National Program were identified:

— Management and decommissioning operations (Actions 2, 6, 8, 9, 10, 11, 12, 13);
— Research, development and innovation on predisposal and disposal (Actions 3, 4, 5, 6);
— Communication (Actions 1, 7, 14,15)
— Management.

7. FORMULATION OF STRATEGIES

A Strength, Weakness, Opportunity, and Threat (SWOT) analysis (or matrix) was used to identify the strengths, weaknesses, opportunities, and threats for making current and future decisions, as well as for identifying four types of strategic initiatives: offensive, defensive, reorienting, and survival.

The strategic initiatives were determined by using the macro-environment analysis described in section 4 as a source of information to determine the opportunities and threats as well as the analysis of strengths and weaknesses from the internal factor evaluation matrix described in section 5, and by subsequently performing the information crossover.

As examples: “Elaborate plot lines for communicating with the (environmental) community” was identified as one of the offensive strategies, “Develop a robust and dynamic technological platform for managing knowledge and communication” was identified as one of the defensive strategies, “Improve the relationships with the internal and external institutional management in order to maximize visibility of the radioactive waste management issue and its urgency” was identified as one of the reorienting strategies, and “Determine the radioactive waste management fees to sectors of the National Atomic Energy Commission which provide profitable services” was identified as one of the survival strategies.

8. STRATEGIC MAP

The strategic map model for the development of the Balanced Scorecard (BSC) proposed by Kaplan and Norton in 1996 [15] as developed for organizations seeking an economic–financial benefit was adapted by Niven [16] for public sector non-profit organizations like the National Program created by law within the scope of the

National Atomic Energy Commission. In this way, an alternative model was proposed by renaming and reordering the perspectives of the original model and then applied to the National Program.

9. BALANCED SCORECARD

Once the strategies have been ordered according to the perspectives, the metric, goal, and means for each defined objective so-called were determined for constructing the BSC. The following sections list the strategic objectives identified.

9.1. Strategic objectives for financial management

- Trust Fund
- Financing Alternatives
- Charges for Services

9.2. Strategic objectives for the development of organizational capabilities

- Human Resources Management
- Training Platforms
- Job Profiles
- Staff Recruitment and Retention
- Decommissioning Planning
- Technical Cooperation Projects (Internal / External)
- Environmental Team
- Knowledge Management and Preservation
- Knowledge Management Platform
- Critical Knowledge Capture and Retention

9.3. Strategic objectives for process management

- Decommissioning Scenarios Development
- Site Characterization
- Project Management
- Reprocessing Options
- Operations and Decommissioning R&D Orientation Broadening

9.4. Strategic objectives for interested parties

- Higher Management Involvement
- Interested Parties Communication
- National Programme Visibility
- National Programme Hierarchisation
- Communication Hierarchisation

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IMPLEMENTATION OF DEEP GEOLOGICAL REPOSITORY PROGRAMME IN LITHUANIA

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Abstract

Fulfilling the obligations set out in Protocol 4 of the Treaty of Accession to the European Union, i.e. the final shutdown of the Ignalina Nuclear Power Plant (INPP) and its decommissioning, Lithuania finally shut down the first INPP Unit on 31 December 2004, and the second INPP Unit on 31 December 2009. According to Council Directive 2011/70/Euratom of 19 July 2011 and the Law on Radioactive Waste Management of the Republic of Lithuania implementing the Directive, high level radioactive waste and long lived radioactive waste generated in Lithuania has to be disposed of in a Deep Geological Repository (DGR) built in the territory of Lithuania. Since 2019, INPP has been the institution responsible for the implementation of the DGR Project. Based on the implementation of the DGR programmes of more advanced countries, a preliminary schedule for the implementation of the Lithuanian DGR Project for a radioactive waste repository has been prepared. Initial studies, including planning, site selection for the DGR and underground laboratory, geophysical and geological investigations, and other activities, prior to the approval of the site for construction of the DGR and underground laboratory will be performed in 2022–2047. Planning and site selection for the investigation borehole is currently in progress (2019–2024). The initial studies are focused on screening of all potentially prospective geological formations as host formations. After eliminating the regions in accordance with negative screening criteria, 110 potential regions have been identified in all geological formations selected as potential formations for the DGR.

1. INTRODUCTION

All spent nuclear fuel will be transported to the spent fuel dry storage facility at the Ignalina Nuclear Power Plant (INPP) in interim storage casks by 2022, and other long lived radioactive waste to a low level waste (LLW) storage facility by 2038.

Upon expiry of the design term for the safe operation of casks and storage facilities for high level radioactive waste (in 2050 and 2067, respectively), it is necessary to get ready for the final disposal of high level radioactive waste and long lived radioactive waste, or appropriate safety justification prepared for prolongation of such storage.

According to Council Directive 2011/70/Euratom of 19 July 2011 and the Law on Radioactive Waste Management of the Republic of Lithuania implementing the Directive, high level radioactive waste and long lived radioactive waste generated in Lithuania has to be disposed of in a Deep Geological Repository (DGR) built in the territory of Lithuania.

Since 2019, the INPP has been the institution responsible for the implementation of the DGR Project. Based on the implementation of the DGR Programmes of more advanced countries, a preliminary schedule for the implementation of the Lithuanian DGR Project for a radioactive waste repository has been prepared. The preliminary schedule includes the following stages:

Initial studies, including planning, site selection for the DGR and underground laboratory, geophysical and geological investigations, and other activities, prior to the approval of the site for construction of the DGR and underground laboratory will be performed from 2022–2047.

Other key stages of the DGR Project include design (2048–2057); construction (2058–2067); operation (2068–2074); closure (2075–2079); and time after the closure (from 2080).

Planning and site selection for the investigation borehole is currently in progress (2019–2024). The initial studies are focused on screening all potentially prospective geological formations as host formations.

2. OVERVIEW OF GEOLOGICAL CONDITIONS IN LITHUANIA

The territory of Lithuania is in the north-eastern part of the East European platform. Crystalline basement occurs at the depth of 100–2600 metres (m) below the Earth's surface. The sedimentary layers cover the crystalline basement and consist of the deposits of all geological systems. Hydrogeologically, the territory of Lithuania appertains to the Baltic artesian basin (BAB). The structural elements — the Baltic depression, the slant of Baltic shield and Belarussian–Mozurian High — are defined in the BAB. The groundwater of BAB occurs in the sedimentary cover and in the fractured rocks of the crystalline basement [3].

The general overview of the geological structure and composition of the sedimentary cover and crystalline basement started in the Lithuanian geological survey (LGT) in 1998. The primary investigations of geological media and the possibility to install the DGR in Lithuania was performed in 2001–2002. The clayey formations, the crystalline basement rocks, evaporites (anhydrite and rock salt) were selected as potential rocks for future investigations as host rocks for the DGR (Fig. 1).

The general analysis of the geological structure and composition of all the suitable for DGR clayey succession was fulfilled. Two perspective clayey formations—the Lower Cambrian and the Lower Triassic sequences—were selected as host rocks for the DGR. The clayey formations have a sufficient thickness and lithological composition in terms of the DGR, the geotechnical properties of potential clayey formations are appropriate, as well.

The Lower Cambrian Baltija Formation occurs only in the eastern part of Lithuania. The top of the formation occurs at a depth of 200–1000 m, dipping to the northwest. The thickness is 115 m in the eastern part decreasing in the west to 50 m [1]. The Lower Cambrian clayey formation is comprising of compact dark greenish grey, sometimes brown and violate fine-laminated claystone with interbeds and interlayers of abundant siltstone and glauconitic sandstone layers varying from 1 to 5.6 m thick. The Lower Cambrian claystone formation of marine origin with pyrite inclusions and a relatively high glauconite content is overlain by the Ordovician carbonaceous-shaley rocks, that shows good sealing properties. The formation is underlain by the Vendian strata that consists of sandy sediments [3].

The Lower Cambrian clayey formation is distributed on the restricted territory of Lithuania. Therefore, the formations depth of occurrence and complex geological structure is poorly investigated. The sediments are also rather poorly studied in terms of mechanical–engineering properties – only a few parameters are available (density of the rock equals 2.22–2.25 g/cm^3, magnetic susceptibility is $0.08–0.14 \cdot 10^{-3}$ SI) [2].

Lower Triassic sediments are distributed in the southwestern part of Lithuania. The thickness of the layer increases towards the southwest from a few metres in north-eastern and eastern Lithuania to 280 m. The top of the Triassic formation in the north-eastern part of Lithuania almost outcrops to the surface, gradually plunging in the same direction to 500 m depth. The Triassic formation is underlain by the Permian Zechstein carbonates in the north and drapes the crystalline basement in the south. The upper boundary of Triassic sediments is distinct; dark grey Jurassic terrigenous deposits overlie the Triassic red beds [3].

The Lower Triassic formation usually consists of a red-rusty coloured claystone sequence with grey-coloured claystone intervals with siltstone and sandstone intercalations and interlayers as well as dolomitic carbonate marlstone intervals, separated by oolitic limestone layers. The claystone represents dense and solid material with rare mud cracks (mud cracks are filled with gypsum and silty matter) and slicken slides. Nevertheless, the sediments are quite lithologically homogenous, that most homogenous layers are distributed in the central part of the Triassic section [3].

The Triassic formation has been more studied geologically (~2600 wells penetrate the Triassic formation) and in terms of physical–mechanical properties than the Cambrian succession; still, more-detailed investigations are required. The formation is represented mostly by montmorillonite and illite; the void ratio of claystone is defined as 0.299–0.565, the natural density of the sediments is 1.96–2.29 Mg/m^3, dry density 1.0–2.12 Mg/m^3, and the density of solid particles reaches up to 2.65–2.82 Mg/m^3. The index of plasticity of sediments exceeds 0.08 (reaching 0.12–0.29 for the most favourable layers). The maximal moisture content ranges from 11.2 to 15.8%, the natural moisture content from 0.1 to 0.178, and the hydraulic conductivity attains values of 10^{-6}– 10^{-7} m/d [2]

Two potential formations of Upper Permian (anhydrite and rock salt) for the DGR have been found. The Upper Permian (Zechstein) anhydrite and rock salt of the Prieglius Formation occurs at the depth of 150–790 m in the south and southwest of Lithuania.

Anhydrite and gypsum layers overlie the carbonate sediments of the Upper Permian Naujoji Akmenė Formation. 70–80 % of the evaporites are composed of anhydrite. From above and below, anhydrite is covered by the Upper Permian gypsum. The thickness of gypsum is 5–8 m above the anhydrite and 3–5 m below [4]. According to the distribution of gypsum, dolomite, and clay, the anhydrite layer is subdivided into spotted in the lower part and banded in the upper part of the seam. The spotted anhydrite, 16–20 m thick, is grey, yellowish brown, massive, strong rock consisting only of anhydrite minerals. Some admixture of gypsum, clay, and dolomite is observed in some parts of the layer. Banded anhydrite occurs over spotted. The thickness is typically about 17–22 m. Both varieties are of the comparable composition and physical–mechanical properties. The anhydrite density is 2.92–2.98 g/cm^3, the banded anhydrite porosity is 0.5–0.8%, the spotted is 0.8–0.9%, water absorption in both varieties is 0.1–0.12%, compression strength range from 40–65 MPa (banded variety) to 55–70 MPa (spotted anhydrite), bending strength is 18.3–20.7 MPa, and tensile strength is 2.54–2.88 MPa. Thermal conductivity at 25 °C is 1.16–1.26 W/mK, at 100 °C – 11.7–12.5 W/mK, coefficient of thermal expansion in 20 °C…+20°C temperature interval varies from 0.95 to 0.99 1/°C 10^{-5}, in +20 °C…+200 °C interval reaches 2.2–1.91 1/°C 10^{-5} [4]. Inspection of the available information and studies of well logs of areas drilled with no core sampling showed the salt domes are the anhydrite and gypsum bodies. Therefore, the Usėnai dome is the only salt body known in Lithuania. After analysis of available information was concluded, rock salt could not be a high potential host rock for the DGR [3].

Rock salt of Prieglius Formation occurs in the southwestern part of Lithuania (Šilutė and Šilalė regions). In general, the thickness of salt beds and the depth of their occurrence increases southwestwards. The thickness of the rock salt in the central part of the deposit is 56.5–69.0 m, and the suspected thickness is about 75 m [5]. In Šilutė and Šilalė regions rock salt domes have been observed at a depth of 350–380 m. Isolated rock salt domes can be detected in other areas as well. Rock salt of Lithuania is well investigated in a very small areas—only several single domes are detected by seismic exploration in other places [3].

The crystalline basement rocks were considered one of the most perspective geological media for DGR. It occurs over the region, the depth of crystalline basement in Lithuania varies from 200 m to 2600 m. However, the most perspective area of the crystalline basement with depths ranging from 210 m to 700 m was confirmed in the southeastern part of Lithuania. The crystalline basement of south Lithuania comprises different rock types, including migmatites containing scarce remnants of supracrustals (gneisses, amphibolites), mafic and felsic intrusions, cratonic (anorogenic) granitoids, and other lithologies. The petrographyc composition of the basement rocks is of minor concern in DGR siting, as the lithology has little effect on the properties (tightness) of rocks, by contrast to sedimentary deposits. The fracturing (faulting) and shearing of the basement rocks is the main parameter controlling the permeability for fluid flow. A wide spectrum of tectonic rocks is documented in the drill cores. The tectonic studies of south Lithuania showed a rather dense network of faults. Still, large enough blocks without tectonic damage are observed and, therefore, are suitable for the DGR. The eastern part of south Lithuania seems to be more tectonized than the western part. According to the previous investigations, the most prospective rock types are represented by cratonic (anorogenic) granitoid intrusions that, in some places, compose rather large massifs. These rocks are the least damaged by tectonic activity. Other rock types (gneisses, mafic intrusions, migmatites) compose someplace weakly fractured blocks that may be prospective for the DGR, as well [3].

3. CONSIDERATION OF INVESTIGATION OF POTENTIAL FORMATIONS FOR THE DGR IN LITHUANIA

Based on the research of the geological formations described previously, the negative screening of Lithuanian territory has been performed, i.e. preliminary unsuitable regions have been identified by the established boundary conditions, including water body protection zones, protected areas, areas of mineral deposits, cities, sites referred to the European Ecological Network Natura 2000, among others. After eliminating the regions according to the above-mentioned criteria, potential regions have been identified in all geological formations selected as potential formations for the DGR. The total area of potentially suitable formations occurrence is 28 069 km^2. According to geological data, 110 potential sites have been defined (Fig. 1).

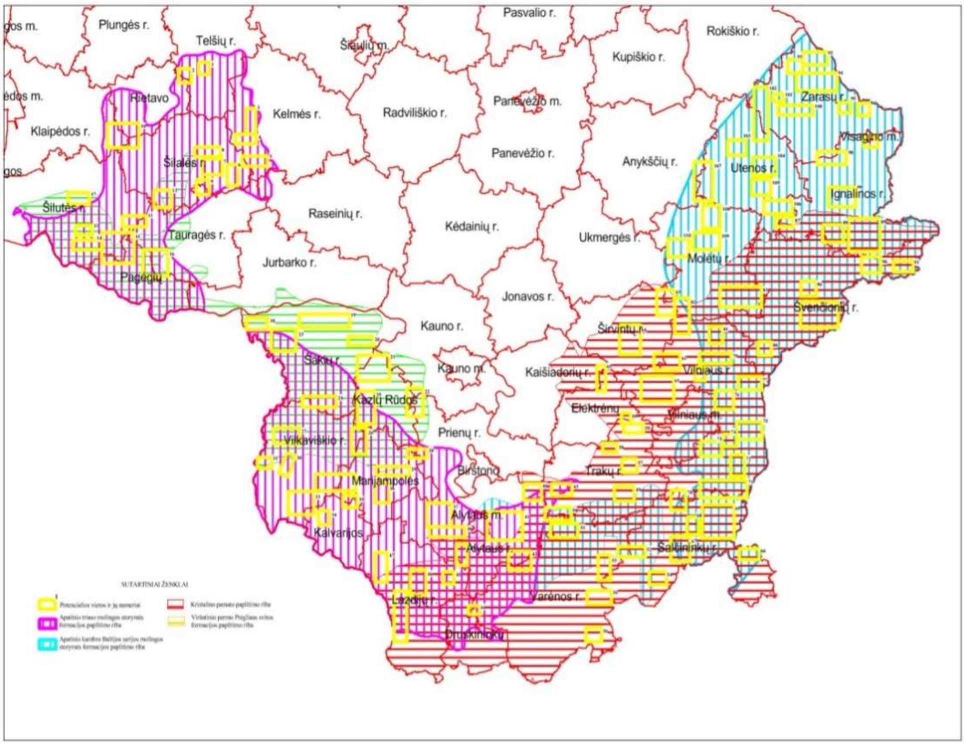

FIG. 1. Occurrence of potentially suitable geological formations: purple indicates areas of distribution of the Lower Triassic; blue - Lower Cambrian; brown - Crystalline basement and yellow - Upper Permian; and distribution scheme of potential sites for DGR (yellow squares) [7]

As the investigations of all potential areas vary, the total area of 5 730 km² could be suitable for the investigations using two-dimensional (2D) seismic surveying method. However, ~85–95% of this territory is not currently investigated by geophysical methods, there are no boreholes together with seismic surveying in ~50–60% of the area, geological data availability is poor in ~30–40% of the area, and only ~20–30% of the area has quite good data availability [7].

The area of occurrence of the Lower Triassic clayey formation covers an area of 10 394 km^2, ~49% of it overlaps with the Upper Permian, Lower Cambrian, and crystalline basement formations: the total area of overlapping territories is 5 081 km^2. It is investigated by 2600 boreholes, but only 214 of which penetrate the lower Triassic formation. The distribution of boreholes is not uniform; those are drilled in ~67% of the territory. The highest density of the boreholes is in the territories of Kudirka and Kybartai (southern west Lithuania) oil fields and accumulations. However, 33% of the occurrence area is investigated neither by drilling nor by geophysical methods [7].

During previous investigations, a comparison between the Lower Cambrian conditions for DGR and Lower Triassic Formation was made [3, 6]. That is why the characteristics of the structure were analysed in more detail for this formation. During the investigations in 2005, data on parameters of various properties of the Lower Triassic were collected and systematized. Parameters on permeability, mineral chemical composition, grain size, geotechnics were collected and analysed. For the laboratory tests, 145 samples were taken from the old borehole core. Plastic and liquid limits were determined in 27 samples, chemical analysis was performed in 38 samples, and permeability and pore water composition parameters of 4 samples were analysed in the Belgian SCK–CEN center [7].

The area of occurrence of the Upper Permian Prieglius evaporite covers 4 935 km² at the land surface large part of the formation (~62%) and overlaps the Lower Triassic Formation—the total area of the overlapping territories is 3 042 km^2. Anhydrite and rock salt of the Upper Permian occur in southwestern Lithuania. There are

107 boreholes in ~70% of the formation distribution area. The distribution of boreholes is not uniform. Most of the boreholes were drilled in the southwestern part of the occurrence area and the southern part, near the Lithuanian state border. However, 30% of the total occurrence area is investigated neither by drilling nor by geophysical methods. Most of the boreholes that pass through the Upper Permian Formation also pass through the Lower Triassic [7]

The area of occurrence of Lower Cambrian Baltija clayey formation is 10 868 km^2, part of which (~59%) overlaps with Crystalline basement and Lower Triassic Formations: the total area of the overlapping territories is 6 452 km^2. This formation was investigated by 65 boreholes concentrated in the southern part (~23% of the occurrence area). The area in the lower Cambrian Formation was not investigated by seismic surveying except small territories around the Ignalina NPP (site evaluation for the Visaginas NPP project for a new NPP in Lithuania, which was closed in 2016) [7].

The area of occurrence of Crystalline Basement Formation reaches 13 225 km^2, 59% of the formation overlaps with Lower Cambrian and Lower Triassic Formations, the total area of the overlapping territories is 7804 km^2. The number of boreholes of different depths in this area is nearly 1000. However, only 187 are deep enough to investigate the upper part of the Formation. Most of deep boreholes are in the south in ~43% of the Formation occurrence area, around the towns of Varėna and Lazdijai [7].

Although 2D seismic surveying is not reasonable in the area of the Visaginas NPP project, relatively new 2D and even three-dimensional seismic investigations were performed in 2009–2010 for characterization of Visaginas NPP sites. The Crystalline Basement was investigated in relative detail by drilling in southern Lithuania. Some investigations for the characterization for a potential radioactive waste repository also were performed [6]. During that survey, previous data were reinterpreted, and new high resolution data was added and analysed. Analysis did not confirm the complex blocked structure of Crystalline Basement or the existence of most of the previously detected faults near the Visaginas NPP project site [7].

During previous investigations, the hydrogeological conditions of the Crystalline Basement were analysed in detail for some areas. It was determined that Crystalline Basement groundwater forms in the active water exchange zone and has hydraulic relation with deep tectonic faults.

In Lithuania, the reports of geological investigations have been collected. Most of them are available from the archives and the library of the LGT. These sources contain mainly information concerning structural (depths of occurrence, thickness of strata, boundaries of extension), lithological, and hydrogeological properties of geological formations. They also contain some experimental data characterizing parameters. The available information includes research reports (mainly geological mapping), monographs, published papers, and other literature [3].

4. DEVELOPMENT PLANS OF THE DGR PROJECT

Based on the implementation of the DGR Programmes of more advanced countries, a preliminary implementation schedule for the Lithuanian DGR Project for a radioactive waste repository has been prepared. Planning and site selection for the investigation borehole is in progress (2019–2024). Whereas many potential DGR sites are currently selected, detailed investigations are difficult to implement and, in some cases, not appropriate. It is necessary to assess and prioritize them based on certain acceptability criteria. During the initial phase, a set of various DGR site selection criteria will be developed covering geological, socioeconomic, and safety criteria. Based on all the above-mentioned criteria combinations, all 110 potential sites for the DGR installation will be re-evaluated, ranked, and several sites that best meet all the criteria will be selected for further evaluations.

Two-dimensional geophysical surveys (seismic surveys) are planned in the prioritized areas. Considering the limitations of 2D seismic surveying method, all potentially suitable formations planned 2D seismic surveying results are expected to provide [7]:

— Identification of the surface of the crystalline basement;

— Depth of occurrence and inclination angle of the entire Lower Triassic, Upper Permian, and Cambrian successions (without the lithological interbedding);
— Identification of tectonic faults, their location, strike, amplitudes, inclination angle with some amplitude;
— Structural features of the top and base of the formation (depressions, elevations, domes, highs, steps, etc.);
— Palaeoincisions (or confirmation of the palaeoincisions defined by geological data).

5. CONCLUSIONS

This work reviews the current implementation of the DGR project in Lithuania and discusses geological formations identified during previous research as suitable for the DGR installation. Detailed planning for the DGR project for 2022–2030 is currently underway to determine the essential criteria for the installation of the DGR in Lithuania. The criteria will include the suitability of the geological environment for the installation of the DGR and the safety criteria for the DGR. Much attention at this stage is paid to the assessment of socioeconomic conditions and criteria. In the future, a combination of the aforementioned criteria will be used to select sites for more-detailed geological surveys and, subsequently, based on more-detailed surveys, for a potential DGR site.

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PLANS AND PROGRESS IN ESTABLISHING THE AUSTRALIAN RADIOACTIVE WASTE AGENCY NATIONAL RADIOACTIVE WASTE MANAGEMENT FACILITY

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Abstract

The paper describes progress to date in siting a RWM facility for management of Australian radioactive waste. The project will secure and support the ongoing production of nuclear medicines and diagnostics in Australia, of great importance to health services, through up to date management of existing and future wastes. The Australian Radioactive Waste Agency (ARWA) was established in July 2020 to manage Australia's radioactive waste in line with domestic and international regulations; deliver and operate Australia's National Radioactive Waste Management Facility (NRWMF); facilitate communication between government, industry, stakeholders and local communities; and centralize best practice and knowledge about radioactive waste management (RWM), including developing a disposal pathway for intermediate level waste (ILW). ARWA is undertaking a process specified by Australian Commonwealth Law to select a suitable site for the NRWMF from voluntary land nominations. The process includes assessment of technical suitability and community acceptability. The low level waste (LLW) disposal operations are planned for 100 years and ILW storage for several decades whilst an ILW disposal pathway is developed. Development of concept designs and work on a safety strategy or safety case to support environmental and radiological regulatory authorizations is underway.

1. BACKGROUND TO AUSTRALIAN RADIOACTIVE WASTE MANAGEMENT

Australian government involvement in radioactive waste management (RWM) dates to the early 1900s with uranium mining activities, such as at Radium Hill in South Australia, along with radium extraction for commercial and medical uses. In the 1950s, the Australian Atomic Energy Commission (AAEC) at Lucas Heights, on the southern outskirts of Sydney, was working closely with the United Kingdom Atomic Energy Authority (UKAEA) Harwell in developing new reactor technologies. At the same time, the Commonwealth Council for Scientific and Industrial Research was trialling uranium extraction techniques at its Melbourne site. This was also the time of UK atmospheric atomic bomb tests in the South Pacific and Australia, activities which have left a significant lasting negative impact on Australian public and political opinion regarding nuclear technology to this day, including the civil use of nuclear power.

The organizations working on nuclear research and RWM in Australia have changed over time. The AAEC and Commonwealth Council for Scientific and Industrial Research were the predecessors of the Australian Nuclear Science and Technology Organisation (ANSTO) and the Commonwealth Science and Industrial Research Organisation (CSIRO) respectively.

The key Commonwealth (federal) regulatory bodies controlling RWM activities in Australia are the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA, the nuclear regulator), the Australian Safeguards and Non-Proliferation Office (ASNO, the Safeguards regulator) and the Department of Agriculture, Water and Environment (the environmental regulator). The development of proposed RWM facilities is subject to regulation by these bodies. It should be noted there are also Australian State and Territory regulators that licence and regulate radioactive waste holders under their jurisdiction.

In 2013, the Department of Industry set up a task force to take forward development and siting of a National Radioactive Waste Management Facility (NRWMF). The role of the task force has now passed on to the Australian Radioactive Waste Management Agency (ARWA), which was established in July 2020 [1] to:

- Manage Australia's radioactive waste in line with domestic and international regulations;
- Deliver and operate Australia's NRWMF;
- Facilitate communication between government, industry, stakeholders, and local communities;
- Centralize best practice and knowledge about radioactive waste management, including developing a disposal pathway for intermediate level waste (ILW).

Although Australia has chosen not to develop a nuclear power industry, it has built a series of research reactors, all at Lucas Heights, on the southern outskirts of Sydney. The Moata reactor is now fully decommissioned, the HIFAR reactor is defueled awaiting decommissioning, and the OPAL reactor is currently operational, undertaking a range of experimental programmes and production of nuclear medicines. Australia has benefitted from nuclear medicines and diagnostics produced by its research reactors since the 1980s. It has been estimated at least two thirds of the Australian population will at some point receive a nuclear medicine procedure.

2. WASTE MANAGEMENT

Most of the radioactive waste to be managed in Australia originates from the research reactors and associated nuclear medicine activities at ANTSO and is currently stored on the Lucas Heights site [2]. The remainder arises from other medical and applied research activities, and from industrial uses in the mining, surveying, and electronics sectors. These latter wastes are stored in many locations across Australia. All radioactive waste is managed by waste holders in compliance with the ARPANSA regulatory and licensing regime, or the equivalent State or Territory regulatory regime.

Australia currently implements a closed fuel cycle policy for its research reactors. Spent reactor fuel is reprocessed overseas and waste residues are returned as vitrified waste forms, which are currently stored at Lucas Heights, ANSTO campus. The reprocessed wastes are subject to the principle of substitution with the canisters of vitrified waste to be repatriated to Australia selected to meet ARPANSA ILW regulatory classification (activity level and heat generation). This arrangement is consistent with Australia's commitments under the Joint Convention. Current plans are to manage this waste storage and disposition within the ILW waste stream.

The Australian government identified the following drivers for a permanent RWM facility, as part of the Detailed Business Case justification for development of a National Radioactive Waste Management Facility. The NRWMF facility would provide a solution to:

- Lack of permanent RWM pathways (that) risks regulatory intervention in nuclear medicine production;
- Widely distributed, undocumented holdings of radioactive waste (could) pose a risk to the public;
- Lack of established radioactive waste disposal or storage pathways leading to storage and accumulating inventory rather than waste treatment and minimization;
- Interim storage locations are coming to the end of their technical life or capacity.

ARWA collects and compiles Australian radioactive waste inventory information by waste producer and waste stream. Currently inventory information is updated annually, to facilitate waste holders to undertake a stepwise process to develop, collect and report sufficient information about the physical, chemical, and radiological properties of their waste holdings for RWM planning.

Existing (legacy) wastes by volume are estimated to be approximately 5000 cubic metres of low level waste (LLW) and 2000 cubic metres of ILW [2]. Similar volumes are expected to be produced over the next 50 years, assuming there is no step change in radioactive waste generation over this time.

3. THE NRWMF SITING PROCESS

3.1. Historical context and progress

Australia has endeavoured to find a disposal pathway for its radioactive waste on numerous occasions over the last 50 years. The process began in the 1970s when the Little Forest Legacy Site at Lucas Heights finished its limited waste management operations (this site is not discussed here but represents a near surface trench disposal site for LLW). Various initiatives to select a technically, socially, and politically acceptable site for RWM have been unsuccessful as documented in Table 1. Sites were identified through a variety of processes; however, efforts to take them forward failed for a variety of social and legal reasons. This resulted in replacement of the Commonwealth Radioactive Waste Management Act (2005) by the National Radioactive Waste Management Act (2012), which set out the current legal framework for siting a national facility on volunteered land.

Although waste is safely stored at current locations, the need for workable disposal options to be developed is international good practice and is a regulatory expectation of ARPANSA, which has stated, “The Lucas Heights site is not actually able to be a disposal site; that is part of the Australian Nuclear Science and Technology Organisation (ANSTO) Act. The site currently being considered for the national radioactive waste management facility will be a disposal site for LLW, and cannot be Lucas Heights under the current legislation. World’s best practice establishes that long term storage is not an option; a disposal pathway is always needed. So the establishment of a national radioactive waste management facility is to attempt to locate a site for a LLW disposal facility. The waste that is currently stored at ANSTO cannot remain there indefinitely.”

TABLE 1. PREVIOUS GOVERNMENT PROCESSES TO ESTABLISH A NATIONAL RADIOACTIVE WASTE FACILITY IN AUSTRALIA [3]

Process	Details	Period	Summary Outcome(s)
1. National waste repository concept established	The joint Commonwealth and State and Territory National Health and Medical Research Council (NHMRC) endorses the concept of a national waste store. Commonwealth agrees to coordinate a national approach for the management of Australia’s radioactive waste.	1975 to 1985	Commonwealth/State Consultative Committee on radioactive waste is established (1980). In 1985 it recommended a project to identify potential near surface radioactive waste disposal sites. In 1986, following studies by State and Territory authorities, the CSCC concluded most states and territories were likely to contain suitable sites and state governments should advise the Commonwealth if they wished to proceed with potential sites to the next, detailed assessment stage.
2. States and Territories* identify suitable sites	States and Territories required to identify potentially suitable sites for a national near surface radioactive waste repository. Northern Territory (NT) Government feasibility study in 1988, resulted in proposal of a site in NT and feasibility assessment.	1985 to 1991 6 years	Political and community concerns in the NT lead to suspension of the project in 1991. States pass legislation prohibiting a national repository in their jurisdictions.
3a. The National Repository Project	NHMRC approves a code of practice for near surface disposal of radioactive waste in Australia. The Commonwealth considers potential sites in South Australia (SA), with a preferred location identified for a near surface	1992 to 2004 12 years	Acquisition of the site by the Commonwealth is blocked by the High Court of Australia. The Commonwealth abandons plans for a national low level waste repository.

Process	Details	Period	Summary Outcome(s)
	repository for Australia's low level radioactive waste.		
3b. The National Store Project	National above-ground store facility proposed for ILW. Three sites in NT and SA identified. However, detailed site selection was not completed. SA site withdrawn in 2003.	2000 to 2004 3 years	Discontinued following abandonment of the National Repository Project
4. Commonwealth Radioactive Waste Management Facility	Commonwealth explores options for a co-located LLW repository and ILW store for Commonwealth waste. Commonwealth Radioactive Waste Management Act (2005) provides a legal process for nomination of land in the NT. Consideration of a NT site (2007) nominated by the Northern Land Council as the preferred location. Initial business case for detailed project development funding sought.	2005 to 2013 9 years	Opposition by traditional owners resulted in withdrawal of the nomination of the NT site by the Northern Land Council.
5. NRWM Act 2012	National Radioactive Waste Management Act (2012) replaces the Commonwealth Radioactive Waste Management Act (2005) and sets the legislative framework for siting a national facility on volunteered land.	2012	Bill to allow for volunteer nomination process is passed and provides basis for a fresh multi-stage site selection process for a co-located LLW disposal site and ILW store.
6. NRWMF Project (current)	NRWMF Task Force formed in Department of Industry. Project initiated to develop a co-located national LLW disposal and ILW store on a volunteered site, in accordance with National Radioactive Waste Management Act (2012). Three short listed sites.	2013 to present	Initial Business Case for the storage/disposal concept approved by government (2013). Detailed Business Case 2018 builds upon recommendations from 2013 initial business case. Three shortlisted volunteered sites in SA. Amendment to 2012 Act passed by Australian parliament to allow preferred site to be selected and for Judicial Review of any such decision. Site specific design prepared for LLW disposal and ILW storage, site characterization work and safety case development work planned. Indigenous heritage assessments planned.

* In addition to the Federal Government, Australia has six state and two territory governments that can enact laws which apply to their jurisdictions and government scope.

3.2. The current siting process

The current siting process has been based on volunteerism, with the voluntary site proposal process and legal constraints set out in the National Radioactive Waste Management Act 2012 (NRWM Act) [4]. The process aims to facilitate broad and local support for selection of a site for Australia's NRWMF which will provide permanent disposal of LLW (waste suitable for near surface disposal), and co-located storage of ILW for a period required to develop an ILW disposal pathway. The NRWM Act excludes management of HLW at the proposed NRWMF. Furthermore, it states that no foreign waste will be accepted at the NRWMF.

The NRWM Act defines legal, technical, economic, and sociopolitical aspects of the siting process. At each stage, the Minister is only required to consult with, and consider comments from, the nominator and persons with a right or interest in the nominated land. However early in the process the government stated that it would not impose the NRWMF on an unwilling community.

The current process has undergone the following stages:

- The call for nominations was conducted between March and May 2015. Additional screening of Commonwealth land holdings was undertaken, but no suitable land was identified as being available.
- A total of 28 landowner nomination applications were received.
- Six nominated areas were assessed as potentially suitable.
- Between November 2015 and March 2016, the consultation process for the six potentially suitable nominated sites was undertaken. Presentations and town hall meetings were used to provide information to the communities. Further assessments were carried out and public consultation undertaken to assess the level of community support. As a result, some site nominations were withdrawn, and some communities clearly did not support the proposal.
- At the end of this phase, three potential sites in two communities were shortlisted as potential locations for the site. All locations were in arid/semi-arid areas of the state of South Australia, in sparsely populated rural agricultural communities.
- A community benefits programme, as detailed in the NRWM Act, was activated which recognized and financially mitigated the continued resources that the communities were committing to the project. Community development projects were funded through this mechanism benefitting the two communities.
- Further site characterization and technical investigation and evaluation was undertaken at the three shortlisted sites.
- In autumn 2018, the Australian Electoral Commission collected local community sentiment in the two shortlisted communities on behalf of the two local authorities, the District Council of Kimba and the Flinders Ranges Council. Voter turnout was very high, with the Kimba community clearly supporting the facility (62% in favour). In contrast, the vote in the Flinders Ranges did not demonstrate majority local community support.
- At the same time, the sentiment of local businesses and neighbours was also collected by an independent research company, following input from the local Consultative Committees in each community.
- A Public Submission process, which was open to all Australians, was run between August 2018 and December 2019 to gather sentiment towards the proposal. This resulted in over 3000 submissions being received.
- The department supported local Traditional Owner groups to collect the sentiment of their members in ways that were appropriate to those groups. The organization representing the tradition owners around the Kimba sites does not support the establishment of the facility.
- Engagement with Traditional Owners has been a priority for the project, including conduct of Cultural Heritage Assessments. ARWA will endeavour to identify areas of cultural heritage on the site and to adapt its facility designs accordingly, to avoid or minimize impact to culturally significant aspects. ARWA has also delayed any further site investigations that interfere with the surface of the land or vegetation until the cultural heritage of the host site can be assessed.
- In the meantime, the government developed and passed in June 2021 the National Radioactive Waste Management Amendment (Site Selection, Community Fund, and Other Measures) Act 2021 [5], which establishes a $20 million community controlled fund, updates the legal framework for the siting process, and confirms judicial review of the Minister’s decision should any qualifying party choose to do so.

Before deciding on a site for the facility, the Minister will first issue an “intention to declare” a preferred site, which will trigger a minimum 60-day period during which people with a right or interest in the property can register their interest. Once this process is complete, the Minister can declare a site. There is an opportunity for persons or organizations to challenge the Minister’s decision through a judicial review process. After acquisition, the government will provide financial compensation to the current owner (and potentially to others with a valid right or interest). ARWA will then conduct detailed site characterization work to support facility design progress, safety analyses, licensing, and NRWMF operations.

4. CONCEPT DESIGN DEVELOPMENT

The NRWMF will include an LLW disposal facility and a temporary storage facility for ILW. Radioactive waste management activities at the site will overcome physical capacity limitations to ILW storage at Lucas Heights and provide a modern ILW storage capability while ARWA develops a pathway for ILW disposal.

ARWA has employed ANSTO and Jacobs to undertake NRWMF design and safety analysis work. ARWA has produced a safety strategy to guide the design and form the basis and guide for the development of a safety case for the disposal of LLW. Design will be a phased process moving from concept (as shown in Fig. 1), to schematic, to preliminary, then detailed design. Currently the concept stage has been completed and the schematic design phase is underway. Disposal operations are planned for 100 years and ILW storage for several decades.

FIG. 1. Illustrative depiction of NRWMF design concept [6].

The LLW disposal concept selected by ARWA is a modern, highly engineered, near surface reinforced concrete vault design. This was adopted following multi-criteria analysis of several potential design types [7] and represents modern and international good practice for LLW disposal. It is conceptually similar to the vault designs used at ENRESA El Cabril, ANDRA CSA, and DSRL Dounreay. Selection of a modern design concept also provides clear evidence to the host community of ARWA's ongoing commitment to their safety. A cast concrete lid and an engineered earth layer will cover the waste-filled LLW vaults to further protect the disposals from physical and hydrological disturbance. The LLW wastes are expected to be compacted and conditioned in cementitious grout before disposal.

The ILW storage facility concept is based on waste packages stored in concrete and steel buildings. Some ILW will be stored in highly robust steel containers, which provide the required containment and isolation safety functions and shielding. The buildings for these wastes will primarily protect the waste packages from the weather. Some ILW waste packages will require further isolation, containment and shielding and these buildings will be designed to incorporate shielding and containment structures, which provide those further safety functional requirements.

ARWA aims to establish an ILW disposal pathway once the national storage facility has been established. In the interim, the ANSTO and Australia's CSIRO have, in an international collaboration, begun desktop analyses and development for a deep borehole disposal system which is likely to be suitable for disposing Australia's ILW.

The facility layout and security design use a zoned approach to provide a layered security design which has physical and technological aspects. This includes security arrangements for Safeguarded materials. The administrative area is located outside of the secure parts of the site.

The facility will be energy selfsufficient with other services supplied from the local community infrastructure nodes.

Site layout and design will take account of environmental and cultural aspects of the site. Along with operability, the need for later decommissioning will be considered in the design.

5. SAFETY CASE DEVELOPMENT AND LICENSING

The ARWA has produced a safety strategy for the facility, which sets out a strategic approach to operational and long term safety [8]. It details ARWA strategy and key activities for the development of a site which is safe for LLW and ILW operations, and in the long term for the disposal of LLW. It describes regulatory licensing requirements and the development of information needed to underpin a safety case and safety assessments. It summarizes existing knowledge, areas of uncertainty and knowledge limitation and describes how ARWA intends to address issues important to safety. The strategy is an iterative document which will evolve with the design and with the licensing stages of the facility, as indeed will the safety case.

Safety assessment priorities highlighted in the strategy include development of a general understanding of the radiological capacity of the disposal design and of the wider physical, chemical, and radiological requirements of the waste, particularly in the context of the near field associated with the chosen design. This information will be used to inform and update the current generic waste acceptance criteria.

Appropriate codes and models are being used to generate near field and geosphere radionuclide fluxes for estimation of doses to people and the environment in the long term. Human intrusion scenarios are also being developed for long term safety modelling. Operational safety analyses are also being undertaken. In addition to normal or reference scenarios a range of variant scenarios are being developed to gain a better understanding of design and system robustness.

The NRWMF will be subject of three licensing regimes, one each for environmental or ecological impact, radiological impact, and safeguards [9, 10, 11]. The radiological licensing regime provides a phased approach, establishment of a site, construction, operations, closure, etc. ARWA intends that its approach to facility design, to site selection, facility construction and operations, and the long term effects of the disposed LLW, will meet the requirements of these regimes.

6. CONCLUSIONS

Following the process specified in the 2012 Act, volunteered land nominations were sought and assessed to identify a potential site for RWM in Australia. Three potentially suitable sites were identified, and further assessed regarding their technical suitability and community acceptability, for near surface disposal of LLW and for interim storage of ILW. A ministerial decision on the preferred site will be made shortly and a legally based process for acquisition of the site finalized.

Site specific concept designs for the disposal system and storage facility have been prepared, and safety assessments and safety case(s) are being developed to support facility applications for regulatory authorizations. The safety work references the disposal system design, the near field and geosphere characteristics, and biosphere aspects. Once the preferred site has been acquired, a programme of site characterization studies will be undertaken, which will further support aspects of facility design, regulatory authorization applications and safety cases or safety analyses.

The development of the NRWMF will secure and support the ongoing production of nuclear medicines and diagnostics in Australia, of great importance to health services, through the safe and secure management of existing and future wastes.

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Paper ID#294

RADIOACTIVE WASTE MANAGEMENT IN TÜRKIYE

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Abstract

Türkiye began studying the field of nuclear energy and radiation applications in 1956 and established a Radioactive Waste Management Facility to process and store radioactive wastes resulting from various applications. In addition to radiation application activities, Türkiye plans for three nuclear power plant (NPP) projects include ongoing construction of the Akkuyu NPP project, an approved Environmental Impact Assessment for Sinop NPP projects, and ongoing site selection studies. Türkiye published its National Radioactive Waste Management Plan in December 2020 to plan for the expected increase in radioactive waste inventory. Studies continue for establishing a near surface radioactive waste disposal facility for very low, low, and intermediate level radioactive waste. Decree Law No. 702 requires spent fuels have to be stored at the NPP site throughout the operational life of an NPP.

1. INTRODUCTION

Türkiye has made significant contributions to nuclear energy and radiation applications at its nuclear research and education centers in Istanbul and Ankara since the Atomic Energy Commission was established in 1956. From 1982 to 2018, the Turkish Atomic Energy Authority (TAEA) has jointly carried out nuclear regulatory functions and research and development (R&D) operations in nuclear energy and radiation applications. In 1989, the Radioactive Waste Management Facility (the only licenced radioactive waste facility in Türkiye) was commissioned to process and store radioactive wastes resulting from various applications at Istanbul Çekmece Campus (former Çekmece Nuclear Research and Training Center).

After 2018, Presidential Decree No. 702 established the Nuclear Regulatory Authority (NDK) to perform regulatory duties previously performed by the TAEA. In line with the new institutional structure, the NDK also assigned the TAEA the task of carrying out R&D, radioactive waste disposal, and capacity building development for Türkiye to benefit from nuclear energy and radiation applications. A new regulation made on 28 March 2020, delegated all the TAEA's authority and power to Turkish Energy, Nuclear, and Mineral Research Agency (TENMAK).

Decree Law No 702 also requires TEMAK to dispose of radioactive wastes generated as a result of the activities carried out in the sovereignty of the Republic of Türkiye. The law also requires TENMAK to prepare and submit a draft National Radioactive Waste Management Plan to the Ministry of Energy and Natural Resources (MENR) by the end of December in the years which end with zero (0) and five (5). The plan is a basis for determining the national radioactive waste management policy and strategy covering all radioactive wastes and spent fuel resulting from activities in the Republic of Türkiye. In line with this law, the first National Radioactive Waste Management Plan was approved by the Minister in December 2020. The plan sets out the necessary strategies, activities, and technical solutions required for managing radioactive wastes and spent fuels, decommissioning of nuclear and radiation facilities, and other related works such as cost and financing.

There are three NPP projects in Türkiye, the details of which are provided in subsequent sections. With the planned NPP projects in Türkiye, it is foreseen that radioactive waste will be produced at various levels and these radioactive wastes will constitute a large part of the inventory. While preparing the radioactive waste management plan, these planned NPP projects were also considered.

2. TÜRKIYE NUCLEAR ENERGY PROGRAMME

This section provides a summary for two of the three NPP projects Türkiye plans for at Akkuyu and Sinop. Site studies are ongoing for the proposed third project, so it will be discussed in another report.

2.1. Akkuyu NPP project

An intergovernmental agreement signed between the Government of Türkiye and the Government of the Russian Federation on 12 May 2010 established an NPP consisting of four VVER-1200-type reactors and related facilities in the Akkuyu field within the borders of Mersin province (south of the country).

On 2 April 2018, the TAEA (the former nuclear regulator) granted a construction licence for Unit 1 and the first concrete was poured on 3 April 2018. The main components of Unit 1 (such as core catcher, reactor vessel, and steam generators) have been transferred to the NPP side, the Unit 1 reactor vessel installation has been completed, and other components are ongoing. The NDK (established in 2018) granted a construction licence for Units 2 and 3 on 26 August 2019 and 13 November 2020, respectively. Akkuyu Nuclear Joint Stock Company has also signed the Connection Agreement to the Electricity Transmission System with the Türkiye Electricity Transmission Company on 9 December 2019. The Construction Licence application has been submitted to NDK for Unit 4 on 12 May 2020. [1]

2.2. Sinop NPP project

Intergovernmental Cooperation agreements between Government of Türkiye and the Government of the Japan were signed on 3 May 2013 to develop four ATMEA-1-type reactor units and related facilities at the Inceburun site in Sinop province (the north of the country).

Technical and commercial feasibility studies for the Sinop NPP project were submitted to MENR for review and approval. After reviewing the feasibility report, the MENR determined the Sinop site suitable for nuclear power plant construction. The Ministry of Environment and Urbanization approved the Sinop NPP Project Environmental Impact Assessment (EIA) on 11 September 2020. [2]

However, both governments decided not to continue the cooperation on Sinop NPP Project.

3. RADIOACTIVE WASTE MANAGEMENT RESPONSIBILITIES

The radioactive waste management policy sets goals and objectives for the safe and secure management of radioactive waste in Türkiye. This policy, which was prepared in accordance with the relevant international agreements to which Türkiye is a party to and the requirements of its national regulation, aimed to manage radioactive wastes in a safe, secure, sustainable, and responsible manner within the framework of international agreements and well-accepted standards. The organizational structure for radioactive waste management in the Republic of Türkiye is given in Fig. 1.

- The government is responsible for establishing the legal framework for the activities of institutional infrastructure for managing radioactive waste, determining national radioactive waste policies, and supervising its implementation.
- The Funds Board is responsible for managing the revenues and expenses of the Radioactive Waste Management Special Account and Decommissioning Special Account created within the MENR.
- TENMAK is responsible for disposal of the radioactive waste generated as a result of the activities carried out in the sovereign territory of the Republic of TürkiyeTürkiye. In addition, TENMAK prepares the National Radioactive Waste Management Plan Draft in the years ending with (0) and (5) and presents it to the MENR.
- Waste producers are responsible for managing spent fuels or radioactive wastes that arise, including reimbursing relevant costs, and any transport within or outside the facility. Waste producers make payments in the determined amount to the Radioactive Waste Management Special Account and the Decommissioning Special Account. In addition, management responsibilities of decommissioning and radioactive wastes that will arise in the meantime belong to the waste producer. The costs of the activities of waste producers during decommissioning are borne from the Decommissioning Special Account.
- The NDK is responsible for regulating and supervising activities related to radioactive waste facilities and the possession, transfer, processing, transportation, storage, export, import, trade, and disposal of radioactive wastes.

— The Ministry of Environment and Urbanization is responsible for examining the EIA report, which includes the activities to be carried out in determining the potential impacts of the projects planned to be realized and evaluating the measures to be taken to minimize these impacts, determining and evaluating the selected location and technology alternatives, and monitoring and controlling the implementation of the projects.

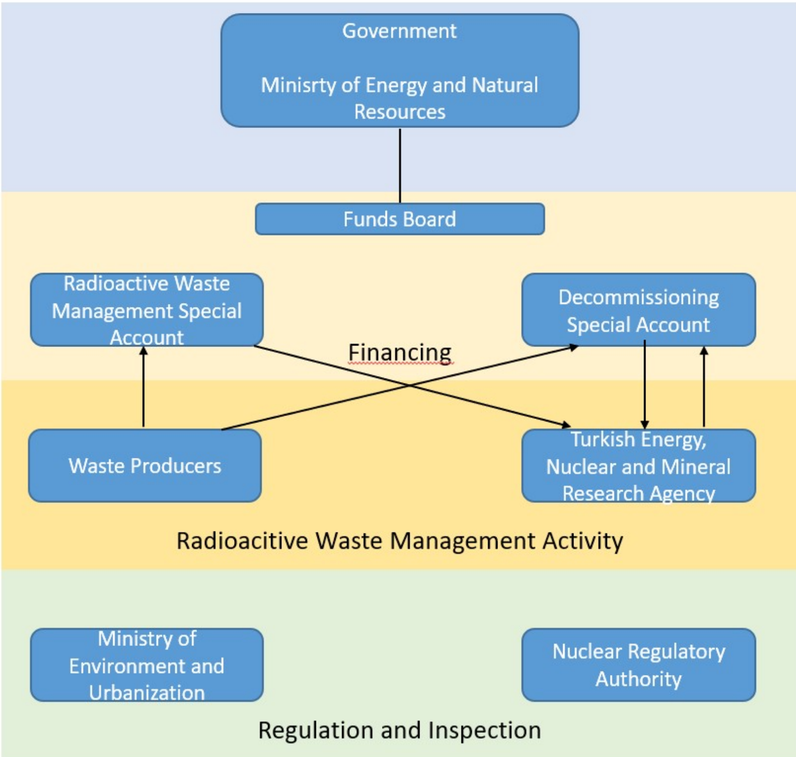

FIG. 1. Organizational structure for radioactive waste management.

4. RADIOACTIVE WASTE MANAGEMENT IN TÜRKIYE

4.1. Radioactive sources in Türkiye

The sources of radioactive wastes currently generated and likely to be generated in Türkiye are summarized under the following headings:

— NPP Operation and Decommissioning
— Research Reactor Operation and Decommissioning
— Industrial Applications
— Medical Applications
— Research and Calibration Activities
— Production of Radioisotope and Radiopharmaceutical
— Petroleum Exploration, Mining, and Scrap Metal Trading Activities
— Consumer Products
— Nuclear / Radiological Accidents
— Radioactive Waste Facilities.

4.2. Very low level and low intermediate level waste management

The TENMAK Radioactive Waste Processing and Temporary Storage Facility (Fig. 2) receives very low level (VLL) and low and intermediate level waste (LILW) resulting from activities other than radiation applications and scrap processing, petroleum exploration, consumer products, etc. The facility, operating since

1989, also receives waste from radiation applications and radioactive sources, where the owner is unknown. Established on a 10,000 m^2 area in Küçükçekmece, Istanbul, the facility contains four sealed radioactive waste storage units, one waste treatment facility, and a temporary storage area. The facility's 5000 m^3 storage capacity meets all of Türkiye's radioactive waste storage needs but can be increased, if deemed necessary.

FIG. 2. Radioactive waste processing and storage facility.

The former nuclear regulator (TAEA) approved this facility's Operation Licence in March 2013. In addition to accepting radioactive waste from all around the country, TENMAK transports radioactive waste in accordance with the IAEA Regulations for the Safe Transport of Radioactive Material. Up to now, waste originating from industrial and medical applications is accepted, classified, processed, stored, and documented by the Low Level Radioactive Waste Management Unit.

As there is no facility in Türkiye to dispose VLL and low ILW, Türkiye has initiated efforts to establish a Near Surface Disposal (NSD) facility to meet the disposal needs expected in the meantime, especially with the start of the nuclear power programme.

4.3. Spent fuel management in Türkiye

Although there is currently no spent fuel and high level waste (HLW) inventory in Türkiye, generation of HLW and spent fuel is expected from NPP operation and research reactors.

Decree Law No. 702 states licence holders are responsible for managing radioactive wastes until transferred to another authorized person. Also, spent fuels have to be stored at the NPP site throughout the operational life of a NPP.

According to plans of licence holder at Akkuyu NPP, operational spent fuels are first stored in pools and then transferred to the temporary dry storage facility at the NPP site throughout the operational life of the Akkuyu NPP. All spent fuels generated within Türkiye will be transferred to TENMAK for final disposal.

As stated in the intergovernmental agreement signed with the Russian Federation on 12 May 2010, Russian spent fuel can be reprocessed in the Russian Federation if the parties agree and sign a separate intergovernmental agreement. However, currently there is no such agreement.

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Paper #310

AN INTEGRATED APPROACH TO WASTE MANAGEMENT

How the UK is integrating radioactive waste management to deliver enhanced waste management services, a stronger workforce, more sustainable supply chain, and better value for money for the UK taxpayer

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Abstract

Developing a UK approach to integrated waste management will combine capability, capacity, and skills to develop national waste solutions and deliver better innovation and services in waste management, thus generating future value and operating in a more efficient way. It will ensure an effective thread between policy, strategy, and implementation to support programme acceleration for the UK Nuclear Decommissioning Authority (NDA) and provide lower cost waste solutions.

This is the opportunity for NDA to design a more agile waste management system and organization, with single culture and set of business priorities designed for its future mission. Key advantages of this approach include:

— Centralized capability and knowledge management, which will be more efficient and effective;
— Financial savings from lack of duplication and rationalization of management internally and with waste producers;
— A sustainable waste infrastructure and transport system;
— Increased buying power for NDA estate for waste services;
— Increased productivity and efficiency for waste services;
— Improved methods for scheduling infrastructure availability;
— A stronger UK supply chain in the decommissioning sector;
— Driving the required change in waste management behaviour and culture.

The paper describes the key drivers for change and plans for its implementation and highlights external factors contributing to the pace of change.

1. INTRODUCTION

As the remaining UK Nuclear Decommissioning Authority (NDA) sites move away from operations to full-scale decommissioning and environmental remediation, businesses are generating larger volumes of radioactive waste, as well as non-radioactive waste, and the nature of the waste is changing. This brings an opportunity to think differently about waste management, focusing on how to avoid, minimize, reuse, or recycle waste to create a more sustainable environment, supply chain, and workforce.

This is the opportunity for the NDA to design a more agile waste management system and organization, with a single culture and set of business priorities designed for its future mission. Key benefits of integrated waste management include:

— A centralized capability and knowledge management, which will be more efficient and effective;
— Financial savings from lack of duplication and rationalization of management, both internally and with waste producers;
— A sustainable waste infrastructure and transport system;
— Increased buying power for NDA for waste services;
— Increased productivity and efficiency for waste services;

— Improved methods for scheduling infrastructure availability;
— A stronger UK supply chain in the decommissioning sector;
— Driving the required change in waste management behaviour and culture.

To encourage and support a more integrated approach to waste management in the UK, the government is expected to update the UK policy on radioactive waste management, removing barriers to change the way the UK's radioactive waste is managed and disposal of. This will be a key step in optimizing waste management approaches in the future.

In November 2020, the NDA launched the Integrated Waste Management Programme (IWMP) to optimize end-to-end waste management and deliver increased value to the taxpayer. Following the creation of the IWMP, in January 2021, NDA announced the intent to create a single waste division Nuclear Waste Services (combining LLWR and RWM) delivering both strategic and operational benefits that embodies a One NDA mindset.

A key driver for creating a more integrated approach to waste management was the Nuclear Sector Deal that formed a key part of the UK Government Industrial Strategy which led to industry and government working in partnership to deliver a clean approach to economic growth with benefits for the UK taxpayer.

To deliver the workforce commitments described in the nuclear sector deal the Nuclear Skills Strategy Group was empowered to work on behalf of the sector to consider the future skills needed to deliver the full UK nuclear programme for civil and defence needs whilst at the same time diversifying the workforce and supporting a new range of jobs for developing a greener economy for the UK.

The developments made in waste management over recent years and the further commitment to a more integrated and collaborative approach will revolutionize the way the NDA operates in the in UK nuclear sector. NDA businesses are committed to delivering the nuclear sector deal providing value for money for the taxpayer and creating a workforce to the future needs of the mission. The next two years will see the changes embedded and measured benefits for the new way of working.

2. UNITED KINGDOM CONTEXT

Over 90% of the UK's predicted volume of radioactive waste is generated by the NDA group operating companies. The decommissioning landscape in the UK is changing in ways that will increase the amount of waste arising in the near term and change the types of waste being generated, which will require further development in radioactive waste management.

In addition to securing the decommissioning of its sites, the NDA has responsibilities to provide strategic direction for waste management and the necessary capabilities and access to facilities to enable management of the waste through the full life cycle, including new build reactors for fission and fusion technologies, including small modular reactors (SMRs) and advanced modular reactors (AMRs). The NDA has a responsibility to ensure that this capability is optimized and provides value for money and is available to other waste producers, such as Ministry of Defence and medical facilities, within the UK as required.

The majority of spend on waste management within the NDA estate is by the three main decommissioning organizations, such as Sellafield Ltd, Dounreay Site Restoration Ltd and Magnox Ltd, as they progress the NDA's mission to decommission the legacy sites they operate. The sites manage waste throughout its life cycle, from initial characterization, retrieval, treatment, packaging, and storage and provide some disposal capacity at Sellafield and Dounreay. They also manage the interface with the relevant regulators with respect to their waste. The waste-producing businesses use a combination of their own infrastructure, infrastructure at other waste producer sites, and the supply chain.

3. INTEGRATED WASTE MANAGEMENT STRATEGY

Over the last five years, the NDA has developed an Integrated Waste Management Strategy, which is articulated in several key documents including the NDA Strategy 2016 [1] and, most recently, the NDA Radioactive Waste Strategy (RWS) [2] and NDA Strategy 2021 [3].

Within the NDA Strategy, Integrated Waste Management features as one of its five Strategic Themes, indicating the focus being placed on it and contains an articulation of seven principles for IWM and the NDA's strategic positions and preferences, focusing on the following stages of managing waste:

— Planning and preparation
— Treatment and packaging
— Storage
— Disposal.

Currently, UK radioactive waste is largely managed within the waste category framework of high level waste (HLW), intermediate level waste (ILW), low level waste (LLW), very low level waste (VLLW), with the waste category effectively constraining the options for managing the waste. NDA has been working towards a more integrated approach to waste management, where waste management decisions are driven by the properties of the waste (radiological, physical, and chemical properties) rather than by the category and where all NDA businesses take ownership for this delivery of this part of the NDA mission.

The NDA RWS is a clear statement that this is the expected way forward. It will enable opportunities for managing waste across the standard waste categories and embed the Integrated Waste Management principles, such as the application of the waste hierarchy and sharing treatment and storage assets.

3.1. Policy background

The Radioactive Waste Strategy (Appendix 1) sets out the policy context for the management of radioactive waste in the UK, notably:

— Implementing Geological Disposal – Working with Communities (UK policy);
— The Welsh Government – Geological Disposal: Working with Communities policy;
— The Scottish Government Higher Activity Waste policy;
— Policy for the Long-Term Management of Solid Low Level Radioactive Waste in the UK.

The government has advised that it is undertaking a review of radioactive waste policy to bring further clarity and provide a more enabling policy environment for realising the potential benefits of integrated waste management. NDA is actively supporting the government in this activity, as it means that it can implement its strategy, whilst ensuring alignment of its future aspirations with emerging government policy.

3.2. NDA Integrated Waste Management Capability

The RWS represents a clear statement of the direction of travel for waste management in the NDA group and commits to putting in place an integrated waste management (IWM) programme that will provide a capability across the NDA Group for the full life cycle of waste that will:

— Optimize and coordinate the management of waste and share good practice;
— Identify and refine opportunities to enhance waste management, supporting the development of strategy and policy in this area;
— Deliver change, implement new initiatives and opportunities, and provide access to the necessary infrastructure to deliver the mission.

4. WASTE MANAGEMENT CAPABILITY – HISTORICAL BACKGROUND

Whilst the NDA's two waste management organizations, Low Level Waste Repository Ltd (LLWR) and Radioactive Waste Management Ltd (RWM), undertake broadly similar activities, their histories are very separate, which has resulted in two notably different organizations. The current NDA waste management organizations are shown in Fig. 1.

LLWR Ltd was formed in 2007 as the operator and Nuclear Site Licence holder of the LLW Repository. Before this, the repository was owned and operated by British Nuclear Fuels Ltd as a part of the Sellafield site. The separation from Sellafield and the creation of the standalone organization was undertaken to enable the first of the NDA's Parent Body Organization competitions. After competition, LLWR Ltd transferred into the ownership of an international consortium UK Nuclear Waste Management (UKNWM Ltd). In July 2021 LLWR Ltd transferred back into the NDA group as a wholly owned subsidiary as a precursor to the changes planned for integrating waste management in the UK.

Radioactive Waste Management Ltd was formed as a subsidiary of the NDA on 1 April 2014. Prior to this, the organization was a directorate of the NDA (Radioactive Waste Management Directorate). This was deemed a necessary step to enable RWM to apply for and hold the regulatory permits and licences required for the siting, construction, and operation of a geological disposal facility (GDF). Prior to being part of the NDA, RWM was known as NIREX and had supported Government and the industry in developing geological disposal since 1985.

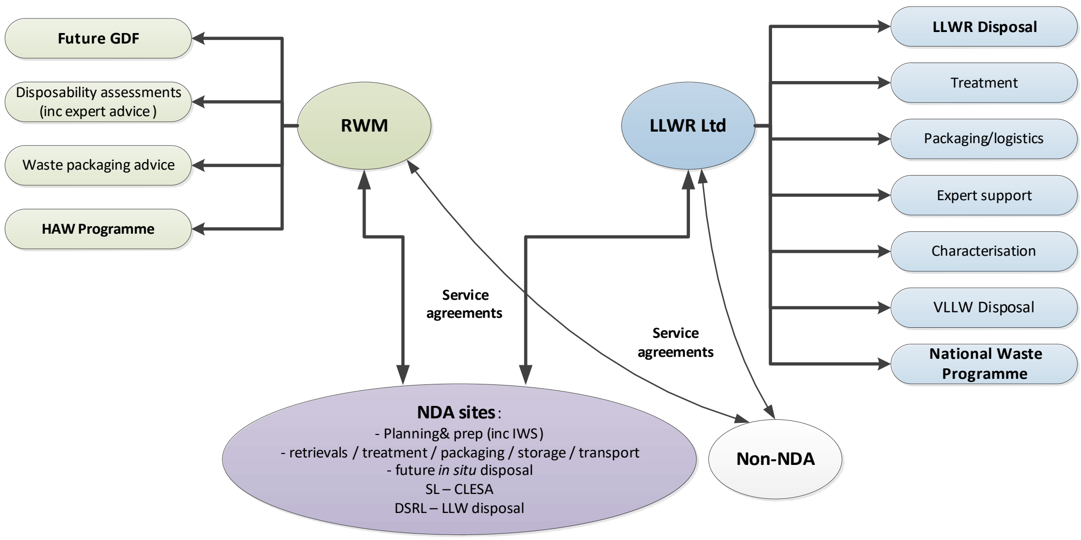

FIG.1. Current NDA Waste Management Landscape

LLWR Ltd and RWM have essential roles in supporting the decommissioning mission, using their capabilities to support the waste producers, by enabling the management of radioactive waste:

- RWM is charged with developing the geological disposal facility, which will provide a final disposal route for Higher Activity Wastes. RWM also provides advice on the packaging of that waste now to reduce the risk of it not being disposable when the GDF is available.
- LLWR Ltd operates the UK's main low level waste disposal route and provides access to the supply chain for wide range of services for the management of LLW. Diversion of waste to these alternative supply chain routes (treatment, incineration, landfill disposal for some LLW) has made huge progress in preserving capacity at the Low Level Waste Repository, in turn securing its availability for many decades. LLWR waste diversion metrics are shown in Fig. 2.
- Whilst LLWR Ltd and RWM work in different parts of the radioactive waste spectrum, many aspects of what they do are the same. Both organizations:
  - Undertake design and safety case development for radioactive waste disposal facilities;
  - Undertake disposability assessments;

- Provide expertise in the packaging and transport of radioactive waste;
- Advise organizations about how best to manage their waste;
- Implement collaborative programmes designed to optimize waste management.

The main difference between the organizations is that LLWR Ltd operates an active facility and therefore holds a nuclear site licence.

As shown in Fig. 2, LLWR Ltd also operates the National Waste Programme (NWP) on behalf of the NDA [4], and RWM delivers a Higher Activity Waste (HAW) programme, both of which support waste producers and develops opportunities to further optimize the management of radioactive waste. Both programmes contribute significantly to the integrated project teams that support strategy development and progress opportunities in topic-specific areas (e.g. problematic wastes).

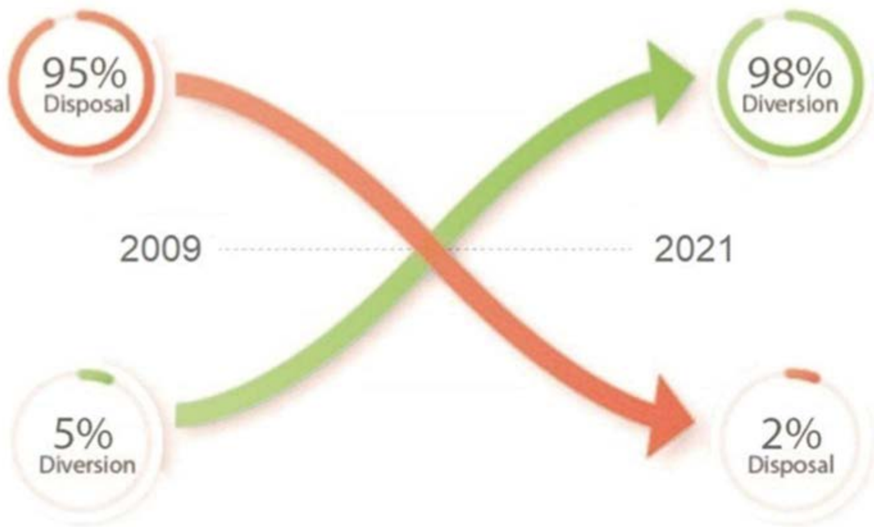

FIG. 2. Waste Diversion at LLWR.

5. INTEGRATED WASTE MANAGEMENT PROGRAMME

As described earlier, the NDA is transitioning to work more collaboratively across all its businesses to gain the benefits from working as “One NDA.” Creating an IWM programme embodies a One NDA mindset, increases ownership for the challenges of managing different wastes and ensures decisions can be made, timely and with the benefit of the whole estate considered.

Opportunities exist to deliver an integrated programme, to make more effective waste management decisions for the estate (e.g. treatment, packaging, storage, transport, and disposal), sharing best practice across all waste producers and using economies of scale to improve buying efficiencies. There are opportunities for strategic change such as near surface disposal and thermal treatment for certain wastes that are currently being considered. The integrated waste programme will ensure these critical projects are delivered in the most effective way, providing step changes in waste management in the UK.

The IWM programme has clear objectives which are core to delivering the NDA’s mission. These are:

— Enabling the industry to manage its radioactive waste in an integrated way, according to its hazard, without its routing being restricted due to its classification;
— Ensuring the appropriate infrastructure and arrangements are in place when required;
— Avoiding unnecessary utilization of resources on packaging, conditioning, and storage where more appropriate alternative treatment, storage and disposal options could be made available;
— Supporting the acceleration of decommissioning programmes and supporting earlier risk and hazard reduction;

— Exploring, researching, and exploiting all potential opportunities for additional efficiencies and improvements to waste management;
— Engendering and embedding a change in culture so waste producers think and act more flexibly about how they manage their waste;
— Enabling faster implementation of waste solutions;
— Facilitating a positive impact on the UK supply chain providing global export opportunities.

The success of the IWM programme will be evident across all waste producers with a collective baseline from which to measure successful outcomes and benefits against established targets. IWM programme outcomes and benefits are:

— Reduced cost of waste treatment, packaging and storage for waste producers and consignors;
— A sustainable waste infrastructure and transport system;
— Near term waste disposal options available for waste producers reducing reliance on interim storage;
— Increased buying power for NDA estate for waste services;
— Increase productivity and efficiency for waste services;
— Improved methods for scheduling infrastructure availability;
— The potential introduction of a national logistical network;
— A positive impact on the UK supply chain providing global export opportunities.

Waste management activity that falls within the IWM programme accounts for £25bn of the total nuclear provision of £130bn. Initial plans have identified potential savings of around £2.3bn that could be delivered through a range of new waste treatment facilities, packaging, and disposal routes. Figure 33 shows the estimated cost savings due to the integrated waste management programme.

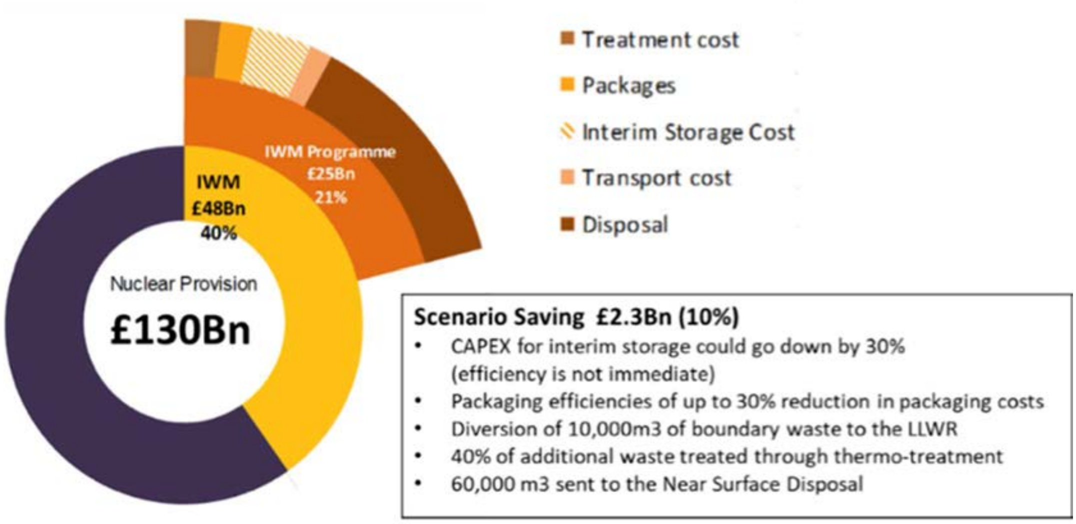

FIG. 3. IWM Programme Cost Savings.

The IWM programme adopts a systems approach and comprises a broad spectrum of activities. Work programmes already under way include a scenario modelling tool that looks at the entire waste life cycle across the NDA group and enables understanding of the impacts of any changes to waste streams, production rates, treatments, etc. A key focus is to initiate new ways of treating waste, such as thermal treatment technology being tested through a technology pilot programme at Sellafield.

A key focus is to enable the supply chain to support the development of new methods and techniques to reduce the costs of decommissioning, avoiding unnecessary use of resources such as waste packaging and interim storage costs. The programme is focused on developing and instilling a single waste management culture with a common approach to radioactive waste management. This in turns develops groupwide waste management solutions, resulting in shared good practice and learning from experience – within the UK and internationally.

This is a major change in the way the NDA works, and its success relies upon initial investment in new infrastructure, technology and skills and the creation of a dynamic and flexible workforce.

6. SINGLE WASTE ENTITY – NUCLEAR WASTE SERVICES LTD

The next phase in creating an integrated approach to waste management is to form a single waste management business and LLW Repository Ltd recently becoming a direct subsidiary of the NDA was a key enabler to this becoming a reality. The NDA will combine capabilities from LLWR Ltd, Radioactive Waste Management (RWM) and the IWM programme, to form a single waste management division. This will exist with a common identity, Nuclear Waste Services, and a single executive management team. Combining these talents will allow us to grow capability even further and simplify how the NDA operates – helping to deliver the overall NDA mission and supporting its 'One NDA' approach. Figure 4 provides the vision for integrated waste management.

FIG. 4. Integrated Waste Management Vision.

While the missions of LLWR Ltd and RWM remain unchanged, the approach and capabilities required for waste management need to adapt to deal with changes in the operating environment. The liabilities NDA is trusted to manage are changing, e.g. the pace of decommissioning on Magnox sites and the inclusion of the AGR fleet for decommissioning.

There is a growing urgency to act on NDA corporate commitments (e.g. recycling 50% of waste produced from decommissioning and >70% reduction in 'secondary wastes' by 2030), the UK's Nuclear Sector Deal, and commitments under the UN's Sustainable Development Goals. These all drive a heightened need to better address expectations of our customers, through a single 'front door'.

Given the nature of the drivers of change, the following factors are critical for helping the NDA to meet its challenging mission - which span multiple stakeholders, waste forms, geographies, and phases of the waste life cycle:

- Integration (of data, ideas, whole system thinking and decision making);
- Collaboration;
- An outward looking mindset.

A whole system and enterprise approach is needed to capture and realize the benefits of these factors. An approach which embraces delivery of critical enablers (e.g. People, Information Governance, Transport & Logistics, R&D, Stakeholder Engagement and International Relations) by leveraging the strengths of the whole waste and decommissioning ecosystem. This approach also leverages the benefits of organizational scale, e.g. to contract on a long term and volume basis, thereby encouraging suppliers to innovate to create value and reduce costs of waste management.

Nuclear Waste Services will adopt the following principles as a basis for delivering waste services:

— Assist waste producers to overcome a range of challenges and to capitalize on opportunities by enabling a flexible approach to long term waste management;
— Optimize waste management routes across the NDA estate;
— Increase efficiency in the treatment, storage, transport, and disposal of wastes;
— Promote and support robust decision making processes to identify the most advantageous options for waste management.

The intent is to create a customer focused, single integrated waste management business. This will operate under a single interface agreement with NDA, with one name and one executive management team. It will be a centre of excellence that brings together science, engineering, safety, operational, project management, commercial, and regulatory expertise in nuclear waste management. Figure 5 shows the business line and matrix organization structure for Nuclear Waste Services. Individuals and teams will work in a unified way, be highly networked and have a broad range of opportunities for personal development and progression.

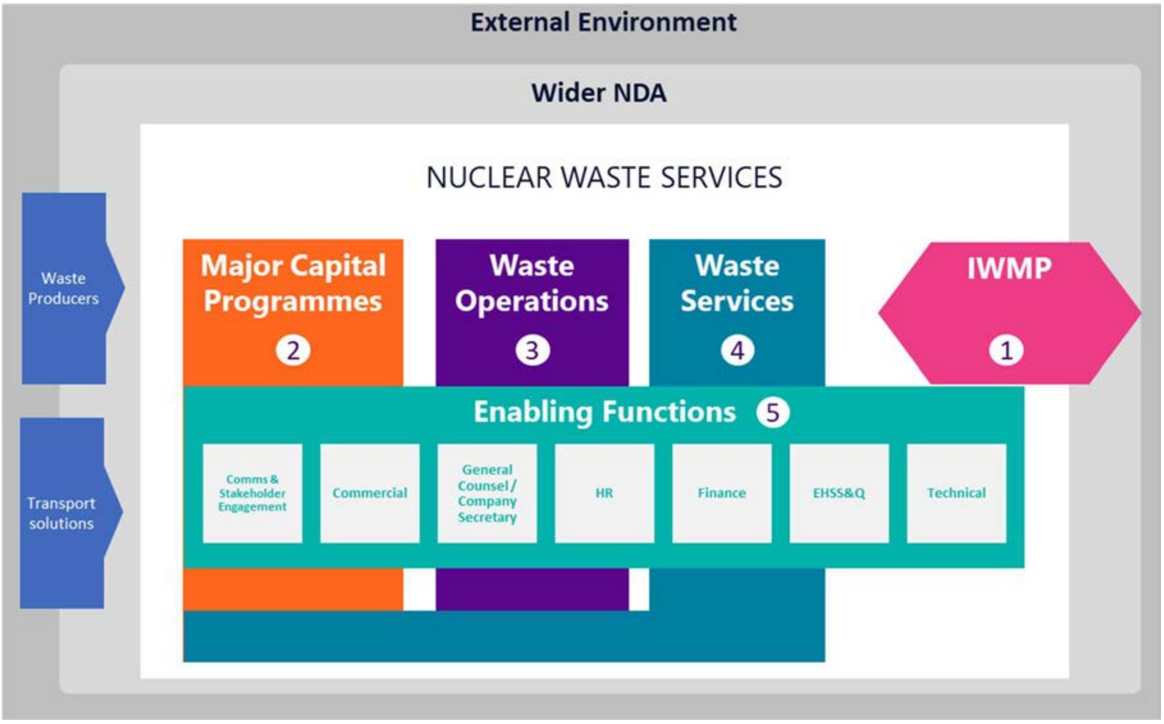

FIG. 5. How Nuclear Waste Services will operate.

Nuclear Waste Services will have three lines of business and the IWM programme, supported by enabling functions.

Major capital programmes: Will define requirements, develop designs, acquire social licence, and procure capabilities to design, build waste disposal facilities, and transfer into operations.

Waste Operations: Will own, operate, and care for nuclear waste management facilities, including the national Low Level Waste Repository, and others over time.

Waste Services: Will support waste producers to address the legacy of industrial activities, by providing expert advice and waste solutions to complex nuclear and non-nuclear decommissioning and cleanup activities in the UK and internationally. The NDA will help amplify, mobilize, and showcase capabilities of the UK supply chain for the benefit of UK plc, by helping to export technical excellence, technology, and intellectual property.

7. NUCLEAR SECTOR DEAL

A key driver for creating a more integrated approach to waste management was the Nuclear Sector Deal, launched on 28 June 2018, [5] as part of the UK Government Industrial Strategy which led to Industry and Government working in partnership to deliver a clean approach to economic growth with benefits for the UK taxpayer. The deal included 82 commitments between industry and government, with four key targets currently led by five champions of industry who hold significant influence and authority. The governance structure that is accountable for the delivery of the deal reports to the Nuclear Industry Council (NIC).

Whilst the initial focus of the Nuclear Sector Deal is to deliver on a vision up to 2030, the deal has the potential to be the foundation for much longer-term progress and activity, setting out an ambition for the nuclear sector to deliver by 2030:

- A 30% reduction in the cost of new build projects;
- Savings of 20% in the cost of decommissioning compared with current estimates;
- 40% women in the nuclear sector;
- Up to £2 billion domestic and international contract wins.

The Nuclear Sector Deal aims to promote greater collaboration within the sector and government to meet the NDA's Clean Growth Grand Challenge, provide jobs and growth across the country, and foster innovation to demonstrate best in class construction, operation, support, and decommissioning of nuclear facilities, capitalizing on domestic and international opportunities.

Over the last three years, a significant scope of work has been delivered through combined efforts and a coordinated approach between industry and government; whilst not without challenge, these outcomes have exceeded expectations.

Significant successes since the launch of the Nuclear Sector Deal include:

- Industry have identified 14 key enablers of risk reduction [6], which for the first time enables developers, investors, and government to hold a common understanding of risk on nuclear industry mega projects.
- Industry and government have jointly developed and published a National Decommissioning and Waste Management Pipeline in 2019 [7], which for the first time, enables the civil and defence nuclear supply chain to have sight of the planned work at NDA nuclear sites through 2040 and beyond.
- Industry and government have identified six key target export regions, with a total market size of £429bn, and are implementing actions to put the UK supply chain in the best position to win contracts in these regions.
- Industry and government published a Gender Roadmap in 2019 [8], which 25 key organizations across civil and defence nuclear pledged to realizing, enabling a unified commitment across the sector.
- The government has successfully run Phase 2 of the Advanced Modular Reactor competition, which for the first time provides the supply chain with £40m funding and confidence to advance the development for the Generation IV reactor technology.

8. NUCLEAR 2050 PROGRAMME

A recent development of the Nuclear Sector Deal is to deliver the developing commitment to meet the Nuclear 2050 vision that requires the sector to collectively focus on unity, simplicity, and delivery.

The Nuclear Industry Association's (NIA) roadmap of how civil nuclear power will contribute toward achieving Net Zero is detailed in 'Forty by Fifty: The Nuclear Roadmap' [9]. The paper sets out how nuclear can provide up to 40% of the UK's clean power by 2050, through a range of reactor technologies, delivering a £33bn annual gross value (GVA) to the economy, and up to 300,000 new jobs.

Nuclear 2050 provides a common delivery system for the mutual capability and capacity across skills, supply chain, and innovation. Integrated waste management continues to be an essential enabler to deliver the commitments and will provide through the IWM programme and creation of Nuclear Waste Services the opportunity to achieve a large proportion of the legacy cost reduction, support an export market, and contribute to the reducing in new reactor costs. The three commitments made by the sector have been updated in the latest Nuclear Sector Deal 2021.

(a) **20% decommissioning and waste management cost reduction.** The sector needs to deliver major reductions to the cost of nuclear decommissioning and waste management, a key driver for integrated waste management. Managing the nuclear liability more efficiently through unification and simplification across the sector will not only deliver 20% cost savings to the UK taxpayer but will support the NDA's contribution to Net Zero through use of the waste hierarchy and sustainable innovation.
(b) **30% new reactor cost reduction.** The sector needs to deliver major reductions to the cost of new nuclear. A target cost to the consumer of less than £64.50/MWh (a 30% cost reduction) will set a benchmark for all nuclear reactor technologies. Achieving this milestone will ensure affordable nuclear energy continues to play a key role in the Net Zero energy mix through to 2050 by making nuclear energy competitive with other green energy sources. Securing a sustainable future for nuclear power provides the UK with a robust and reliable UK-based energy supply, long term jobs and therefore significantly contributing to the UK's energy security.
(c) **£65bn of new export contracts.** The UK needs to exploit domestic nuclear capability to win a share of growing export markets. The UK has an experienced and established nuclear sector, with world-leading emerging innovations nearing fruition. To support the UK's economic recovery, the nuclear sector will target £65bn of new export contracts of UK-based capability, technology, and expertise by 2050. Whilst such a significant expansion of nuclear exports supports UK economic development and a 'Global Britain,' it will also enable the UK to support international partners with their national efforts to reduce carbon emissions in support of the Paris Agreement.

In order to ensure the delivery targets can be achieved in the most efficient, effective, and sustainable way, the right leadership and governance structure has to be in place and the sector has to be focused on the right innovation to deliver short term and long term value. Additionally, the sector needs to have the right capability and capacity within the supply chain and skills base across the UK's nuclear regions to meet demand. Nuclear 2050 continues to deliver on the key capability target of achieving 40% female participation in the nuclear sector by 2030, whilst building on this and developing regionalized diversity targets to meet skills demand.

By reducing new infrastructure and legacy costs, strengthening the supply chain to unlock existing and new markets nationally and internationally, and creating green jobs in sustainable way, NDA will increase its contribution to the economic recovery, Net Zero, the levelling-up initiative, deliver better value to the taxpayer and safeguard our national security.

9. THE NUCLEAR SKILLS STRATEGY GROUP

As described in the previous section, meeting the UK's ambition for continued nuclear power and associated activities for decommissioning and waste management is only possible with the right workforce. The challenge faced by the nuclear sector is the required development time to train nuclear specialists and compounded by the age profile of the existing workforce that add to attrition rates.

The Nuclear Skills Strategy Group (NSSG) is the employer-led nuclear industry skills group and provides 'one voice' to government. The members of NSSG include major employing organizations responsible for implementing major development programmes such as EDF or with accountability for a high expenditure, such as NDA and MOD. Members also include government departments responsible for nuclear development and skills leadership and representatives of the trade unions in the nuclear industry. Key aims of the NSSG include:

- To ensure the sector can meet the demand for skilled jobs into the future – both skills for nuclear and nuclear skills;
- To diversify the workforce for the future attracting talent from a broader range of society. An initial goal of including 40% female representation by 2030 has been set;
- To grow subject matter experts to replace those retiring and to ensure world class innovation and development of new technology;
- To encourage sector transferability, improving the mobility of skilled people;
- To excite the next generation about nuclear energy and play a key role in education at schools providing material to support the curriculum in this area.

The NSSG is accountable for developing a Nuclear Skills Strategic Plan [10], aligned to the commitments made in the Nuclear Sector Deal to address the key risks to skills and resources facing the industry, as it approaches a time of unparalleled growth.

The NSSG is accountable for:

- Developing an overall Delivery Plan to implement Nuclear Skills Strategy;
- Monitoring and optimizing employer investment for education, training, and skills development;
- Commissioning and endorsing solutions from relevant bodies, as appropriate, within funding limits;
- Establishing new requirements for skills services and products to the nuclear industry;
- Ensuring arrangements are put in place to ensure the quality of delivery of the activities;
- Creating an annual report for Nuclear Workforce Assessment;
- Identifying and reporting the overall performance/effectiveness of initiatives and activities through key performance indicators, such as the measurement of a reduction in skills gaps and return on investments.

In 2019 the NSSG Published Nuclear Workforce Assessment [11], which alongside the Nuclear Sector Deal set out the skills challenges associated with a new build programme, existing nuclear operations, and decommissioning and waste management activities in the civil and defence sectors, particularly in the context of an aging workforce. The recently developed workforce planning tool enables NSSG to test the impact of a variety of scenarios and the influence they will have on future workforce needs, essential for long term sector planning.

In June 2019, the UK was the first major country to legislate for a target of net-zero carbon emissions. The implication of this legal commitment for the nuclear sector is not yet clear; however, the publication 'Forty by Fifty: The Nuclear Roadmap' [9] presents proposals for the contribution of nuclear that would result in the need for additional large and/or small scale reactors. This increased role for nuclear would lead to increased workforce demand, a demand that needs to be to be met through effective skills planning.

NSSG members also bring international best practices and cross sector learning to the UK. This is achieved through shared initiatives from other sectors, or the international nuclear sector, secondments, and broader recruitment activities focused on other sectors. The external viewpoints can bring innovation to the NDA's sector, leading to new ways of working and cost reduction which align to the key aims of the NDA to provide value for money to the UK taxpayers in the areas of decommissioning and waste management.

10. CONCLUSION

The paper describes the recent development in the NDA's approach to integrated waste management that has been enabled by policy, strategy, programme, and organizational changes. Whilst there is still some way to go to embed a more integrated approach to waste management and deliver against commitments laid out in the nuclear sector deal and for the development of the future workforce, NDA is committed to this change, to delivering the commitment as set out in the nuclear sector deal. and to the transparent measurement of the benefits delivered.

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DEVELOPMENT OF A COMPREHENSIVE NUCLEAR WASTE MANAGEMENT PROGRAMME IN A SMALL-INVENTORY STATE

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Abstract

Norway had a total of four research reactors in operation from 1951 to 2019. All have now been taken out of operation. To enable decommissioning, a new infrastructure for management of radioactive waste has to be developed. That infrastructure need to comprise all classes of radioactive waste, including 17 tons of spent research reactor fuel. It has to describe the entire range of activities covered by a waste management strategy: from collection, treatment, and transport of waste to storage and disposal. Few facilities with the required capabilities, capacities, and remaining lifetime exist in Norway. Therefore, practically all types of facilities for management of radioactive waste have to be at least considered and, in many cases, built. The spent fuel has a variety of properties. 10 tons consist of metallic uranium in aluminum cladding, which is chemically unstable when in contact with water or air. This makes storage and disposal more challenging than for modern commercial fuel. Hence, different options for predisposal treatment are being considered. Facilities for predisposal management of low- and intermediate level waste are being planned, along with storage and disposal facilities for both spent fuel and low- and intermediate level waste. The programme may include the establishment of a combined national facility for disposal of all classes of radioactive waste. For spent fuel or high level waste from predisposal treatment, two alternative disposal concepts are being developed: a mined repository or deep borehole disposal. Despite the relatively small amounts of radioactive waste to be managed, Norway will need to develop solutions for the same waste types as many states with commercial power plants. Therefore, many of the same questions need to be answered, such as how to select the site for a disposal facility and how to collaborate with other nations in the pursuit of safe and sustainable solutions.

1. INTRODUCTION

A comprehensive nuclear waste management programme has to describe how to handle waste in a cradle-to-grave-perspective, which means that it needs to contain the following processes [1]:

- Collection: Radioactive waste can only be delivered to facilities that have an appropriate permit from the competent authority.
- Characterisation: Determination of the physical, mechanical, chemical, radiological, and biological properties of waste.
- Treatment: Operations intended to benefit safety and/or economy by changing the characteristics of the waste, reducing the volume, removing radionuclides, or changing the composition of the waste.
- Conditioning: Operations that produce a waste package suitable for handling, transport, storage, and/or disposal.
- Transport: Deliberate physical movement of radioactive material.
- Storage: The holding of waste in a facility that provides for its containment, with the intention of retrieval.
- Disposal: The emplacement of waste in an appropriate facility without the intention of retrieval.

Mature technologies for all these processes exist. However, countries with small inventories of nuclear waste face some unique challenges when it comes to studying, assessing, implementing, and financing the right combination of technologies. The term ‘small inventory’ is ambiguous but useful for describing inventories of intermediate level waste (ILW) or high level waste (HLW) whose volume could make it challenging to finance waste management through levies on nuclear generated electricity [2]. Such countries generally have few or no nuclear power plants that can contribute to financing a nuclear waste management programme, but still need to handle radioactive waste from medical, industrial, or research activities. Depending on country-specific circumstances, lack of nuclear-related competences could be as great a problem as a lack of finances.

Norway is a small-inventory state. The paper describes ongoing work to establish a nuclear waste management programme, with an emphasis on considerations and potential solutions that may distinguish small-inventory states from countries that have large commercial nuclear power programmes.

In the 1950s, Norway was a pioneer in nuclear technology. When the country's first research reactor, Joint Establishment Experimental Pile (JEEP I), went critical in 1951, only five other countries had previously achieved this distinction [3]. Table 1 lists the research reactors operating in Norway since then. All have been taken out of operation. Plans for decommissioning are being developed.

TABLE 1. NORWEGIAN RESEARCH REACTORS.

Reactor name	Thermal power (MW)	Location	Period of operation
JEEP I	0.4	Kjeller	1951 to 1967
HBWR	25	Halden	1959 to 2018
NORA	0	Kjeller	1961 to 1968
JEEP II	2	Kjeller	1966 to 2019

The current infrastructure for handling radioactive waste includes the following facilities [4]:

— Facilities for storage of spent fuel (SF) from the research reactors, both at Kjeller and Halden.
  - At-reactor wet storage within the reactor halls of the JEEP II and the Halden Boiling Heavy Water Reactor (HBWR).
  - JEEP I dry storage at Kjeller, intended as a short term measure when it was commissioned in 1965.
  - "Brønnhuset" dry storage at Kjeller, commissioned in 1965.
  - Fuel Bunker Building, Halden, commissioned in 1961–62.
— METLAB II, a hot-cell facility for handling, refabrication, and testing of SF and other radiation sources at Kjeller, commissioned in 1965.
— A facility for receiving, sorting, handling, treatment, and conditioning of low- and intermediate level waste (LILW), located within the nuclear research site at Kjeller. This was built in 1959 and expanded by adding a storage in 1966.
— A storage building for LILW, located at Kjeller, built in 1978.
— A cavern-type combined storage- and disposal facility for low level waste and short lived ILW at Himdalen (mid-way between Kjeller and Halden), commissioned in 1999.

There are also disposal facilities for naturally occurring radioactive material (NORM) in Norway, but NORM is outside the scope of the paper.

The Institute for Energy Technology (IFE), a private research foundation, holds the license for the facilities in Halden, Kjeller, and Himdalen (the Himdalen facility is owned by the state but operated by IFE). In 2018, the Government established Norwegian Nuclear Decommissioning (NND), whose purpose is to act as a national agency for decommissioning the nuclear research facilities at Kjeller and Halden and to implement a comprehensive programme for management of nuclear waste. A process for transferring the reactor sites and the waste management infrastructure at Kjeller, Halden, and Himdalen to NND, is ongoing.

2. THE PROBLEM

The nuclear waste management programme should enable decommissioning of the nuclear facilities at Kjeller and Halden and ensure all radioactive waste is handled safely. In Norway, spent nuclear fuel is considered as waste [4].

The NORA and JEEP I reactors were partially decommissioned when operations ceased in the late 1960s. Operations of HBWR and JEEP II stopped in 2018 and 2019, respectively. The HBWR has been placed in a subcritical state by lowering the control rods all the way into the reactor and detaching the mechanisms for retracting them. However, fuel remains in the reactor vessel, and the primary circuit remains filled and in circulation. This is due to insufficient available capacity in the fuel storage facilities and an ongoing safety review of the storage facilities. The safety review includes a reassessment of criticality calculations [5]. Fuel has been removed from JEEP II, and the primary circuit has been drained.

Fuel for NORA was leased from the U.S. Atomic Energy Commission. It was, except for a few rods, returned at the end of the leasing term [6]. To return SF from JEEP I, JEEP II, and HBWR to the country of origin has not been an option, unlike research reactors in several other countries [7]. Therefore, Norway needs to implement near term and long term solutions for managing SF.

The total mass of the SF is 17 tons, 10 of which consists of metallic uranium in aluminium cladding, see Table 2. This was used in JEEP I and for the first charge of HBWR. The chemical properties of metallic uranium make it less favourable for storage and disposal than modern nuclear fuel, which is most often made of uranium oxide (UO_2) or mixed oxide. Metallic uranium corrodes when in contact with water or air, whereas UO_2 is chemically stable [8]. Therefore, metallic fuel cannot contain radioactivity within the waste form in the same way as oxide. When metallic uranium corrodes, it can lead to the formation of uranium hydride (UH_3). UH_3 is pyrophoric, which means that it can ignite and burn in a self-sustaining oxidation reaction [9]. The corrosion reaction is exothermal, which means that its heat output has to be accounted for in the safety case of a repository. The corrosion products are less dense and do not have the structural integrity of metallic uranium. This means that swelling and geometric rearrangement can take place, both of which complicate the safety case for storage and disposal [10]. A similar but not as critical issue relates to the fuel from JEEP II, which consists of UO_2 in aluminium cladding. Aluminium is more prone to corrosion than zircaloy, which in which modern fuels are usually clad [11].

TABLE 2. NORWEGIAN SPENT FUEL.

Material type	Reactor	Mass (tons)
Metallic U in Al cladding	JEEP I, NORA, and HBWR (1959-1961)	10
UO_2 in Al cladding	JEEP II	1.5
UO_2 in zircaloy	HBWR (1961–2018)	3.9
Booster and experimental	HBWR	1.4

The remaining service life of the fuel storage facilities is undetermined. It is necessary to either assess and define the remaining lifetime or remove the fuel. The JEEP I dry vault storage has exceeded its service life; groundwater penetration into some of the storage positions has been detected. Removing the fuel from this facility is therefore a high priority. Removal of fuel from the reactor core at the HBWR is of similar importance because the reactor is not designed for prolonged storage [5]. Currently, some fuel is stored in designated at-reactor storages within the reactor halls of JEEP II and HBWR (in addition to storages outside the reactor buildings). Removal of fuel from the reactor halls is a prerequisite for decommissioning those facilities.

While the reactors remained in operation, their operational waste made up approximately half of the 20 to 40 m^3 of LILW generated annually in Norway. The other half originated in medical, industrial, and research applications of radioactivity. LILW is treated at the treatment facility at Kjeller and disposed of in Himdalen. Some of the waste that has been produced over the years has not complied with the waste acceptance criteria (WAC) of Himdalen. This legacy waste is stored at Kjeller and consists of, for example, some strong industrial sources, radium-needles from medical use, and residues from a pilot plant for reprocessing that IFE operated from 1961 to 1969 at Kjeller. In addition, 166 drums of plutonium-contaminated legacy waste from a former disposal trench at Kjeller is stored in one of the caverns in Himdalen. One of the goals of the waste management programme is to establish permanent solutions for all legacy waste.

Decommissioning at Kjeller and Halden will generate substantial quantities of waste during the next couple of decades. The radioactivity in the facilities to be decommissioned has not been mapped (so far, the priority has been to maintain the facilities in a safe state). Nor have methods for disassembly, sorting, conditioning, and treatment been decided. Therefore, the amount, composition, and characteristics of the waste remain uncertain. Estimates have been made, based on the layout of the facilities and experiences from similar decommissioning projects in other countries [12]. These estimates are frequently updated, as more information about the facilities and historical waste becomes available. Current conservative estimates are that 6500 m^3 of very low level waste (VLLW), 2100 m^3 of LLW and 1600 m^3 of ILW will need to be stored and disposed of following dismantling, treatment, and conditioning [13].

The reception and treatment facility at Kjeller is outdated and has neither the qualitative nor quantitative capacities required for handling waste from decommissioning. The remaining capacity at the combined storage and disposal facility in Himdalen (600 m^3) is insufficient for the prognosed waste quantities, and it is not licensed to receive long lived intermediate level waste or HLW, both of which are components of the Norwegian waste inventory. The license permits disposal of LLW containing up to 4000 Bq/g long-lived alpha emitters in a waste package, and up to 400 Bq/g on average for all waste.

In summary, Norway needs to implement a completely new infrastructure for handling all classes of radioactive waste.

3. TECHNICAL SOLUTIONS

3.1. Treatment, conditioning, and storage of spent fuel

Because of the chemical instability of metallic uranium and relatively poor corrosion resistance of aluminium, several studies have concluded that metallic and aluminium-clad fuel types are unsuitable for direct disposal and should therefore be pretreated in a way that produces a chemically stable waste form [11, 14, 15, 16]. Until a couple of years ago, reprocessing was considered the only available treatment technology. Recently, de-cladding and dry-air oxidation of metallic uranium has been developed as an alternative technology [17, 18]. At least one study has questioned whether predisposal treatment is needed at all, arguing that it may be possible to develop a repository design robust enough for disposal of metallic fuel [19]. No suitable treatment facilities exist in Norway. Therefore, the studies recommending treatment have concluded it should be performed by existing service providers abroad with the intention of returning residues from treatment to Norway where they would be disposed of. A study in 2020 recommended either reprocessing at Orano in La Hague, France or de-cladding and oxidation at Studsvik, Sweden [17]. Section 16-11 of the Norwegian waste management regulations states that export of radioactive waste requires a permit from the competent authority (DSA). Such permit can only be granted if it is considered necessary for ensuring environmentally defensible treatment of the waste, based on a comprehensive assessment of available treatment options in Norway, the properties of the waste, and environmental hazards associated with different alternatives. Further requirements apply as well, including permission from the authorities in the receiving country. At the time of this writing (July 2021), a government-sanctioned process for evaluating different predisposal handling options is ongoing. Preliminary results of that study suggest a need for further investigation of mechanical pretreatment and geological disposal without chemical conversion.

The current storage facilities are outdated and do not have enough capacity. Renewed and increased storage capacity is needed, especially if a decision to send fuel to treatment abroad is not made within the near future. Even if it is decided to treat the fuel, a new interim storage facility is necessary, to ensure that the waste can be returned after treatment or in case of unforeseen developments during treatment. This is required by the national regulations. If some, but not all the fuel is sent to treatment abroad, then the remaining fuel has to be stored safely. Wet storage (in pools of water) is unsuitable for the Norwegian SF because of the poor corrosion resistance of aluminium and metallic uranium [20]. Dry storage in purpose-built vaults or casks are mature and suitable technologies. Of these, dual-purpose (transport and storage) casks are considered the most promising option, because they can be procured from international suppliers, and their safety assessments can to some extent be based on previous licensing processes in other countries. Furthermore, transportability gives flexibility to move the fuel without having to repackage it. Transportability has strategic value, as no decisions have been made regarding predisposal treatment or sites for storage and disposal of SF.

3.2. Treatment, conditioning, and storage of LILW

A variety of technologies for predisposal treatment exist [21]. Given the small amount of waste and the limited experience in waste handling, a high level strategic decision has been made to limit the complexity of predisposal operations. Emphasis is placed on ensuring that treated and conditioned waste complies with transport regulations and WAC of storage and disposal facilities, rather than maximizing waste minimization. This strategy leverages the use of those facility types that have to be constructed in any case, such as storage facilities and disposal facilities. For example, decontamination will only be done when it is easy and highly beneficial (i.e. when material is surface contaminated to a limited extent and the contamination can be removed by techniques that do not require highly specialized competence or equipment). It is also important to consider how to handle the secondary waste that arises from decontamination. Materials that cannot be easily decontaminated will be processed, stored, and disposed of as waste. Flexibility is another important feature of predisposal management because the waste characteristics are uncertain and the WAC of future storage and disposal facilities are undetermined [22].

Decommissioning cannot begin until sufficient storage or disposal capacity for LILW becomes available. For technical, regulatory, and societal reasons, it is considered likely that a storage facility can be established faster than a disposal facility, especially when uncertainty in rate of progress is considered; establishing a disposal facility could in the worst case take an indeterminable amount of time. Therefore, construction of one or more storage facilities reduces the risk of delays in decommissioning. Potential consequences of extended delays include loss of competence, increased costs for maintaining and securing the facilities, and transferring the burden of decommissioning to future generations.

An early concept design prescribes establishing storage buildings with concrete walls that enable storage of treated and conditioned LILW for 50 years or more [22]. This is sometimes called engineered storage [21]. Siting and approval of such solutions could take five to ten years. Existing buildings or use of waste containers may be used in the interim. It is important that waste emplaced in engineered storage complies with the waste acceptance criteria of both the storage and disposal facilities, so waste can be transported directly from the storage to the repository once disposal commences. This will not necessarily be the case for waste stored in short term interim solutions. For this limited amount of waste, it can be acceptable to just segregate the waste for later waste treatment towards the goal of meeting the necessary waste acceptance criteria for the engineered storage facility and disposal facilities.

A process for identifying and evaluating potential sites for waste processing (treatment and conditioning) and storage facilities is ongoing. NND are considering placing them at Halden, Kjeller or at a new location. One interesting possibility is to choose a hybrid between, for example, Halden and a new location. Placing them at one of the nuclear sites at Kjeller or Halden, could have some benefits:

- Pooling of human resources working on decommissioning and predisposal waste management.
- Waste generated at the site where the processing facility is would not need to be transported off-site for processing. On the other hand, long term storage and some treatment technologies will only be implemented in one central facility, which means that there will be some transportation of waste in any case.
- Systems for security and environmental monitoring could be shared with the original facilities on the site.

On the other hand, to construct new nuclear facilities within these historical nuclear sites may be more complex than to do so at a third location. There is limited space available within the current sites. Before ground can be excavated and buildings demolished or modified, one needs to ensure safe handling of the resulting waste, which may be radioactive. Facility modifications are subject to regulatory approval. Local acceptance will differ between sites.

3.3. Disposal

Different classes of radioactive waste generally require different types of disposal facilities. ILW and HLW contain significant amounts of long lived radionuclides and therefore have to be disposed underground. Emplacement at depth protects the waste from surface processes such as erosion and reduces the probability of human intrusion. If a site is appropriately selected, the host rock can contribute to the containment of the radioactivity, along with the engineered barriers [23]. Several repositories for VLLW, LLW, and ILW have been built around the world [24]. Technical solutions also exist for HLW, but no repositories have been put in operation. A mined repository is being constructed in Finland, with plans to start operations around the year 2024 [25].

A generic design for a national facility that combines repositories for all different classes of radioactive waste has been developed. The concept includes the following repository types, located at the same site [26]:

- A landfill with engineered barriers for non-radioactive waste from decommissioning and potentially VLLW.
- Caverns approximately 100 m below ground for LLW and ILW in separate caverns with different types of engineered barriers. 200-liter drums of ILW are emplaced in concrete overpacks and emplaced in concrete sarcophagi that provide added containment and waste package protection. Waste packages of LLW are disposed of without additional engineered barriers, except tunnel plugs and backfill.
- Two alternatives for disposal of HLW: Either a mined repository modelled based on the Swedish/Finnish KBS-3 concept at approximately 400–500 metres depth, or deep borehole disposal (DBD).

Some of advantages of building the different repository types on the same site are:

- Only one site-selection process is needed. To select a site for a repository can be challenging, particularly for social and political reasons. The fewer sites that are needed, the greater the probability of success.
- Human and capital resources can be concentrated in one place. Much of the same type of knowledge, tools, and methods could be used for the different repository types.
- Auxiliary facilities such as a visitor centre are only needed in one place.

These advantages translate into a general expectation of lower costs if the different types of repositories are built on the same site, rather than building one repository for LILW and another for HLW.

The KBS-3 concept has been selected as reference design for a mined repository because it is compatible with crystalline bedrock, which dominates the Norwegian geology [27], as opposed to concepts based on disposal in natural clay formations such as in France [28] or Switzerland [29], and KBS-3 could probably be adjusted to the waste form from either of the predisposal treatment options being considered [26, 30, 31]. KBS-3 is also the most mature disposal concept, worldwide [32]. Disposal of SF in storage and transport casks has been considered. This could be feasible if the casks are emplaced in a low-permeability and self-healing host rock such as clay or salt [33]. Another slightly exotic option is to emplace 200-liter drums containing LILW in 500-metre-deep boreholes. This could be an interesting option for very small amounts of ILW (up to a few hundred cubic metres) and could perhaps be combined with DBD of HLW at some point in the future. But disposal in a cavern is a more like option for the Norwegian ILW, given the amounts (1600 m^3) and the possibility to dispose of ILW and LLW in caverns that share the same access tunnels, ventilation shafts etc.

3.4. Mined repository versus deep borehole disposal

Technical solutions for disposal of HLW (mined repository or DBD) and the site-selection strategy are being studied but have not been decided yet. These are topics of an ongoing study into technologies and strategies for storage and disposal. This study follows a general project model for large public infrastructure projects, that enables appropriate government and parliamentary decision making.

17 tons of SF is an extremely small amount compared to the approximately 250 000 tons of SF and 120 000 tons of reprocessed SF in storage worldwide [34]. The most mature disposal programmes in Finland, France, and Sweden, have been developed to handle thousands or tens of thousands of tons [32, 35, 36, 37]. It is possible to apply the same types of solution to the much smaller Norwegian inventory, but the cost per ton is greater because of economies of scale [26, 38]. The French, Swedish, and Finnish concepts are mined repositories that include tunnels and shafts that lead down to hundreds of metres below ground. The cost of access tunnels and shafts are independent of the amount of waste emplaced in the repository. Therefore, the minimum cost of such repositories is relatively high, and the cost per amount waste becomes high for small amounts [39].

Lower fixed costs is one reason why DBD is an interesting alternative to mined repositories. DBD involves drilling a hole one to five km below ground, emplacing containers of high level radioactive waste, and then sealing the borehole [40, 41]. The idea has been researched since at least as early as 1976 [42], which means DBD is as old as the KBS-3-concept, which is now the most advanced concept for deep geological disposal [32, 43]. In recent years, advances in drilling technology, simultaneous lack of progress for some disposal programmes, and an increased interest in small waste inventories have reinvigorated research into borehole disposal. This has shown that DBD is feasible with available drilling technology and that its safety can be demonstrated by using similar methods as for mined repositories [40, 41, 44, 45, 46]. However, DBD is generally less mature than disposal in mined repositories.

There is a close interface between predisposal treatment and disposal of SF. Regardless of which treatment option is selected (no chemical treatment, reprocessing, or dry oxidation), the returned waste can be disposed of in either a mined repository or a borehole [30, 31, 41, 46].

One factor that could tip the balance in favour of DBD is the technical difficulties and costs of encapsulation. Before it is emplaced in a repository, HLW needs to be placed in canisters with appropriate strength and at least enough durability to contain the radioactivity for the time when the heat output can cause advective transport [41], which means approximately 1000 years [37, 48, 49]. Swedish Nuclear Fuel and Waste Management Co (SKB) has estimated that its encapsulation facility for the KBS-3 concept will cost around 500 million EUR [50]. It may be possible to establish a less sophisticated and, therefore, less costly facility for encapsulating the small amounts of Norwegian SF, or encapsulation for disposal in a borehole may cost less than encapsulation for KBS-3. The design and functional requirements of a canister depends on the overall design of the repository, including the host rock and any engineered barriers placed around the canister. In the KBS-3 concept, the canister is essential for ensuring safety in the very long term [37]. For borehole disposal, the host rock can be relied upon to a comparatively greater extent. If this means that the canister and thereby encapsulation could be simpler and cheaper, then that may make DBD more favourable overall; this remains unclear.

One option is to defer the decision on mined repository or DBD until one or more actual sites have been identified as potentially suitable based on technical, regulatory, and political conditions. This could enable greater flexibility in overall site selection criteria. The two concepts require similar but not identical geological conditions [27]. A site could be suitable for one but not the other. Keeping both technical options on the table could therefore mean more sites are suitable overall.

3.5. Site-selection process for a disposal facility

A site-selection process for a disposal facility is being planned. The plan will describe:

- How to foster trust and confidence among stakeholders.
- Regulatory framework and procedures.
- Roles and responsibilities of the organizations involved.
- How to identify and assess potentially suitable regions and sites.
- Decision points and milestones such as the steps in a licensing process.
- A time schedule for site selection.

— Criteria on which a decision on a site can be based. These include safety, security, geological suitability, costs, logistics, infrastructure (roads, electricity, water supply), relations to neighbouring countries, and local acceptance.

4. POLICY AND STRATEGY

The government has prepared a white paper for decommissioning and the nuclear waste management programme [51]. It describes:

— The historical background of the Norwegian nuclear research programme.
— Principles and processes for selecting solutions for managing nuclear waste, and which prospective solutions that currently exist.
— Principles for how to select a site for facilities for storage and disposal of radioactive waste, as well as the potential benefits from a multinational repository. Norway follows a dual-track approach to geological disposal, meaning that national solutions are being developed while at the same time keeping multinational solutions open for as long as reasonable [52].
— A framework for how to maintain safety and security, and how nuclear safeguards are maintained.
— How the State has organized the nuclear waste programme, including establishment of NND and transfer of facilities and personnel from IFE to NND.
— The regulatory framework and the responsibilities of the competent authority (DSA).
— International commitments related to management of SF and radioactive waste.
— The need to ensure sufficient access to relevant competences.
— Opportunities for developing commercial enterprises related to decommissioning and management of nuclear waste.
— Costs, factors that influence costs, and related administrative and economic consequences.
— Principles for stakeholder involvement.

NND has developed a draft waste management strategy that describes principles for waste handling, relevant regulations, schemes for waste classification, forecasted waste amounts, waste sources, potential technical solutions, and means to ensure sufficient competence. Radioactive waste will be handled according to national laws and regulations as well as international guidelines such as the IAEA safety standards (for example, see [53]).

It is important to preserve the competence and historical knowledge of the workforce at the facilities in Kjeller and Halden. Staff with operational experience from the facilities should assist in the planning and execution of decommissioning. Therefore, approximately 200 employees will be transferred from IFE to NND, along with ownership of the facilities. This transfer is intended to take place in 2024. There is currently almost no other nuclear industry in Norway. As a result, there is a lack of domestic competence and training. This makes it even more important to preserve the existing competence. It also makes it essential to learn from international best practices. NND achieves this by:

— Issuing international tenders on developing technical solutions;
— Having a board of advisors that includes experts from similar organizations in other countries.
— Actively participating in activities and projects organized by IAEA and other international entities;
— Being a member of the European Repository Development Organisation (ERDO).

The purpose of ERDO is to support development of national and multinational waste management solutions. This includes both supporting the concept of multinational repositories and developing shared or standardized predisposal waste management solutions. Results from an ongoing ERDO project about DBD suggest that DBD could enable small-inventory States to build separate national borehole repositories by sharing supporting infrastructure and development capacities.

5. SUMMARY

A new and comprehensive nuclear waste management programme is being developed based on national policy and regulatory framework, as well as international guidelines and practices. It can be described in terms of the separate processes collection, characterisation, treatment, conditioning, transport, storage, and disposal. However, managing the interdependencies between policy, regulations, and separate technical solutions is at least as important and challenging as developing the separate pieces of the whole. Given the small amount of waste and the complexity of the system, emphasis is placed on flexible solutions and on leveraging the use of those facilities that have to be built in any case. Disposal is the part of the programme where the limited inventory may drive innovation the most, because DBD is more easily scalable to small waste amounts than mined repositories. Nevertheless, DBD is subject to the same challenges and processes and its safety both can and has to be demonstrated by the same types of methods. It is just one step in the cradle-to-grave journey of radioactive waste.

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3.2. SESSION 2 – IMPLEMENTATION OF WASTE MANAGEMENT STRATEGIES

Every State needs to have some form of policy and strategy for managing its arisings of radioactive waste and spent fuel (where appropriate). Such policies and strategies are important; they set out the nationally agreed position and plans for managing radioactive waste and are visible evidence of the intent of government and relevant organizations to ensure that wastes are properly taken care of.

Furthermore, radioactive waste producers and waste management organizations have need for such strategies to provide the high level framework for their more detailed waste management plans and programmes. This is particularly important where there are interfaces between different organizations and facilities to be considered, some of which may not yet exist and are planned for the future. This is the case in many countries where wastes are being conditioned and packaged now and consigned to interim storage awaiting provision of future disposal facilities.

This Session provided updates from several Member States on progress made towards implementing their waste management strategies. It should perhaps not be a surprise to hear that the road to implementation is often challenging and not without problems. Speakers provided examples of constraints and boundary conditions considered, methods and approaches for implementation, problems arising, and solutions adopted. Several presentations described preparatory steps that were found to be necessary such as the establishment of new organizational structures, re-definition of roles and responsibilities, improved regulatory arrangements and engagement with stakeholders and the wider public.

All presentations highlighted the need to consider the views and needs of stakeholders and to work to engender public confidence and build trust.

The standout news from the Session was the good progress being made in Finland with the construction of the Olkiluoto geological disposal facility for spent fuel. This facility hailed as a ‘game changer’ by the DG Mr Grossi, is on course to start the trial run phase of commissioning in 2023. Whilst this may be the highest profile project discussed, there were numerous other examples of progress being made by a range of organizations and for a range of waste types, all contributing to our shared objective of a sustainable future.

The Session also saw timelines for implementing waste management strategies and one thing in common is that successful implementation does take a long time. These are complex projects involving multiple strands of interconnected science, engineering, safety studies and social science. The latter we have learned from experience is as important as the technical strands and cannot be rushed.

Several papers gave examples of where waste management organizations had to face problems, acknowledging past mistakes, and coming forward with revised strategies and action plans. Each facility and society in which it sits is unique, and these strategies and action plans are to be informed by the learning and tailored to be suitable for the environment, the wastes and the society. Learning from experience is an important principle adopted by all successful programmes and one that has often been facilitated by international cooperation.

Radioactive waste management might be a back end activity, but it needs planning from the outset of the project and not left as an afterthought as in many historical cases it has been. This planning will not only have to cover the technical aspects of the project but also be wide ranging and recognize that the long timescales involved will require the baton to be passed on to future generations. Planning therefore also addresses the training and skills needed by the younger generation to equip them to take on their future roles in strategy development and implementation.

Session Chairs: C. Tweed (United Kingdom) and R. Pilania (India)

Session 2 comprised eight papers from Finland, Republic of Korea, Germany, Pakistan, the Russian Federation, France and South Africa, with an additional paper from one of the conference's Young Professionals Showcase Leads (Russian Federation).

- **Paper ID#249 by T. Jalonen (Finland)** presented an overview of progress in Finland in developing the geological disposal facility for spent fuel being developed at the Olkiluoto site on the West coast. The facility is in its final stages of construction and the operator Posiva Oy, is aiming to submit the operating licence application at the end of 2021. It is anticipated that a trial-run phase with full-size dummy canisters will be undertaken in 2023 to demonstrate the complete encapsulation and disposal system, prior to full-scale, fully active operations. On a visit last year, the DG of IAEA Mr Grossi described the project as a "game changer".
- **Paper ID#167 by S. Cha (Republic of Korea)** described the South Korean radioactive waste disposal programme and progress to date in its implementation. A site for disposal of short lived ILW, LLW and VLLW has been established at Wolsong following a community voluntarism process and is being developed in 3 stages. An underground silo-type repository is already operational. An engineered vault-type repository for the disposal of LLW is ongoing in Phase 2 and a near surface trench-type repository for the disposal of VLLW for which a conceptual design is being developed is the focus of Phase 3. In 2016 Korea developed a plan for site selection and construction of a geological disposal facility for the country's HLW. The Basic Plan is currently under review in order to respond to expectations of the public and NPP host communities.
- **Paper ID#288 by T. Lautsch (Germany)** described progress at two major waste management sites, the Konrad repository and the Asse mine. The Konrad geological disposal facility is the first to be fully licensed under German national nuclear law, is under construction at the site of a former iron ore mine. Initially it was envisaged that existing underground infrastructure could be utilized, but it turned out to be a major challenge to bring the structures up to a standard compliant with nuclear regulation. Instead, new infrastructure including a new nuclear surface site (Konrad 2) and access shaft is being constructed. At the Asse facility radioactive wastes emplaced as part of earlier R&D activities are being recovered and returned to the surface where they will be repackaged and stored awaiting provision of final disposal elsewhere.
- **Paper ID#47 by M. Rizvi (Pakistan)** described steps taken to undertake a major overhaul and update of Pakistan's radioactive waste management practices, which had grown and developed over the years in an ad-hoc manner. Following close cooperation with and review of the radioactive waste programme by IAEA, a national radioactive waste management policy and associated strategy was established in 2011, defining roles and responsibilities along with waste management routes for defined waste streams. Pakistan now has modern facilities for predisposal waste management at dedicated and licensed facilities at the reactor sites, where optimum treatment and conditioning techniques are adopted. The conditioned waste packages are stored in interim storage facilities awaiting availability of disposal facilities. Two sites for LILW have been identified and site characterization and concept design development are ongoing. He said that technical cooperation with IAEA has been particularly beneficial, giving Pakistan access to the expertise and funding to facilitate the necessary changes. A further cooperation programme is planned.
- **Paper ID#132 by O. Kryukov (Russian Federation)** presented the Russian Federation's national strategy for radioactive waste management. The Federal Law on Radioactive Waste Management enacted in 2011 established for the first time a unified state system with a standardized categorization of waste types and defined criteria for determining disposal options. A first step was to analyse the existing ca 800 facilities and sites in Russia holding radioactive waste, and to determine how much waste should be recovered and how much disposed of in-situ. For disposal of the retrievable waste, several near surface facilities have

been identified and will be further developed leading to a total capacity of 420,000 m³. For the non-removable wastes, he described several successful projects with the emptying and in situ isolation of contaminated lagoons and reservoirs and decommissioning of plutonium production reactors. The Russian Federation is now constructing an underground URL in crystalline rock and a geological repository is planned to be operational by about 2035.

- **Paper ID#147 by D. Delort (France)** presented an update on the status of French disposal projects, namely Cigéo, the geological disposal facility for HLW and certain ILW, and Cires, the disposal site for VLLW. These projects are governed by the National Radioactive Materials and Waste Management Plan (PNGMDR) which aims to clarify and improve the management framework of these materials and waste. A central part of the PNGMDR is the disposal of HLW and certain ILW in the geological repository Cigéo, which will be developed adjacent to the existing underground research laboratory at Bure in Eastern France. The licensing process commenced in 2020 with the Declaration of Public Convenience and Necessity (DUP) which allows for land acquisition and modification to the local authority plan. Approval is expected in the beginning of 2022 and will trigger the application for authorizations for the construction of nuclear and non-nuclear facilities. The Cires site has been accepting waste since 2003 and is predicted to reach its authorized disposal capacity in 2028–2029. Plans are now being implemented to seek a licence to extend its capacity.
- **Paper ID#307 by A. Carolissen (South Africa)** presented an overview of progress in South Africa to develop and its radioactive waste management facility at Vaalputs which has been operational since 1986. From the outset, the operator has adopted the principles of continuous improvement, and together with learning from experience and international peer review, has sought to build confidence in the safety of the design and its operation. Improvements have been introduced to address issues with waste package design, trench design, and waste acceptance criteria. Further site characterization studies have concluded that the site could also be used for hosting a storage facility and geological repository for spent fuel as well as a borehole disposal facility. It was recognized early on that a successful waste disposal programme develops public confidence and builds trust, and that this is essential to ensure societal acceptance of any waste disposal programme.
- **Paper ID#143 by A. Kuznetsov (Russian Federation)** presented a novel concept to recover boron from PWR primary circuits for re-use in other industries. Large amounts of boron and associated wastes, arise yearly on reactor sites as a result primary circuit cleanup. The main idea is to capture the boron with an inorganic selective sorbent from which borate products for use in concrete, glass making, enamels and ceramics can be separated. The primary circuit does have to be topped up with additional fresh boric acid (perhaps by an extra 10–20%) but the waste generated is decreased, there's no need to recycle organic resins, nor to incur personnel dose in measuring boron-10 content. The process also leads to a saleable commercial product and is a good example of the application of the waste hierarchy.

Paper ID#249

POSIVA PREPARING FOR OPERATING A FINAL DISPOSAL FACILITY FOR SPENT NUCLEAR FUEL

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Abstract

Posiva is preparing to submit, as the first in the world, an operating licence application for an encapsulation plant and a final disposal facility for spent nuclear fuel (SNF) situated at Olkiluoto, in southwest Finland[1]. The application gathers decades of scientific and technological research, development, and design work of the final disposal concept, the safety case addressing safety of the disposal, and design and construction of the facilities. As part of the application process, Posiva is preparing for operating the facilities by performing a Trial Run of Final Disposal (TRFD), the final disposal system test. The TRFD comprises the entire disposal process from interim storage, with dummy fuel assemblies, to the encapsulation plant, and finally to the final disposal facility with final disposal systems and machinery. The TFRD addresses Posiva's preparedness to start the final disposal of SNF.

1. INTRODUCTION

Site investigations for hosting a deep geological repository as a final disposal facility began in the 1980s at Teollisuuden Voima, (Fig. 1). In 1994 the Finnish Parliament stipulated a law preventing the export and import of SNF. Hence, the other NPP operator in Finland, Fortum (former Imatran Voima Oy), joined the final disposal project and a company dedicated for nuclear waste management, Posiva Oy, was established. The first objectives of the company were to prepare an application for a political Decision-in-Principle (DiP) for geological final disposal of SNF and to find a suitable site for the final disposal facility. In Finland, licensing of a nuclear facility is done according to the Nuclear Energy Act through a stepwise process beginning with a DiP, continuing with a construction licence and, after nuclear facility construction, culminating in an operating licence.

Posiva selected the final disposal facility site in 1999, which was approved by the municipality of Eurajoki. Posiva applied for a DiP to construct the final disposal facility and an encapsulation plant at Olkiluoto in 2000, introducing a KBS-3 method applicable for crystalline host rock as the disposal concept. The DiP was made by the Finnish Government and ratified by the Parliament in 2001. Because the DiP required the preliminary site investigations made above ground to be confirmed by site investigations at the actual disposal depth, the underground research and rock characterization facility, ONKALO, was constructed in 2004–2016. Posiva's programme for the final disposal of SNF is illustrated in Fig. 1.

[1] On 30 December 2021 Posiva submitted the application for operating licence for encapsulation and final disposal facility of spent nuclear fuel

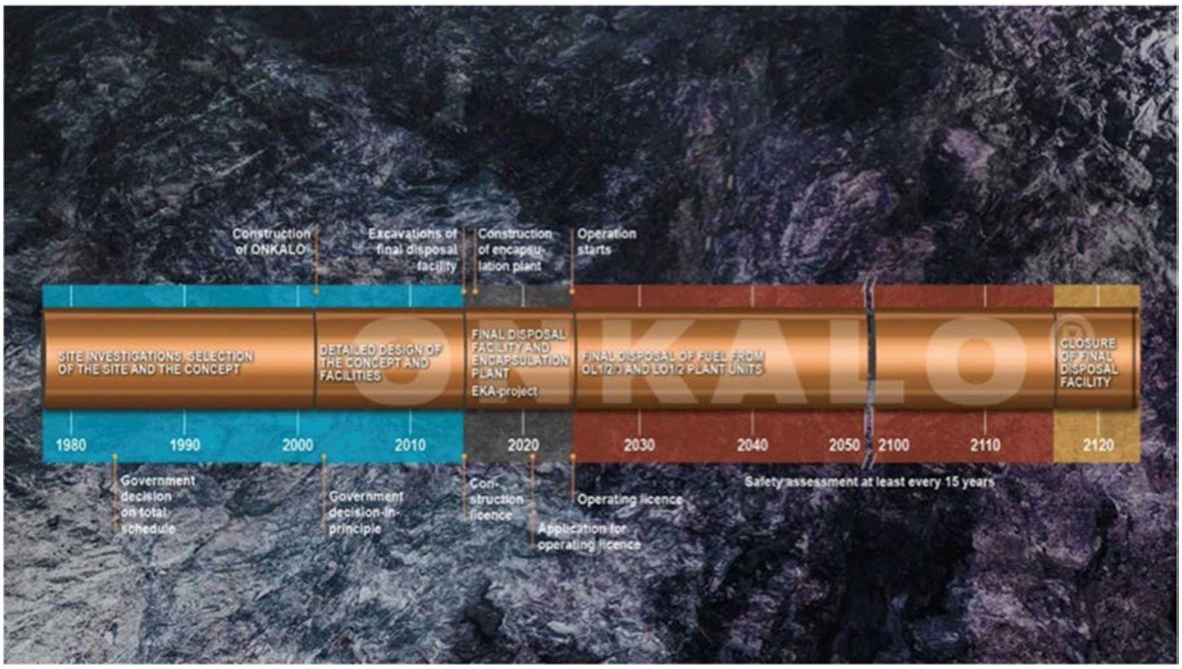

FIG 1. Posiva's programme for final disposal of spent nuclear fuel. Courtesy Posiva Oy.

ONKALO has been constructed under supervision of the Nuclear Safety Authority STUK, because from the early planning phase it has been designed to be a part of the final disposal facility for SNF.

Rock construction methods, including a drill-and-blast excavation method and grouting of rock fractures to limit groundwater flows, were developed to allow ONKALO to avoid damage of the bedrock and unnecessary disturbance of the groundwater conditions. Also, a specific Rock Suitability Classification (RSC) procedure was developed and tested iteratively along the construction work to assess rock suitability for final disposal and to provide input information for design of the final disposal facility. Two demonstration tunnels and 10 experimental deposition holes were constructed to ensure deposition tunnels and holes would be constructed according to their requirements, and for performing various tests at the deposition level: see Fig. 2. Site confirmation studies continued until the disposal level of 420–430 m below sea level was reached in 2010.

FIG. 2. Experimental deposition holes in the demonstration tunnel #2. Courtesy Posiva Oy.

The principle of geological final disposal is to isolate the nuclear waste from nature until its radioactivity has decreased to an insignificant level. The final disposal concept safety in Olkiluoto is based on the KBS-3 concept, which consists of crystalline bedrock as the natural barrier and of an engineered barrier system (EBS): see Fig. 3. The EBS components include a disposal canister, a bentonite buffer, a bentonite backfill of the deposition tunnels, a deposition tunnel plug, and closure of other underground openings in the final disposal facility. The primary barrier to contain and isolate SNF from the biosphere is the copper–cast iron canister. The buffer surrounding the canister limits the groundwater movement from the bedrock to the canister and protects it from rock movements. Backfill and closure of the deposition tunnels prevent water flowing in the tunnels and the end plug keeps the backfill in place.

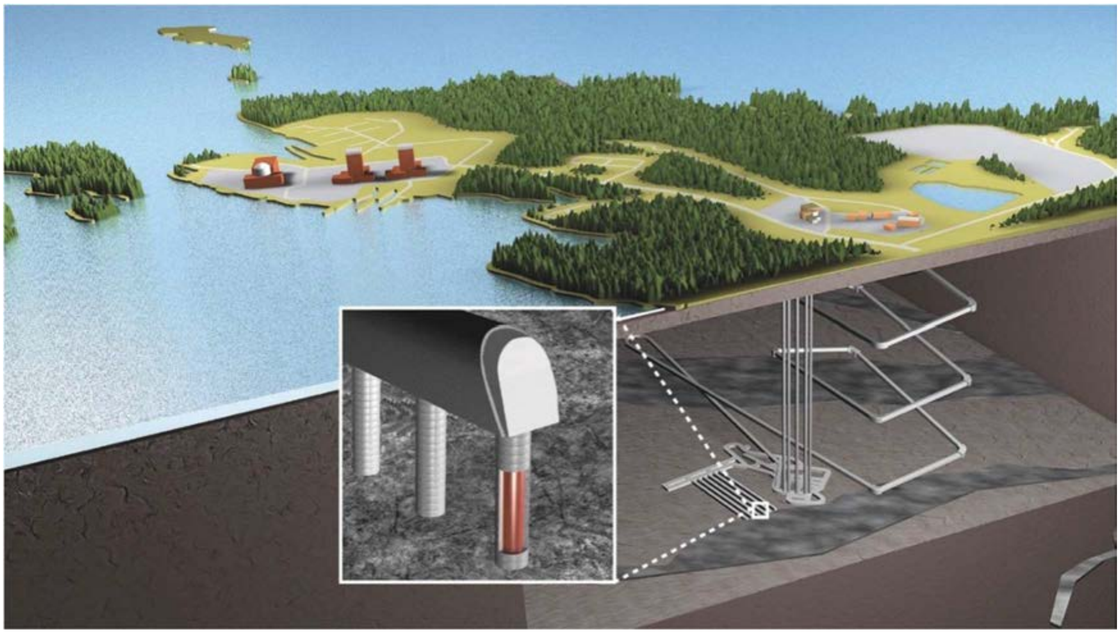

FIG. 3. Final disposal concept in Olkiluoto. Courtesy Posiva Oy.

2. CURRENT STATUS OF POSIVA'S FINAL DISPOSAL PROGRAMME

The disposal concept has been studied iteratively along with site studies and developed in detail by defining requirements for its components, testing material performance in different scales in laboratory, field scale and in ONKALO, and performing manufacturing tests with several potential suppliers of the EBS components.

Posiva applied for a construction licence for a final disposal facility and for the encapsulation plant in 2012. The application included a safety case, TURVA-2012, to address the safety of the final disposal of SNF in Olkiluoto. The construction licence was granted by the Finnish Government in 2015. The construction of the final disposal facility was started in 2016 and the construction of the encapsulation plant in 2019.

Posiva aims at submitting the operating licence application in the end of 2021, including an updated safety case. To prepare for the operation, Posiva will perform the TRFD to ensure all operations from the interim storage of SNF to the encapsulation and final disposal will be performed with accepted systems and instructions and with qualified components. The only difference to the actual final disposal is that dummy fuel elements will be used instead of SNF. The tunnel for performing the TRFD was finished in June 2021.

Posiva is currently constructing the encapsulation plant and the final disposal facility: see Fig. 4. The construction work has proceeded well; as such, the encapsulation plant will be ready for installation and commissioning of the systems in 2022. In addition, the construction of the first five deposition tunnels is on-going in the final disposal facility.

FIG. 4. On-going construction of Posiva's encapsulation plant. Courtesy Posiva Oy.

3. PREPARING THE OPERATING LICENCE APPLICATION

Licensing a nuclear facility is divided in two levels: licensing a facility and licensing the systems in a nuclear facility. By licensing a nuclear facility, it is ensured it is constructed to be safe and it will be operated safely. For licensing the encapsulation plant and the final disposal facility and for operating them safely, Posiva is preparing an operating licence application to be submitted to the Finnish Ministry of Employment and the Economy at the end of 2021.

The operating licence application consists altogether of more than 250 various kinds of documentation including a description of the Olkiluoto site, nuclear waste, nuclear facilities and their systems; scope, extent and financing of the final disposal, design and safety principles; safety case; detailed design, construction, operation, operating personnel, closure and decommissioning of the nuclear facilities; operating plan, radiation protection, incidents and accidents, long term safety, transportation of the SFG, and an updated environmental impact assessment (EIA) since the construction licence application.

Posiva's safety case (see Fig. 5) addressing safety and justifying the reliability of the assessments made of the long term safety of final disposal in Olkiluoto gathers decades of scientific and technological research, development, and design work of the final disposal concept and the facilities.

FIG. 5. Posiva's safety case as a portfolio of reports for the operating licence application. Courtesy Posiva Oy.

During the handling of the application, Posiva is preparing for operating the facilities safely by performing a final disposal system test, the TRFD.

4. TRIAL RUN OF FNAL DISPOSAL

The TRFD is the final phase of Posiva's preparations for operating the final disposal facility. Successful execution and detailed reporting of the TRFD plays an essential role in the future commissioning of the encapsulation plant and the underground final disposal facility.

The TRFD will be the climax of research, development, and design work Posiva has performed for more than 20 years. Until now, Posiva has tested manufacturing, installation, and construction operations one system at a time. Posiva has also performed a full-scale in situ system test in ONKALO, in which final disposal operations have been tested with prototype machinery and test components.

The TRFD will show final disposal operations can be performed as designed, with accepted instructions, components, and systems. The only difference is that SNF will not be used.

A prerequisite for starting the TRFD is that the encapsulation plant and the final disposal facility and all their systems have been commissioned and that the personnel has been trained for operating them. The personnel that is trained to operate the facilities and the machinery for final disposal will also perform the TRFD.

The TRFD includes the construction of a deposition tunnel, four deposition holes bored in the floor of the deposition tunnel, four canisters and bentonite buffer in the deposition holes surrounding the canisters. Management of the supply chain of the components and the overall logistics forms a part of the TRFD.

The first phase of the TRFD is the construction of the deposition tunnel in the vicinity of the first deposition tunnels (see Fig. 6), and the deposition holes. The construction serves as a method test to address that the deposition tunnels and holes can be constructed to meet the requirements set for them and according to the RSC procedure Posiva has developed along with constructing ONKALO. The RSC procedure produces input information for detailed design of the deposition tunnels and holes and after construction, input information for acceptance of the tunnels and holes. The construction of the deposition tunnel for the TRFD was completed in summer 2021 and the deposition holes are to be bored once the deposition hole boring machine is ready made and accepted for use.

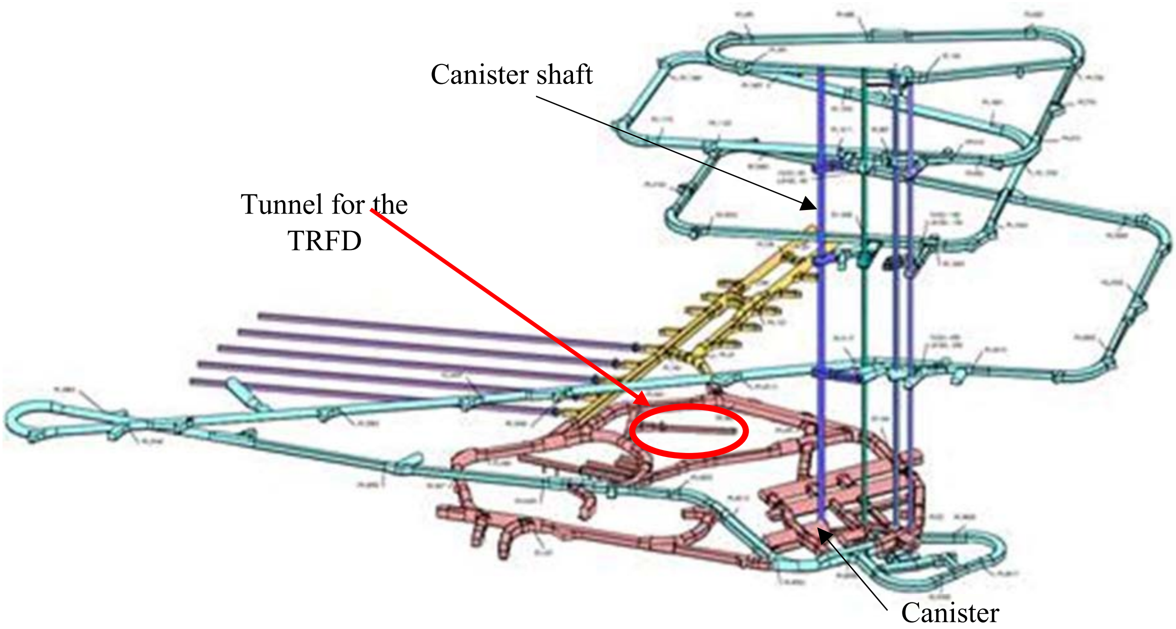

FIG. 6. Location of the tunnel for the Trial Run of Final Disposal and the canister storage below the canister shaft. Courtesy Posiva Oy.

The second phase of the TRFD starts in interim storage of SNF at Olkiluoto, where SNF dummies, made especially for the TRFD, will be loaded to a SNF transport cask. The shape and weight of the fuel dummies is the same as fuel elements with spent fuel, but there is no SNF. The transport cask with the fuel dummies is transported to the encapsulation plant according to Posiva's transport instructions. In the encapsulation plant fuel handling cell (see Fig. 7), the fuel dummies are removed from the transport cask to a drying station, where they are dried, and then loaded into a cast iron insert in a copper canister. Air inside the canister is removed and replaced by inert gas, after which the inner lid of the canister is closed air tight. The canister is moved further along the encapsulation line where a copper lid is installed and welded to the canister. Once the weld is inspected and accepted, the canister will be moved to the end of the encapsulation line, where a lift will take the canister via a canister shaft down to the final disposal facility, located right below the encapsulation plant.

FIG. 7. Fuel handling cell in the encapsulation plant. Courtesy Posiva Oy [1].

In the final disposal facility, the canister will first be taken to a canister storage close to the canister lift waiting for the other canisters of the tunnel to be ready for final disposal. The tunnel for the TRFD is near the first deposition tunnels. In the meanwhile, the tunnel is prepared for the TRFD by installing the bentonite buffer into each deposition hole with a buffer installation machine up to the canister top level. The canisters, once ready in the canister storage (see Fig. 8), are transported and installed one at a time to a deposition hole inside the buffer rings with a specific canister transfer and installation machine, including a radiation shield. Then the deposition holes are filled with the remaining bentonite buffer blocks. The deposition tunnel will be backfilled with granular backfill material by a special vehicle and the tunnel will be closed with an iron-reinforced concrete end plug at the mouth of the tunnel.

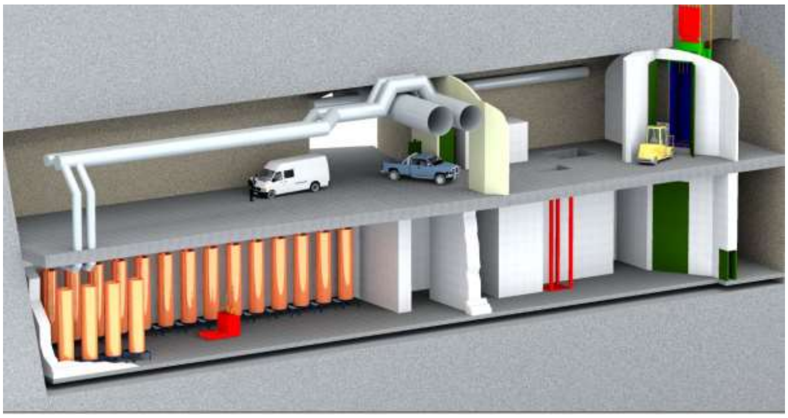

FIG. 8. The canister storage in the final disposal facility. Courtesy Posiva Oy [2].

The TRFD will also include a retrieval test to take a canister from the final disposal facility up to the encapsulation plant, where the canister will be opened and the dummy fuel elements removed from the canister. Posiva will show that reversing the process can be accomplished.

The TRFD provides a demonstration to multiple stakeholders that Posiva can manage the entire final disposal process and is able to start the industrial operation of ONKALO.

Once Posiva receives an operating licence, there will be a 100-year programme ahead for operating the final disposal facility, as defined by the NPP operation schedules. With 60 years of operating time assumed for the newest unit, OL3, and 40 years of cooling time after the spent fuel is taken out of the reactor, the last fuel assembly will be disposed of in 100 years from now.

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Paper ID#167

RADIOACTIVE WASTE MANAGEMENT STRATEGY IN THE REPUBLIC OF KOREA

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Abstract

In the Republic of Korea, national basic plans for the management of low and intermediate level waste (LILW) and high level waste (HLW) are established and updated every five years, and strategies are established annually to achieve the goals established by the national basic plans. Based on these plans and strategies, the Korea Radioactive Waste Agency (KORAD), a non-profit organization for radioactive waste management, has accounted for a safe and pragmatic approach for LILW disposal through three different repository concepts at a single site. Additionally, the basic HLW management plan is under review to enhance scientific feasibility and public and resident acceptability.

1. INTRODUCTION

In the Republic of Korea, 24 nuclear power plants (NPP) are operating with a total installed capacity of 23 GWe. Two units have permanently been shut down, and four units are under construction as of March 2021. Electricity generated from NPPs makes up 29 % of total electricity generation.

The Republic of Korea is safely managing low and intermediate level radioactive wastes (LILW) in the Wolsong LILW disposal center (WLDC) in Gyeongju city. However, there are still significant challenges to overcome for managing high level radioactive waste (HLW), including spent nuclear fuel (SNF). A basic plan for HLW management, issued in 2016, is under review to better respond to public expectations.

LILW is a by-product of operating NPPs, research reactors, and other nuclear fuel cycle facilities, industries, research activities, and other applications of radioactive materials in the Republic of Korea. As of December 2020, approximately 149 000 packages of LILW in 200 L were generated. Approximately 75% of the radioactive waste arises from the operation of NPPs.

The Korean government oversees developing basic plans for the safe management of HLW and LILW. The KORAD, specified as radioactive waste management organization and an operator of WLDC, is responsible for the development of a strategy to achieve goals set out in the basic plan.

2. LEGAL FRAMEWORK FOR RADIOACTIVE WASTE MANAGEMENT

While there are several national laws for the safe management of LILW and HLW, including the Nuclear Safety Act (NSA), the Radioactive Waste Management Act (RWMA), and Environmental Impact Assessment Act, the two supporting pillars are the NSA and the RWMA, as shown in Fig. 1. The NSA is a main law in the perspective of safety, as it stipulates safety regulations for HLW and LILW management. Technical requirements and standards and guidelines are stipulated in the NSA enforcement regulations and the nuclear safety and security commission (NSSA) regulation.

The RWMA is established for regulating safe and efficient management of radioactive waste and provides details regarding managing LILW and SNF and establishing the KORAD and a radioactive waste management fund.

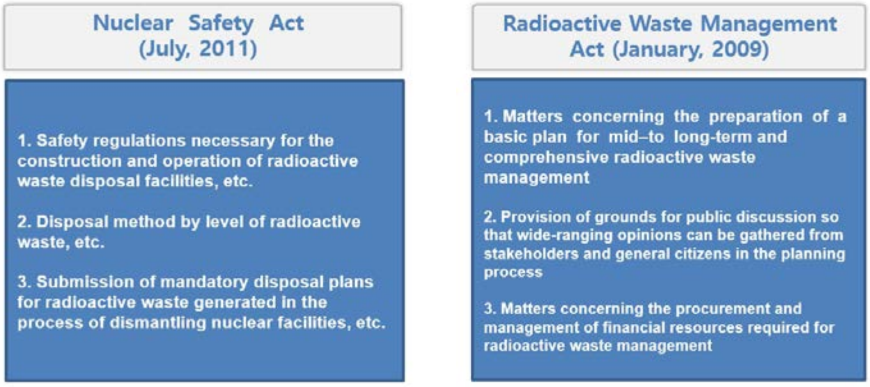

FIG. 1. Contents of the Nuclear Safety Act and the Radioactive Waste Management Act.

3. A BASIC PLAN AND STRATEGY FOR RADIOACTIVE WASTE

The Ministry of Trade, Industry, and Energy (MOTIE) oversees developing a basic plan for safe LILW management every five years. The KORAD is responsible for establishing a strategy to achieve goals set by the basic plan while considering plausible technical options. The strategy needs to be approved by the MOTIE. As a responsible organization for radioactive waste management, the KORAD develops a strategic plan for the disposal of various types of the radioactive waste.

The Korean government has established a basic plan to develop a single and centralized disposal facility for LILW and radioisotope waste. According to the basic plan, KORAD began construction of Wolsong LILW Disposal Center (WLDC) in 2007, and its operation (Phase 1) was granted in December 2014. KORAD's strategy for managing different types of radioactive waste is to host three different repositories in a single site:

— Phase 1: an underground silo-type repository for the disposal of intermediate level waste (ILW) including some low level radioactive waste (LLW);
— Phase 2: an engineered vault-type repository for the disposal of low level radioactive waste (LLW);
— Phase 3: a near surface trench-type repository for the disposal of very low level radioactive waste (VLLW).

KORAD's strategic plan for repository development features containment and isolation of the radioactive waste to be commensurate with the hazard of the radioactive waste. It is the first radioactive waste disposal facility across the globe to incorporate three different repository concepts at one site. Phase 2 is under licensing process for construction, and KORAD is undertaking the conceptual design of Phase 3.

Two NPP units, Kori-1 and Wolsong-1, have permanently been shut down, and Kori-1 is scheduled to be decommissioned in 2026. A considerable volume of concrete and other radioactive waste is likely to arise from decommissioning NPPs. KORAD's strategy is to extend its disposal capacity for decommissioning waste in a timely and safe manner. A large volume of the decommissioning waste is expected to be disposed of in Phase 3 of WLDC.

The KORAD plans to increase its capacity to analyse nuclides contained in radioactive waste in response to stakeholder expectations. A nuclide analysis centre will be built in the perimeter of the WLDC by 2025.

Waste acceptance criteria (WAC) is a cornerstone for the safe and effective operation of radioactive waste repositories. KORAD is responsible for providing waste producers with the WAC in a timely manner. The WAC for Phase 1 is in place; however, some challenges and issues still remain, including mixed and hazardous waste. KORAD plans to continually review and update the WAC.

As of 2020, 149 077 LILW waste packages were generated, and 615 735 waste packages are currently expected to be generated from the operation and decommissioning of NPPs, according to a current national energy policy. Other nuclear facilities and radioactive material applications are expected to generate 118 931 waste packages in the future. All radioactive wastes are going to be safely and effectively disposed of in the WLDC.

4. HIGH LEVEL WASTE MANAGEMENT PLAN

A basic plan on HLW management, which the Korean government issued in 2016, built upon public engagement commission on spent fuel management (PECOS) recommendations. The basic plan stipulated a detailed timeline for developing a DGR, a generic underground research laboratory (URL), and an interim storage facility, as shown in Fig. 2. Site selection for the DGR were expected to take 12 years, followed by URL activities and repository construction. However, the basic plan is under review to incorporate expectations and feedback from various stakeholders including experts, general public and NPP host communities.

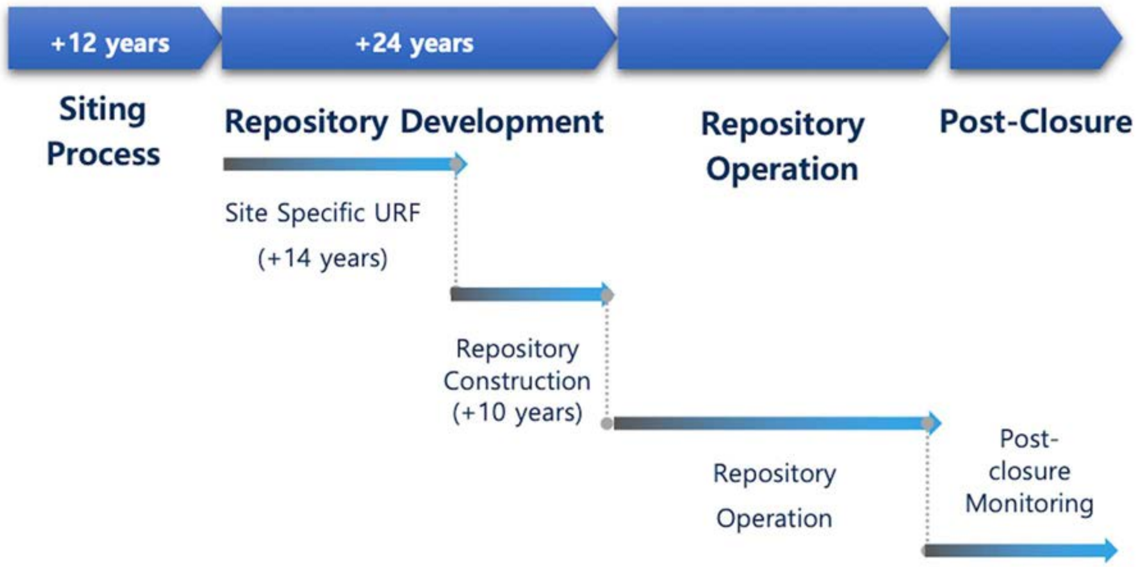

FIG. 2. Timeline for implementing a deep geological disposal programme.

5. CONCLUSION

The legislative framework for the safe management of HLW and LILW is in place in the Republic of Korea. National basic plans for HLW and LILW management are developed and revisited every five years, The KORAD is responsible for establishing a strategy to achieve goals set out at the basic plans. In the perspective of LILW management, KORAD has accounted for an effective and efficient approach to dispose of different types of LILW: three different repository concepts in a single site. A basic plan for HLW management is under review to respond to public and NPP host communities' expectations.

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Paper ID#288

ASSE AND KONRAD – GERMANY'S LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE CONSTRUCTION PROJECTS AT FULL STEAM

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Abstract

The Federal Company for Radioactive Waste Disposal (BGE) is the operator of Germany´s nuclear waste repositories. Founded in 2016, the BGE took over all former entities responsible for Germany´s deep geological repository projects. The goal was to establish a powerful and focused project organization capable of executing Germany´s repository programme. The paper highlights the achievements in the two largest construction projects, namely the Asse and Konrad mines for LAW/MAW (low and intermediate level radioactive waste). Site activities now exceed an annual turnover of 300 million €/a, and a staff of more than 1500, including contractors, move the construction projects towards start of operations in 2027 for Konrad and 2033 for the Asse.

While Konrad´s critical path is the refurbishment of the shafts, the challenge at the Asse project is to develop technology for the recovery of underground radioactive waste. The coming years will see intense activities in these fields.

1. WHERE DO WE COME FROM?

Salt mining at the Asse salt structure, southwest of the Hercynian Mountains in Northern Germany, began in 1906 and ceased in the 1960s. Between 1967 and 1978, about 47 000 m³ of low and intermediate level waste was emplaced in the old mine workings, labelled as a research programme. With an extraction ratio of locally more than 60% the bearing structure of the mine proved to be unsuitable for long term stability. Continued subsidence and rock mass movement in the Southern flank of the steeply dipping structure caused the overburden and some pillars to crack. Subsequently, fluid paths developed connecting aquifers and mine workings. Previously, the total rock mass movement of the southern flank has accumulated up to 7 metres (m), and it is expected that up to 2 m of additional movement will take place in the next decades. The brine influx into the mine measures currently 12 to 13 m³/day, the long term safety case for the repository is compromised. In 2009, German authorities decided to recover the waste. Since then, the operator has prepared the mine for the recovery process by continued backfilling and hydraulic encapsulation of the waste. The "recovery plan" summarizes the basic engineering of the recovery process and is accessible at the BGE website.

The Konrad mine is located 20 km to the west of the Asse mine. It is the first deep geological repository for LAW/MAW waste licensed under the federal atomic law of Germany. Stratigraphically, the Konrad mine is part of the caprock overlying the Zechstein salt sequence, which is the base of the Asse salt structure. In the 1960s and 1970s, the Konrad iron ore mine produced only around 7 million tons of ore. The mine never came to full production capacity because of the growing competition of higher quality overseas ore in the early days of globalization. The safety case of the Konrad repository takes credit from a thick, uniform layer of clay covering the iron ore deposit. Due to the isolation of the mine from all aquifers by the uniform thick clay sequence, the mine is bone dry; as such, the safety case is robust. Final approval for construction of the repository was granted in 2007. Since then work is progressing in various areas of the facility: both Konrad shafts are in the process of being completely refurbished; a new underground infrastructure is being developed to serve the emplacement and backfill technologies, a new field is being developed to the east of the existing underground workings that will accept the 300 000 m³ of waste; and at the surface a completely new infrastructure is under construction to replace the buildings of the former iron ore mine. Because the waste will be handled at shaft #2, all buildings, equipment, and construction around this emplacement shaft, in the underground and at the surface, is regulated by atomic law and fulfils the highest quality standards.

2. RECENT DEVELOPMENTS

In 2017, the newly formed BGE became the new operator of the Asse and the Konrad mines with the goal of merging the former operator, BfS (Germany's radiation protection authority), with the two former engineering, procurement, and construction management (EPCM) contractors of the two mines, namely the DBE and Asse GmbH. The merger was completed on January 1, 2018. The new BGE is more powerful than any of its predecessors as the split responsibility of operator and contractor is combined, as is conceptual planning and project execution. Consequently, construction activities accelerated, and the Asse and Konrad projects are rapidly progressing. In 2021, with a combined turnover at both sites exceeding 350 million €, more than 1500 staff (including subcontractors) build houses, drill holes, sink shafts, and develop underground infrastructure.

Current highlights at the Asse site include continued exploration of the salt structure in preparation for the new recovery shaft, the hydraulic encapsulation of the waste, and the development of recovery technology within the emplacement chambers. At the Konrad site, the inlet at the second level of the emplacement shaft sets new standards for large, long term stable underground infrastructure. The shaft refurbishments are in their final stages with the installation of hoists for shafts #1 and #2. At the surface, six buildings are at different stages of construction. Figure 1 highlights BGE activities in Germany.

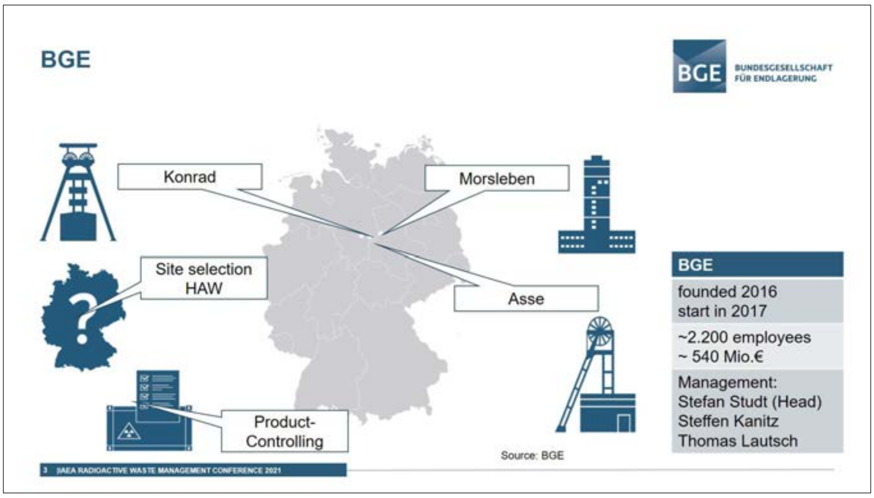

FIG. 1. BGE activities in Germany. Courtesy of BGE GmbH.

3. ASSE HIGHLIGHTS

At Asse, because existing infrastructure does not match the challenges of nuclear safety requirements, a new infrastructure will be developed for waste recovery from the underground and surface emplacement chambers. A new shaft (shaft #5) will be developed, including infrastructure buildings for material and waste handling on the surface. Adjacent to the mine, a waste treatment facility and an interim storage facility accept the waste after recovery. In the underground, shaft #5 will be connected to the emplacement chambers at several levels and a new infrastructure will serve the recovery technology.

3.1. Retrieval process from the chamber to interim storage

In recent years, many repository concepts for high level waste include the option for waste retrieval during operations and after closure. This engineered approach includes specific design considerations for waste canisters, mine layout, and backfill technology. The vocabulary in use is retrieval and retrievability for the readiness to do so.

In contrast, the Asse project recovers waste canisters of unknown condition out of an unstable geotechnical environment. This paper, therefore, uses the term ‘recovery’ for the process within the emplacement chamber and ‘retrieval’ for the entire process, including the engineered process of transferring the overpacks from the emplacement chamber to the waste treatment and interim storage facility.

Between 1967 and 1978, about 47 000 m³ of low and intermediate level waste (LAW/MAW) was emplaced in the Asse II mine on behalf of the German government. For this purpose, existing stopes on the 511m level (medium level waste) and on the 725 and 750 m levels were used as emplacement chambers. Due to increasing public criticism of the plans for the closure of the mine under the mining law, the facility was later placed under nuclear law. Since the long term safety required by nuclear law for the stored waste cannot be proven with the existing knowledge and uncertainties about the hydrogeological situation of the Asse, it was decided in 2009 to recover the waste. The legal basis was created in § 57 b of the Atomic Energy Act.

Recovery and retrieval is a complex undertaking that will require several decades to prepare and execute. It includes all underground and surface process steps that involve the handling of radioactive materials, starting with the activities for recovering the radioactive waste and ending with interim storage. The recovery and retrieval plan describes the basic procedure [1].

The particular challenge of waste recovery is to reconcile basically contradictory requirements in one concept: on the one hand, the mine has to be stabilized by backfilling and closure measures to ensure underground worker occupational safety, to avoid beyond-design-basis brine influx (AüL) as far as possible, and to reduce its potential effects as much as possible. On the other hand, waste chamber access has to be maintained or established to recover the waste. The excavations and underground measures required for this purpose cannot have an unacceptable impact on the stability and hydrogeological conditions.

Figure 2 shows the main steps of the retrieval process, starting underground with the recovery of the waste from the emplacement chambers (ELK). The waste is transported via the retrieval mine that is being built for this purpose and the associated new shaft #5 (see Fig. 3) to the surface in a special overpack. In above ground facilities, waste will be characterized, treated, and packaged (conditioned) before it is stored in an interim storage facility.

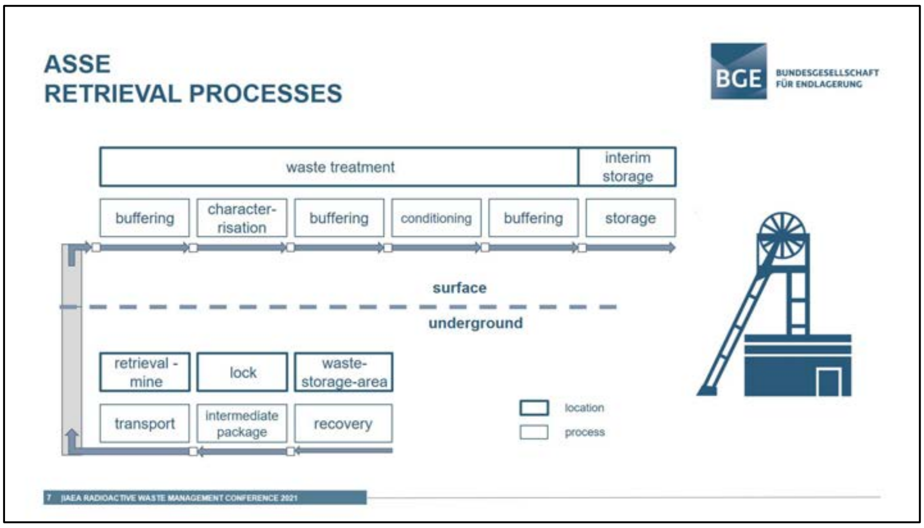

FIG. 2. Waste recovery processes. Courtesy of BGE GmbH.

3.2. Surface infrastructure

The new shaft for retrieval will be located to the east of the existing shafts. Adjacent to the shaft to the west the waste containers will be shifted from the vertical shaft transportation system to the horizontal surface transportation system in the transfer hall. On the other side of the shaft, a second service hall will service the conventional transport into the mine, mainly machinery and ground support.

The new shaft #5 site will be connected to public road, rail service, and via internal transportation system to the waste treatment plant.

To the north of the existing shaft #2, the BGE plans to build the waste treatment plant, combined in one building with the interim storage facility.

The total area of the facility will be increased from 6 ha to 22 ha. This additional footprint has to comply with nature reserve regulations, as the existing mine is in a Natura 2000/ FFH protected zone.

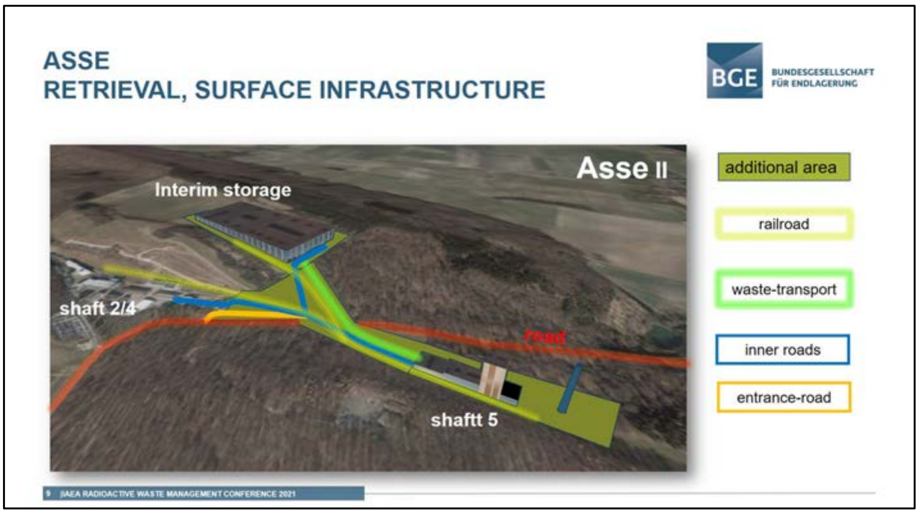

FIG. 3. Surface infrastructure. Courtesy of BGE GmbH.

3.3. Recovery technology

In addition to the existing geological and hydrogeological situation, special challenges for recovery arise from the waste container conditions, which are not precisely known. It needs to be assumed that a considerable part of the containers is no longer intact (i.e. at least leaking or destroyed to such an extent that handling, e.g. by means of a grab, is no longer possible). In addition, it can be assumed containers cannot be easily detached from the surrounding salt crust, as they have been embedded in crushed salt during emplacement. Furthermore, the waste documentation does not allow a clear determination of the radioactive inventory of each container.

The handling and transport of radioactive waste underground needs to meet the safety requirements for the operation of a nuclear facility. Potential incidents during handling have to be controlled. Radiation protection of personnel always has to be ensured during normal operation and in the event of incidents. Radioactive emissions — especially after opening of the emplacement chambers — have to comply with the permissible limits for the personnel below and above ground and for the public.

The technology to be used for recovery has to be designed to account for the geological and hydrogeological conditions, as well as the safety related and radiological requirements. In addition, it has to be able to react to the challenges posed by the waste containers. This includes, for example, dealing with defective casks or casks that are firmly trapped by the salt crust, as well as with the uncontrolled behaviour of casks in stacks and dumping cones.

The detailed planning of the recovery technology for the radioactive waste is carried out based on available concept studies, initially for the waste chambers on the 511 and 725 m below ground surface levels. By using small volume excavation technologies, the structural integrity of the mine will be affected as little as possible. For the recovery of waste from the chambers on the 750 m level a comparison of two technological approaches is currently being carried out.

Figure 4 shows the status of concept planning for recovery technology. Different recovery techniques are being developed, tested, and used for the respective emplacement conditions. For the individual chambers on the 511 and 725 m levels, the current plans envisage a grapple that is guided on the floor or via a rail system on the roof of the chambers. For the geotechnically unstable chamber rows on the 750 m level, sequential recovery with immediate backfilling for stabilization is preferred. Alternatively, using large volume shield tunnelling machines has been considered.

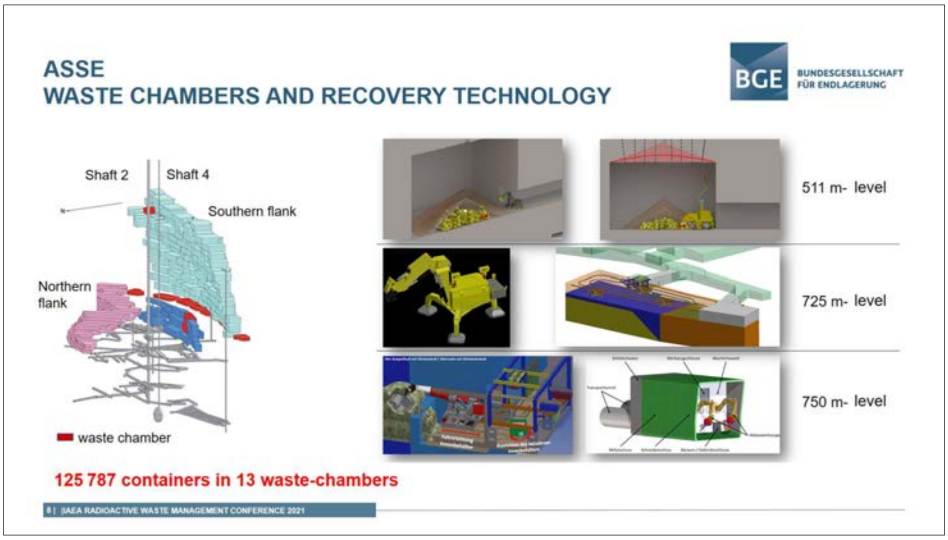

FIG. 4. Recovery technology adapted to specific conditions of emplacement chambers. Courtesy of BGE GmbH [1].

3.4. Waste treatment and interim storage

The first step of waste treatment is waste characterization. As the waste container integrity and content, which has to be recovered, is not fully known, different characterized techniques may be required. To enable constant rates of the recovery process thus making the underground process as constant as possible, the BGE plans for buffer capacities between the recovery shaft and the characterization, as well as between characterization and treatment.

The treatment facility is designed to handle the 50 000 m^3 of recovered waste, as well as another 50 000 m^3 of contaminated salt. It is expected, for compacted and backfilled emplacement chambers, salt will stick to the waste containers or what remains of them. The waste and the salt will be treated and fixed with concrete. The interim storage facility is designed for 200 000 m^3 of treated material.

3.5. Exploration for the new retrieval shaft

The new retrieval shaft #5 will be located around 250 m to the east of the existing mine. Due to the high extraction ratio and the consequent instability of the mine workings, this site was chosen as it is outside the influence of the former mining activities. The structural knowledge of the salt structure in this area is insufficient to develop the new underground infrastructure (shaft # 5 and its mine workings connecting the shaft to the emplacement chambers). As the Asse salt structure is quite irregular and surrounded by hydrogeological risks, the BGE conducts an intense exploration campaign with drilling and geophysics from the surface and underground. More than 10 core drillings and a complex 3-D seismic campaign gather information to validate the geological model and allow for safe development of the underground infrastructure.

4. KONRAD HIGHLIGHTS

The Konrad construction project is divided into three major subprojects, complete refurbishment of shafts #1 and #2, and underground mine improvements.

For the shafts, installed in the 1960s to guide the cages, all wooden installations will be replaced by steel structures to reduce fire hazards. All four hoists of the two shafts will be replaced with modern machinery. Shaft #2, which is the return airway, will serve as the waste container transportation shaft. Therefore, the previous auxiliary shaft of the former iron ore mine will become the centrepiece of the repository. The hoist of shaft #2 will have to comply with all requirements of the nuclear approval process. Shaft #1 will receive major steel works at the headframe and will be converted from lorry/rail haulage to belt conveyor/skip haulage technology.

At shafts #1 and #2, all buildings will be replaced or newly built. In total, more than a dozen major buildings will constitute the infrastructure for the conventional and nuclear parts of the facility.

For the underground mine, a central infrastructure will be developed for concrete production and handling, for workshops, and other facilities to maintain emplacement machinery with long term stable support systems. As the machinery is large, 1.5 km^2 infrastructure rooms will be constructed in a circular design with a diameter of up to 15 m and supported by rock bolts of up to 18 m long and a two layer shotcrete support, up to 1 m thick and reinforced with steel. This massive support system is necessary, as the repository is deep (up to 1000 m) and the rock masses are soft (clay and other sediments). While the central infrastructure in the underground is designed for long term stability over the lifetime of the mine, the emplacement chambers themselves have shorter lifetimes and smaller cross sections.

4.1. Shaft Number 1

The main challenge of the refurbishment of shaft #1 (Fig. 5) is the need to operate during reconstruction to serve the mine. Also, the work schedule is complicated and at different levels. Currently, the construction activities are centred on the installation of the northern hoist. The southern hoist was brought into operation in 2017. At the surface most of the infrastructure buildings are completed, with the workshop as the last large building in construction.

FIG. 5. Konrad shaft number 1. Courtesy of BGE GmbH.

4.2. Shaft Number 2

The main challenge of the refurbishment of shaft #2 is the need to comply with both the stringent requirements of nuclear law (i.e. regarding earthquake protection and load handling, among others) and those stipulated under mining law (e.g. using the shaft as a return airway route and a personnel mine escape way during construction activities).

The inlet connecting the shaft with the mine at the second level, completed in April 2021 after 3.5 years of intense work, was a very complex construction project, particularly due to its complex geometry and setting. The inlet is constructed as a 4-way intersection and has an exceptionally large diameter of 13 metres. Construction of the inlet was further complicated, by the abutment stresses, which necessitated construction outward away from the shaft into the mine to avoid damage to the shaft. This approach was particularly challenging due to the limited space available in the shaft to coordinate the required construction activities and equipment (e.g. infrastructure needed for haulage of spoils, mine ventilation, personnel transportation, equipment manoeuvring, etc.).

The buildings at the surface of shaft #2 (Fig. 6) contain the cranes and transportation infrastructure of the waste containers and the return air infrastructure with a mine fan, return air channel, and exhauster. Everything is controlled and supervised by nuclear regulations. Currently, the focus of the construction site is the construction of the foundation of the future hoist tower, which will weigh 2600 tons and will hold the hoisting machine in the top of the tower.

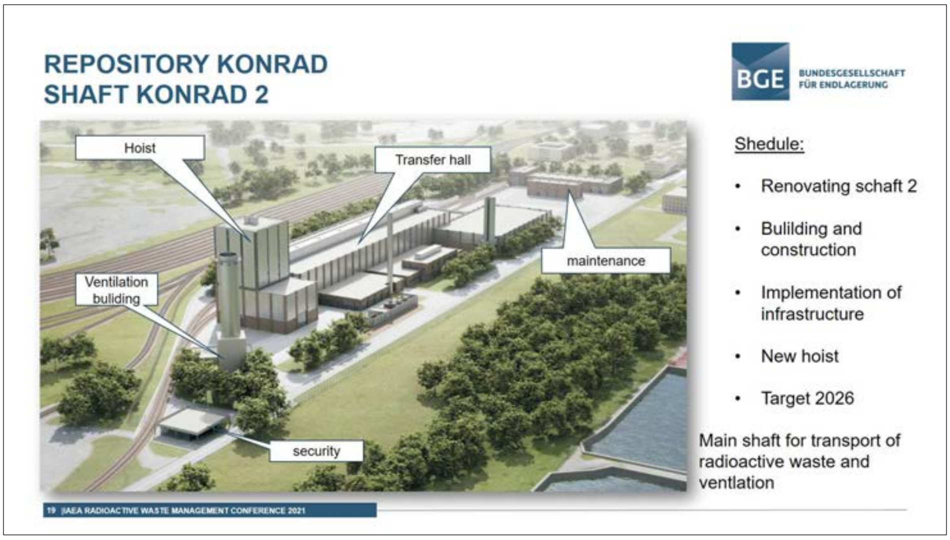

FIG. 6. Konrad shaft number 2. Courtesy of BGE GmbH.

4.3. Underground

Complex in geometry with many intersections, the large diameter underground workings provide room for transportation and concrete technology and they have to last for the entire life of the mine, without any creeping or convergence. Refurbishment of both shafts presented an additional challenge of preventing shaft haulage during underground development. Therefore, all excavated material had to be placed in the old workings of the iron ore mine, which had never been designed and reinforced for that purpose.

5. OUTLOOK

The Asse recovery project entered the licensing process in 2020. Within this stepwise procedure, BGE has to prove it complies with the highest radiological protection standards while recovering waste of unknown conditions in an unstable geotechnical environment. The recovery infrastructure will be developed through 2033, including the sinking of an 800-m shaft and building an infrastructure at the surface to handle, characterize, and treat waste to be ready for intermediate storage at the surface. Upon completion, in around 40 years from now, 200 000 m³ of waste is expected to be safely stored.

Konrad will start emplacement in 2027. Until then the construction site remains busy. Equipping the shafts with new hoists and qualifying them for the repository operation remains a challenge. The installations have to be adjusted to the geometry of the existing shafts, the access to the mine has to be guaranteed at all times and the regulatory framework is dense. The complex organization of simultaneous surface, shaft, and underground activities requires a large degree of detailed engineering.

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Paper ID#47

ADVANCES IN IMPLEMENTING STRATEGY FOR MANAGEMENT OF RADIOACTIVE WASTE IN PAKISTAN

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Abstract

In Pakistan, radioactive waste management began with operation of the first research reactor PARR-I in 1965 and first nuclear power plant (NPP) in 1972. Over time, Pakistan added more nuclear reactors to its national fleet. Additionally, there are numerous nuclear medical, agriculture, and research centres working in the country generating radioactive waste, including disused sealed radioactive sources (DSRS). Although radioactive waste generated from these facilities was managed at facility level, each facility had their own waste processing and packaging techniques. For safe final disposal, there was a need to synchronize the waste processing and packaging techniques generated by each facility. To manage these issues, Pakistan formulated a national strategy for safe management of radioactive waste in 2011, which is currently being revised. The strategy lays out objectives of safe management of radioactive waste under all conditions and for the time it remains hazardous to human health and the environment. This strategy helped to achieve standardized radioactive waste management practices throughout the country. Adoption of modern procedures and optimized waste processing techniques are implemented to align with storage and disposal requirements. As a result of this strategy, waste generators focused on avoidance, minimization, reusing, and recycling of radioactive waste. This leads to proper segregation, decontamination for recycling, evaporation, incineration and super-compaction for volume reduction, and standardized waste packages for storage and disposal. Moreover, for disposal of radioactive waste, two near surface disposal facilities are planned to accommodate low level waste (LLW) – one in the northern part and the other in the southern part of the country. In northern part, a site has been selected and detailed site characterization is in progress. In parallel, the process for designing and safety assessment has also been initiated. For disposal in the southern part of the country, candidate sites are being studied. For sustainability of the disposal projects, finances are assured. The strategy has proven useful as an instrument to implement the plans and goals set out in the National Policy on Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel in the Islamic Republic of Pakistan.

1. INTRODUCTION

For a sustainable and successful nuclear energy programme and to protect human health and the environment, safe management of radioactive waste is of paramount importance. In Pakistan, focus has been given to the management of radioactive waste since the inception of nuclear technology. Operation of the country's first research reactor – Pakistan Atomic Research Reactor (PARR-I) and first nuclear power plant (NPP) – Karachi Nuclear Power Plant (KANUPP-1) started in 1965 and 1972, respectively under the umbrella of the Pakistan Atomic Energy Commission (PAEC). Radioactive waste generated from these nuclear installations is managed at the facility level. With the passage of time, more NPPs and research reactors have been added to meet national energy requirement, research activities and isotope production. There are currently six NPPs in the country, generating almost 2400 MWe, and two research reactors. Consequently, generation of radioactive waste has increased through operation of these nuclear facilities. Besides radioactive waste from the facilities, disused sealed radioactive sources (DSRS) are also generated from agriculture, nuclear medical, and research centres.

A national policy, "National Policy on Control and Safe Management of Radioactive Waste," was issued in 2011 for a sustainable nuclear energy programme to define the role and responsibilities of different stakeholders and to develop a national strategy for standardizing waste management practices. The policy was revised in 2018 to include spent nuclear fuel and decommissioning. To ensure implementation of the policy and to standardize practices of waste management at different waste generating facilities, a national strategy was formulated in 2011 and is being implemented. The strategy clearly defines the roles and responsibilities of all the relevant stakeholders and sets forth means in which different types of radioactive waste will be managed during the entire lifecycle of radioactive waste. The strategy emphasizes radioactive waste generation is controlled to the extent possible and best available waste processing techniques, such as incineration, evaporation, super-compaction, etc. are adopted. Due consideration is given to protection of human health and the environment while managing radioactive waste. Implementation of the strategy not only helped in standardizing waste management practices at different facilities but also resulted in volume reduction and conditioned waste packages acceptable to storage and disposal requirements.

As the majority of radioactive waste generated is low level waste (LLW), two near surface disposal facilities (NSDFs) are being developed, one each in the northern and southern parts of the country. The sites have been selected in accordance with selection criteria. Detailed site characterization of the sites is in progress to determine their geological, hydrological, tectonic, seismic, and erosional traits. Design and safety assessment studies of the site are also in progress.

A Radioactive Waste Management Fund (RWMF) has also been created to ensure availability of finances during the entire radioactive waste life cycle. The majority of contributions to the fund is made through levy generated from sale of electricity generated by NPPs.

2. NATIONAL POLICY ON SAFE MANAGEMENT OF RADIOACTIVE WASTE, DECOMMISSIONING, AND SPENT NUCLEAR FUEL IN ISLAMIC REPUBLIC OF PAKISTAN

It is essential that radioactive waste generated in the country is effectively managed at a national level to protect human health and the environment from harmful effects of ionizing radiations, now and in the future. In this regard, the “National Policy on Control and Safe Management of Radioactive Waste” was issued in February 2011 by Pakistan Nuclear Regulatory Authority (PNRA) with the approval of the Government. The objective of the policy is to establish a national commitment to control and manage radioactive waste generated in the country in accordance with national legislation/regulations and international standards. The policy fixes responsibilities of all relevant stakeholders and adequate allocation of resources. In 2014, the IAEA Integrated Regulatory Review Service (IRRS) mission reviewed Pakistan’s regulatory framework for nuclear and radiation safety. The mission observed that Pakistan’s National Policy on control and safe management of radioactive waste does not mention decommissioning and spent nuclear fuel (SNF) . It was suggested by the mission that the government should consider decommissioning of facilities and the safe management of SNF in the existing radioactive waste management policy. Similarly, corresponding strategies should also be developed, with interim targets and end states.

As per the IRRS mission recommendations, PAEC and PNRA jointly revised the national policy, defining the national stance on SNF and decommissioning. PNRA issued the revised version of the policy as “National Policy on Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel in Islamic Republic of Pakistan.

The policy clearly emphasized the safe management of radioactive waste including DSRS, decommissioning of nuclear facilities, and management of SNF. For implementation of the policy, the PAEC, the nuclear facilities operator, is responsible for formulation of national strategies for safe management of radioactive waste including DSRS, decommissioning, and SNF. Consequently, corresponding national strategies have been formulated and are being implemented in the country.

3. ADVANCES IN IMPLEMENTING NATIONAL STRATEGY FOR SAFE MANAGEMENT OF RADIOACTIVE WASTE AND DISUSED SEALED RADIOACTIVE SOURCES

Before formulation of the national strategy, the practices adopted for management of radioactive waste by different waste generators were different, which resulted in waste packages of different size, activity, and dose rate, making disposal difficult. Furthermore, volume reduction techniques for solid waste were also not being practiced properly. Hence, to standardize waste management practices and to implement volume reduction techniques, a strategy was formulated for each waste stream type. The strategy emphasized that standard waste containers, as per specifications and dimensions, will be used for holding and conditioning radioactive waste. The strategy adopted is divided into two main parts (i.e. predisposal management and disposal management). Waste generators are responsible for predisposal management of waste, which is carried out in licensed waste management facilities at generating sites. A central directorate called Directorate General of National Repository (DGNR) is responsible for radioactive waste disposal. For DSRS management, sources having half-life greater than 1 year and initial activity greater than 100 GBq are returned to the supplier, while sources with half-life less than 1 year and activity less than 100 GBq will be disposed of in the country as per the national strategy.

3.1. Predisposal Management at Nuclear Power Plants

In Pakistan, the majority of radioactive waste in liquid, solid, and gaseous forms is generated from the operation of NPPs. Four Pressurized Water Reactors (PWR) each of almost 300 Mwe are in operation at Chashma Nuclear Power Generating Station (CNPGS), in the northern part of the country. While in southern part of the country i.e. at Karachi site, one pressurized heavy water reactor (KANUPP-1) of 137 MWe and one PWR (KANUPP-2) of 1100 MWe started operation in May 2021. Another PWR (KANUPP-3) of 1100 MWe is in the commissioning phase. KANUPP-1 will complete its service life in August 2021 and will be completely shut down.

A dedicated management system for managing each waste stream type exists, as per the strategy. The subsequent section outlines the management strategy being adopted for each waste stream type.

3.1.1. Liquid Radioactive Waste Management System at CNPGS

The Liquid Radioactive Waste Management System at CNPGS has the capabilities to collect, process, store, and monitor all potentially radioactive liquid waste generated as the result of normal operation, including anticipated operational occurrences (start up, shut down, refuelling, etc.) and maintenance. This section discusses the following types of liquid radioactive waste streams generated from operation of NPPs:

— Spent ion exchange resins;
— Clean drains;
— Process drains;
— Floor drains.

Spent Ion Exchange Resins

Ion exchange beds are used to minimize soluble radioactive material. This material results from corrosion in the primary circuit and activation of chemicals in the primary circuit. The sources of spent resins are from the demineralizers of the following systems:

— Chemical and volume control system;
— Boron recycle system;
— Liquid waste treatment system;
— Spent fuel pool cooling and cleanup system;
— Steam generator blowdown system.

The ion exchange resins in the beds are periodically changed to optimize their performance. The spent resins are treated as radioactive waste. The spent resins from different systems are flushed to the spent resin holdup tank. The resin is stored underwater (300 to 400 mm water level above resin level) in the holdup tank at normal atmospheric pressure and is loosened by compressed air to prevent possible resin agglomeration. The air in the tank is slowly bled through an aeration waste line to prevent accumulation of any radioactive gas released during storage.

To create space, for future arising of spent resin in holdup tanks and to immobilize spent resin for final disposal, it was decided to solidify the spent resin using cement. In this regard, a necessary modification was made in Liquid Radioactive Waste Solidification System (LR). Spent resin, cement, and water are fed into an empty 200 l mild steel (MS) drums at the LR building grouting station and is conveyed by roller to a mixing device, where the mixing process starts. After cementation of spent resin, the conditioned MS drums are stored in the Solidified Radioactive Waste Storage Building (SR), until a disposal facility is available.

Moreover, research and development (R&D) on treatment of spent resin through advanced oxidation process is also in progress. Once successful, the spent resin will be treated through this process.

Clean Drains

The clean drains are made up of the drains and leakages from components and piping of the following systems:

— Chemical and volume control system;
— Boron recycle system;
— Sampling system;
— Containment reactor coolant drain system;
— Spent fuel pool cooling and cleanup system.

The calculated activity of clean drains from different streams is below the design activity limit of 2.29×10^{10} Bq/m^3. The clean drains are stored in a holdup tank before further treatment. Evaporation is used for volume reduction of radioactive liquid effluents because it is the most effective method for chemical and radiological purification of liquid effluent from an NPP. The evaporator separates the dissolved and suspended liquid effluent constituents, concentrating the radioactivity in the resulting residue. Evaporation has the following main advantages:

— Reduces radioactive discharges by concentrating particulate in the concentrate:
— Minimizes discharges of chemical and solid impurities:
— High decontamination factor:
— Proven system design/technology:
— Well documented operational experience:
— Continuous and automatic operation.

Clean drainage from the holdup tank is transferred to an evaporator. Evaporation of clean drains results in the production of a sludge-like concentrate that contains the bulk of the radioactivity initially present in aqueous clean drain streams. The evaporator concentrates are discharged to the concentrate transfer tank for transfer to solidification in LR building. Vapours from the evaporator are condensed in a condenser and, depending upon the activity of condensate, it is recycled or discharged directly following monitoring to confirm compliance with discharge authorizations.

Process Drain

The process drains are made of the water from resin regeneration, flushing, and component washing from the following systems:

— Boron recycle system;
— Containment reactor coolant drain system;
— Chemical and volume control system;
— Spent fuel pool cooling and cleanup system;

— Sampling system;
— Decontamination system;
— Steam generator blowdown system.

The calculated activity of process drains is within the limit of design activity of 2.29×10^8 to 10^9 Bq/m^3. Like clean drains, the process drains are stored in a holdup tank before transferring to the evaporator. After evaporation, the resulting concentrates are solidified through cementation in LR building. Solidified drums are stored in SR building.

Floor Drain

The floor drains consist of the following input sources:

— Radioactive equipment compartments floor drains from the auxiliary building;
— Nuclear island building floor drains;
— Low activity drains of the radiation monitoring system.

The floor drain is collected by the floor traps and gutters in the radioactivity component room and then routed into the floor drain sumps. There are two floor drain sumps in the auxiliary building where the liquid waste is transferred by pump to the floor drain tank. Generally, the radioactivity of the floor drain is low enough for direct discharge after radiation monitoring. Under certain circumstances, the floor drains may be contaminated by radioactive material and its specific activity may exceed the specified limit for discharge. In such case the floor drain is transferred to process drain holdup tank and processing flow paths are the same as that for process drain.

3.1.2. Solid Radioactive Waste Management System at CNPGS

Spent Process and HEPA Filters

Process filters are used throughout the nuclear island of the NPP to maintain water quality and remove radioactive corrosion and wear products. The systems incorporating process filters are:

— Chemical and volume control system;
— Reactor coolant pump seal water system;
— Boron recycle system;
— Spent fuel pool cooling and cleanup system;
— Steam generator blowdown system.

Filters are withdrawn from operation based on clogging and/or dose rate. These withdrawn filters, considered as radioactive waste, are encapsulated in RCC barrels (Vol.: 0.88 m^3, Dia: 0.93 m, Height: 1.3 m). The RCC barrels are then stored in the Radioactive Waste Treatment and Storage Building (RS) until the availability of a disposal facility.

All radiation controlled areas of the nuclear auxiliary building, fuel building, reactor building, main control room, access building and waste treatment building are served by dedicated ventilation systems. The exhaust from these systems is subject to several airborne activity abatement techniques, including the use of high efficiency particulate air (HEPA) filtration before discharge to the environment. The abatement systems therefore produce several spent HEPA filters over the course of reactor operations. HEPA filters have the potential to be classed as radioactive waste if they have arrested any radioactive particulate or aerosol. Spent HEPA filters are placed in plastic bags which are then packed in a special 1310 × 1110 × 910 mm cask (MS box). Each cask holds six filters. The casks are stored in RS building until the availability of a disposal facility.

Dry Active Waste

Dry active waste is generated through routine and maintenance operations. The waste consists of contaminated personal protection equipment, monitoring swabs, plastic, clothing, rags, contaminated tools, equipment and other process consumables. Mainly arising during outages these wastes are collected into plastic bags. The plastic bags are put into a 200 l drum and compacted through an in-drum compaction process.

The combustibility of the generated dry active waste requires developing an incineration facility to extensively reduce the volume of waste. The facility is being developed and will be able to incinerate 25 to 35 kg of waste per hour. This will reduce the volume of waste by almost 80 to 100 times. The incineration facility main systems are the waste pretreatment subsystem, incineration (pyrolysis and combustion furnaces), ash collection (discharge and collection), off-gas cleaning (dry and wet), air supply and exhaust, compressed air supply, cooling water circulation, lye supply and circulation, emergency exhaust, and waste liquid storage and dispersal.

3.1.3. Gaseous Waste Management System at CNPGS

The gaseous radioactive waste treatment system of each power plant at CNPGS is designed to process gaseous wastes that may contain appreciable amounts of radioactive fission product gases and hydrogen. Each treatment system consists of one gaseous waste surge tank, two compressors, six decay tanks, two HEPA filters, two moisture separators, and associated piping, valves, and instrumentation.

The gaseous waste treatment system receives its inputs from the following sources:

— A degassing of the reactor coolant and purging of volume control tank prior to a cold shutdown;
— Purging of certain equipment;
— Boron recycle process operation;
— Sampling and gas analyzer operation.

Gaseous waste is collected in the surge tank, which is designed to provide a storage capacity for transient gas volumes that exceed compressor capacity. The surge tank outlet header is provided with a nitrogen supply for purging components prior to maintenance. A relief valve is provided on the tank top to prevent over pressurization.

Collected gas is directed to one or two diaphragm compressors depending on the pressure of waste gas surge tank. Compressor discharge flow is directed through a cooler to the waste gas decay tanks through a flame arrestor, which prevents the spread of gas combustion throughout the system. The six decay tanks receive the compressed waste gas for storage.

Each decay tank has a motor operated diaphragm valve for supply of cover gas to holdup tank or boric acid storage tank. Periodic discharges of stored gas are made to the environment through HEPA filters under the control of a motor operated flow control valve. An inline radiation monitor downstream of the HEPA filter continuously monitors the discharge.

3.1.4. Liquid Radioactive Waste Management System at KANUPP-1

KANUPP-1 is a PHWR, and unlike a PWR, liquid radioactive waste generated is low in quantity and activity. At KANUPP-1, two types of liquid streams are generated i.e. inactive liquid effluent and active liquid effluent.

Inactive liquid effluent is generated from personnel showers, sinks, cotton laundry, etc. and does not contain sufficient activity. Inactive liquid effluent is continuously monitored. If the radioactivity is within permissible limit (Sr-90: 4×10^{-7} μCi/ml (0.015 Bq/ml)) it is diluted with plant cooling water and then discharged into the sea. Otherwise, the liquid effluent is diverted to a holdup tank.

Active liquid effluent is generated from the reactor building, chemical laboratory, maintenance shop and decontamination facility. Liquid waste from these facilities is collected in reactor building sump and then transferred to a holdup tank of 7000 gallons capacity for radioactivity decay. When this tank is full, its contents are transferred to a 40,000 gallon dispersal tank. Then effluent is pumped out to sea after mixing it with the plant cooling water to such an extent that the radioactivity does not exceed 0.015 Bq/ml Sr-90 (4×10^{-7} μCi/ml) at the discharge point.

3.1.5. Solid Radioactive Waste Management System at KANUPP-1

Solid radioactive waste generated from operation of KANUPP-1 includes soft waste, hard waste, and spent resin. Soft waste consisting of contaminated clothing, gloves, papers, etc. are collected in 200 l MS drums and an in-drum compaction technique is used to reduce volume. After volume reduction, drums are stored in thet Radioactive Waste Storage Area (RAWSA) of KANUPP-1.

Hard waste consists of high activity filters, shield plugs, contaminated tools, pipes, etc. The hard waste is transported is shielded containers to RAWSA, and is stored in concrete lined trenches, covered with RCC slabs.

Highly radioactive spent resin is generated from columns of coolant, moderator, spent fuel bay water and vault cooling water. The spent resin is flushed directly into spent resin storage tanks. Initially, two 20 m^3 (800 ft^3) tanks were used for storage of spent resin. These tanks are installed inside the concrete room in service building. After the fixed tanks were filled in 1993, portable tanks of stainless steel, each of capacity 2 m^3 (70 ft^3), are being used. Annually one portable tank is required for storage of spent resin. It is planned that spent resin will be characterized and then transferred to treatment/conditioning facility of KANUPP-2, where the spent resin will be cement solidified in MS drums (200 l) for final disposal.

3.1.6. Radioactive Waste Management at KANUPP-2

KANUPP-2 is an 1100 MWe PWR and started operation in May 2021 as a dedicated licensed waste management facility for radioactive waste generated from operation, refuelling, and maintenance activities. The waste management facility comprises the following:

- Evaporators for volume reduction of liquid waste;
- Cement solidification facility for liquid concentrates and spent ions exchange resin;
- Encapsulation/grouting facility for spent filters;
- Super compaction facility of 2000-ton force for compactable waste;
- Gaseous waste management facility.

3.2. Predisposal Management at Research Reactors

Two research reactors, Pakistan Research Reactor-1 (PARR-1) and PARR-2 of 10 MWth and 27 kW, respectively, are in operation at Pakistan Institute of Nuclear Science and Technology (PINSTECH), Islamabad. The following sections describe management of radioactive waste generated from operation of these research reactors.

3.2.1. Liquid Waste Management System

Almost 600 to 700 m^3 very low level liquid waste is generated annually from research reactor operations. Liquid waste generated is transferred to delay and decay tanks, where 3 to 4 months decay time is given to achieve activity level of 3 MBq/m^3. After delay and decay tanks the waste is transferred to disposal pits having beds of sand, gravel, and charcoal, each 30 cm thick.

3.2.2. Solid Waste Management System

Almost 1000 to 1500 kg of compactable waste is generated annually from operating research reactors and other allied facilities, comprised of polythene and rubber gloves, tissue papers, cotton overshoes, polythene sheets, glass, plastic bottles, etc. The waste volume is reduced through in-drum compaction techniques by deploying a 30 ton force compactor.

Non-compactable waste, almost 165 to 225 kg/annum, comprising resin and adsorbent columns is cement solidified in RCC barrels. Conditioned waste packages are stored until disposal facility availability.

3.3. Management of Disused Sealed Radioactive Sources

As per "PNRA Regulations on Radioactive Waste Management- (PAK 915) (Rev.1)," DSRS containing long lived radionuclides (half-life more than one year with initial activity of 100 GBq or more) are returned to the manufacturer or supplier. For DSRS with a half-life less than one year and activity less than 100 GBq, orphan sources and sources that could not be returned to the supplier are stored at designated storage sites in the country until the availability of a disposal facility. Currently, two designated storage sites are in operation in the country for storage of previously mentioned sources, one each at KANUPP and PINSTECH. At KANUPP, the Radioactive Waste Storage Area (RAWSA) is used for storage of DSRS from Sindh and Baluchistan. While the PINSTECH Predisposal Radioactive Waste Management Facility (PPRWMF) is used for storage of DSRS from Punjab, Khyber Pukhtunkhwa (KP), Federal Territory and Azad Jammu Kashmir. The strategy for the management of disused/orphan radioactive sources and ownerless radioactive waste is shown in Figs 1 and 2.

3.4. Disposal Management of Radioactive Waste

Based on the location of NPPs, two NSDFs are being developed in the country. The first facility, the National Institute for Conservation of Environment (NICE), is based in the northern part of the country to support disposal of low level and intermediate level wastes generated from CNPGS, PINSTECH, and other small generators, including DSRS. The second, the Karachi Disposal Facility (KDF), is being developed in the southern part of the country to meet disposal requirements for low level and intermediate level wastes from operation of NPPs in the southern part of the country and the decommissioning waste of KANUPP-1 and DSRS.

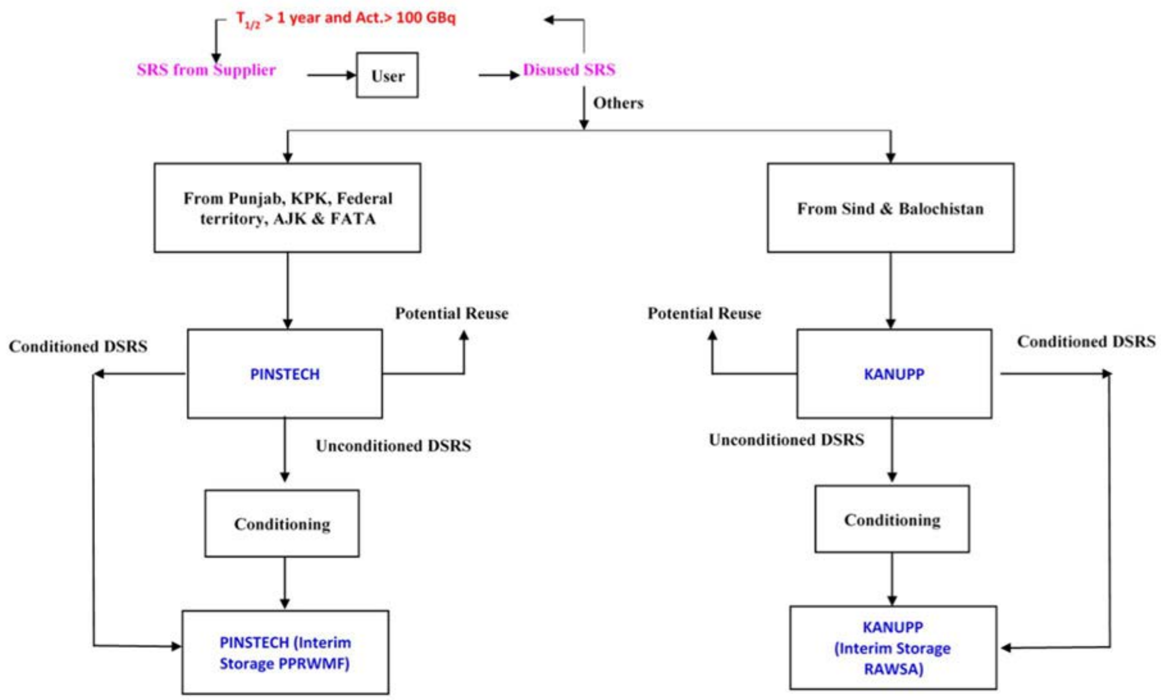

FIG. 1. Short Term Management of DSRS

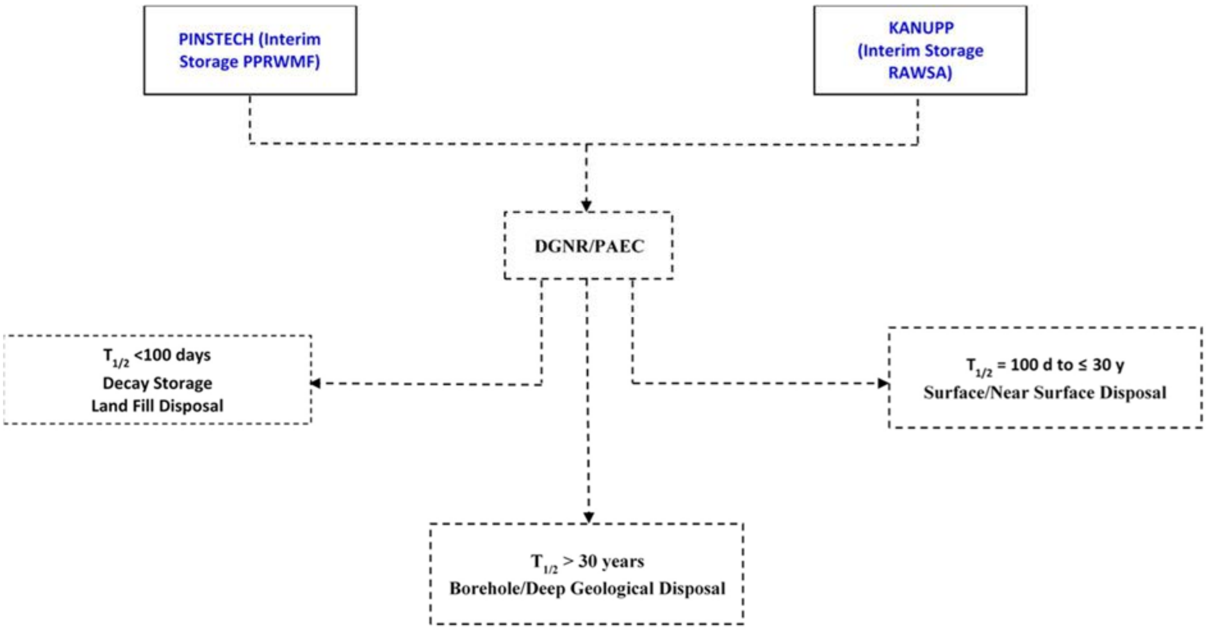

FIG. 2. Long Term Management of DSRS

3.4.1. National Institute for Conservation of Environment

A site has been selected for development of the NICE as per the site selection criteria for NSDF. The selected site is a semi-arid region with dissected topography and very low rainfall. The regional geology around site consists of rock formations, ranging in age from late Pliocene to Eocene. These are limestone, sandstone, and shale. Geological survey conducted in the area revealed the studied area is hosted by the rocks of Chinji Formation, which is underlain by Kamlial Formation and overlain by Nagri Formation. Chinji Formation is characterized by bright brick red, thick clay/shale with inter-bedded ribbon-like ash-grey soft sandstone which does not extend laterally for long distances, having a general dip of 8 to 10^{o} NW.

Different site characterization work including lithology, topography, geology, flood potential, flora and fauna have been completed. Work on the seismic hazard and hydrological studies of the selected site are in progress.

Registration of the site with PNRA is also in progress with a site evaluation report being prepared. Additionally, different No Objection Certificates (NOCs) are required to register the site with PNRA. In this regard, reports have been prepared by DGNR and submitted to relevant departments. Consequently, NOCs have been obtained from the Environmental Protection Department, Mines and Minerals Dept., Forest Dept., and Local Govt.

The conceptual design of the facility has also been completed with a multiple barrier protective system design. Waste will be contained by a waste matrix conditioned in already approved waste containers. Isolation will be achieved by different barriers and proper institutional control of the facility. It is planned that a modular vault type disposal facility will be developed. Each vault will have dimensions of almost 20 × 20 × 6.5 m. Detailed designing and safety assessment of the facility are in progress.

3.4.2. Karachi Disposal Facility

To meet the disposal requirements of radioactive waste generated from NPPs, other small generators and DSRS in the southern part of the country, a NSDF is being developed. This facility is named as the Karachi Disposal Facility (KDF). A site has been selected within the boundary of KANUPP-1. Detailed site characterization studies of KDF have been recently started. The site is mainly composed of Pliocene to recent sedimentary deposits of Nari and Manchar formations of shallow marine, deltaic to alluvial depositional environments. The lithological area is mainly composed of sandstone, clay stone, mud stone and silt stone.

The disposal facility will be comprised of reinforced concrete vaults built on the surface. Different engineered barriers will be incorporated for isolation and containment of the disposed waste.

4. RADIOACTIVE WASTE MANAGEMENT FUND

The Radioactive Waste Management Fund (RWMF) finances all activities associated with management of radioactive waste generated from NPPs. Electricity sales contribute to this fund, as determined and allowed by the National Electric Power Regulatory Authority (NEPRA). The PAEC is responsible for collecting and using funds as per the requirement.

However, for other facilities like research reactors, the expenditure is borne by the respective generators from their annual budget. In case of non-availability of funds with the generators, and for ownerless waste, orphan sources and sources cleared by PNRA, the Government of Pakistan is responsible for financing of their management of radioactive waste.

5. CONCLUSION

The majority of radioactive waste in Pakistan is generated from six NPPs and two research reactors operated by PAEC. Additionally, DSRS are also being collected from application of radioisotopes in medicine, research, agriculture, and industry. A strategy has been formulated and is being implemented in Pakistan for its National Policy on Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel to ensure sustainable operation of nuclear facilities and protection of human health and the environment. The strategy describes how predisposal management of radioactive waste is carried out in dedicated and licensed waste management facilities. In these facilities, optimum treatment and conditioning techniques are adopted. The conditioned waste packages are stored in interim storage facilities until the availability of disposal facilities. Different advancements have been made in predisposal management of radioactive waste, like cement solidification of spent resin, development of an incineration facility and super compaction facility. For management of DSRS having a half-life less than 1 year and initial activity less than 100 GBq, PINSTECH and KANUPP are authorized in the north and south of the country, respectively. DSRS with a half-life greater than 1 year and initial activity greater than 100 GBq are returned to the supplier as per national regulations. For disposal management of radioactive waste, two NSDFs are being developed. Based on the location of load centres, one NSDF (NICE) is being developed in the northern part of the country, with a site selected and detailed site characterization in progress. Reinforced concrete vaults on the surface will be developed for disposal of low level and intermediate level waste. A second NSDF (KDF) is being developed in the southern part of the country. The site for KDF has also been selected and its detailed site characterization studies have begun. A radioactive waste management fund with contributions made through levy generated from sale of electricity has been established to cope with financial expenditure associated with management of radioactive waste.

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Paper ID#132

NATIONAL STRATEGY OF THE RUSSIAN FEDERATION IN THE FIELD OF RADIOACTIVE WASTE MANAGEMENT: KEY PROVISIONS AND PROGRESS IN ITS IMPLEMENTATION

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Abstract

The report summarizes the progress achieved in the last decade in the key areas stated under the National Strategy of the Russian Federation in the field of radioactive waste management with its main provisions outlined in a new Federal law On Radioactive Waste Management enacted in 2011.

1. INTRODUCTION

In 2011, the following basic principles governing radioactive waste management activities were first legally established in the Russian Federation: mandatory radioactive waste disposal; separation of the entire radioactive waste inventory into retrievable and non-retrievable waste; state liability for non-retrievable radioactive waste disposal; establishment of an internationally recognized financial liability principle (i.e. the *polluter pays* principle).

The report presents the main achievements in the implementation of the national radioactive waste management strategy [1]:

— Establishment of a regulatory framework;
— Commissioning of a near surface RW disposal facility;
— Progress in the establishment of an underground research laboratory (URL);
— Commencement of radioactive waste conditioning operations and its transfer for disposal;
— Disposal of non-retrievable radioactive waste (legacy waste);
— Enhancement of radiation monitoring systems;
— Improvement of safety analysis tools and methods, as well as their application addressing several practical tasks.

The paper also briefly summarizes some urgent tasks that are planned to be solved by 2030.

2. LEGAL FRAMEWORK IN THE FIELD OF RADIOACTIVE WASTE MANAGEMENT

Following the federal law enactment, the key criteria governing the main aspects of radioactive waste management activities were set forth by the Government are as follows:

— Criteria for radioactive waste categorization either as retrievable (subject to retrieval, conditioning, and disposal in a centralized radioactive waste dispoal facility (RWDF)) or special (non-retrievable radioactive waste subject to in situ disposal suggesting the installation of some additional safety barriers). In fact, it’s object-based decision making (“according to the situation”). To allow such a decision making, for the first time a specific methodology was purposely developed and applied in practice for over 100 facilities allowing for a comparison of retrieval and in situ disposal options according to the following aspects: 1) collective doses and risks of potential exposure for personnel and the public, 2) disposal costs (including costs for retrieval, processing, conditioning, transportation to the disposal site, and disposal itself), and the total potential environmental damage to the environment in case of in situ radioactive waste disposal and the actual disposal costs.

— Criteria governing radioactive waste disposal methods associated with relevant disposal tariffs.

Based on the new criteria, the radioactive waste inventory and the inventory of radioactive waste sites were compiled. Two key tasks have been addressed: the amount of federally owned radioactive waste was identified (state liability was established) and the radioactive waste was categorized either as non-retrievable (special) or retrievable. These efforts completed in two years (2013–2014) allowed for the investigation of over 800 radioactive waste storage facilities belonging to over 100 organizations [2].

3. ESTABLISHMENT OF A CENTRALIZED RADIOACTIVE WASTE DISPOSAL SYSTEM

In 2016, the first RWDF section with a design capacity of 15 000 m^3 was commissioned in the Sverdlovsk region. The second RWDF section is undergoing the licensing process, and, if completed successfully, the total design capacity of the facility will be 55 000 m^3 [3].

In addition to the Sverdlovsk facility, other RWDFs are being established in the Chelyabinsk and Tomsk regions. For these facilities, the review of construction license applications has been partially completed (in terms of support and auxiliary systems and structures), with the one associated with disposal facilities themselves still underway. The first sections of these facilities (scheduled for commissioning around 2023) will increase the total design near surface disposal capacity to 131 900 m^3. The expected expansion of the RWDF is planned for 2030 (up to a total capacity of 407 000 m^3). The corresponding disposal capacities are supposed to fully meet the needs of waste generators by 2040.

In 2016, the construction license for the URL was obtained, and the corresponding pre-construction efforts were launched. Considering the significant progress achieved by the Russian Federation over the past decade in the development of nuclear fuel fabrication and reprocessing technologies, as well as those associated with radioactive waste conditioning, the Strategy for the Development of a Deep Radioactive Waste Disposal Facility was developed and approved in 2018. In 2019, the development of a Comprehensive R&D Program for the Demonstration of Long-Term Radioactive Waste Disposal Safety and Optimization of its Operational Parameters [4–12].

4. RADIOACTIVE WASTE PROCESSING, CONDITIONING, AND TRANSFER FOR DISPOSAL

Processing of the accumulated radioactive waste inventory is viewed as a key area of activities performed under the national radioactive waste management strategy. Due to gradual upgrading of radioactive waste processing capacities at nuclear power plant (NPP) sites, the rate of radioactive waste processing and conditioning has exceeded that of its generation allowing not only to fully manage the newly generated waste, but also to start processing accumulated radioactive waste stored at NPP sites [13]. From 2016–2018, over 14 100 m^3 of radioactive waste was retrieved, processed, and conditioned to meet relevant radioactive waste acceptance criteria for disposal at five NPPs. Of these, approximately 13 300 m^3 were handed over for disposal with the rest of the waste placed into temporary storage facilities at the NPP sites [14, 15].

Significant progress has also been achieved in the management of radioactive waste generated during the cleanup of nuclear legacy sites in the North-West and Far East regions [16, 17]. Centres for radioactive waste processing and storage were established in the Sayda-Guba branch of the SevRAO’s Northwest Center for Radioactive Waste Management, the LRW processing complex at the site of FSUE FEO’s DalRAO branch was commissioned, as well as a center for solid radioactive waste conditioning. The established infrastructure is actively used in the dismantlement of nuclear submarines and service vessels [1, 18, 19]. Dismantling and disposal of unguarded radioisotope thermoelectric generators (RTGs) previously used at autonomous navigation facilities and potentially posing significant radiation and environmental risks due to the high activity level of their radioactive content was also completed. All the 1007 RTGs have been decommissioned.

5. CONSERVATION OF FACILITIES HOLDING SPECIAL (NON-RETRIEVABLE) RADIOACTIVE WASTE

According to relevant legal provisions, all facilities holding special radioactive waste should be upgraded to disposal facilities via staged installation of new safety barriers (or by demonstrating the adequacy of the existing ones). These efforts should first address the most dangerous category of such facilities, namely, surface storage reservoirs.

The main progress in this area achieved to date involves the completion of five facilities, including PA Mayak’s V-9 reservoir (Lake Karachay), literally considered as a symbol of Russia's nuclear legacy that can be viewed as a most illustrative example in this regard: its backfilling with calibrated rocky soil took more than 40 years and was completed in 2015. This facility was deemed to hold the greatest activity not only as regards the facilities available in Russia but also considering the global scale. For a long time, its complete isolation could not be implemented since some compensating radioactive waste management capacities had to be commissioned, the water level in the reservoir depended on relevant weather conditions, the possibility of liquid radioactive waste (LRW) overflow outside the reservoir had to be completely avoided, highly active bottom sediments and a high level of external radiation was present. In the future, this facility is planned to be fitted with an anti-seepage covering screen [20].

Similar technology was implemented at several more LRW storage reservoirs: B-1, B-2, B-25 (JSC SCC), and facility 354 (FSUE MCC).

A fundamentally different approach was applied at another facility at PA Mayak site: the Techa cascade of water reservoirs (TCR) consisting of four man-made reservoirs connected in series (V-3, V-4, V-10, and V-11). This waterbody holds a record for another indicator, namely, the volume of the disposed of LRW inventory. In the case of the TCR, the use of a standard approach (with the water area capped assuming subsequent installation of a multifunctional covering screen) was considered not feasible enough due to its large surface area (capacity of over 360 million m^3 and a surface area of about 50 km^2). As such, the preferred final TCR state was identified (reservoirs V-10 and V-11 were removed from regulatory control considering the radiation factor; reservoirs V-3 and V-4 were upgraded to near surface SRW disposal facilities; all types of economic water uses were allowed for the Techa River) with the adequacy of relevant arrangements and technical measures required to achieve it approximately in a 200- to 300-year perspective demonstrated. At the current stage, relevant efforts mainly focus on the reduction of the radioactive waste inventory (in terms of its volume and activity) handed over for storage.

Conservation of production uranium-graphite reactors (PUGRs) being decommissioned according to the entombment strategy should be highlighted separately. Regarding PUGR decommissioning, the following measures are being gradually implemented:

- Upgrading the facilities to a nuclear safe state;
- Partial dismantlement of process equipment and systems;
- Strengthening of individual building structures;
- Backfilling of emerging cavities with a purposely developed clay-based buffer mixture;
- Installation of a multifunctional covering screen.

EI-2 (PDC UGR) is considered as the only facility fully completed to date with another facility, namely AD (FSUE MCC), being at the final decommissioning stage with the completion expected in 2021 [21–24].

6. ADVANCEMENTS IN MONITORING SYSTEMS AND SAFETY DEMONSTRATION FOR RADIOACTIVE WASTE FACILITIES

The national programme places special emphasis on the monitoring of radioactive waste disposal conditions. To date, an industry-wide system for facility-level subsoil monitoring has been introduced at 55 enterprises of the State Atomic Energy Corporation Rosatom. It focuses not only on the current levels of radioactive contamination spread but also on the establishment of an information base for long term safety assessments with the methodological and software support being viewed as its second component. Over the past five years, the core package of Russian calculation codes required for the safety assessment (thermomechanics, geomigration, radiation fields, uncertainties, etc.) has been persistently developed.

7. SHORT TERM TASKS

In the next 5 to 10 years, the Russian Federation will continue to focus on the following tasks:

— Conservation of surface LRW storage reservoirs at SCC, PA Mayak, and MCC sites;
— Dismantling of ships and floating technical bases of the nuclear icebreaker fleet;
— Contaminated areas cleanup;
— Further development of near surface radioactive waste repository system;
— Establishment and operation of an underground research laboratory;
— Improvement of the legal framework in the field of atomic energy use and scientific and methodological support for spent nuclear fuel and radioactive waste management activities;
— Development of promising technologies designed to reprocess the main types of accumulated spent nuclear fuel considering relevant radioactive waste management requirements [25].

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FRENCH PROGRESS ON RADIOACTIVE WASTE MANAGEMENT DISPOSAL PROJECTS

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Abstract

The year 2020 was important for the overall French radioactive waste management strategy. A revision of the Multi-annual Energy Plan (PPE) has been debated and published, and the conclusions of the 4th French National Radioactive Materials and Waste Management Plan (PNGMDR) have been released. The year 2020 also saw the launch of the licensing process for the French Deep Geological Repository (DGR), called Cigéo, with the application for a Declaration of Public Convenience and Necessity (DUP) in August. Public inquiries are to take place in 2021 for final approval during the first semester of 2022 by the French government. In parallel, Andra is completing the construction license application (DAC) for Cigéo, to be submitted to the French Nuclear Safety Authority (ASN) in the coming months. Additionally in 2020, Andra entered into a licensing process for the extension of the disposal capacity of the Cires facility (VLLW disposal facility), to accompany the French dismantling programme in line with the PPE. Finally, Andra is involved in the periodic safety re-examination of its LILW surface disposal facilities in the Manche (CSM) and Aube (CSA) regions.

1. INTRODUCTION

In France, Andra is responsible for identifying, implementing, and guaranteeing safe management solutions for all French radioactive waste to protect present and future generations from the risks inherent in such substances. Andra is a state-owned governmental agency, independent from waste producers, and supervised by the Ministries in charge of energy, research, and the environment. Since 1991 and the Programme Act, Andra has overseen leading the studies on deep geological repository for highlevel waste (HLW) and intermediatelevel long-lived waste (ILW-LL). The French Deep Geological Repository (DGR) became the reference solution for long term waste management in 2006 with the Planning Act. By 2020, Andra had launched the licensing process of the DGR that — if authorized — will be built in Meuse–Haute-Marne in eastern France during the next decade.

Andra is also the industrial operator of the radioactive waste disposal facilities in France:

- A radioactive waste disposal centre for low and intermediate level short-lived waste (LILW-SL) located in Normandy (northwestern France), the Manche Disposal Facility (CSM) under monitoring since its caping in 2003;
- The Aube Disposal Facility (CSA) for LILW-SL, which has provided disposal of operational waste since 1992;
- The Industrial Facility for Grouping, Sorting and Disposal (Cires) for the management of very low level waste (VLLW).

2. MULTI-ANNUAL ENERGY PLAN (PPE) AND THE NATIONAL RADIOACTIVE MATERIALS AND WASTE MANAGEMENT PLAN (PNGMDR)

The multi-annual energy programme (PPE) is a tool for steering energy policy in France. An updated version the PPE, considering the French commitments on energy transition, was published by the French government in 2020. It sets targets for energy production in the coming years, including nuclear energy production. By 2035, the share of nuclear energy production will be reduced to 50% of French electricity production (vs. >70% today). Four to six nuclear reactors should be shut down by 2028 and 14 nuclear reactors are planned to cease electricity production by 2035. The PPE has a direct impact on the volume of waste that

Andra will have to dispose of, the timeframes for disposal capacity needs, and the necessary flexibility to conduct the programme.

The National Radioactive Materials and Waste Management Plan (PNGMDR) aims to clarify and improve the management framework of these materials and waste. To this end, it assesses the management policy, identifies needs, and determines the objectives to achieve in the future. It also provides the main deadlines and timeframes indicating the priorities. In February 2020, the Ministry of Ecological Transition and the Nuclear Safety Authority presented the follow-up to the public debate organized in 2019 on the management of radioactive materials and waste. The goal was to prepare the next National Radioactive Materials and Waste Management Plan (PNGMDR). The opinions and contributions following the public debate around the PNGMDR, organized from September 2020 to April 2021, will be added to the fifth edition.

The main conclusions emphasize the importance of a comprehensive analysis of impacts on hosting regions (transport/infrastructure, health, economy, etc.), the need to continue studying VLLW management options, and the continuous work on low level long-lived waste (LLW-LL). Regarding Cigéo, the DGR project, there is a need for more details about reversibility (decision making process, governance, and role of the pilot phase of Cigéo) and additional studies concerning the disposability of bituminous waste.

3. LICENSING PROCESS OF CIGÉO

3.1. Cigéo project

For the past 30 years, Andra has been studying a DGR solution. Cigéo, is a deep geological disposal facility for radioactive waste, to be built in the eastern part of the Paris Basin (Fig. 1). It will serve for disposal of highly radioactive long-lived waste (after reprocessing) produced by France's current fleet of nuclear facilities (58 reactors with 50 years operation and Flamanville EPR) until they are dismantled. The centre is designed for the disposal of 85 000 cubic metres of waste. HLW and ILW-LL will be disposed of at a depth of 500 metres in a layer of clay rock (Callovo-Oxfordian) in 15 km^2 of underground galleries. If the construction license is granted, the site will be located near Andra's Underground Research Laboratory (URL) in Meuse–Haute-Marne.

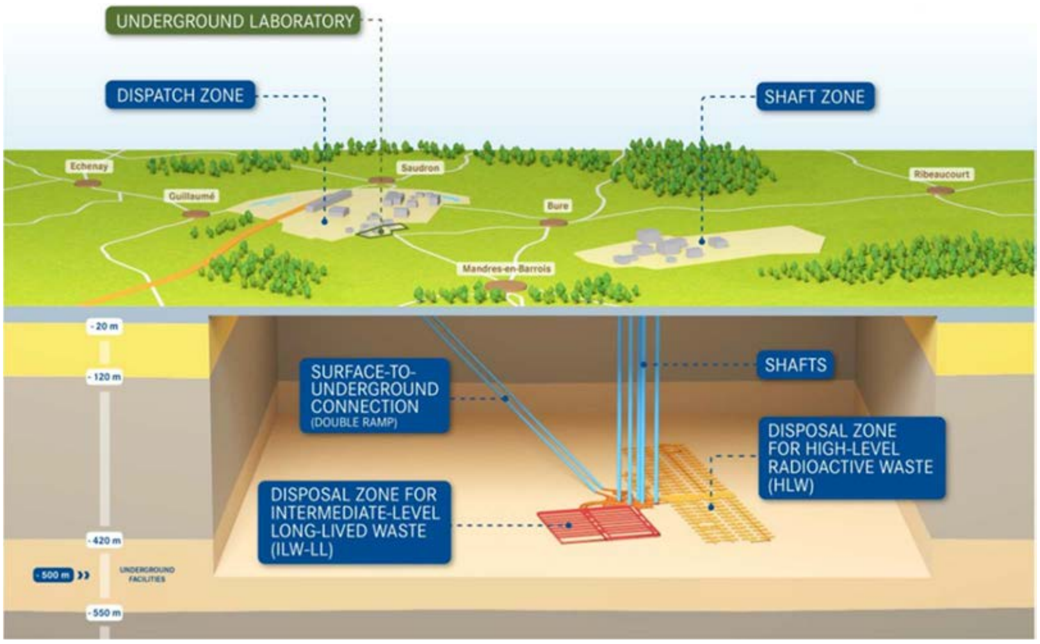

FIG. 1. Cigéo project.

3.2. Overview of Cigéo licensing process

The year 2020 was marked by the submission of the application for a Declaration of Public Convenience and Necessity (DUP) for Cigéo. It was a major step in the project's progress. With more than 3,000 pages, it is an important document, built around a global environmental assessment.

This application aims to obtain recognition of Cigéo's public utility. After consideration by the government, members of the public will be able to obtain information and give their opinion as part of a public inquiry planned for the end of 2021. The declaration of Cigéo's public utility can then be validated by a prime ministerial decree, after the French Council of State issues its opinion.

The DUP, if granted, will allow Andra to acquire, with expropriation, the land required for creating the Cigéo disposal facility if amicable negotiations, always the Agency's preference, break down. The DUP also paves the way for other authorization applications relating to development works that are crucial for creating Cigéo, such as preventive archaeological works, road and railway construction, electricity, and water supply network construction, etc.

In early January 2021, the Environmental Authority (EA) of the French General Council for the Environment and Development published 40 recommendations and comments on the global environmental study provided by Andra with the DUP application file.

Andra has also carried out a socioeconomic assessment of Cigéo. This assessment is a genuine tool for public decision making, as required by French law. It investigated large-scale projects involving significant public investment. The aim was to assess the benefit of the investment for the community by comparing its effects in monetary terms over its entire lifetime with a so-called "counterfactual" situation (i.e. what should be done if the project is not carried out). Cigéo's socioeconomic assessment, which has been counter-examined by the French government, has resulted in a favourable opinion regarding the Cigéo project, with recommendations and conditions for its success. The General Secretariate for Investment (SGPI) issued a positive opinion on the independent counter-examination of the project's socioeconomic assessment and underlined Cigéo's "strong prudential and insurance value" compared to other radioactive waste management options (such as surface storage).

The next step to declare Cigéo's public utility is the public inquiry to be initiated in autumn 2021 based on a dossier compiling Andra's application, EA and stakeholder positions and requests, and Andra's proposal/responses. Figure 2 shows the future steps in the licensing process for Cigéo. This dossier will include a general presentation of the Cigéo project, the characteristics of the disposal facility, and the legal and administrative documents or the documents concerning dialogue, economy, urban planning, and the local community. The global environmental assessment (Cigéo facility and off-site supporting works – railway, power, and water supplies, etc.) is the centrepiece of this dossier. It presents the current condition of the environment and the expected consequences—positive and negative alike—of the project in terms of environment (atmosphere, soil, subsoil, water, natural surroundings, human environment, etc.), health, and development of the area. It also presents Andra's measures to prevent, reduce, and offset negative impacts.

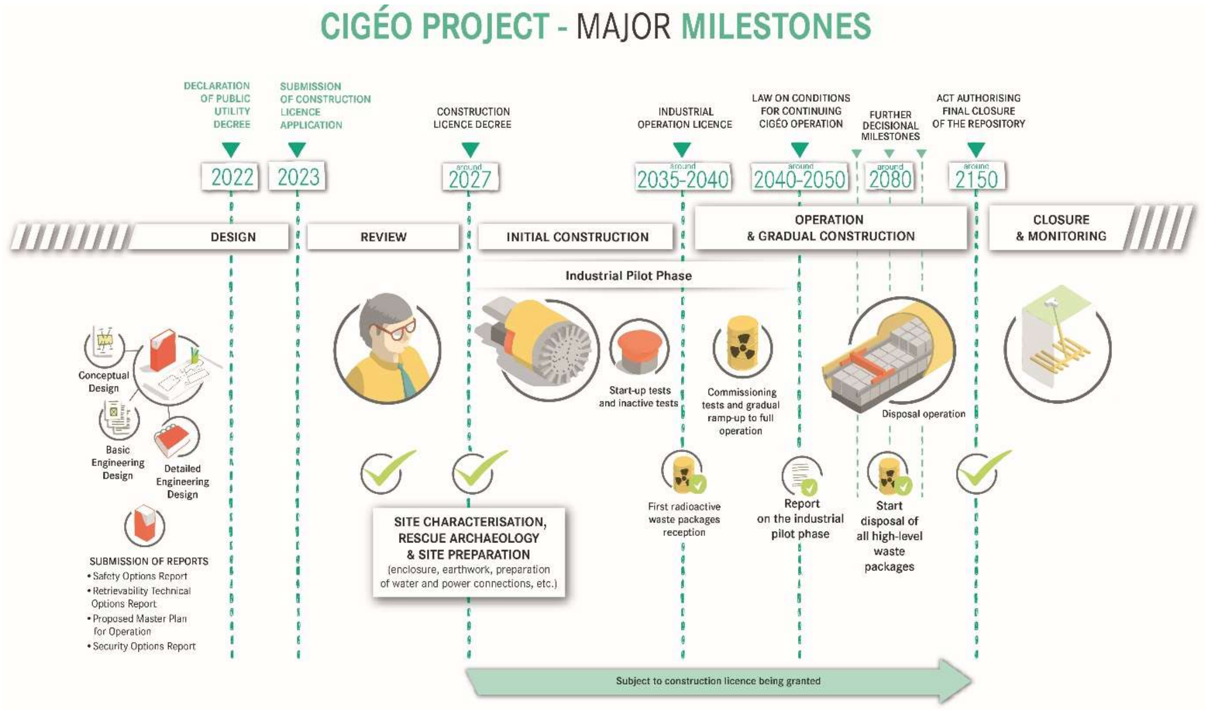

FIG. 2. Cigéo project future steps. Courtesy of Andra

The Declaration of Public Convenience and Necessity (DUP) does not give authorization to start construction activities, but it does initiate the process and final land acquisition. Many other authorizations and permits will then be needed for preparing to build the Cigéo facility. A Construction License Decree (DAC) needs to be published before construction of surface nuclear buildings and underground repository drifts are effectively started. The DAC application is planned for between the end of 2021 and early 2022.

3.3. Other advances in the Cigéo project

The Cigéo project has made progress on other aspects. The detailed design studies have been completed. Numerical modelling and building information modelling (BIM) and product life cycle management (PLM) have been developed with many specific design inputs at various scales (i.e. the Cigéo facility, as a whole, and the Industrial Pilot Stage (Phipil)).

The Phipil corresponds to the first years of construction and operation of Cigéo. It will confirm in situ, in the actual environment conditions, Andra's ability to manage construction and industrial operation of the disposal centre and to confirm choices made at various design stages. This Phipil should last about 25 years (until around 2050).

The detailed design studies, completed in 2020, enable a detailed safety analysis to be carried out. A sorting review will identify which actions and studies should be done now and which need to be prepared for later development. This prioritization facilitates research and engineering scheduling.

In 2020, the funicular demonstrator for waste package access in the DGR was completely built and installed at Froncles in Haute-Marne. A complete test programme is planned. The consultation programme and the new experimentation phase known as Site 4 at the underground laboratory are ongoing. The URL is in Meuse–Haute-Marne. After 20 years of activity, the laboratory now has 2 km of galleries 490 metres below the surface in the Callovo-Oxfordian clay layer (Fig. 3). Dozens of experiments have been conducted (mechanical, thermal, chemical, hydraulic, digging, monitoring, etc.). In 2020, the construction of three new disposal cell demonstrators for HLW began and a four-branch intersection was dug out. Numerous sensors and analyses are being carried out to properly understand the effect of such digging on the rock and the behaviour of the supporting layer.

FIG. 3. Celebrating 2000 m of galleries at the underground research laboratory (l). Funicular full-scale demonstrator (r).

4. ANDRA’S INDUSTRIAL ACTIVITIES

Andra operates three industrial facilities in France. The Manche Disposal Facility (CSM) is in northwestern France and is now in the process of closure. Andra’s Aube industrial facilities in eastern France are in operation (Cires, the industrial facility for grouping, sorting and disposal, VLLW; and CSA, the Aube Disposal Facility for LILW-SL).

The year 2020 was marked by the Covid-19 pandemic. From the very beginning of the pandemic, Andra adapted its work organization to protect the health of its staff, while continuing essential activities. Two lockdowns occurred: in spring and fall 2020. The security of the facilities, and in particular the safety of radioactive waste disposal facilities, remained among Andra’s major concerns throughout. During the first lockdown, the Agency limited on-site activities to strictly essential functions: security, nuclear safety, environmental monitoring, and management of radioactive waste for the continuity of indispensable activities, such as power generation and medical treatments. During the second lockdown, an adapted system provided for continuation of industrial activities.

4.1. Manche Disposal Facility (CSM)

CSM is the first radioactive waste disposal facility operated in France (Fig. 4). It has been in the monitoring phase since 2003. The final disposal operations took place in 1994 and capping construction was completed in 1997.

Today the monitoring programme includes active monitoring and permanent inspections of the overall disposal facility: environmental monitoring, monitoring of the cover, logistics, servicing, and maintenance of installations, etc. These activities essential to disposal safety will be maintained for hundreds of years, along with public visits and providing information to the public. In September 2020, Andra signed a new multi-annual contract with radioactive waste producers to cover the CSM’s monitoring and maintenance fees until 2024. This contract considers the CSM’s operating costs, taxes, insurance premiums, and funds for refurbishment works specified over the contract period to pursue the monitoring programme.

Examination of the safety review file started in 2020. Several meetings, including a technical inspection with the French Nuclear Safety Authority (ASN) and the Institute for Radiological Protection and Nuclear Safety (IRSN), took place in 2020. The focus was on long term safety, environmental monitoring, and cover monitoring. Long term memory and transmission is also a topic of interest at the CSM. This process is ongoing and should be concluded in 2021.

FIG. 4. Aerial view of the CSM. Courtesy of Andra

4.2. Aube Disposal Facility (CSA)

The Aube Disposal Facility (CSA) is the second radioactive disposal facility constructed in France (Fig. 5). In 1984, the French government made an official decision to create a new repository for low- and intermediate level short-lived waste to ensure the continuity of the disposal function and carry on the functions of the CSM. The licensed capacity of the repository is 1 000 000 m^3, which should satisfy the needs of all LILW-SL radioactive waste producers in France for the current fleet of nuclear facilities.

At the CSA, the tenth construction stage, started in 2018, is almost completed. Despite the Covid-19 pandemic, operational activities were maintained with an adapted management and operational procedure to avoid storage saturation at producer sites.

FIG. 5. Aerial view of the CSA. Courtesy of Andra

4.3. Disposal Centre for Very Low Level Short-Lived Waste (Cires)

Cires (Industrial Facility for Grouping, Sorting and Disposal), shown in Fig. 6, has been accepting waste since 2003 and will reach its authorized disposal capacity; that is 650 000 m^3; by 2028 or 2029. Launched in 2018, the project to increase the Cires disposal capacity (ACACI) is one of the solutions studied by Andra to meet the challenges of managing the VLLW that will be produced in the years to come, in particular during dismantling of nuclear facilities. ACACI is based on the expected deliveries of VLLW indicated by the producers in the coming years.

Specifically, the Agency is studying the possibility of increasing the authorized disposal capacity of Cires without changing the acreage of the facility itself. This option is made possible by design optimizations implemented step by step during the last decade. With gradual improvements of the disposal capacity of new trenches, savings of 56% of the disposal area, as compared to the initial layouts, can be expected. If the extension of capacity is accepted, it would provide an additional 10 to 15 years of operation to the facility and would leave more time to evaluate the relevance of other solutions for managing all VLLW to be generated until the completion of the decommissioning/dismantling programme of the current nuclear power plant fleet. According to data from the National Inventory of Radioactive Waste Materials, the total volume of VLLW produced in France would be between 2 100 000 and 2 300 000 m^3 after dismantling of nuclear facilities.

The ACACI project licensing process reached a new milestone in 2020 with Andra's decision to initiate preliminary consultations. Public meetings were held in May and June of 2021, and several subjects were addressed, including management of excavated soil and environmental monitoring. Consultations and the process of examining dossiers will continue. In 2022, an environmental permit application file should be submitted. If accepted, the works should start in 2025.

FIG. 6. Aerial view of Cires. Courtesy of Andra

5. CONCLUSION

Despite the impact of the Covid-19 pandemic, Andra was able to fulfil its missions and register significant progress on various essential projects. For Cigéo, the licensing process launched in 2020 with the application for a Declaration of Public Convenience and Necessity (DUP) will be followed by several authorization/permit applications to prepare the site to host Cigéo. The nuclear license application for the construction (DAC) of the Deep Geological Repository will be submitted to the ASN in 2023. Important meetings and public inquiries are planned for the end the year. In parallel, consultations on the project are being implemented even more broadly, with new subjects of discussion with the public: the industrial pilot phase (Phipil) and the governance of Cigéo.

For the extension of the capacity of Andra's Cires VLLW disposal facility — the ACACI project — a preliminary consultation took place in May/June 2021, under the auspices of its guarantors. At the Aube Disposal Facility (CSA) and at the Manche Disposal Facility (CSM), safety re-examinations are ongoing with intense discussions with the ASN and the IRSN.

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ENSURING THE SAFE, SECURE AND SUSTAINABLE DISPOSAL OF RADIOACTIVE WASTE: A SOUTH AFRICAN PERSPECTIVE

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Abstract

The Republic of South Africa generates radioactive waste through numerous activities such as the generation of nuclear power and manufacturing of radioisotope. To ensure the long term viability and public acceptance of nuclear energy and its applications, it is essential that generated radioactive waste is safely, securely, and sustainably managed from the point of generation through to disposal (the cradle-to-grave approach). The disposal of radioactive waste on a national basis has been entrusted to the National Radioactive Waste Disposal Institute (NRWDI), a public entity wholly owned by Government. Radioactive waste has been disposed since 1986 at the National Facility Disposal Facility for Low Level Waste, Vaalputs, which has an impeccable operational and radiological safety track record. There is widespread acceptance of the Vaalputs radioactive waste disposal programme and operations within the local communities, as well as the public at large. Public engagement, based on the principles of transparency, fairness, openness, inclusivity, confidence, and trust is the cornerstone and bedrock on which the success of the radioactive waste disposal programme is established. To accomplish the strategic goal of continuously improving, maintaining, and further developing Vaalputs as a world class near surface disposal facility, much effort is applied in keeping abreast with international radioactive waste management and disposal practices, as well as evolving regulatory requirements. The establishment and implementation of a successful radioactive waste disposal programme is not predominantly a technical issue. It is imperative that all key stakeholders be involved in a stepwise process of consultation, involvement, technical work, and decision making. The paper will provide information on how South Africa has implemented a successful low level waste disposal programme that is technically sound, socially acceptable, environmentally responsible, and economically feasible and sustainable for protecting the health, safety, and security of humans and the environment, now and in the future without putting an undue burden on future generations.

1. INTRODUCTION

The introduction of nuclear power programme in South Africa during the late 1970s called for the establishment of a national site for the disposal of low level radioactive waste. In addition, such a waste disposal site should be further investigated for hosting a storage facility and a deep geological repository for spent nuclear fuel. The Koeberg Nuclear Power Plant (NPP), comprising of two Framamtome Power Reactors of 900 Mwe each, began operation in 1984 and the first shipment of low level was disposed at Vaalputs disposal facility in November 1986.

2. VAALPUTS NATIONAL RADIOACTIVE WASTE DISPOSAL FACILITY

From 1979 to 1982, a comprehensive site selection programme was undertaken in accordance with criteria that were regarded as internationally acceptable. Three potential sites were selected: the central portion of the Richtersveld, the Kalahari roughly north of Upington, and an area in Namaqualand/Bushmanland. The Vaalputs site emerged as the preferred option from the candidate sites and was subsequently acquired in 1983.

Some of the factors that contributed to Vaalputs being regarded as a suitable site were:

- Low population numbers;
- Sparse agricultural activities - the main agricultural activity around Vaalputs is sheep farming;
- Low potential for economic mineral exploitation;
- The disposal area on the Vaalputs site is locally elevated above the surrounding area, reducing flooding potential;

- Low seismic activities in and around the Vaalputs area;
- Long term geological and geomorphological stability.

Detailed site suitability studies commenced in 1983. A preliminary safety report was compiled and submitted to the regulatory authority in 1984. The report was approved for building operations to commence. An intermediate safety report was issued to the regulatory authority in October 1986, according to which Vaalputs was granted a nuclear authorization to operate. The Vaalputs site area measures approximately 10 000 hectares, of which 350 hectares is currently being used for disposal activities.

Preliminary site investigations concluded that Vaalputs has the geological, geotechnical, and seismic characteristics to host the storage facility and a deep geological repository for spent nuclear fuel, as well as the Borehole Disposal Facility for Disused Sealed Radioactive Sources.

South Africa is in a privileged position to have a single site that can host disposal and related infrastructure for all classes of radioactive waste and it will maximize the benefits from economies of scale and scope, pertaining to all activities associated with disposal and waste management.

2.1. Disposal concept

The type of repository design ultimately selected depends on country specific issues such as disposal requirements as dictated by national strategies, regulatory approaches, social and economic factors, and in particular public concerns over safety, climate, geological and hydro-geological conditions, characteristics of the waste, technological advances in waste disposal, etc. The common goal, however, is that repository design is aimed at meeting radiological performance requirements by limiting the release of contaminants to the biosphere, minimizing exposure of workers and the public at large and minimizing maintenance required during the post-closure phase

The current disposal concept at Vaalputs is based on near surface disposal (Fig. 1) consisting of near surface trenches (Fig. 2) up to 8 metres deep but above the groundwater table. The disposal facility safety incorporates the Multiple Barrier System (MBS) approach and includes the Natural Barrier System (NBS) (i.e. the near field, geosphere, and biosphere) (Fig. 3) and the Engineered Barrier System (EBS) (i.e. the conditioned waste form, the waste container, and other engineered enhancements).

FIG. 1. An aerial view of Vaaalputs, the National Radioactive Waste Disposal Facility.

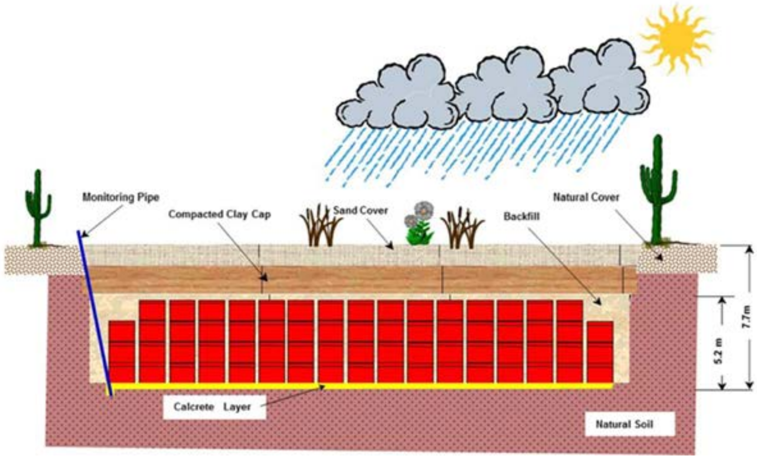

FIG. 2. Graphical illustration of the Vaalputs LLW near surface disposal concept (not to scale).

FIG. 3. Near surface trench at Vaalputs. Courtesy of National Radioactive Waste Disposal Institute.

Safety assessments of Vaalputs, which incorporate the near field, geosphere, and biosphere, have demonstrated that the disposal facility is being operated without compromising the safety of current and future generations by:

— Providing a high level of operational and long term safety;
— Demonstrating compliance with performance standards, thus enhancing public confidence in the disposal system;
— Preventing or substantially delaying movement of water or radionuclides toward the accessible environment (i.e., biosphere and geosphere);
— Can be safely closed once all operations have ceased, given that the necessary after care measures are taken within the institutional control period.

2.2. Continual improvement of disposal practices

South Africa has adopted the principle of international collaboration and strategic partnerships to ensure appropriate benchmarking and compliance with applicable legislation and international best practice regarding its waste management and disposal practices.

These international collaboration and strategic partnerships are a vital part of the national programme to enhance nuclear safety and security and radioactive waste management and disposal. South Africa's international activities link to the world's evolving waste management practices and provide a forum for exchanging strategies and technologies with other nations. Participation in such activities benefits South Africa through the acquisition and exchange of information, and peer review by experts of other participating nations.

These international projects serve the national goals in advancing scientific understanding, enhancing environmental protection, and improving global safety and security. In fostering international cooperation on spent nuclear fuel and radioactive waste management and disposal, the goal is to lead to an optimized national disposal system and promote the exchange of institutional and technical knowledge with the international community.

Although repository safety needs to be technically acceptable it is also necessary to demonstrate the safety concept to the public. The public understanding of risk does not necessarily coincide with the technical interpretation thereof.

When Vaalputs was developed more than 34 years ago, it was designed with limited engineered features, at least by present day standards. The emphasis was placed on the performance of natural barriers (e.g. low permeability geosphere) rather than engineered barriers.

Following the 1997 occurrence where several concrete waste packages experienced rimming cracking due to extended exposure time to environmental and climate conditions, the public perception of repository safety appears to be largely based on the quality of the EBS, i.e., the quality of waste packages. The public seems reluctant to accept a natural barrier system as being sufficiently safe.

For this reason, the benefits of an EBS and thus introducing some degree of redundancy and defence in depth into the disposal system had been recognized as non-negotiable and would further ensure public confidence in the Vaalputs disposal system.

The following improvements to the waste packages have since been implemented:

— Waste packages have to in general comply with the IAEA regulations for the safe transport of radioactive materials. These regulations impose requirements on, e.g. impact performance, fire performance, external dose rates, levels of removable surface contamination, restriction on the release of radioactivity during a credible transport or handling incident, etc. In most cases, these regulations impose the most restrictive requirements.
— The waste package has to provide containment at least up to repository closure for all reasonably expected conditions associated with storage, transport, and final disposal. Any containment loss has to be gradual, resulting in only fractional release rates. Waste form, waste container, over pack and backfill is regarded as being interrelated.
— The retrievability of waste packages within the repository operational period (i.e. up to repository closure) has to be ensured.
— It has to be demonstrated that, considering the repository climatic conditions, the waste package will not degrade because of thermal cycling effects, unless the producer has provided proof of the insulating properties of the container.
— Corrosion due to the interaction of the immobilized waste form with the container (internal corrosion) as well as the interaction of the geological disposal environment with the waste package (external corrosion) presents the major routes for the escape of radionuclides into the environment. It therefore needs to be demonstrated that the material chosen for the fabrication of the waste package is compatible with the immobilized waste form as well as corrosive elements in the repository environment. The corrosion rates and fractional leach rates because of corrosion have to be determined per waste package type.
— Tests have to be formulated and conducted to demonstrate possible interaction and effects between the waste form and the waste container and possible interactions and effects between the container and the geological medium in the repository environment.
— The stacking load on waste packages is to be calculated in accordance with stacking arrangements in a disposal trench, which includes the load imposed by the overburden. Under this load the waste package cannot show structural damage or any other abnormality.

To minimize the exposure of waste packages to the environment, design changes were introduced with regards to the disposal trenches to optimize the disposal actions and the backfill and capping of the waste packages thereafter to prevent these packages from being exposed to environmental agents for extended periods. Metal waste packages are covered within one month and concrete waste packages within two months after being placed in the respective trenches. The disposal trenches are covered and capped soon after emplacement of the packages in the trench.

South Africa strongly supports the circular economy to create jobs, reduce emissions and contribute to sustainable development. The predisposal activities focussing on reduce, reuse, and recycling and has resulted in that less than 11% of the total current disposal capacity of 350 hectares for low level waste at the Vaalputs disposal site has been utilized over a period of 34 years.

3. DEEPENING AND STRENGTHENING OF STAKEHOLDER TRUST AND CONFIDENCE IN DISPOSAL PRACTICES

The greatest single obstacle that a successful waste disposal programme has to overcome is the erosion of public confidence and trust in order to ensure societal acceptance of a waste disposal programme.

In the past, design decisions were often based on expert opinion. The acceptability of the final design of the repository will involve trade-offs between technology, societal, institutional, economical, and political drivers. In the end, societal and political acceptance may be the deciding factor on whether a disposal programme will be implemented.

Stakeholder confidence and trust are of utmost importance for the societal acceptance of a waste disposal programme and, therefore, a high premium is placed on stakeholder empowerment, capacity building, communication, and participation. Figures 4 and 5 show photographs taken during various stakeholder meetings.

The Stakeholder Engagement Strategy is underpinned by the following set of values namely:

- Ensuring the diversity and inclusivity of stakeholders;
- Acknowledgement that each stakeholder group has its own set of values, needs, goals and objectives, which may differ from those of the organization;
- Accommodating divergent values and beliefs equally, considering them all when making decisions;
- Empowering stakeholders with the necessary knowledge to enable them to participate in decision making process in an informed manner and as equal partners.

FIG. 4. Stakeholder capacity building session to demystify the myths associated with radioactive waste. Courtesy of National Radioactive Waste Disposal Institute.

FIG. 5. Multi-stakeholder safety information forum meeting. Courtesy of National Radioactive Waste Disposal Institute.

4. KEY LESSONS LEARNED

South Africa has learned the following key lessons for a successful radioactive waste management programme, namely:

- The planning for the introduction of a nuclear power programme needs to go hand in glove with the site selection of a waste disposal repository.
- International peer reviews of waste management practices are imperative to ensure appropriate benchmarking and compliance with applicable legislation and international best practice.
- Stakeholder confidence and trust are of utmost importance for the societal acceptance of a waste disposal programme and, therefore, it is of critical importance to place a high premium on stakeholder empowerment, capacity building, communication, and participation.
- Empower stakeholders with the necessary knowledge to enable them to participate meaningfully in decision making process in an informed manner and as equal partners.
- Stakeholder confidence and trust can be strengthened and deepened by the ratification of international treaties such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the “Joint Convention”) governing radioactive waste management and disposal.

5. CONCLUSION

South Africa’s radioactive waste management practices and disposal operations have evolved over the years and are in line with international best practices due the implementation of recommendations made by peer reviews and exchange of experience and knowledge with its global strategic partners.

There is widespread acceptance of the Vaalputs radioactive waste disposal programme and operations within the local communities, as well as the South African public at large. Public engagement based on the principles of transparency, fairness, openness, inclusivity, confidence, and trust is the cornerstone and bedrock on which the success of our radioactive waste disposal programme is established.

The NRWDI, the implementing agent for Government, remains committed to fulfilling the expectations of South Africans that all classes of radioactive waste can be safely, securely, and sustainably managed in a manner that meets or exceeds all applicable local and global regulatory standards and requirements for protecting the health, safety, and security of humans and the environment now and in the future without putting an undue burden on future generations due to past, current, and future involvement in nuclear energy applications.

Paper ID#143

COMPLETE RECYCLING OF BORIC ACID FROM THE PRIMARY CIRCUIT COOLANT OBTAINING COMMERCIAL BORATE PRODUCTS

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Abstract

The application of the novel concept of boron control to pressurized water reactors (PWRs) can reduce costs and produce radiation-free borate products. The main idea is to remove the boric acid regeneration unit, which annually forms tens of cubic metres of spent ion-exchange resins and generates radioactive compounds. Being immediately removed from the reactor, boric acid is depleted into ^{10}B and is deactivated by ion-selective sorbents and processed into a commercial product. At the same time, the consumption of boric acid during the period of the reactor operation increases by 10 to 15%, with the total amount of waste annually generated at a nuclear power plant (NPP) being significantly reduced.

1. INTRODUCTION

Nuclear waste treatment along with the safety of nuclear technologies have always been the key issues and largely determined the prospects for the further development of the nuclear industry. There is an identical instrumental and technological scheme developed back in the 1960s [1] based on evaporation technologies that enables processing of liquid radioactive waste (LRW) generated during operation at almost all Russian NPPs. LRW generated from various sources (regenerated ion-exchange resins, decontamination solutions, water from special laundries, etc.) are fed into a unified system for collecting drainage waters and then sent to water treatment system evaporators, where they are purified from radionuclides to obtain a salt concentrate as secondary intermediate level waste with a salinity of 200 to 600 g/dm^3.

Each NPP has storage tanks for LRW in which hundreds of thousands of cubic metres of radioactive waste have already been accumulated and their total volume is only increasing. One of the possible options, to set the negative dynamics of the accumulation of radioactive waste at NPPs, it is necessary to revise the concept of the water-chemical regime of the main circuits of the pressurized water reactor (PWR) (according to the IAEA power reactor information system (PRIS), 443 power reactors are currently in operation in the world, of which 304 are PWRs). In particular, by changing the boric acid regeneration technology, it is possible to almost completely convert the used boric acid into borate products that meet all the criteria for borate materials used in industry. This approach will reduce the overall waste generation at nuclear power plants, which is the primary goal of radioactive waste management [2].

2. BORON CONTROL

Power reactor start-ups require large initial reactivity margins and, hence, large quantities of absorbers to compensate. However, displacement of “heavy” absorbers in the core can cause a strong distortion of the neutron field in the reactor, increasing the uneven distribution and thereby reducing the economic performance of the power unit. Moreover, in some cases, the distortions of the neutron field can be dangerous, as they lead to instability of the neutron field in the reactor. Therefore, materials such as boric acid (a natural mixture of boron isotopes 0.2 ^{10}B + 0.8 ^{11}B, where ^{10}B has a high neutron capture cross section of 3837 barn), cadmium, gadolinium, etc. can be used as burnable absorbers.

In reactors, such as the PWR-1000, liquid boron regulation is widely used. The main principle is to add an amount of concentrated boric acid to the water circulating in the primary circuit, which simultaneously acts as a heat carrier and a moderator (it is believed that a solution with a concentration of 40 g/kg is a concentrated solution of boric acid). The boric acid concentration depends on time and is determined by the rate and depth of fuel burnup in the period between partial refueling. After each partial refueling, the boric acid concentration is at its maximum and is designed to compensate for reactivity (usually 16 g/kg) due to excess fuel above the critical mass. By the beginning of the next partial overload, boric acid is completely removed from the circulating water and its concentration becomes zero.

To create a closed system for the input and output of boron from the reactor, NPPs are equipped with a special boric acid regeneration system designed for processing and returning the resulting concentrate to the station's technological cycle. The boric acid regeneration system is based on the method of concentrating boron-containing water discharged from the primary circuit in an evaporator. A schematic representation of the evaporative recycle system is depicted in Fig. 1.

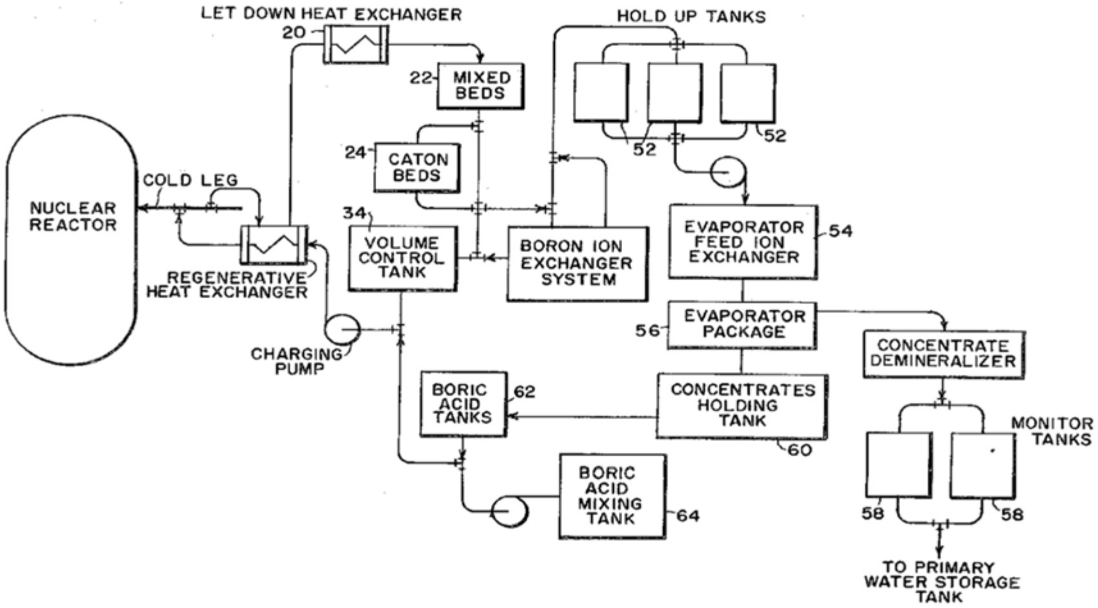

FIG. 1. Schematic representation of the evaporative recycle system flow schematic and its cooperative relationship with the ion-exchange system.

The streams of the removed coolant of the primary circuit of a nuclear power plant always contain radioactive isotopes – fission products and activated corrosion products. With an average concentration of boric acid removed from the circuit of 8 g/kg, the maximum concentration of boric acid in the distillation residue reaches 40 g/kg. This means that when boron concentrate is obtained, the impurities dissolved in it, which are in cationic and anionic forms, are also concentrated by a factor of 5. Therefore, it is purified using ion-exchange filters before reuse [3].

So, annually, 17 tons of boric acid and tens of tons of various chemicals are used and disposed of for the regeneration of ion-exchange filters used to purify boron-containing solutions at each PWR-1000 unit [4]. During the entire operation of a nuclear installation, hundreds of thousands of tons of radioactive boron-containing solutions of a very complex composition have been accumulated and stored on the territory of the NPP, since the used boric acid is mixed with numerous radioactive solutions formed during the operation of the nuclear power plant. These liquids, after energy-consuming concentration in evaporation plants, are poured into storage facilities for liquid radioactive waste and periodically boiled to obtain still bottoms. The content of borate ions in one stripped off solution reaches 20 to 30%. It is very difficult and expensive to extract borates from these complex radioactive media.

Disadvantages of standard technology include:

- Thousands of cubic metres of radioactive regeneration solutions (acids, alkalis, wash water, etc., necessary for the regeneration of ion-exchange filters) that require evaporation, storage, and disposal are formed annually at each NPP unit [5];
- Low efficiency of cleaning boron-containing solutions from isotopes of antimony and silver;
- Gamma-emitting radionuclides accumulate in the primary coolant of the NPP, leading to an increase in the doses to personnel;
- As boron-containing solutions are mixed with other liquid components of NPP activities in the process of evaporation and storage, boron-containing substances in the storage of bottoms turn into a complex mixture of undefined composition and it is almost impossible to extract boron in the form of a pure commercial product from this mixture;
- The need for periodic removal of boron-containing radioactive solutions from the technological cycle of NPP operation for evaporation and transfer to the state of intermediate level waste, requiring the construction and maintenance of capital-intensive and expensive storage facilities for LRW on the territories of operating NPPs;
- It is impossible to use boric acid, processed according to this method, to obtain radiochemical commercial products, ready for their use in various industries;
- The need for complex, expensive, and hazardous disposal of large volumes of spent radioactive ion-exchange resins;
- Constant, very complex, and expensive control of the ^{10}B isotope content in boric acid in the primary loop of the reactor is required, since during the operation of a nuclear reactor, ^{10}B interacts with neutrons, the ^{10}B concentration decreases, and the characteristics of the coolant change [6].

3. NEW CONCEPT OF REACTOR BORON CONTROL

The concept shown in Fig. 2 suggests that boron-containing solutions after being used in the technological cycle of NPP operation, are not sent to ion-exchange filters and are not returned after them to the reactor for repeated use, but to be purified with selective inorganic sorbents. A commercial borate product, obtained from the radiochemically pure solution, can be used in evaporation, precipitation, filtration, and drying processes to obtain a finished commercial borate product (boric acid, borax, borates, perborates) that meets all criteria for borate materials used in industry.

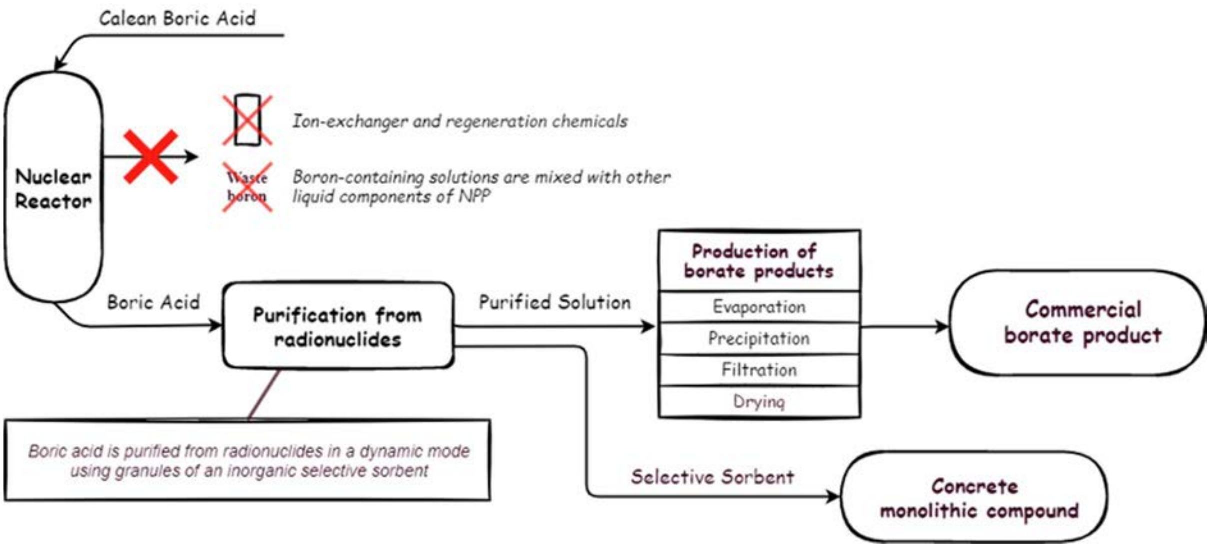

FIG. 2. Boron control circuit - new concept.

The decrease in the amount of ^{10}B isotope in the primary coolant is compensated by the addition of the required amount of new boric acid. An increase in the consumption of boric acid, due to the feeding of the primary coolant with portions of fresh boric acid, will increase its annual consumption by 10 to 15%, but at the same time, all boric acid used at the NPP will be converted into a commercial product and sold on the market (Table 1).

TABLE 1. COMPARISON OF BASIC ANNUAL CONSUMPTION OF REAGENTS TO MAINTAIN WATER CHEMISTRY OF THE PRIMARY CIRCUIT AND MANAGE THE SPECIAL WATER TREATMENT AT THE ZAPORIZHZHYA NPP (ZNPP-3) AND PWR REACTORS WITH THE NEW REGIME BORON CONTROL

Reagents	**The amount of the reagent, tons (100% of the active substance)**	
	ZNPP-3 1000 MW (a typical PWR-1000 reactor with an ammonia-potassium water-chemical regime)	**PWR-1000 reactor with new boron regulation mode**
Boric acid with natural isotope B-10	17	18.7 to 19.55
Consumption of chemical reagents to ensure the operation of the water supply system		
Nitric acid	7.8	—
Sodium hydroxide	11.6	—
Potassium hydroxide	1.17	—

Boric acid can be purified from radionuclides in a dynamic mode using granules of an inorganic selective sorbent. Boron-containing solutions can be purified with selective sorbents based on sulfides, hydroxides, phosphates, ferrocyanides, silicates, or their mixtures (Table 2) . Due to their high selectivity, sorbents completely purify boric acid from radionuclides with the formation of a minimum amount of solid radioactive waste (according to our calculations, about 100 kg/year is required), which are reliably packed by standard methods into a monolithic compound for long term storage.

TABLE 2. COMPARISON OF ANNUAL CONSUMPTION OF SORBENT FOR THE SUPPORT OF SPECIAL WATER TREATMENT AT THE ZAPORIZHZHYA NPP AND PWR REACTORS WITH THE NEW REGIME BORON CONTROL

ZNPP-3 1000 MW (a typical VVER-1000 reactor with an ammonia-potassium water-chemical regime)		Type reactor PWR-1000 new regime boron control	
Ion-exchange resin, ton/year	2 to 3	Selective sorbents, ton/year	0.1

As a result of this boron regulation concept:

- Used boric acid is completely processed into a commercial product;
- Dozens of cubic metres of spent ion-exchange resins and regeneration radioactive solutions are not formed;
- Control over the ^{10}B content in the reactor is significantly simplified;
- Doses to NPP personnel are reduced.

4. CONCLUSION

The application of the proposed concept of boron regulation at power units with a PWR reactor will lead to a significant minimization of the generated waste volume and optimization of economic costs. The main volume of waste from the blocks will be medium level ion-selective sorbents and non-radioactive salts (melt). It is economically advantageous to use purified boron burned out in the reactor (depleted in the isotope ^{10}B) in non-nuclear industries, although its consumption will grow by 10 to 15%.

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3.3. SESSION 3 – SOLUTIONS FOR SPECIFIC WASTES

Radioactive material for which no further use is foreseen and with characteristics that make it unsuitable for environmental discharge or clearance from regulatory control, is considered as waste and henceforth managed as radioactive waste.

IAEA safety requirements (see for instance GSR Part 5, Requirement 10) specify that wastes are required to be processed so the radioactive material is appropriately contained during normal operations and in accident conditions that could occur during handling, storage, transport and disposal. This is normally achieved by conditioning the waste material inside a suitable container thereby forming a waste package. The objective of these processing steps is to enhance the safety of the waste making a waste package that is compatible with future waste management stages.

The conditioning process is intended to result in a stable and passive waste form and be designed based on consideration of the radioactive and chemical characteristics of the waste material and of the demands expected to be imposed by the different steps in its future management. This is normally achieved by solidifying the waste (if liquid) or fixing solid items in a matrix within the waste package. The package thus formed is expected to be manufactured in line with waste acceptance criteria for storage, transport, and disposal, as appropriate.

This Session described several case studies illustrating waste management challenges posed by specific wastes and the solutions that have been developed and successfully implemented. In all cases, initial investigations have been needed to better understand the waste and its characteristics and in cases where the intent is to produce a conditioned wasteform, it has been necessary to have knowledge of the waste acceptance criteria, whether for storage, transport, or disposal. Presentations covered small-scale specific wastes to large scale cleanup operations with multiple waste streams.

An example from Italy highlighted the steps taken to solidify and package a small volume of liquid alpha-contaminated waste, and from Iran an example of technology and infrastructure development to improve the management and safety of radioactive wastes from the nuclear industry and from the oil and gas sector.

From small-scale specific waste problems, the Session also heard about the challenges involved in the cleanup in and around the Fukushima Daiichi nuclear power plant site, where there are large volumes of solid ‘rubble’ wastes, felled trees, and used protective equipment, often stored outside and awaiting treatment. Plans are now being implemented with a view to providing a long term solution by the provision of characterization facilities, incineration, volume reduction, and solid waste storage buildings.

For wastes that have been difficult to condition using conventional methods, innovative techniques have been developed using geopolymers to produce waste forms offering long term stability and good performance. In one case study, the geopolymer is based on phosphate mine tailings: a good example of waste recycling and the circular economy. Other examples of the technologies contributing to the circular economy (or waste hierarchy as it is referred to in some of the papers) are metal melting and thermal pyrolysis methods which are finding increasing use for the treatment of low level waste (LLW) and very low level waste (VLLW).

Session Chairs: M. Lindberg (Sweden) and A. Rajkumari (Germany)

Session 3 comprised eight papers from the United States of America, Italy, Iran, Sweden, India, Japan, Slovakia, with an additional paper from one of the conference’s Young Professionals Showcase Leads (Morocco).

- **Paper ID#262 by N. Butler (USA)** presented (on behalf of T. Taplin) an overview of the Off-site Source Recovery Program initiated by the US Office of Radiological Security and designed to recover orphan disused sealed radioactive sources (DSRD) that otherwise would be a potential public health or security risk. Since its initiation, the OSRP has recovered some 43,000 sources from across USA and 27 other countries and placed them into secure storage where they can no longer pose a risk to the public. The Office's experience is that safety during DSRS recovery can be ensured by following the principles of integrated safety management and fostering a positive safety culture.
- **Paper ID#36 by F. Pancotti (Italy)** described the work undertaken to characterize alpha-contaminated aqueous liquid wastes in store at the Casaccia Research Centre and the steps taken to develop and qualify an appropriate encapsulation technique. Based on the characterization results and initial trials, the team decided to pursue a cementitious encapsulant, which would need to be demonstrated against preliminary WAC for handling, transport, storage, and disposal. The encapsulation process was successfully applied using a purpose designed conditioning unit enclosed in an alpha-sealed glovebox. The process system and operation is designed to be flexible and able to treat other types of small-volume liquid wastes.
- **Paper ID#295 by A. Maleki Farsani (Iran)** described the steps taken in Iran to improve the country's radioactive waste management arrangements. Despite restrictions due to international sanctions, Iran has established a safe and reliable system and the corresponding facilities for managing all radioactive waste types and waste streams and has developed a national waste management strategy based on national and international requirements. In doing so, it became apparent that the arrangements for the management of NORM from the oil and gas industry were not adequate and steps were taken to tighten the regulation of this sector. Iran now has radioactive waste management arrangements suitable for all types and sources of waste, including both waste from the nuclear industry and NORM activities, as well as DSRS.
- **Paper ID#242 by A. Larsson (Sweden)** described the development of metal melting and waste treatment facilities developed in Sweden by Studsvik and now Cyclife. Metal melting technology offers an efficient method for treatment of contaminated metals with activity being concentrated in the slags and off-gas filters, allowing bulk metals to be recycled and even free-released into conventional industry. Case studies were presented illustrating how the technique can play an important role in the application of the waste hierarchy.
- **Paper ID#59 by K. Pancholi (India)** presented the results of work in India to apply a small-scale plasma pyrolysis-based incineration technology for destruction of cellulose, plastic and rubber. The technology provides high volume and weight reduction factors and the end products meet environmental criteria and can be solidified or supercompacted. The technology is being scaled-up for the processing of combustible VLLW and LLW wastes from nuclear and radiological facilities of the country.
- **Paper ID#273 by N. Saito (Japan)** presented an update on the progress and remaining challenges for waste management from the cleanup after the Fukushima Daiichi accident. The cleanup operation has resulted in a large volume of solid waste 'rubble' (concrete, metal, soil), felled trees and used protective equipment. The wastes have been segregated and subject to some initial treatments to achieve some basic volume reduction and have been placed into various outdoor storage facilities in and around the site. A target has been set to find a long term solution by 2028. A management plan which sees the provision of characterization facilities, incineration, volume reduction, and solid waste storage buildings is being implemented.
- **Paper ID#308 by M. Prazska (Slovakia)** presented an overview of the development of an advanced geopolymer solidification technology by a combined Slovakian and Czech project team. The technology offers an alternative route for waste streams which have been found to be problematic for conventional conditioning processes. The geopolymer technology has been successfully applied for the conditioning of ion exchange resins and contaminated sludges.

- **Paper ID#113 by H. Hamdane (Morocco)** presented development of an alternative to cement-based solidification of ion exchange resins using geopolymers based on phosphate mine tailings. Wasteform development was undertaken to identify the optimum formulation and ion exchange loading with tests for chemical stability, compressive strength and leaching. The trials concluded that the wasteform would have good properties and provide a safe and cost effective conditioning matrix and at the same time allowed recycle of waste from mine tailings.

Paper ID#262

INCREASED SAFETY MEASURES FOR REMOVAL OF SELF-SHIELDED IRRADIATORS CONTAINING CATEGORY 1 AND 2 SEALED RADIOACTIVE SOURCES

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Abstract

In response to lessons learned from a 2019 contamination incident during a source removal in Seattle, WA, the National Nuclear Security Administration's (NNSA) Office of Radiological Security's (ORS) Off-Site Source Recovery Program (OSRP) has implemented new procedures and contracting requirements to enhance safety during the removal of self-shielded irradiators containing category 1 and 2 sealed radioactive sources. These new measures are applied based on the complexity of each removal, which is determined by the irradiator and shipping configuration. For lowest complexity removals, the entire irradiator is packaged in a certified transportation container after the electronics and motor, etc. are removed. A recovery is considered among the highest complexity removals when radioactive sealed sources have to be removed from the source holder and packaged into a certified transportation container. The NNSA is committed to completing the source recoveries using the lowest complexity procedures.

New OSRP safety requirements include submission of detailed work control documents, including site-specific hazard analyses and emergency response plans, which are reviewed by a panel of subject matter experts. The right and responsibility of all parties, including the on-site facilities representative, contractors, and regulators, to pause work in the event of an unanticipated condition related to safety or other considerations is explicitly stated in a document that outlines the roles and responsibilities of these stakeholders. These improvements will help prevent the recurrence of similar contamination incidents and ensure safe and secure disposition of category 1 and 2 sealed radioactive sources.

1. INTRODUCTION

Radioactive sealed sources in one form or another have been produced in the United States (U.S.) and a few other countries for more than 100 years. Therefore, the problem of disused or otherwise unwanted radioactive material widely distributed around the world is recognized as a global threat. These unwanted sources create a supply of hazardous material that could be used in a radiological dispersal device or may simply present a health and safety hazard to the public and the environment if left unattended.

The Off-Site Source Recovery Project (OSRP) was established by the Department of Energy (DOE) on November 15, 1998, to address the threat presented by disused sources. Today, the OSRP continues to operate at Los Alamos National Laboratory (LANL) and Idaho National Laboratory (INL) and is currently part of the National Nuclear Security Administration's (NNSA) Office of Global Material Security. The programme continues to recover and manage disused and unwanted radioactive sealed sources that pose a potential risk to national security, public health, and safety, focusing on sources with few or no commercial disposal options. The Source Collection and Threat Reduction Program (SCATR), a federally supported programme, exists to facilitate the recovery and disposal of sources with commercial disposal options.

Since 1997, the programme has been able to recover over 45 000 sources from more than 1400 sites around the world. This includes all 50 States, the D.C. area, Puerto Rico, and removal of U.S.-origin material from 26 foreign countries. In total, the programme has removed and secured nearly 47 600 TBq of radioactive material as of June 30, 2021. Sources containing radioactive plutonium, americium, californium, caesium, cobalt, curium, radium, strontium, and others have been recovered from medical, educational, agricultural, research, industrial, and government facilities.

In addition to direct involvement in removal of unwanted sources, OSRP team members have visited almost half of the world's countries to promote proactive management of radioactive sources. The team has been involved with site assessments, training, consultancy meetings, inventory evaluations, source recoveries, and other missions related to source management, packaging, transportation, storage, and radiation safety.

2. THE INCIDENT

On May 2, 2019, a subcontractor for the DOE/NNSA's OSRP was removing a Mark 1 irradiator with an approximately 100 TBq ^{137}Cs source from the University of Washington (UW) Research and Training Building in Seattle, Washington. During the recovery operation, the sealed source was breached while being removed from the source holder to be placed in a special form capsule for packaging. This breach resulted in contamination within the facility, impacting multiple on-site personnel. Medical evaluations later cleared all individuals and determined the exposure did not pose a health risk to the individuals or public.

The Mark 1 Series Irradiators consist of an irradiation chamber with a door on the front side, a source holder containing the sealed source attached to the end of a source rod that moves vertically (to the "shielded" and "irradiate" positions within the source chamber), and shielding around the source and irradiation chamber, including walls and door of the irradiation chamber. Figure 1 shows a JLS Mark 1 irradiator.

FIG. 1. JLS Mark 1 Irradiator.

The irradiator contained a JL Shepherd & Associates (JLS) Model 6810 sealed ^{137}Cs source capsule that was designed for use in various JLS devices including category 1 and 2 irradiators, category 2 and 3 calibrators, and panoramic irradiators. A "special form radioactive material" certification is issued by the company that provides the capsule body (usually JLS for this source model). Special form capsules have to meet 10 CFR 71.55, Qualification of special form radioactive material, requirements. The use of these capsules allows a shipper to package material with higher activities in type A containers, using the A1 special form limits, due to the additional testing requirements for the special form capsules, instead of the A2 normal form limit for that isotope. For example, the A1 value for ^{137}Cs is 2.0 TBq and the A2 limit is 6.0×10^{-1} TBq. Higher activities would require a type B shipping container.

United States regulations require each offeror of special form Class 7 (radioactive) materials to maintain on file for at least two years after the offeror's latest shipment and, on request, to provide to the Associate Administrator a complete safety analysis, including documentation of any tests, demonstrating that the special form material meets § 173.469 requirements. An International Atomic Energy Agency (IAEA) Certificate of Competent Authority issued for the special form material may be used to satisfy this requirement (49 CFR 173.476(a)).

The identified transportation container for the Seattle recovery required the sources to be special form. As the subcontractor who attempted to recover the source did not have a complete safety analysis for the Model 6810 source, the source had to be encapsulated in a special form capsule provided by the subcontractor. The subcontractor planned to remove the source from the source holder, shown in Fig. 2, with the use of the subcontractor's mobile hot cell (MHC), shown in Fig. 3. The MHC is a carbon steel box 142 cm L × 142 cm W × 117 cm H with five digital cameras and a monitor attached to the side of the MHC to allow the operators to view the MHC activities. The manipulators are inserted through unsealed ports in the top of the MHC.

FIG. 2. Example of a JLS Model 6810 source holder.

While removing the source from the source holder, the source was breached releasing ^{137}Cs into the MHC and resulting in the spread of radioactive contamination.

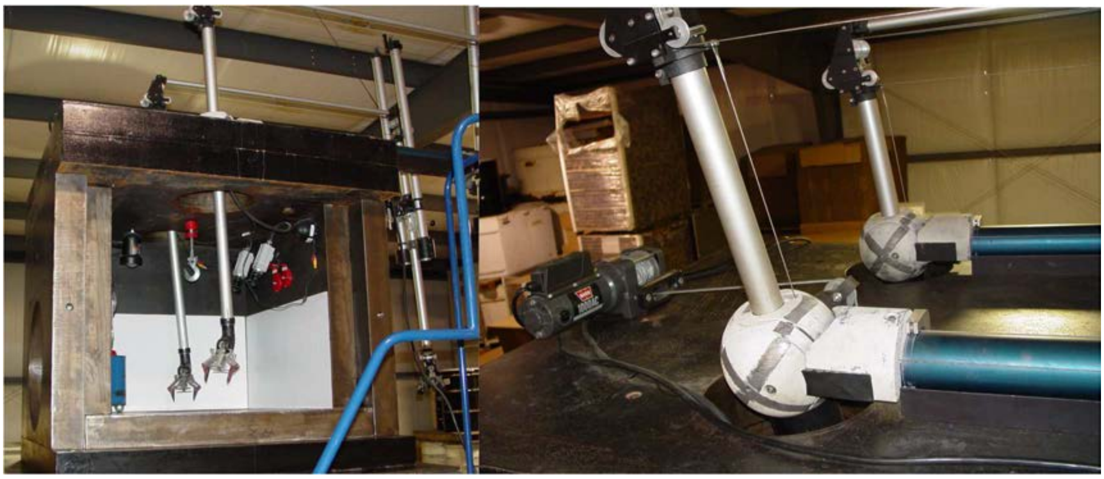

FIG. 3.Contractor's mobile hot cell.

A Joint Investigation Team, including NNSA employees and Triad National Security, LLC (Triad) employees, was appointed to perform an investigation to identify root causes and Lessons Learned from the incident. The investigation found two root causes, which if corrected would prevent recurrence of the same or similar accidents.

— Root Cause #1: The OSRP's contracting process did not effectively implement safety requirements for off-site work
— Root Cause #2: The DOE is managing work regulated by the NRC or an Agreement State without clearly defined roles and responsibilities.

Although the root causes are different, there are other examples of incidents involving radioactive materials resulting in damage. A theft of a ^{60}Co teletherapy source in Tepojaco, Mexico, occurred due to failures in procedures, regulatory controls, and requirements, which caused severe detrimental effects. A transport security plan would have identified safe havens, an appropriate rest stop for the drivers, and safe transportation routes. The IAEA Nuclear Security Series No 9, Security of Radioactive Material in Transport, states "All shippers, carriers, receivers, and others engaged in the transport of radioactive material packages assigned to the enhanced transport security level should develop, implement, periodically review as necessary and comply with the relevant provisions of a transport security plan and if a road movement cannot be completed without overnight or extended stops, then the radioactive material should be protected during such stops in accordance with a graded approach." Additionally, "the shipper and carrier should develop and implement a contingency plan to ensure an adequate response to malicious acts." Although additional safety and security measures may not have prevented these incidents from occurring, they may have mitigated the resulting personal and economic damage.

3. INTEGRATED SAFETY MANAGEMENT SYSTEM

As can be seen from the previous section, one root cause was the ineffective implementation of safety requirements. The Department of Energy Acquisition Regulation (DEAR) requires that contractors are to perform work safely, in a manner that ensures adequate protection for employees, the public, and the environment. The DEAR also identifies the contractor, regardless of the performer of the work, as responsible for complying with environmental, safety, and health (ES&H) regulations.

The manner in which the DOE meets these requirements for on-site work is through its Integrated Safety Management (ISM) system. An objective of an effective ISM system is to integrate safety into management and work practices at all levels, addressing all types of work and all types of hazards to ensure safety for workers, the public, and the environment.

The following five core functions of the ISM process are not independent, sequential functions, rather they are a linked, interdependent collection of functions that often occur.

— Define Scope of Work
— Analyze Hazards
— Develop–Implement Hazard Controls
— Perform Work
— Feedback

The core functions are applied in a continuous cycle as shown in Fig. 4.

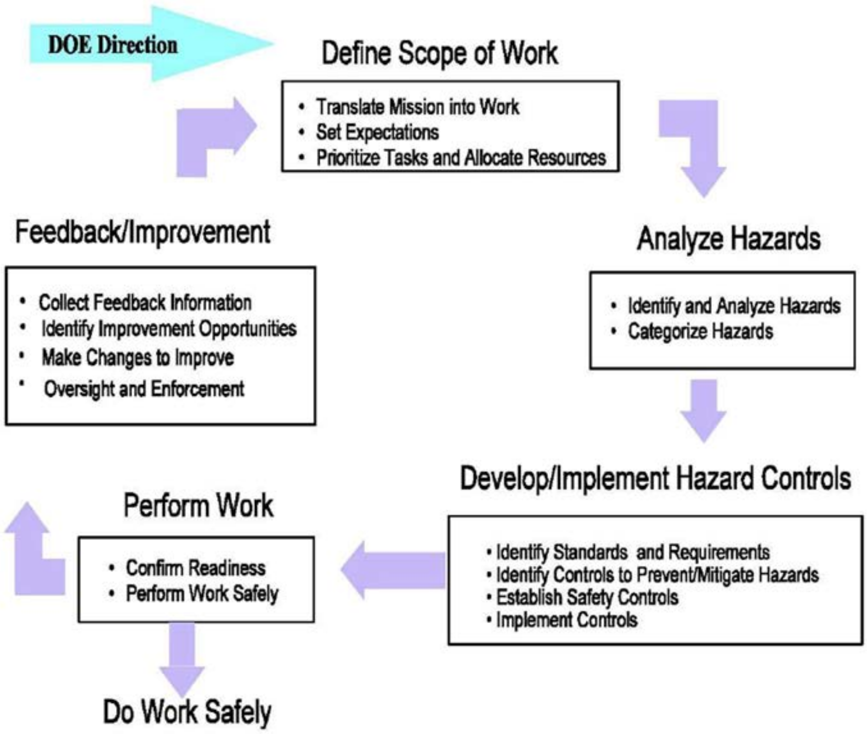

FIG. 4. Integrated safety management functions.

One of the guiding principles of ISM Systems is clear roles and responsibilities. For example, it is important that the responsibility and authority for safety are well defined and clearly understood by all parties prior to performing the work and is integral in the performance of the work. All parties should also be knowledgeable on their roles and responsibility authorities that are clearly defined at the institutional, facility, and activity levels.

4. NEW REQUIREMENTS

Using the ISM System as a guide, the OSRP instituted changes to how contracts are issued for the removal of self-shielded irradiators containing category 1 and 2 radioactive sources to ensure the ISM principles are flowed down to its subcontractors. These new requirements ensure that the full scope of work is understood by all parties, there is increased engagement with regulators, contractors have the license capability to complete the scope of work, all hazards are identified and appropriately mitigated, work is performed safely in accordance with work documents, and any lessons learned are appropriately distributed. The safety changes made to the programme are listed below.

Defining the Scope of Work

- A new policy was implemented to require all parties (the M&O Contractor, licensee, and subcontractor) to sign an Acknowledgement of Roles and Responsibilities.
- Subcontractors are required to submit their current license with the proposal for each subcontract to ensure the work falls within the license. Additionally, subcontractors are required to provide notification of any changes to their license applicable to OSRP work. This ensures the removal contractor can complete the proposed work in accordance with their radioactive material license during the contracting process.
- Subcontractor provides the applicable regulator(s) with the site-specific work plan, so they fully understand the work to be performed.

Analyzing the Hazard

- All contracts require a site-specific work plan and Hazard Analysis and Mitigation Response Plan–Health and Safety Plan to address hazards that can be reasonably expected while performing source recoveries.

Developing/Implementing Hazard Controls

- Detailed site-specific work plans and the Hazard Analysis and Mitigation Response Plan–Health and Safety Plan will be reviewed by a panel of subject matter experts prior to each recovery.

Performing Work

- On-site safety oversight is required for each recovery. The individual performing oversight needs to be knowledgeable of the site-specific work plan and ensure all work is performed in accordance with the approved work plan. Any work deviating from the work plan will trigger a work pause to re-evaluate the activity, any new health and safety hazards, and mitigation measures required for the deviation.
- All individuals (contractor, subcontractor, facility representative, regulatory authority) participating in the activity have the right to pause or stop work due to safety or other concerns.
- Subcontractors are required to have a copy of operating and emergency procedures on hand during source recovery operations.

Feedback/Improvement

- All subcontractor performance assessments will be completed yearly, at a minimum.
- Safety-related lessons learned will be communicated as soon as possible to all contractors.
- A lesson learned review will be completed at least yearly.

5. CONCLUSION

While the new OSRP requirements for source recoveries were instituted to address gaps identified after the breached source incident, these principles can be applied to improve all aspects of the sealed source life cycle. For instance, if a hazards analysis had been completed prior to the Tepojaco theft, increased concern may have been raised about developing an adequate transportation security plan for the shipment, identifying safe havens along the transportation route, and use of a platform trailer with an integrated crane. Incorporating lessons learned from the May 2019 breached source event will make ongoing OSRP source recovery operations safer. Successes and failures provide the necessary opportunity to evaluate and continuously improve radiation work and safety processes. Implementation of the five principles of ISM Systems (Defining the Scope of Work, Analyzing Hazards, Developing/Implementing Hazard Controls, Performing Work, and Feedback/Improvement) help ensure radioactive handling and management activities are completed safely, and that worker and public safety is continuously addressed.

Paper ID#36

APPLICATION OF DIRECT CEMENTATION SYSTEM FOR SMALL VOLUME OF ALPHA CONTAMINATED AQUEOUS WASTE (CEMENTATION SOGIN CASACCIA PLUTONIUM PLANT)

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Abstract

Management of small volumes of alpha contaminated liquid waste can pose significant challenges during the predisposal and disposal phases. Although the radiochemical characteristics of the waste have a major influence on the selection of waste management technology, the quantity of the waste may have a considerable influence on the scale and design of the waste treatment and conditioning facility.

The Sogin Casaccia Plutonium Plant (IPU) stores about 310 l of alpha contaminated aqueous liquid wastes (ILW) from the past activities conducted in the REBA Project (that involved TESEO Process and PUREX Process) and from other laboratory activities.

After a preliminary evaluation of the possible technical and strategical options, Sogin selected on-site direct cementation as the best solution. Due to the limited amount of waste, a dedicated processing plant has been designed to implement the treatment and conditioning process in a small volume process system inside a glove box (Cementation SAG IPU). The design of the drum to be coupled with the cementation system has also been included within the project.

The characterization of the waste evidenced the presence of two main streams: acidic (about 70 l) and alkaline (about 240 l). A laboratory scale testing programme has been carried out to select the treatment and conditioning materials and to define the main process parameters. The stability and durability of the cemented waste form have been verified through a specific qualification programme. A final full-scale mock-up test has been conducted to complete the process and waste form qualification activities.

The paper describes the results of the performed testing activities and the development of the glove box cementation system.

1. INTRODUCTION

Most radioactive waste existing in Italy was produced during the operation of the nuclear installations connected to the national nuclear power programme, which were definitively closed in 1987.

Until the National Repository is available, radioactive wastes are stored at the originating nuclear installations. Interventions are in progress to enhance the safety level of waste by implementing specific treatment and conditioning projects and by refurbishing existing buildings or by constructing new interim storage facilities at the sites.

The Casaccia Research Centre (near Rome) stores about 310 l of alpha contaminated aqueous liquid wastes (ILW) arose from the past activities conducted in the Plutonium Plant (IPU): REBA Project (that involved TESEO Process and PUREX Process) and from other laboratory activities.

Those kinds of waste pose a significant challenge for waste management due to their specific characteristics:

— Physical form: risk for the potential mobility of radionuclides in liquid form.
— Radiochemical content: high level of alpha radionuclide (mainly Plutonium) in acidic and alkaline solutions.
— Small volume: only 310 litres to be treated.

The selection of the preferable waste management strategy needs to account for technical and non-technical criteria, and it needs to be demonstrated that the selected treatment and conditioning processes lead to the production of a chemically and physically stable form to achieve a passively safe state.

The selection of the waste management strategy, the process and waste form qualification activities and the development of the integrated conditioning system are summarized in the following sections.

2. SELECTION OF THE WASTE MANAGEMENT STRATEGY

The waste management strategy for the treatment and conditioning of the IPU liquid waste considered the technical characteristics (in terms of performance and applicability of the available technologies) and all the possible implications of the various strategic alternatives, including "no action."

A first screening of the possible technical and strategical options to be applied was carried out based on the following Technical and non-Technical Criteria:

- Physico-chemical and radiological characteristics of the waste and all those properties that may influence the treatment and conditioning technology to be selected;
- Total quantity of waste to be treated, which defines the scale of application of the technology;
- Availability of the technology and its applicability for the considered waste;
- Degree of maturity and reliability of the technology;
- Complexity of the technology and its implementation;
- Production of secondary waste and subsequent treatment;
- Volume and characteristics of the final product;
- Costs of the process or technology;
- Socioeconomic factors (i.e. realization of the new facility);
- Regulatory or prescriptive constraints (e.g. for transport);
- Authorization constraints (i.e. for technologies currently not approved by the safety authority).

The different technologies and strategic options were fully analysed to underline PROs and CONs in terms of safety, technical and systems implications and final waste package characteristics and volume. The main driving constraint was the limited amount of waste to be treated and its alpha content.

Homogeneous direct cementation was selected as the preferable conditioning technology. Cementation is one of the most common methods for conditioning radioactive waste, providing a cost effective solution for encapsulation of various kinds of waste into a solid, safe form, suitable for long term storage and disposal. The cementation of liquid wastes achieves very good and homogeneous dispersion of the waste in the cement matrix, as the water of the waste itself reacts with the cement powder.

Considering the small volume of the waste and its radiological composition, the strategy for treatment and conditioning will be implemented in a small volume process system inside a glove box (Cementation SaG IPU). This system allows to manage small batch volumes with semiautomatic operations on site.

Following the selection of the technology and the integrated strategy, process qualification activities and system preliminary design activities started in parallel. The outputs of the process qualification (relevant parameters) were used for defining specific requirements for the glove box system and its components that were fully integrated in the basic design.

3. PROCESS QUALIFICATION ACTIVITIES

The aim of qualification process is to demonstrate, on a documented basis, that the conditioning system has the capability to put the waste into a form suitable for handling, transport, storage, and disposal. In particular, the final waste form and package need to have some specific characteristics and properties (i.e. low leachability, long term chemical stability, mechanical strength, radiation resistance, and low water content) which are in line with the long term safety assessment provided by the disposal facility.

Even if in Italy there are no operating repositories, a set of preliminary waste acceptance criteria (WAC) is defined by the National Inspectorate for Nuclear Safety and Radiation Protection (ISIN) in its Technical Guide no. 26 [1] and the list of the tests to be performed on the container, waste form, and waste package are reported in the national standard (UNI 11193:2006) [2].

Those documents provide specific safety requirements for low level radioactive waste (LLW) and, in case of intermediate level radioactive waste (ILW), the specific conditioning requirements are established on a case by case basis.

Sogin, as operator of the future National Repository, defines additional preliminary WAC based on waste characterization and dialogue with waste producers, repository preliminary design, preliminary ‘site independent’ safety assessments, IAEA safety standards [3], and international best practices.

The ISIN is responsible for approving the Qualification Process for conditioning specific waste streams; Sogin is involved in the approval procedure and is required to issue ‘Letters of Compliance’ (LoC) for the potential disposability or long term storage of waste conditioned with the approved process (Disposability Assessments). Such procedure minimizes the risk of reconditioning waste for future acceptance.

Process qualification activities involve the execution of specific tests in laboratory scale and trials in a full-scale mock-up system. Those tests are performed with surrogated solutions (non-radioactive materials, or limited amounts of radioactive materials) to reproduce the main components of the waste, with particular reference to those that can affect the setting and hardening characteristics of the solid product.

3.1. Experimental tests - waste simulation

The total quantity of radioactive liquid waste present in the IPU plant are collected in high-density polyethylene (HDPE) bottles of different volumes (5, 10, 25 l), confined in a double PVC bag and stored in stainless steel containers (Sant'Andrea type). They have a total activity of 6.6E+11 Bq (alpha activity of 3.6E+11 Bq) and are classified as ILW for the presence of relevant quantities of plutonium and uranium.

The physico-chemical characterization of the waste revealed the presence of two main streams: acidic stream and alkaline stream.

Considering the small volume, the cementation process will be realized in a 10 litre batch-scale to allow the manual handling of the different bottles to be treated. For this reason, in some cases, a preliminary mixing–grouping phase is foreseen.

The laboratory scale testing programme started with the definition of the two waste stream surrogated solutions that need to envelope the variability on the composition of the different bottles.

3.1.1. Alkaline stream

The total quantity (about 240 l) of the alkaline stream is collected into 28 bottles of different volume (from 5 to 10 litres). The first hypothesis for the waste simulation was developed considering not to mix the different bottles prior the cementation and trying to find a cementing recipe as flexible as possible. For this reason, the maximum concentration of the relevant chemical components present in the different bottles was considered in the enveloping solution to be tested. The obtained cement paste showed low workability and no hardening, caused mainly by the high content of sodium carbonate (~ 295 g/l).

Because the maximum sodium carbonate concentration value was present in only one bottle (the others were all considerably lower), the first simulation hypothesis was revised to consider using a preliminary mixing–grouping phase with a considerably lower amount of sodium carbonate for the final 10 litre batch to be cemented. The new reference value for sodium carbonate concentration was defined as the mean value present in the various bottles, increased by about 30%, to maintain a certain flexibility in the preparation of the batches. This solution allowed having a sodium carbonate concentration in the surrogated solution of about 100 g/l (see Table 1).

TABLE 1. ALKALINE WASTE STREAM SURROGATED SOLUTION COMPOSITION

Component	g/l
$Na_4(UO_2(CO_3)_3)$	22.77
Na_2CO_3	100
$NaNO_3$	110.36
NaCl	1.27
Na_2SO_4	0.65
TBP	7.63
Dodecane	11.06

3.1.2. Acidic stream

The total quantity (about 70 l) of the acidic stream is collected into five bottles of different volumes (from 5 to 25 l). In this case, the preliminary mixing–grouping phase is needed (at least for the 25 litres bottle) to have the right batch volume to be treated. For this reason, the surrogated solution was developed considering the average concentration values for all the relevant chemical components (see Table 2).

TABLE 2. ACIDIC WASTE STREAM SURROGATED SOLUTION COMPOSITION

Component	g/l
TBP	3.61
Dodecane	5.23
$UO_2(NO_3)_2{*}6H_2O$	246.67
$Al(NO_3)_3{*}9H_2O$	16.45
$Fe(NO_3)_3{*}9H_2O$	1.46
KNO_3	0.26
$Ca(NO_3)_2$	0.23
HNO_3 (69.5%)	398.62
$NaNO_3$	1.42

3.2. Experimental tests - waste treatment

3.2.1. Alkaline stream

As part of the experimental phase activities, the need for pretreating the alkaline waste stream was highlighted as the carbonates present in the solution negatively influenced, as mentioned earlier, the medium and long term performances of the matrix.

Among the various reagents tested, the most suitable was found to be the calcium nitrate used in the form of an aqueous solution (1kg/l of $Ca(NO_3)_2$). This pre-treatment allows total precipitation of the carbonates, according to the following reaction:

$$Ca(NO_3)_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaNO_3$$

Following the addition of calcium nitrate to the solution (under stirring), it was possible to observe the formation of a biphasic system consisting of a fine white precipitate (that can be easily resuspended) deposited on the bottom and a yellow supernatant solution (see Fig. 1).

FIG. 1. Biphasic solution after alkaline stream pretreatment.

3.2.2. Acidic stream

The acidic wastes need to be neutralized prior the cementation. A NaOH 4 M solution was identified as the optimum reagent and is added to the acidic liquid in excess of 5%, compared to the stoichiometric value, to avoid lowering of the pH in the acidic field due to the presence of possible parallel equilibriums that consume hydroxide ions.

The choice of a liquid reagent allows easier process engineering, and the 4 M concentration was chosen with the aim of complying with the prescription in force in the IPU plant which requires that a temperature of 50°C cannot be exceeded inside the glove boxes.

The alkalization reaction is carried out by adding, with constant stirring, the NaOH solution directly to the acid stream to be neutralized. Even if the waste volume increases, the temperature during the exothermic reaction doesn't rise to 40°C in less than 3 hours.

The uranium present in the solution precipitates totally as sodium diuranate ($Na_2U_2O_7$) that can be easily resuspended and transferred.

3.3. Experimental tests – waste form qualification results

Different tests were performed to identify the optimum type of cement to be used and the reference parameters for the cementing recipes. The best results were obtained using Pozzolanic cement (CEM IV A - 42.5R) with a water:cement ratio equal to 0.38 for the alkaline stream and 0.42 for the acidic stream.

A complete set of qualification tests was performed to study the stability and durability of the selected waste forms. The specific requirements for ILW are reported in Table 3 together with the related results obtained for the two waste forms.

Alkaline and acidic waste forms both demonstrated to have low leachability, long term stability under different conditions, high mechanical strength, and high radiation resistance.

During the experimental activities, the process relevant parameters were identified as those that may have a significant influence on the chemical, physical, and mechanical characteristics of the final waste form and that need to be constantly monitored during the process itself. They include the variability on the dosage of the main components: liquid waste, pre-treatment reagent, and cement.

A specific study on the tolerance range for those dosages was carried out in laboratory scale tests and in full-scale trials by using a specific mock-up system (see. Fig. 2). The mock-up allowed to also test the mixing system included in the drum (disposable impeller) and, to verify the homogeneity of the matrix inside the drum, it was sectioned and some coring samples were extracted (see Fig. 3).

The samples showed homogeneous compressive strength values in line with those measured on the laboratory specimens, confirming the correct drum, impeller, and mixing system preliminary design.

TABLE 3. QUALIFICATION TEST RESULTS

Test	ILW Requirements	Alkaline waste form	Acidic waste form
Compressive strength	After 28 days curing $f_c \geq 10$ MPa	$f_c = 28.6$ MPa	$f_c = 26.2$ MPa
Thermal cycling	After 30 cycles (+40°C ÷ –40°C) there can be no cracks and $f_c \geq 10$ MPa	No cracks and $f_c = 33{,}8$ MPa	No cracks and $f_c = 26{,}7$ MPa
Radiation resistance	After an integrated gamma dose of 10^6 Gy, there can be no cracks and fc ≥ 10 MPa	No cracks and $f_c = 38.8$ MPa	No cracks and $f_c = 43.4$ MPa
Fire resistance	Incombustible or self extinguishing	All samples are incombustible	All samples are incombustible
Biodegradation resistance	After fungi and bacteria incubation, there can be no cracks and fc ≥ 10 MPa	f_c (bacteria) = 18.8 MPa fc (fungi) = 25.8 MPa	f_c (bacteria) = 25.8 MPa f_c (fungi) = 26.1 MPa
Leaching	Li ≥ 7 for Cs-137	Li = 7.97	Li = 8.07
Immersion resistance	After 90 days of immersion in water, there can be no swelling or cracks and fc ≥ 10 MPa	No swelling or cracks and $f_c = 22.9$ N/mm^2	No swelling or cracks and $f_c = 22.2$ N/mm^2
Linear shrinkage	Linear shrinkage ≤ 2.000 µm/m	Linear shrinkage (270 days) = 1826 µm/m	Linear shrinkage (270 days) = 1411 µm/m
Water permeability	Water penetration ≤ 20 mm	Average value = 8 mm Maximum value = 12.6 mm	Average value = 6 mm Maximum value = 12.3 mm
Thermal conductivity	k ≥ 0.5 W/(m*K)	K = 0.57 W/(m*K)	K = 0.58 W/(m*K)
Gas permeability	The resulting value will be compared with the international literature data	1.66×10^{-19} m^2	3.89×10^{-18} m^2
Free liquids	Less than 0.5% of the gross volume	No detectable free liquids	No detectable free liquids

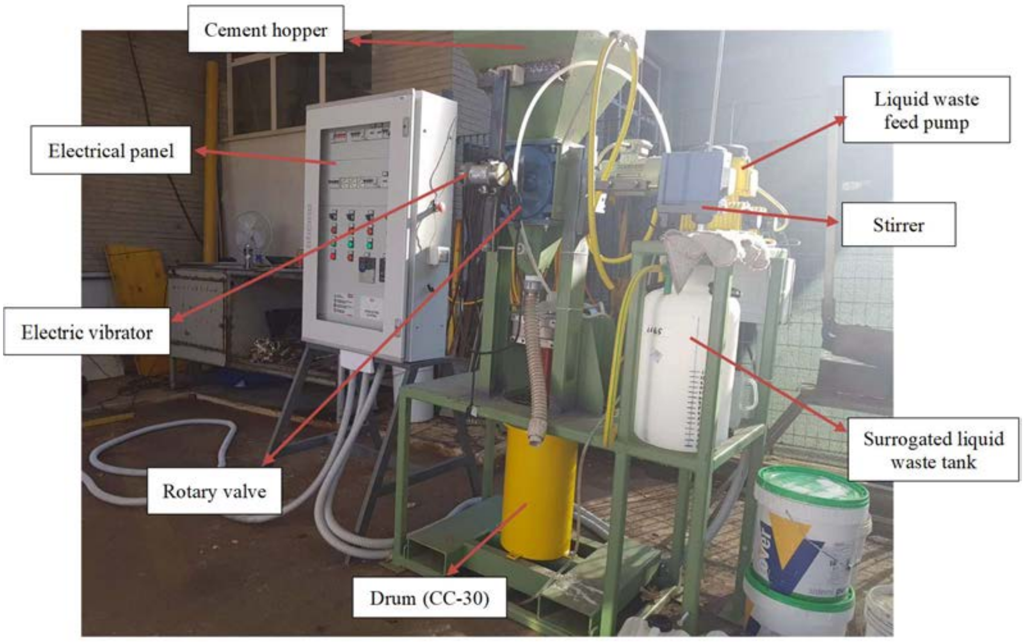

FIG. 2. Mock-up system.

FIG. 3. Drum sectioning and coring.

4. PLANT DESIGN

The design of the glove-box cementation system (Cementation SaG IPU) started with some basic assumptions:

— The system will be built into an existing building and connected to the existing safety and auxiliary systems providing, where necessary, the appropriate modifications and adaptations to guarantee their correct operation in safe conditions.
— Batch volume: the maximum batch volume for the production of a single waste package was fixed to 10 litres.
— Cementation process: in order to optimize the filling of the drum (minimizing the voids) and the homogenization of the mixture, the cementation process will be conducted through simultaneous addition of cement powder and liquid waste to the drum (in the ratio defined for the qualified recipe).
— Handling systems: forklift, pallet truck, and a motorized roller conveyor system will be used for handling the drum within the working area.

— The cementation SaG IPU and all its components have to be designed and manufactured considering a useful life of 25 years.
— All parts in contact with process fluids have to have adequate compatibility characteristics (e.g. corrosion resistance, etc.).
— Maintenance and decommissioning: the components inside the SaG (except for the tanks) have to be dimensioned such as to be able to pass through the foreseen openings. In view of the future dismantling activities of the SaG, all the components inside and outside the SaG that can be disassembled have to be made preferring bolted joints rather than welded joints and, to allow cold cutting operations, the thicknesses of the steel parts cannot exceed 10 mm. The components need to be easily decontaminated to proceed easily with any maintenance operations.
— Heat welding operations cannot be carried out inside the IPU plant. Therefore, the structure should be pre-assembled in the factory in relation to the parts with welded joints.

The final system (Cementation SaG IPU) is composed by three different confinement systems (see Fig. 4):
— Process Area: in which the pre-treatment, homogenization, liquid transfer, and cementation operations take place.
— SCDC (Cement Loading and Dosing System): positioned above the process area, where the cement powder is loaded and dosed.
— BCF (Drum Confinement Box): positioned below the process area, where the drum handling operations take place.

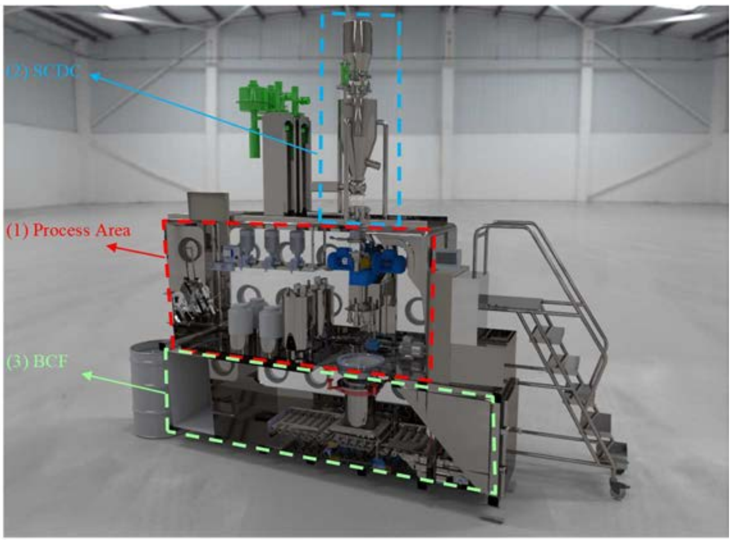

FIG.4. Cementation SaG IPU - confinement systems.

The cementation area (process area) mainly consists of the following components:

— A box-like structure consisting of a metal frame and transparent panels placed on a metal support frame;
— Tanks, pumps, and tools to implement the liquid pre-treatment, homogenization and dosage to the drum;
— A series of glove ports to allow the manual operations inside the SaG;
— Penetrations for the utilities (for example the power supply);
— Bag port of adequate size for the introduction of the liquid waste bottles and any necessary equipment, for the extraction of solid waste produced during the process and for maintenance operations;
— A double valve penetration for the coupling with the cement adduction pipe;
— An alpha tight coupling system for the connection with the drum.

A detail of the process area is reported in Fig. 5.

The Cement Loading and Dosing System (SCDC) consists of a loading hopper and a dosing system by means of a rotary valve. It is equipped with a high containment butterfly valve that allows to disconnect the entire system while maintaining the required confinement.

The BCF (Drum Confinement Box) mainly consists of the following components:

- A system of double doors (SAS) used to access the drum inside the secondary confinement. This system, opening alternately, allows the maintenance of the expected levels of depression imposed by the ventilation system;
- A series of glove ports to allow the manual operations inside the BCF and the introduction and extraction of tools and/or equipment necessary for the ordinary or extraordinary maintenance phases, or both;
- Penetrations for the utilities (for example, the power supply);
- A series of handling roller conveyors;
- A drum lifting system.

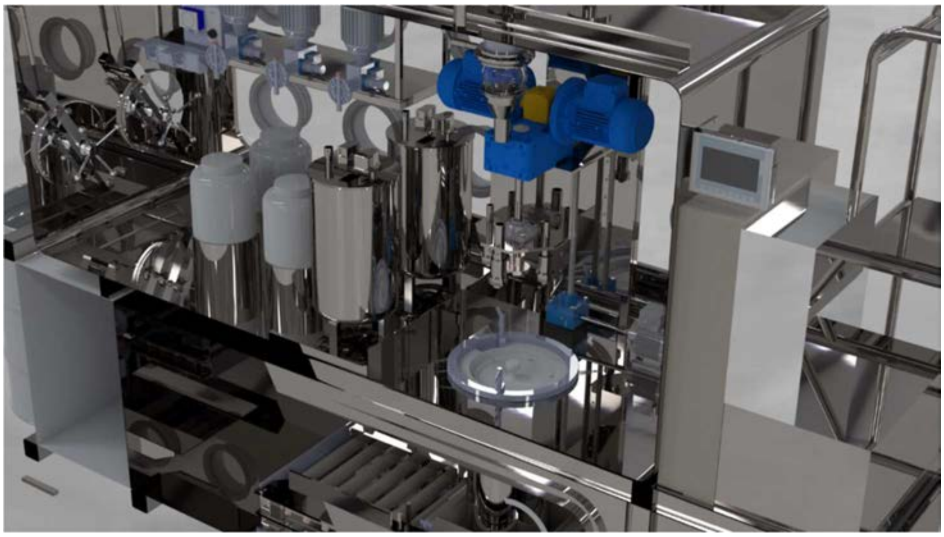

FIG. 5. Cementation SaG IPU - process area.

For each batch, a specific sequence of operations is defined, as well as the values and parameters to be used for cementation (i.e. quantities of reagents and cement). The Process Automation Systems (PAS) enables the process to be conducted in a semiautomated way. The Process Flow Diagram is shown in Fig. 6.

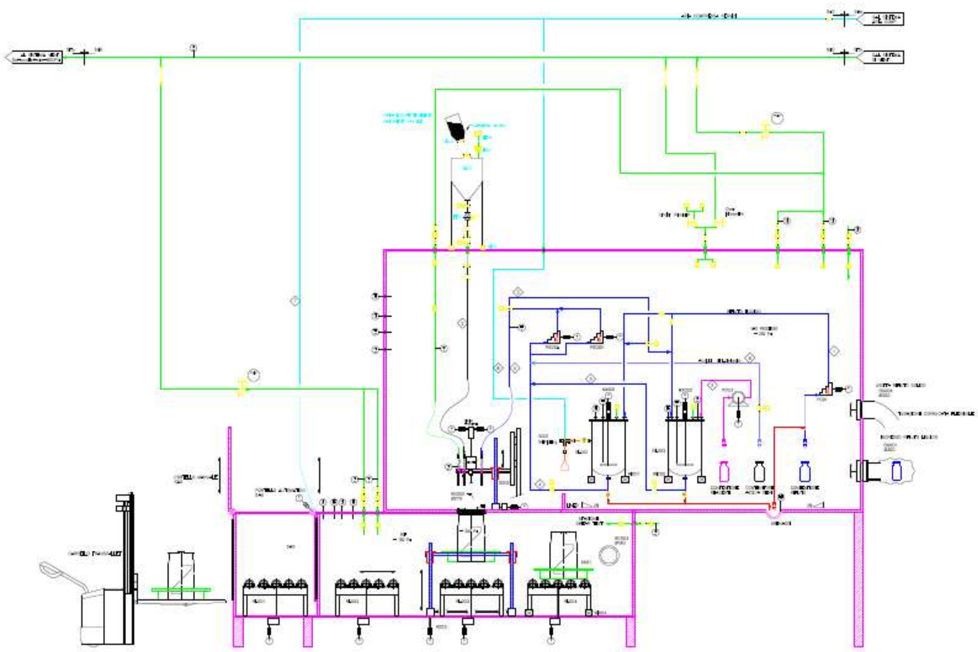

FIG. 6. Process flow diagram.

Mass balances were defined for the two waste streams and the final number of packages produced were estimated (see Fig. 7).

	TOTAL WASTE VOLUME (310 l)	
	Alkaline waste stream (240 l)	Acidic waste stream (70 l)
PRE-TREATMENT	$Ca(NO_3)_2$ (sol. 1kg/l) ~ 1,5 l Raw Waste ~ 10 l	NaOH 4M ~ 6,5 l Raw Waste ~ 5 l
CONDITIONING	Pre-treated waste ~ 11,5 l	Pre-treated waste ~ 11,5 l
FINAL PACKAGES CC-30	n. 24 CC-30 (useful volume ~ 22 l)	n. 14 CC-30 (useful volume ~ 22 l)

FIG. 7. Mass balance.

4.1. Drum design

The design of the drum to be coupled with the cementation system was included within the project. According to the fixed maximum batch volume (10 l), the cylindrical drum was designed to have an internal useful volume of about 22 l (geometric volume about 30 l). The small size of the drum allows it to manually couple and uncouple from the SaG.

The main functions of the drum inside which the waste will be cemented are:

— Ensure the first containment of the cement matrix.
— Allow the correct homogenization of the liquid waste with the cement powder by means of a disposable impeller connected to the cementation head engine.
— Ensure correct coupling with the cementation head (vent line, waste feed line, cement feed line, impeller rotation shaft).
— Guarantee the tightness of the SaG plus drum system during the connection and during the cementation process.

— Constitute the second barrier, after the matrix, against the diffusion towards the external environment of radioisotopes immobilized in the matrix itself. This additional sealing function has to be carried out from the moment the drum is closed with the second lid, equipped with a long-lasting metal seal, at least until it is transferred to the final disposal site.
— Allow, in case of need, an easy decontamination of its external surface by minimizing the discontinuities present.
— Guarantee the resistance to degradation (which in the case of steel containers essentially consists of the corrosive phenomena that occur on the surfaces of the container) for a at least 50 years from the date of manufacture.
— Minimize the entry of moisture and the release of gas and/or particulate matter (which could be formed, for example, due to radiolysis reactions). This passive venting system provides for the presence of two special filters mounted on the first lid and on the second lid of the drum, and will prevent the pressure increase inside the drum without affecting the ability to confine the radionuclides.
— Guarantee an adequate shielding of the radioactive waste cemented in it to respect the limit value of the fixed contact dose rate equal to 2 mSv/h.

The SaG and the drum are equipped with an alpha tight system mainly composed by two separate units with interlocking tabs and opposing seals to achieve the required tightness. One part is mounted on the bottom of the process area and the other on the drum.

The drum is equipped with a special lid called the "first lid" to distinguish it from the closing lid, which is also called the "second lid." The coupling with the sealed door takes place through an appropriate gasket system capable of ensuring the alpha sealing during the cementation phases and ensuring the absence of contamination on the external surface of the drum and of the first lid. This system allows to have only the internal volume of the drum in communication with the interior of the SaG during the liquid waste cementation, thereby preventing the external surface of the drum from contamination.

A schematic representation of the drum is reported in Fig. 8.

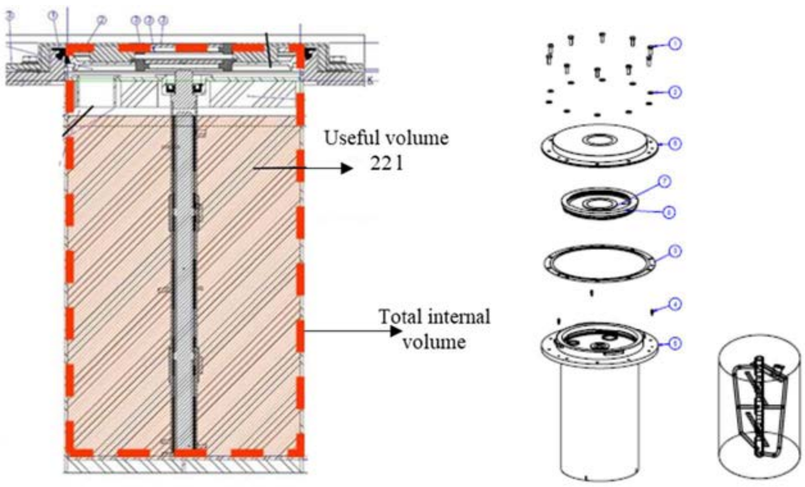

FIG. 8. Drum and impeller drawing.

The drum has a stainless steel upper plate welded to the internal surface for the connection with the cementation head with three circular penetrations: one for feeding the liquid waste, one for feeding the cement powder and the other for connecting to the extraction system. A fourth circular penetration, in a central position, is used to house the disposable impeller head.

Prototype drums will be constructed to perform the following qualification tests for Industrial package Type 3 (Type IP-3):

— Staking, drop, and penetration tests on the package (according to IAEA SSR-6 [4]);
— Thermal test on the package (according to IAEA SSR-6 [4]);

— Free liquid on the package (repetition with the final prototype of the test already performed see Table 3);
— Leak test and degradation test on the container.

5. CONCLUSION

The waste management strategy was developed entirely within the Sogin group through its long-lasting experience and expertise in cementation plant design and process and waste form qualification.

The innovative treatment and conditioning system realized with equipment and components installed in a small volume process system inside a glove box (Cementation SaG IPU) allows, in an enclosed alpha-sealed environment, to perform semi-automatic handling operations aimed at cementing alpha contaminated aqueous liquid waste. This technique simplifies and reduces components and equipment normally used in large industrial plants. The system offers the nuclear decommissioning sector a solution to treat and condition small volumes of liquid waste without having to build complex industrial plants that involve long authorization procedures, environmental impacts, and significant construction and management costs.

The process components and the process operation scheme have great flexibility to be adapted for treatment and conditioning of different liquid radioactive waste types.

The full system is designed to be easily decontaminated for reuse in future conditioning campaigns and finally easily dismantled.

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RADIOACTIVE WASTE MANAGEMENT ISSUES AND CHALLENGES IN ISLAMIC REPUBLIC OF IRAN

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Abstract

The Iran Radioactive Waste Management Co. (IRWA) is designated by the Atomic Energy Organization of Iran (AEOI) as the Central Waste Management Organization in Iran to be responsible for performing all aspects of radioactive waste management activities in the country, and for transportation, processing, and storage of institutional radioactive waste received from the minor waste generators. The IRWA will also be responsible for the disposal of all radioactive wastes in Iran including operational and decommissioning wastes. This vast scope of responsibilities creates challenges and the necessary practical efforts to simultaneously satisfy regulations and stakeholders.

Based on present and future requirements, effective and safe management of such wastes requires a comprehensive programme coordinated by a defined national waste management strategy. Since 2001, the International Atomic Energy Agency (IAEA) has provided technical assistance and support for the development of the National Waste Management Strategy & Policy (NWMSP) and Radioactive Waste Disposal Program, covering the entire spectrum of generated and anticipated radioactive waste.

Novel strategies over a short time require solutions to problems that arose from operating the first nuclear power plant (NPP) in Iran, limited access to novel technology and expertise, undefined responsibilities, and design and sometimes training deficiencies. Additionally, the sudden increase in the application of sealed sources and radioisotopes and operation of nuclear fuel cycle facilities in the country generated a large amount of disused sealed radioactive sources (DSRS) and a variety of waste streams. In the last decade, the IRWA started siting and construction of a near surface disposal facility to increase its capabilities for dealing with such a sudden increase in waste streams and volumes. The NPP wastes issues were quite varied: unsuitable formulation for stabilizing the wastes leading to improper final waste packages, improper design of stabilization process devices leading to cost increase and non-conformances, lack of a final solution for high activity wastes (group III), non-compliance in number and radioactivity of generated final waste in comparison to the final safety analysis report (FSAR), among others.

The licensing process and dealing with the INRA as the disposal facility was also a challenge because of the lack of experience with waste disposal and the specific and unique issues in disposal of radioactive waste.

By increasing generation of DSRS, the IRWA devised a storage methodology to store a large volume of DSRS in a small, controlled area and to retrieve them for reuse, which is one of the main solutions of DSRS management.

1. INTRODUCTION

The IRWA is designated by the AEOI as the Central Waste Management Organization in Iran to be responsible for performing all aspects of radioactive waste management activities in the country, and for transporting, processing, and storing institutional radioactive waste received from the minor waste generators [1]. The IRWA will also be responsible for the disposal of all radioactive wastes in Iran, including operational and decommissioning wastes.

In Iran, radioactive waste is generated from many different activities, including the application of radionuclides in medicine, research, and industry, and the use of nuclear reactors for research, training, radionuclide production, and power generation at the Bushehr Nuclear Power Plant (BNPP). In addition, waste containing naturally occurring radionuclides is generated in mining and milling of uranium ores. Waste with technologically enhanced concentrations of naturally occurring radioactive materials (NORM or TENORM) is also generated in the oil industry and in some other industrial or mining activities.

2. NATIONAL POLICY AND STRATEGY

The National Radioactive Waste Management Strategy (NRWMS) is a key tool and comprehensive framework for ensuring the long term implementation of practices needed to manage radioactive waste within the national and international legal principles [2]. NRWMS concerns all categories of radioactive waste arising from different streams regardless of origin except spent nuclear fuel coming from research or power reactors.

The set of declared national goals and requirements for the safe management of radioactive waste has to be translated into a more practical and operational form or strategy to provide for their implementation.

Considering the importance of stages such as treatment, conditioning, storage, and volume reduction of radioactive waste, it is necessary to develop a national strategy for radioactive waste management. Strong relation between radioactive waste management and waste generators has a prime significance to improve waste management conditions.

In 2005, the IRWA developed the first revision of the NRWMS through a Technical Cooperation (TC) project with the International Atomic Energy Agency (IAEA). Since then, the NRWMS was revised a few times based on the Iran Nuclear Regulatory Authority standards (INRA) and organizational and technological changes.

The NRWMS was developed based on:

— National Act of AEOI (1974);
— National Act of Radiation Protection (1989) and related regulations;
— The basic waste management principles formulated by the IAEA;
— IAEA Safety Principles, RADWASS Program;
— Joint Convention on the Safety of Spent Fuel and Radioactive Waste Management (1997).

The National Policy is briefly addressed in the same document and consists of the following principles:

— Protection of human health;
— Protection of environment;
— Protection beyond national borders;
— Protection of future generations;
— Burdens of future generation;
— National legal framework;
— Control of radioactive waste generation;
— Radioactive waste generation and management interdependencies;
— Safety of facilities;
— Security and physical protection of the facilities;
— Research and development (R&D);
— Decision and policy making;
— Financial and human resources.

The responsibilities of the parties involved in radioactive waste management activities are presented in Table 1.

TABLE 1. RESPONSIBILITIES OF THE PARTIES INVOLVED IN RADIOACTIVE WASTE MANAGEMENT IN IRAN

Activity	INRA	Nuclear Facilities & NPPs	Industry & Medical Radiation centres	IRWA	
				Mandatory	Upon Request
Collection	C	R	R	TA*	A
Characterization	C	R	R	TA	O+A
Waste transportation	C	R	R	TA	O+A
Unprocessed waste storage	C	R	R	TA	O+A
Decay storage (short half-life)	C	R	R	TA	O+A
Disposal of exempt waste	C	R	R	TA	O+A
Treatment	C	R	R	TA	O+A
Conditioning	C	R	R	TA	O+A
Delivery & loading	C	R	R	TA	O+A
Transportation	C	R	—	—	O
Interim and long term storage**	C	—	—	R	—
Disposal	C	—	—	R	—
Long term monitoring of repository	C	—	—	R	A

C – Control & Licensing R – responsible, A - advisory services, O – Operation, TA - Technical Audit

*Technical audit is a service process through which weak points of main waste generators will be detected and suggestions to optimize waste management operation will be presented.

**According to IRNA regulations and based on the existing contracts, all responsibilities related to delivered waste, have to be taken over by IRWA.

3. MAIN ISSUES IN RADIOACTIVE WASTE MANAGEMENT IN IRAN

Novel strategies over a short time require solutions to problems that arose from operating the first nuclear power plant (NPP) in Iran, limited access to novel technology and expertise, undefined responsibilities, and design and sometimes training deficiencies. Additionally, the sudden increase in the application of sealed sources and radioisotopes and operation of nuclear fuel cycle facilities in the country generated a large amount of disused sealed radioactive sources (DSRS) and a variety of waste streams. In the last decade, the IRWA started siting and construction of a near surface disposal facility to increase capabilities for dealing with such a sudden increase in waste streams and volumes. Waste issues at the NPP were quite varied: unsuitable formulation for stabilizing the wastes leading to improper final waste packages, improper design of stabilization process devices leading to cost increase and non-conformances, lack of final solution for high activity wastes (group III), non-compliance in number and radioactivity of generated final waste in comparison to the final safety analysis report (FSAR), among others.

Another challenge included the licensing process and dealing with the INRA for the disposal facility because of the lack of waste disposal experience and the specific and unique issues in disposal of radioactive waste.

Because of increased in DSRS generation, the IRWA devised a storage methodology to store a large amount of DSRS in a small and controlled area and to enable their retrieval for reuse. Reuse is one of the main solutions for DSRS management.

3.1. Development of a near surface disposal site and effective communication with regulatory authority (INRA)

The Islamic Republic of Iran plans to build a 7000 MW nuclear power capacity near surface disposal site as the first attempt of this programme at Bushehr NPP. The planned NPP and operation of other peaceful activities, such as a centralized waste management facility for processing of low and intermediate level waste (LILW), will generate a large volume of LILW to be finally disposed in a suitable repository.

In 2001, the IRWA decided to launch a site selection project for a near surface disposal site. In 2003, the IRWA requested assistance from the IAEA through a TC project to obtain international experience and to train its engineers. An integrated, stepwise approach was adopted.to develop the Iran Near Surface Repository (INSuRe). Based on IAEA recommendations, a four stage site selection process (Fig. 1) was adopted as follows:

— Conceptual and planning stage;
— Area survey stage;
— Site characterization stage;
— Site confirmation stage.

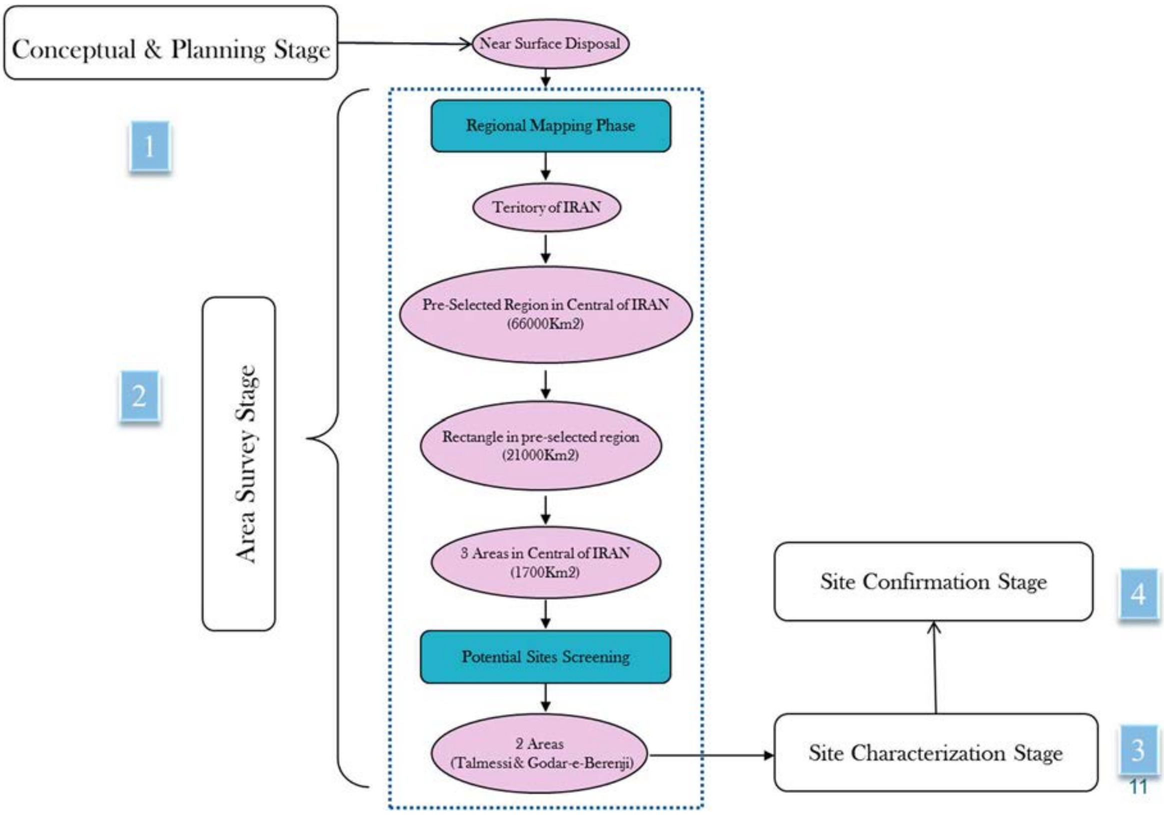

FIG. 1. The main activities performed in the siting stages.

Based on detailed criteria in each stage and application of GIS integration and analysis methodology and socioeconomic factors, a site has been chosen in the District of Anarak, 25 km west of Na'ein-Anarak road. The INRA issued the site license in 2010.

The 1 km^2 area site is in a red syncline structure consisting of clayey formation with an elevation of approximately 2000 m above mean sea level. This bowl shaped structure with an elevation of approximately 1480 m above mean sea level can serve as the best protector for the disposal site. Very low precipitation and high evaporation rate are the dominant desert climates in this site, so there is no runoff in the entire site except some streams resulting from short seasonal rainstorms.

This site plays an important role in the ability of the IRWA to provide safe and effective management of different types of the wastes. All the waste management process steps (long term storage, treatment, volume reduction, conditioning, and final disposal) will be available at this site.

3.1.1. Effective communication with the regulatory authority (INRA)

Due to low storage capacity in the Bushehr Nuclear Power Plant (BNPP), early construction of a temporary storage was needed in this site. The IRWA negotiated with the INRA to apply for a series of constructions and operation permits for minor buildings to facilitate faster construction of storage building(s). It was agreed to continue the construction work based on the issuing permits until final application for the operating licence of the whole disposal site. Figure 2 shows the schedule and activities for the life-cycle of INSuRe.

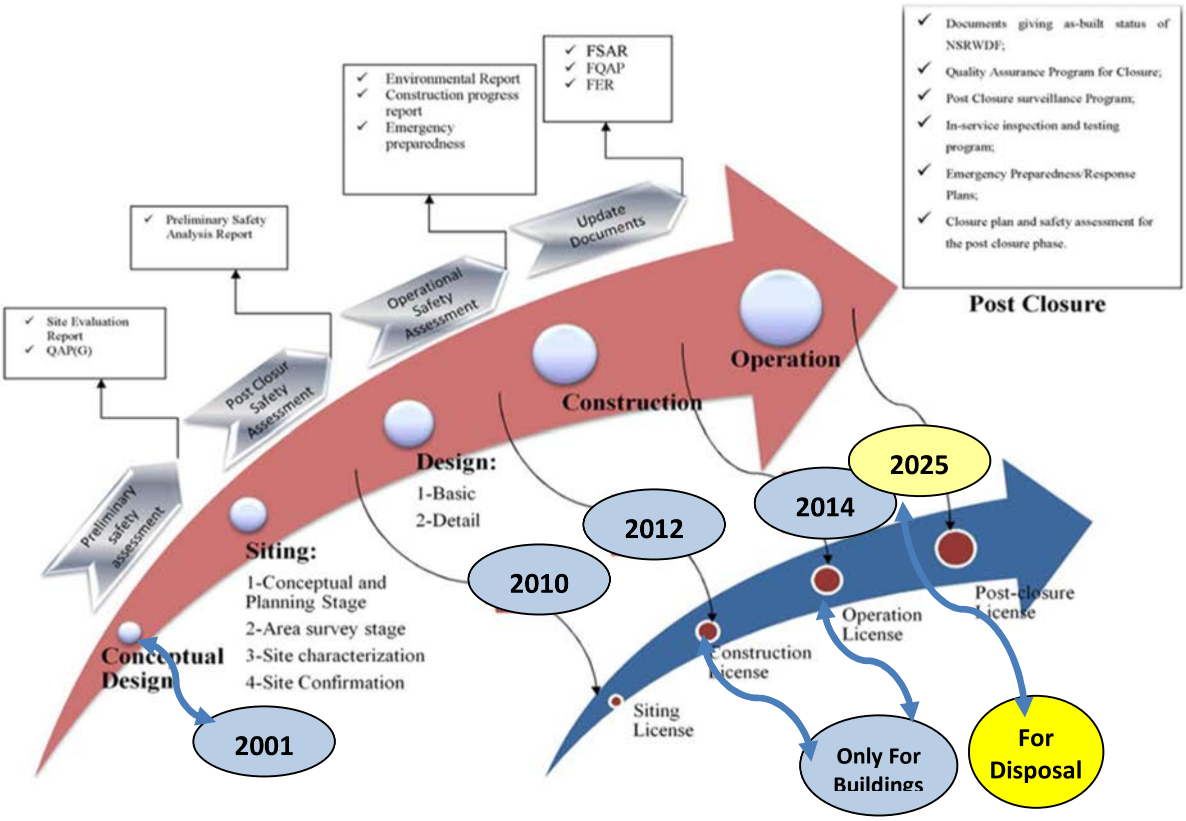

FIG. 2. The schedule and activities for the life-cycle of INSuRe.

3.1.2. Development of Waste Acceptance Criteria

Based on the trench design features and outputs of safety assessment, waste acceptance criteria (WAC) were developed. Agreement on the WAC by the BNPP operator, INRA, and the repository operator presents a real challenge. Resistance to accepting the WAC agreement by the BNPP operator are due to expected cost loads and design alterations. The IRWA is trying to solve this by meeting with the BNPP operator and the regulatory body to promote technical communication and mutual understanding.

3.2. Cooperation with the operator of the first NPP on operational radioactive waste issues

3.2.1. Managing highly active waste from BNPP

The three main categories of waste generated at BNPP are unconditioned solid waste, solidified waste, and highly active spent instruments (neutron activated), all of which should be transferred to IRWA for long term storage and disposal. Solid and highly active spent instruments have fewer problems because of their predefined management plan for long term storage and solid waste management strategy adopted by IRWA for using incineration or super-compaction, or both, which has not been decided yet.

Due to the neutron activation process, neutron channels become radioactive material with the total activity of ~ 4 TBq (100 Curies) each, are removed from the BNPP reactor core, and replaced every four years. These channels, 12 metres (m) long and 1 millimetre (mm) thick, are collected in a coil shape at the end of their service life and are directed into a steel capsule inside a 13-ton container. Each capsule holds about 550 TBq (15 000 Ci) of activity after placing 9 coils inside. Table 2 shows the main radionuclides and their typical activity for one capsule on the time of removal from the reactor core. Most of the activity are short-lived radionuclides; therefore, activity reduces to about 40 TBq (1000 Ci) after 4 years of storage at BNPP.

IRWA has designed new boreholes for long term storage at the INSuRe facility; and has loaded 12 steel capsules inside them (Fig. 3).

TABLE 2. THE MAIN RADIONUCLIDES AND THEIR TYPICAL ACTIVITY FOR ONE COIL

Parameter	Radionuclides				
	Cr-51	Mn-54	Co-58	Fe-59	Co-60
Nuclides %	79.4	3.7	9.2	1.7	6.0
Activity Bq	4.49E14	2.09E13	5.22E13	0.97E13	3.44E13
Total Activity	566 TBq				

FIG. 3. New boreholes for long term storage of steel capsules (highly active solid waste).

3.2.2. Non-conformances in the solidified waste

Solidified waste packages derived from liquid waste evaporation and cementation of its sludges at BNPP did not conform to near surface disposal WAC. A cementation procedure recommended by the BNPP contractor produced about 2000 packages but many of them could not pass disposal WAC due to the unsuitable cementation formula, high amount of boron, and high salinity (800 gr/lit). The formula has been tested in the IRWA laboratory and its result was announced to BNPP.

The technical problems that were found, such as in-drum mixing with the lost paddle approach, high saline concentration caused by the deep evaporator, and others, were reported to the contractor to be considered in their new design for new NPP phases.

The IRWA will prepare a justification report for waste packages non-conformances, to include two main options—overpack and engineered vault. A final decision could be made upon completion of feasibility and financial evaluations.

3.3. Management of NORM waste

The IRWA has undertaken the responsibility of NORM waste management in all Iranian industries. In recent years and along with the growth of nuclear and non-nuclear industries, environmental consequences, and long term intensive impacts of producing wastes is a matter to be seriously considered and dealt with safely and properly.

The development of industries dealing with, for example, oil and gas, mining, and chemical fertilizer has led to a remarkable increase of NORM waste and residue discharge to the environment.

During the different phases of production and operation, and depending on the selected processes, NORM waste and residues are produced and concentrated in different environmental bodies and could endanger the environment and human health. Oil and gas and mineral and ore processing industries are the main contributors to the generation of NORM waste and residues in Iran. Mining and mineral processing activities that extract minerals from ore bodies are the main origins and resources of producing, concentrating, and releasing NORM to the environment. To protect human health and the environment, environmental management activities have to be planned and appropriately carried out in those industries.

Industries in Iran generating NORM wastes and residues include:

- Oil and gas production;
- Mining and mineral processing;
- Phosphate industry, including phosphoric acid and phosphate fertilizers production;
- Ceramics and building materials;
- Metal recycling;
- Water and wastewater treatment facilities.

Much emphasis is being given to the management of NORM wastes and residues due to the existence of numerous industries involved in the processing of NORM (Table 3).

TABLE 3. NORM GENERATING INDUSTRIES IN IRAN

Industry	Number	Industry	Number
Oil and Gas	150	Nonferrous metallic mining	150
Water treatment plants	138	Chemical non-metallic minerals	5
Wastewater treatment plants	196	Coal mining	91
Iron and steel production	7	Iron ore mine	131
Uranium mining and milling	3		

The lack of legal documents to force NORM waste producers to properly manage their waste is one of the main issues related to NORM management in Iran.

As such, INRA has initiated “Determination of action levels, investigation on activity concentration and safe management of NORM waste in oil and gas and mining industries,” a project in which INRA will review and assess NORM management in Iranian industries, including determination of the national inventory of NORM wastes.

Additionally, some case studies are defined and in process to investigate NORM residues among all categories of potential NORM producing industries.

3.3.1. Iodine production facility

Managing NORM residues and wastes caused by iodine extraction from deep underground brine water was assigned to IRWA. First, all process units and operation units are investigated carefully and environmental data were gathered. Based on the provided information, field monitoring by using a portable device was used to provide essential data layers to create gamma dose rate maps.

Water samples, soil and sediment, scale and waste samples, and air particulate samples were gathered and analysed to investigate NORM activity levels. The results of active and passive measurement of NORM, evaluated by using amber code, considered different scenarios for NORM management options. Figure 4 shows a brief project description in four phases.

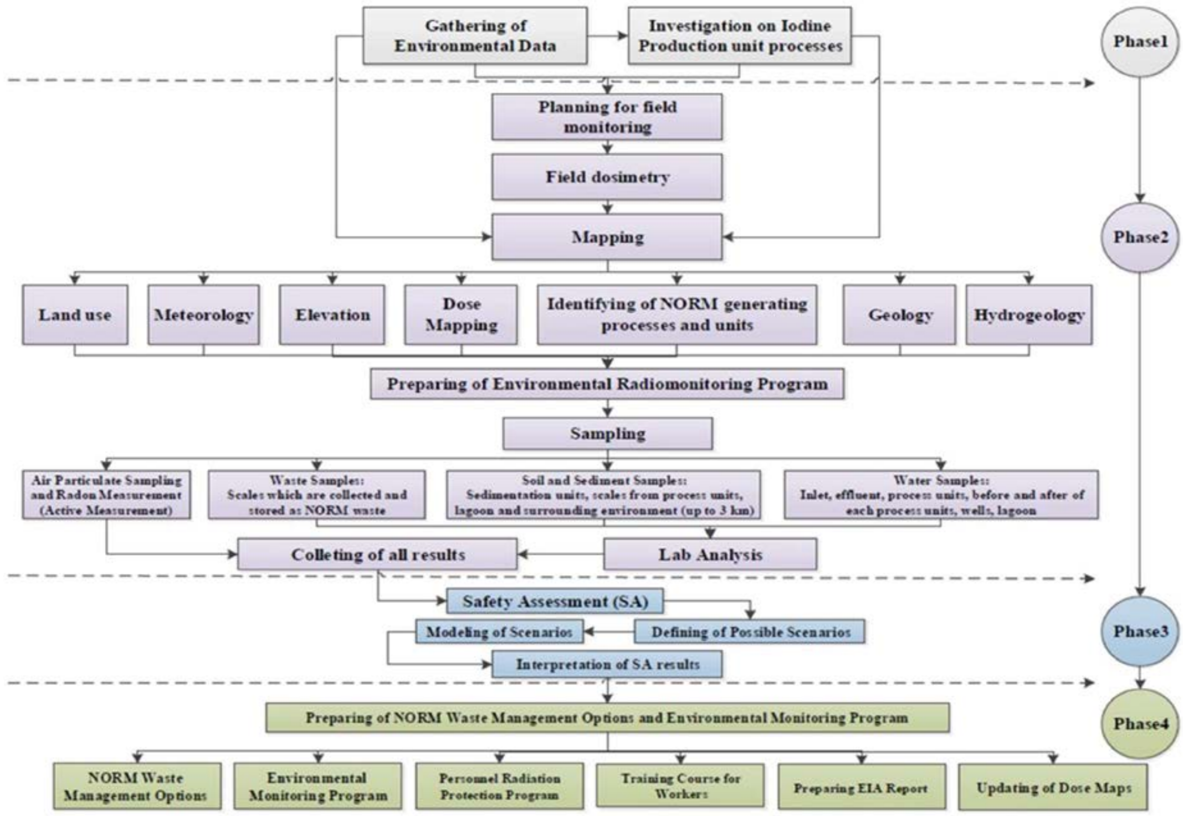

FIG. 4. Schematic diagram for managing NORM waste from Iodine producing industries in Iran.

3.3.2. Uranium mining and milling facility

A two-year monitoring of the uranium milling site has been carried out, including: terrestrial gamma radiation dose measurement, uranium, thorium, and potassium mapping. Eighty samples, including foodstuff, surface and ground water, soil and sediment, radon, and external radiation were gathered and analysed to investigate activity level of various radionuclides.

In conclusion, based on the results derived from environmental monitoring, waste characterization survey, and provided basic information, remediation planning and decontamination techniques were considered for proper management of the uranium waste and tailing pond in compliance with the best national and international practices.

3.4. Development of a novel system for storage of DSRS

Radioactive sources are used in a wide range of practices in industry, medicine, agriculture, research, and education. The sources, used in these applications, contain a variety of radionuclides, forms, and quantities of radioactive material and exhibit a wide range of physical, chemical, and radiological properties.

A radioactive source that is no longer in use or not intended to be used for the practice for which an authorization has been granted is termed as disused. There are several reasons a user may no longer need or want their sealed source; the source may have decayed below a useful activity, the user's priorities may have changed or its business dissolved, the user may have replaced the source with a new source or an alternative technology, or the source/device may have been damaged. If a source is no longer suitable for its intended purpose because of radioactive decay, it is considered as spent. A source that has no foreseeable use or method of recycling is considered waste. Sources classified as waste can be recycled if a new use or recycling method is identified before the waste is permanently disposed of.

It is important to emphasize that a source declared by one user as disused or spent may still be used by a different user, supplier, or manufacturer. A disused or spent SRS may still be highly radioactive and potentially hazardous to human health and the environment and are commonly placed into long term storage.

As mentioned previously, the IRWA has played a clearing house role in radioactive source management in Iran. A clearing house is a centralized collection, inspection, and characterization facility with the role of identifying source disposition paths which would include disposal, storage for decay, and identifying sources that are good candidates for reuse or recycling. This role became more prominent when international sanctions were added.

The IRWA DSRS management strategy steps include:

— Return to supplier;
— Transfer to another user;
— Storage for decay and conditioning;
— Storage and disposal.

In the past, the IRWA had only a room with some small holes and more than one disused source placed in one big shield (Fig. 5). There was some old DSRS that stabilized with cement in barrels, as well.

Considering the industry need and difficulties of finding suitable sources among others, the IRWA decided to make a new system to reuse them with fewer difficulties and characterization of all sources (Fig. 6).

Some main features and advantages of this new system are:

— Underground placement; use it as a shield;
— Double parallel pipe which allows retrievability of structure itself (non-routine happening);
— Maximum activity capacity: 9 TBq (240 Ci) of ^{60}Co or 35 TBq (960 Ci) of ^{137}Cs;
— Safe and reliable storage, safe and easy reuse, or recycling of the needed sources.

FIG. 5. Old method of storing DSRS.

FIG. 6. New method for storing and reusing DSRS in small boreholes.

4. SUMMARY AND CONCLUSION

Despite all limitations and sanctions against the Iranian nuclear industry, the IRWA has achieved many of its aims and plans for developing a safe and reliable system for managing all radioactive waste types and streams in Iran. By developing a national waste management strategy and following national and international requirements, it seems the IRWA is now on the right track for effective and sustainable improvement of the in-place waste management systems in the country.

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Paper ID#242

MELTING OF CONTAMINATED METALS FOR CLEARANCE AND RECYCLING, 30+ YEARS OF PRACTICAL EXPERIENCE

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Abstract

Treatment of contaminated metals by melting in Sweden started in 1987 as a joint initiative by the licensee at that time (Studsvik) and the regulators in Sweden. Since 2016, the metal treatment facility is owned and operated by Cyclife Sweden, a company within the EDF Group.

Over the years, the facility and its operations have grown, including extensions of the cutting and segregation areas, a larger furnace hall, installation of abrasive decontamination units, as well as advanced equipment for treatment of large components. The treatment methods have been extended and enhanced over the years, as well as the type of metals possible to treat aiming for clearance.

The installation of the advanced mechanical decontamination technology in 2000 increased the potential for clearance of contaminated metals after treatment significantly to the benefit of the licensees in the countries sending scrap metals and redundant large components to the Swedish facility for treatment. Their common objective has always been to reduce the amount of radioactive material for disposal as radioactive waste. On average, more than 95% of the metals sent for treatment have been subject to clearance.

One of the largest projects performed was the shipment of 15 Magnox boilers from the United Kingdom (UK) for treatment in Sweden. Other projects which have been discussed broadly are the PWR steam generator treatment campaigns.

The paper summarises the experiences from more than 30 years of operational experience, how the introduction of the waste hierarchy and focus on sustainability have affected the decisions within the nuclear industry etc. The paper will also discuss how to optimize the management of large components and scrap metals in power upgrade and decommissioning projects to make management of the contaminated materials even more sustainable and the projects more cost efficient.

1. INTRODUCTION

The waste treatment facilities at the Studsvik Technology Park outside Nykoping in Sweden has been in operation for several decades. The incineration facility was commissioned in 1977 and the facility for treatment of metals was commissioned in 1987, as a result of a joint initiative by the licensee at that time and the Swedish regulators. The overall aim of the treatment facilities was do reduce the volume of the waste to be disposed. Later on, environmental and sustainability aspects governed by the waste hierarchy has been added and are today very much in focus.

Initially the operations were conducted in small scale in an existing building. Over the years the facility and the operations has developed, the facility has been extended in several steps as described in the following chapters. The treatment methods have also been extended and enhanced over the years, both in terms of what can be welcomed for treatment and in terms of processing result. In the beginning only steel was welcomed for treatment, today most of the metals which exist in large quantities at a nuclear installation can be shipped for treatment.

Over the years more than 50,000 tonnes of metal have been treated aiming for clearance or volume reduction only. Most of the metals have been melted. For certain objects, or parts of objects, decontamination, and clearance of the material in its original shape has been applied. The melting for volume reduction a small fraction of the total amount of metals treated, mainly the tube bundles from steam generators and other tubular heat exchangers with a high radioactivity inventory. A few components, including a BWR steam dryer, which have been melted just to reduce the volume and to homogenise and bind the radioactivity in the metal structure.

On average, more than 95% of the metals sent for treatment have been subject to clearance.

2. THE SITE AND THE FACILITY

The Cyclife site at the Studsvik Technology Park contains treatment facilities, buffer storage areas for material to be treated and for residual waste to be return to customers, as well as storage areas for metal ingots awaiting shipment to the metal industry, is in the process of clearance or is stored for the decay of ^{60}Co. The site is accessible by road and by water. The latter is important when large components are shipped for processing as shown in Fig. 1.

FIG. 1. Steam generator unloaded from sea going vessel (left) and transported to the buffer storage (right).

The metal treatment facility, a small scale operation, has been at the site since its startup in 1987, and in 1994, the facility was extended with a segmentation hall. A major modernization and extension of the facility took place in 1999 when a new furnace hall was built, mechanical decontamination equipment was installed, and the old part of the facility was modernized. In 2007, the large component hall was commissioned to enable large components to be processed more efficiently.

Figure 2 shows the facility as it looks today; it can be divided into three main sections: (1) pre-treatment areas, (2) the furnace hall, and (3) auxiliary areas.

FIG. 2. Boilers awaiting treatment outside Cyclife metal treatment facility.

The largest areas are required for the pretreatment activities, i.e. disassembly and segmentation, sorting and segregation, as well as decontamination. Even though mechanical disassembly operations take place, most objects are segmented by the cold or thermal cutting techniques available in the facility. The thermal cutting techniques are performed in a dedicated hall with a high retention of the air to avoid smoke buildup at low levels. The facility is provided with a set of band saws of different sizes and other cold cutting equipment.

The furnace hall is the area where the actual melting takes place, and is equipped with two induction furnaces, 3.5 tonnes each. The furnace technology used has been properly selected to secure a full homogenization of the metal bath, as well as to transfer some of the key nuclides and other impurities to the slag.

The auxiliary areas contain, for example, different ventilation and filter arrangements, material storage areas, a workshop, a development hall, and dressing rooms and offices for the staff.

3. THE METAL TREATMENT PROCESS

The metal treatment process utilizes a well-structured multi-step approach with several lines of defence to ensure the material shipped for treatment can be safely processed, that the final treatment result will be forecasted with a high level of accuracy, and that the metals are safely cleared and recycled back to the conventional industry. To meet these objectives, the approach includes several lines of defence, as described in subsequent sections.

The typical metal treatment process can be divided into the following steps:

- Pre-shipment activities;
- Shipment and arrival of material for treatment;
- Pretreatment operations;
- Melting;
- Post-treatment activities;
- Reporting;
- Return of residual waste.

Figure 3 illustrates the main activities after the arrival of containerized material for treatment.

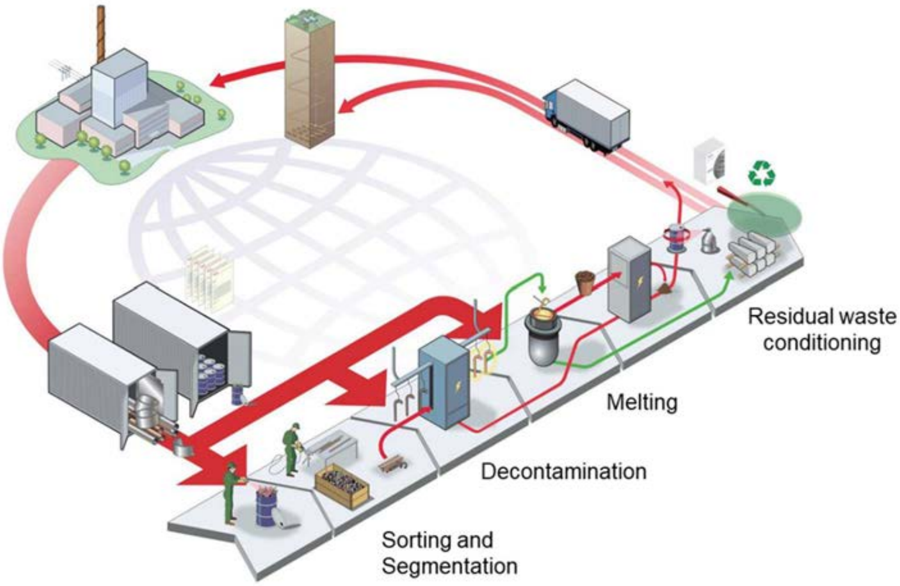
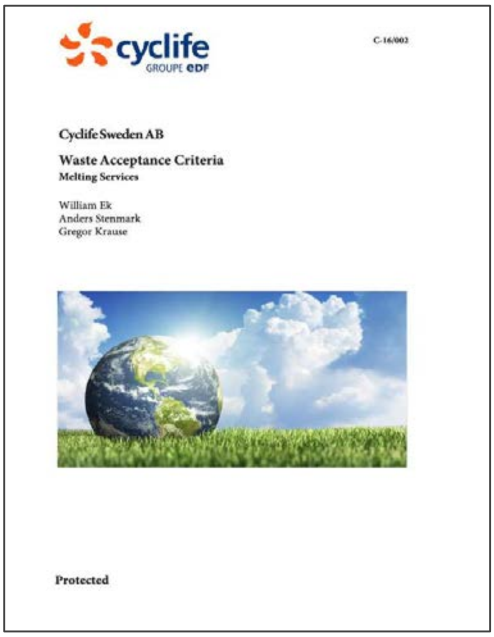


FIG. 3. Schematic view of the scrap metal treatment process at Cyclife site.

3.1. Pre-shipment activities

A typical project starts when a licensee who has redundant metallic material or components which have reached end of life contacts Cyclife. The potential customer is asked to provide radiological and physical data for the objects and to confirm that the material meets the waste acceptance criteria (WAC) for melting services, see Fig. 4. If so, a tender is submitted for evaluation and further discussions. This is the first layer of defence.


C-16/002

Cyclife Sweden AB

Waste Acceptance Criteria

Melting Services

William Ek
Anders Stenmark
Gregor Krause

Protected

FIG. 4. Cover page of Waste Acceptance Criteria for treatment at Cyclife. Courtesy of Cyclife.

Prior to shipment, Cyclife performs a treatability review of the detailed data provided by the customer for the potential shipment of material. Cyclife then prepares a written statement accepting the material for treatment. This is the second layer of defence.

Another important pre-shipment activity is to ensure all required licenses are applied for and achieved. The owner of the material to be shipped for treatment is required to sign the “waste return guarantee” to ensure all residual waste after treatment (i.e. all but the material subject to clearance for recycling) can be shipped back to the owner upon completion of the campaign. The waste return guarantee is to be countersigned by the competent authority in country of origin.

3.2. Shipment and arrival of material for treatment

The material for treatment is either shipped in ISO sea containers (or equal packages) or sent as large components. Depending on the radiological properties, the large components can either be shipped as they are or be wrapped in, for example, a tailormade tarpaulin.

The transport classification is in most cases SCO I to III (surface contaminated objects) as per transport regulations. Some material, due to a very low activity content, may not have to be classified.

At arrival and when applicable when opening the transport containers, health physicists will perform verification measurements, see Fig. 5, which provides the third layer of defence.

FIG. 5. Arrival inspection of a large heat exchanger.

3.3. Pretreatment operations

The set-up of the pretreatment operations varies depending on the physical and radiological properties of the objects. It may contain disassembly and segmentation operations, segregation, and sorting activities, as well as different types of decontamination operations aiming to reduce the radioactivity concentration and to remove paint and other surface coatings from the material. Cold cutting and thermal cutting operations are shown in Fig. 6.

FIG. 6. Cold and thermal cutting operations.

For certain key nuclides, which alloy with the metal, like ^{60}Co, the residual activity in the material has to be reduced below the clearance threshold values in the pretreatment operations. For this reason, the visual inspection and the verification measurements after the decontamination operations are essential (see Fig. 7) and provide another layer of defence.

FIG. 7. Verification of decontamination result.

Prior to releasing the material for melting, a safety inspection is required to verify the metallic objects do not contain any closed compartments. A closed compartment filled with water, or any other liquid, can cause very dangerous situations in melting operations.

3.4. Melting

Melting in the induction furnaces at the facility homogenizes the metal and ensures key nuclides transfer to the slag or to the off-gas filters while it densifies the material. Sampling is performed before slag removal and casting of the molten metal. As a result, the samples taken are proven representative of the entire melting batch. Figure 8 shows the sampling of the metal.

FIG. 8. Sampling of the melting batch.

3.5. Post-treatment activities

The three parts of post-treatment activities (1) management of the residual waste, (2) clearance of metal, and (3) reporting, are described in the following sections.

3.5.1. *Management of the residual waste*

On average, residual waste from treatment operations, approximately 5% of the initial weight, is collected and packed into drums or other suitable packages. The measured content of gamma emitting nuclides, dose rate, weight, and filling level in the package are recorded.

3.5.2. *Clearance of metal*

Thanks to the sampling during the melting process, each melting batch receives a set of fully representative samples. Those samples are, after the initial preparation, sent to the on-site laboratory for analysis of the gamma emitting nuclides, alpha emitting nuclides, and selected pure beta emitters, when required.

The results from the analyses are then, together with the specific nuclide vector, used to assess the total remaining radioactivity in the ingots. If the activity concentration is below threshold values, the ingots will become subject to unconditional or conditional clearance for recycling back to the conventional industry for manufacturing of new products. This is the penultimate layer of defence.

Before finalizing the clearance process, the ingots are surveyed with regards to surface contamination. The measurements are also indirectly confirmation measurements that the ingots do not contain elevated concentration of radioactivity and serve as the final layer of defence.

3.5.3. *Reporting*

The treatment campaign is recorded in a comprehensive treatment report, which describes the operations performed, radiological, and physical data for the ingots produced and the residual waste generated. The report is the foundation for the preparations of the repatriation of the residual waste and the closing of the treatment campaign.

3.6. Return of residual waste

Any material belonging to the shipment of material that is not subject to clearance, is to be returned to the customer for interim storage and final disposal. As mentioned earlier, the amount of residual waste is as a global average in the order of 5% (weight). For material sent as “ready for melt,” the amount of residual waste is estimated to be lower.

4. BENEFITS WITH TREATMENT FOR CLEARANCE BY MELTING

Melting of contaminated metals aiming for clearance brings several advantages and is considered as a proven and robust method to convert a liability to an asset. A few examples of the benefits are listed in this section.

4.1. More metal can be subject to clearance and recycling instead of being isolated

Thanks to the separation of certain critical radionuclides, lower uncertainties, and to certain extent higher clearance threshold values, more metal can become subject to clearance (compared to clearance of the material as is).

4.2. Separation of critical nuclides

In the steel melting process, certain key nuclides as the alpha emitters, ^{134}Cs, ^{137}Cs, and ^{90}Sr will separate from the metal and are captured either in the slag or in the off-gas filters. In many cases, this separation of certain nuclides in the melting step is, in many cases, the only way to make the material subject to clearance.

4.3. Representative sampling and high precision analysis

Thanks to the stirring in the induction furnace, it is well demonstrated that sampling from the molten metal is fully representative for the entire melting batch. In addition, the samples with a fixed geometry allow for high precision analysis for clearance. Together, this provides significantly lower uncertainties and, as a result, a larger "clearance window" compared to other clearance options.

4.4. Homogenization of the residual radioactivity in the metal matrix

The homogenization of the residual activity in the matrix keeps the ingot dose rates very low in further handling. Homogenization gives a ingot dose rate about seven times lower compared to all activity on the surface.

4.5. Minimization of radioactivity release during further handling and melting of the metal

In comparison with surface contaminated material that has been released, there is a significantly lower risk for spread of or concentration of radioactivity during the handling of material before it is melted again.

Since the radionuclides that separate in the metal melting process have already been separated from the metal when the material is melted in the Cyclife furnaces, there should be no concern for any increase in activity concentration in the slag or the off-gas when the material is melted for new product fabrication.

5. CASE STUDIES

Hundreds of metal treatment projects have been conducted in the metal treatment facility now owned and operated by Cyclife Sweden. Subsequent sections summarize a few key reference projects.

5.1. Magnox boilers and gas ducts

Originally, Studsvik (today Cyclife) was awarded a contract to transport 15 decommissioned Magnox boilers, each 310 tonnes, from the Berkeley Nuclear Licensed Site in the UK to Sweden for metal treatment and recycling, see Fig. 9. Treatment results for the Berkeley and Magnox Site Chapelcross boiulers are shown in Table 1 and 2.

FIG. 9. Transport of Boilers (left) and partly segmented boiler (right).

TABLE 1. TREATMENT RESULTS – BERKELEY BOILERS

Treated units	Initial weight each unit	Initial volume each unit	Waste for final storage each unit	Recycling each unit	Waste for final disposal each unit
15	310 t	600 m^3	8 m^3 (1.3 %)	296 t	19 t (6%)

In 2018, Cyclife was awarded a contract to transport 820 tonnes of gas duct assemblies from the Magnox Site Chapelcross to Sweden for metal treatment and recycling (see Fig. 10). The gas ducts connect the reactor with the boilers.

FIG. 10. Transport of Top Gas duct (left) and segmentation of gantry (right).

TABLE 2. TREATMENT RESULTS – CHAPELCROSS TOP DUCTS

Tonnage processed in Sweden	Waste for return	Ingots subject to recycling	Recycling rate in the melting process
765 t	61 t (8%)	98.4%	96.4 %

Remark: Materials not subject to melting (insulation etc.) are included in the waste for return numbers.

5.2. Ringhals NPP steam generators

A unique technical concept for treatment of PWR steam generators has been developed by Cyclife. Nine steam generators have been replaced at the Ringhals nuclear power plant (NPP) and have been shipped to Cyclife for treatment. Six of those were decayed at the NPP site prior to shipment, while the remaining three arrived shortly after the steam generator exchange project (Fig. 11). The projects resulted in significant volume reduction and weight reduction. More than 70% of the initial tonnage became subject to clearance and recycling. The residues were well conditioned in packages for interim storage and final disposal. Most of the waste for disposal was the volume reduced tube material.

FIG. 11. Arriving vessel with three steam generators (left) and SG outside the treatment hall (right).

5.3. NPP Forsmark 1-3 turbine island components

The three NPPs at Forsmark were modernized and upgraded some years back. One part of the programme was the upgrade of the turbine island on all three stations. A large fraction of what was shipped to Cyclife for treatment were large, contaminated components, including turbine parts, heat exchangers, etc. The 1 320 tonnes shipped for treatment resulted in a clearance ratio of 95%, i.e. only 5% of the initial mass had to be sent to the final repository for disposal. A Turbine casing and rotor arriving are treatment are shown in Fig. 12.

FIG. 12. Arrival of BWR turbine casing and turbine rotor for treatment.

5.4. Large components and containerised scrap metal from NPP Würgassen

Decommissioning efforts at the NPP Würgassen in Germany sent several thousand tonnes of contaminated metals to Cyclife for treatment. Although most material was shipped in ISO containers, large components like turbine casings were also shipped for treatment (Fig. 13) and heat exchangers. After treatment, which included segmentation, decontamination, and melting, almost all metal has been subjected to clearance, either directly or after limited decay storage.

FIG. 13. NPP Würgassen turbine casing during segmentation at Cyclife site.

6. DISCUSSION

The decision made more than 30 years ago to construct a metal treatment facility on the Studsvik industrial site in Sweden with the ambition to recycle rather than to dispose of the metal has to be considered exactly right. The metal processing services have been beneficial for many nuclear installation owners throughout Europe, especially when facilities are to be modernized or decommissioned. Records from more than three decades of operation show treatment of metals by abrasive decontamination and melting with aiming for clearance is a safe, efficient, and robust process. The possibility to forecast the results is high, not at least thanks to the experience built up.

Increased capabilities to forecast treatment results and costs improve cost benefit analyses and comparisons with alternative treatment processes and direct disposal. History shows the costs and risks related to the alternatives to clearance, in many cases, have been underestimated. In most countries, the qualification and disposal of radioactive waste is a complex and costly process. As such, in many countries, any material that can be decontaminated to reach clearance leads to cost and risk reductions.

A metal treatment campaign, aiming for clearance of the metal, can be done in many ways. An approach generating the lowest amount of residual waste for disposal is typically more costly than an approach generating slightly more waste for disposal. It is therefore important for the customer to analyse the marginal waste cost and confidently communicate it with the supply chain to enable Cyclife or other processing companies to provide the most beneficial treatment concept.

Finally, the positive message sent to the stakeholders when a liability (radioactive waste for disposal) is converted to an asset (metal for manufacturing of new products), thereby reducing the final disposal volume and aligning with the waste hierarchy should not be underestimated.

7. CONCLUSIONS

The nuclear industry's demand for environmentally sound and cost effective management of all kinds of contaminated scrap and components is becoming increasingly important. The NPP upgrade programmes and the strategy for immediate decommissioning applied by an increasing number of utilities are creating additional requests for effective off-site waste treatment facilities.

Through systematic development of treatment technologies, Cyclife has established a technological sector for treating contaminated metals aiming for clearance and recycling back to the conventional industry.

Clearance and recycling of nuclear installation metals and other back-end materials is an important part of demonstrating how the nuclear industry implements the waste hierarchy and a circular approach.

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TECHNOLOGICAL ADVANCEMENT IN EFFECTIVE MANAGEMENT OF LOW LEVEL RADIOACTIVE SOLID WASTES

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Abstract

In India, low level (LLW) solid radioactive wastes (RAW) contribute more than 90% of the total RAW generated from regular Operation and Maintenance (O&M) of typical nuclear fuel cycle facilities, which ranges from 200 to 600 m^3 depending on type and number of facilities at a site. In general, these wastes are segregated as combustible, compressible, and non-combustible–compressible based on the processing considerations. Predisposal processing is an essential task for optimal utilization of a Near Surface Disposal Facility (NSDF) to contain and isolate the radioactivity from the environment meeting regulatory guidelines. Combustible waste forms, in other words, cellulosic rubber and plastics, contribute about 50 to 60% of the total VLLW and LLW solid wastes. Predisposal steps employed for these combustible radioactive solid wastes are compaction, melt densification, and incineration based on type. Cellulosic waste is incinerated using oil–diesel fired incinerator. Rubber and plastic wastes are compacted using a hydraulic compactor and plastic wastes having thermoplastic behaviour is processed through a melt densification mode achieving a volume reduction factor (VRF) of 30-40, 3-4, and 3-10 respectively. Rubber and plastic wastes, mainly personal protective equipment (PPE), contribute about 70 to 80% of` the total combustible waste. Technological advances in high temperature based processing of these wastes have certain advantages to nullify formation of toxic compounds like dioxin and Furans. The plasma based process having ease of higher temperature availability, is seen as the promising solution for management for all type of combustible radioactive wastes. To achieve higher volume reduction for rubber and plastic wastes, an engineering scale Plasma pyrolysis based incineration demonstration setup of 25 kg/hr capacity has been commissioned at Bhabha Atomic Research Centre (lndia) utilizing in-house developed 30 kW direct current (DC) air plasma source. After lab studies and simulated waste trials, the set-up was commissioned with actual radioactive waste. More than 2000 kg waste has been successfully processed through the setup in various trials. The VRF achieved for all combustible type of waste forms ranges from 30 to 40. The paper highlights waste processing aspects, laboratory scale study for waste decomposition, and demonstration of plasma processing of solid RAW.

1. INTRODUCTION

Operation and Maintenance (O&M) of nuclear and radiological facilities generates accountable amount of solid radioactive wastes (RAW), which are above the exempt or clearance level, i.e., very low level radioactive waste (VLLW), low level radioactive waste (LLW) but less than intermediate level radioactive waste (ILW) and high level waste (HLW) [1,2]. Management and safe disposal of these radioactive wastes is a big challenge faced by nuclear industry all over the world [1,2]. Though the R-3 concept (reduce, reuse, and recycle methods) is well practiced to minimize the waste volume generation, a good amount of VLLW and LLW still require processing for volume reduction before their eventual disposal [3,4]. The waste amenable for direct disposal, as well as processed waste, after applicable conditioning processes is disposed in the engineered disposal modules of a Near Surface Disposal Facility (NSDF) to contain the radioactivity and isolation from the environment meeting regulatory guidelines [4]. The volume generated from a typical nuclear facility ranges from 200 to 600 m^3 depending on type and number of the facilities at a site [3-5]. In India, solid RAW of VLLW and LLW nature contributes more than 90% of the total solid RAW generated from regular O&M of typical closed nuclear fuel cycle facilities [5]. In general, these wastesare segregated as combustible, compressible, and non-combustible–

non-compressible based on the processing considerations. Various constituents of the combustible O&M radioactive waste are mostly comprising of cellulosic (i.e., paper, boiler suits, and lab coat), plastics (i.e., shoe covers, sample bottles, sheets) and rubbers (i.e., surgical and post-mortem hand gloves). Rubbers and plastics contribute about 50 to 60% of the total VLLW and LLW solid wastes, which amounts to about 70 to 80% of the total combustible waste [5]. Though direct disposal is a very simple and energy-less waste disposal option, direct disposal of waste requires unacceptably more land space. Appropriate volume reduction techniques are to be deployed to achieve maximum possible reduction of volume of waste amenable for disposal to NSDF [3-5]. The paper discusses conventional practices used for volume reduction, and technological advancement by installation of plasma based system for management of VLLW and LLW combustible waste forms (cellulose, rubbers, and plastics). The mass and volume reduction during pyrolysis process have been understood through laboratory scale muffle furnace study. The paper also summarizes results of plasma pyrolysis based incineration of solid combustible nuclear waste from nuclear facilities, along with disposal of residual ash with proper conditioning in cement matrix.

1.1. Conventional practices for volume reduction

Compaction, melt densification, and incineration are practiced for volume reduction based on type of waste forms, with achievable volume reduction ranging from 3 for compaction to more than 30 for incineration [4,5]. Compaction for rubber and plastic (non-thermo plastics) type waste results in volume reduction factor (VRF) of 3 to 5, whereas in melt densification for thermo plastic type waste (e.g. high density poly ethylene [HDPE]) results in VRF of about 3 to 10. Incineration of cellulosic material results in effective VRF of about 30 to 40 [5]. Typical compaction, melt densification, and conventional incineration systems are shown in Fig. 1. Incineration processes can effectively treat combustible waste materials in oxygen rich atmosphere with very small volume, reach in inorganics, results as residual ash [5]. Conventional incineration of cellulosic wastes is in practice. Such incineration is not preferred for rubber and plastic wastes due to associated lower operating temperatures of around 800 to 900°C, which may result in discharges of toxic gases like dioxin and furan [5-9]. Effective processing of such wastes requires an intense heat source at higher temperatures, like a plasma environment [6-10].

FIG. 1. Volume reduction techniques for combustible O&M wastes (VLLW and LLW).

1.2. Advance technology

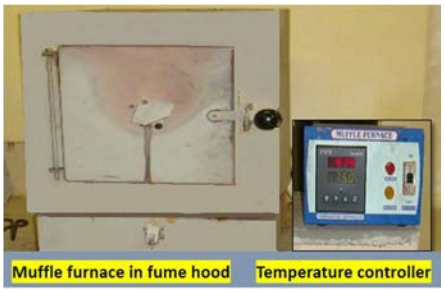
Thermal plasma based applications for managing hazardous industrial and medical wastes have been studied and reported [10-22]. The waste processing in oxygen deficient environment is called pyrolysis, the controlled oxygen environment process is called gasification, and an excess oxygen environment is called incineration [14-22]. A plasma pyrolysis based incineration system, with a higher than 1000°C environment in the waste processing zone, can overcome the limitations of the conventional incinerators with spontaneous decomposition of toxic compounds [6-9, 15-17]. At such higher temperatures in pyrolysis, the organic material is decomposed in oxygen deficient conditions, resulting into lower molecular gaseous compounds like CO, H_2, CH_4, etc. [15-17], which can be further combusted in the secondary combustion chamber with exothermic reactions in excess oxygen environment. Application of plasma incineration for radioactive waste management has also been studied [23-24]. Not much literature is available for plasma pyrolysis based incinerator for radioactive wastes. Pyrolysis also provides the advantage of very low flue gas exit velocity in a process chamber, due to lower mass flow rate and, hence, very low carry-over possibility of particulates and exit flue gases.

2. LABORATORY SCALE PYROLYSIS STUDY WITH RESISTIVE FURNACE

Prior to taking up plasma pyrolysis based system operation and to understand the results from pyrolysis process for all combustible waste forms, i.e. cellulosic, rubber, and plastics, initially a lab scale study was conducted in resistive heating muffle furnace. A typical muffle furnace setup used for the study is shown in Fig. 2 (a). Environment in the furnace was controlled to simulate pyrolysis condition with ~ 3 to 4% of stoichiometric equivalent oxygen available in the furnace. Various samples treated as simulated waste are enlisted in Table 1. All runs were performed with the same sample quantity and treated up to 800°C, the maximum available temperature of the set-up. The results of the study are given in Fig. 2(b), as weight reduction ratio and volume reduction ratio, derived as ratios of weight and volume reduction factors of each waste type to the observed value for mixed cellulosic wastes, respectively. It is observed that weight and volume reduction ratio for all waste types is lower than value for cellulosic waste incineration. It is also observed that mixed rubber wastes have the lowest values followed by HDPE type of wastes, mixed wastes, and PVC wastes in increasing order. This may be due to effect of strong polymeric bonds present in rubber and HDPE compounds. For better weight and volume reduction of such wastes, i.e. for nearly complete destruction of polymeric waste forms, higher temperatures with an intense heat source, like plasma, can be beneficial.

TABLE 1. COMPOSITION OF DIFFERENT PYROLYSIS BATCHES

Batch	Contribution of sample in percentage
1	Mixed Cellulosic
2	Mixed rubber hand gloves
3	Poly Vinyl Chloride (PVC) shoe cover
4	High Density Poly Ethylene (HDPE)
5	Equal portion of feed from batches 1-4



(a) A Typical laboratory setup

Batch	Weight reduction ratio relative to pure cellulosic waste	Volume reduction ratio relative to pure cellulosic waste
1	1	1
2	0.51	0.7
3	0.92	0.99
4	0.75	0.94
5	0.78	0.95

Note: The maximum temperature achieved in study was 800 °C

(b) Observations from the study

FIG.2. Laboratory scale decomposition study for weight and volume reduction in pyrolysis condition.

3. PLASMA PYROLYSIS BASED INCINERATION SYSTEM

Based on observations from laboratory studies, a plasma pyrolysis and incineration set-up of 25 kg/hr capacity (Fig. 3), has been developed and installed at Bhabha Atomic Research Centre, India [25]. The chamber is designed to process waste using the intense heat from indigenously developed 30 kW DC non-transferred type air plasma torch (Fig. 3), which is operated using 50 kW insulated-gate bipolar transistor (IGBT) based power supply unit. Plasma is ignited using high frequency spark using argon as the initial plasma gas. Later, air is supplied to sustain plasma plume and the argon supply is cut off. Air supply, including leakages into the system, contributes ~ 5% of the stoichiometric requirement nearing the pyrolysis condition in the plasma chamber. Overall temperature in the pyrolysis chamber has reached >1000°C, whereas plasma plume (Fig. 3) provided in the chamber could have a plume temperature >1500°C. The core of plasma can achieve temperature equal or greater than 10 000°C.

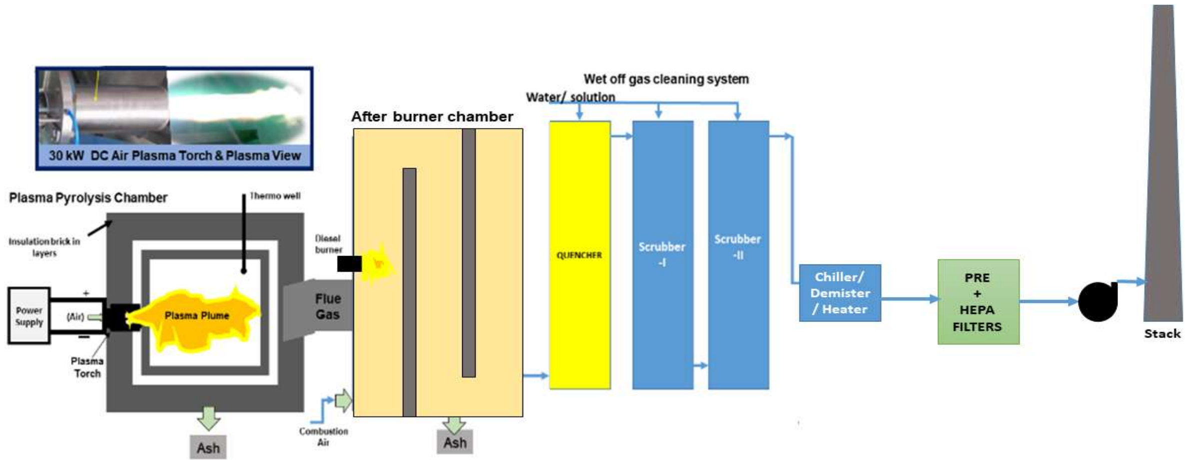


FIG. 3. Plasma pyrolysis based incineration system and 30 kW DC non transferred air plasma torch.

The gaseous products from plasma pyrolysis are allowed to react with excess air supply to give exothermic combustion reaction in after combustion chamber, which is followed by elaborate wet off gas treatment system, including quencher and scrubbers for preventing recombination possibilities of dioxin and furan, as well as removal of other polluting gases [25]. In the secondary chamber, the preliminary heat source is a diesel fired burner. Temperature in the secondary chamber is maintained at > 1000°C with the flue gas residence time > 3 sec. Flue gas exit mass flow rate from plasma pyrolysis chamber will be less than 20% of the value for a similar capacity stoichiometric air supplied incinerator chamber. The lower exit velocity helps in reducing carry-over from the processing chamber.

The system was tested and commissioned in phases. Initially, the set-up was tested with various combinations of simulated wastes in different trials. After successful trials, actual radioactive waste was processed through the set-up at the rated capacity of 25 kg/hr. Waste was packed in standardized cardboard boxes for uniform feeding condition. Various combinations of waste feeds were processed (Table 2). More than 2000 kg of actual radioactive waste, having contact dose less than 0.2 mGy/h, has been processed successfully. Observed temperatures inside the chamber cavity during continuous waste processing was 1200 to 1350°C, which is higher than observed values for conventional incinerators and adequate for spontaneous decomposition of toxic gases, like dioxin and furans [6-9]. The effective VRF achieved for all type of wastes was more than 30 and weight reduction factor (WRF) observed was between 18 and 25, where cellulosic waste gave more VRF and WRF than the rubber and plastic wastes. Relative values of volume and weight reduction for each waste type with respect to cellulosic waste is also summarized in Table 2.

Observations from engineering scale plasma system has shown improved values than observations during the laboratory scale resistive furnace study, indicating effectiveness of the plasma system. The environmental discharges during the plasma setup runs, after elaborate flue gas management system, were monitored at regular intervals, and observed to be meeting the national regulator guidelines. Discharge activities were also monitored continuously and observed to be Below Detection Limit for all runs.

TABLE 2. DETAILS OF WASTE PROCESSED AND OBSERVATIONS FROM PLASMA PYROLYSIS-BASED INCINERATOR

Feed waste type	Waste composition	Ratio of Reduction factors with respect to mixed cellulosic wastes	
		Weight reduction ratio	Volume reduction ratio
Mixed Cellulosic	Cotton PPE3 [Higher %] + mops with wooden plug+ papers+ Cardboard box	1 (as reference)	1 (as reference)
Mixed Rubber and plastics	Post-mortem hand gloves+ PVC* + surgical hand gloves (equal weight) + cardboard box	0.78	0.82
Mixed Cellulosic, rubber, and plastics	Cotton ppes+ paper + mops+ cardboard box (~ 70%) + post-mortem hand gloves + PVC + surgical hand gloves (~ 30%)	0.89	0.96

*PVC: Poly Vinyl Chloride

4. MANAGEMENT OF RESIDUES FROM THE INCINERATORS

Residual ash having very small volume from each run was collected in standard 200 L drums. After adequate quantity of ash collected per drum, the ash was immobilized in the cement matrix before eventual disposal to the NSDF. Product properties was evaluated for integrity and stability aspects. Leach rates on the order of 10^{-4} g/cm^2/day were observed, which is quite acceptable for cemented waste products. The product's mechanical strength was ensured to be greater than 35 kg/cm^2, the limit set for indirect measure of product integrity under disposal conditions. The immobilized ash drums were disposed in engineered disposal modules of NSDF having multi-tier defence in depth concept. The disposal sites have elaborated surveillance schedule in place for environmental survey, as well as water and soil sample analysis, in line with international practices. Observed surveillance results are well within the acceptable limits set by regulatory authorities indicating adequate confinement of the disposed wastes.

5. CONCLUSIONS

The advanced technological study shows plasma has a very potential application as a uniform process for all potentially contaminated radioactive combustible waste forms. The plasma pyrolysis based incineration technology, indigenously developed at Bhabha Atomic Research Centre, India, has been found more suitable for radioactive waste processing at rated processing rate. End products from the process, i.e. flue gases and ash, are managed effectively while meeting environmental disposal criteria. The NSDF surveillance results show quite good integrity of disposal packages and engineered disposal modules. Based on the feedback and encouraging results from this plasma based set-up operational runs, enhanced capacity plant (50 kg/h) is being set-up for managing combustible VLLW and LLW wastes at the country's nuclear and radiological facilities.

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CURRENT STATUS OF SOLID WASTE MANAGEMENT AT FUKUSHIMA DAIICHI NUCLEAR POWER STATION

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Abstract

The Fukushima Daiichi Nuclear Power Plant (NPP) plans to reduce the volume of waste as much as possible from its many outdoor storage areas utilizing a solid waste management plan developed by Tokyo Electric Power Company Holdings (TEPCO) and reported in “Eliminating the temporary outdoor storage area within FY 2028” by the Inter-Ministerial Council of Japan. The plan includes waste reduction and storage in a solid waste storage warehouse by constructing two miscellaneous solid waste incineration facilities, volume reduction equipment for metals and concrete, and additional solid waste storage warehouses.

1. INTRODUCTION

Ten years after the Fukushima accident, Tokyo Electric Power Company Holdings (TEPCO) is utilizing its domestic and international expertise to steadily and safely decommission the Fukushima Daiichi Nuclear Power Plant (NPP) to fulfil its responsibility for the March 11, 2011 accident.

Over the last decade, significant progress has been made in decommissioning work on the Fukushima Daiichi NPP, including reducing the amount of contaminated water generated due to the intrusion of groundwater into the reactor building. All fuel assemblies from Unit 4 were completely removed in December 2014 [1] and at Unit 3 in February 2021 [2]. Surveys inside the containment vessels using robots and other means have also progressed. In 2018, deposits containing possible fuel debris were found at the bottom of the pedestal inside the Unit 2 primary containment vessel (PCV) [1]. In February 2019, a contact investigation on the detected deposits inside the Unit 2 PCV was successfully conducted [1].

Because almost all the premises at the Fukushima Daiichi NPP are still designated as a controlled area, most of the waste generated from the decommissioning work has to be treated as radioactive waste. Because it is currently impossible remove waste from the premises, the volume of stored solid waste at the Fukushima Daiichi NPP has gradually increased. The paper provides the history, current status, and future plan for solid waste management at the Fukushima Daiichi NPP.

2. WASTE MANAGEMENT CHALLENGE AFTER THE ACCIDENT

Immediately after the accident, the tsunami and hydrogen explosions generated numerous fragments (or “rubble”) around Units 1 to 4, which prevented workers from approaching the area to perform emergency measures and build necessary facilities. The first measure taken was to remove the high dose rubble using remote controlled heavy equipment. Another important step was to clear the forest and prepare the ground on the site to facilitate installation of various facilities needed for decommissioning. As a result, this effort generated a vast amount of contaminated soil and felled trees.

Before the accident, eight solid waste storage warehouses with a capacity of about 57 000 m^3 had been constructed and operated [3]. However, after the accident, there was not enough room to accommodate the waste in the existing storage buildings, because they already contained about 37 000 m^3 of operating waste [3]. As it was necessary to secure waste storage areas urgently, temporary solid waste storage areas had to be set up outdoors.

The rubble is classified as rubble, trimmed trees, and used protective clothing. Because there is minimal information concerning the presence of radionuclides, especially long half-life nuclides, rubble is further categorized by material type and surface dose rate level.

Figure 1 shows the storage management method for the rubble and other waste [4]. Rubble is stored in sectioned areas with storage systems for each dosage category to block and prevent dispersion. For example, rubble with a surface dose rate of 0.1 mSv/h to 1 mSv/h should be covered with protection sheet and that with a surface dose rate of 1 mSv/h to 30 mSv/h should be stored in a container or 'covered-type' temporary storage facility. Figure 2 shows photos of several examples of outdoor storage areas [5]. Figure 3 shows a 'covered-type' temporary storage facility [6].

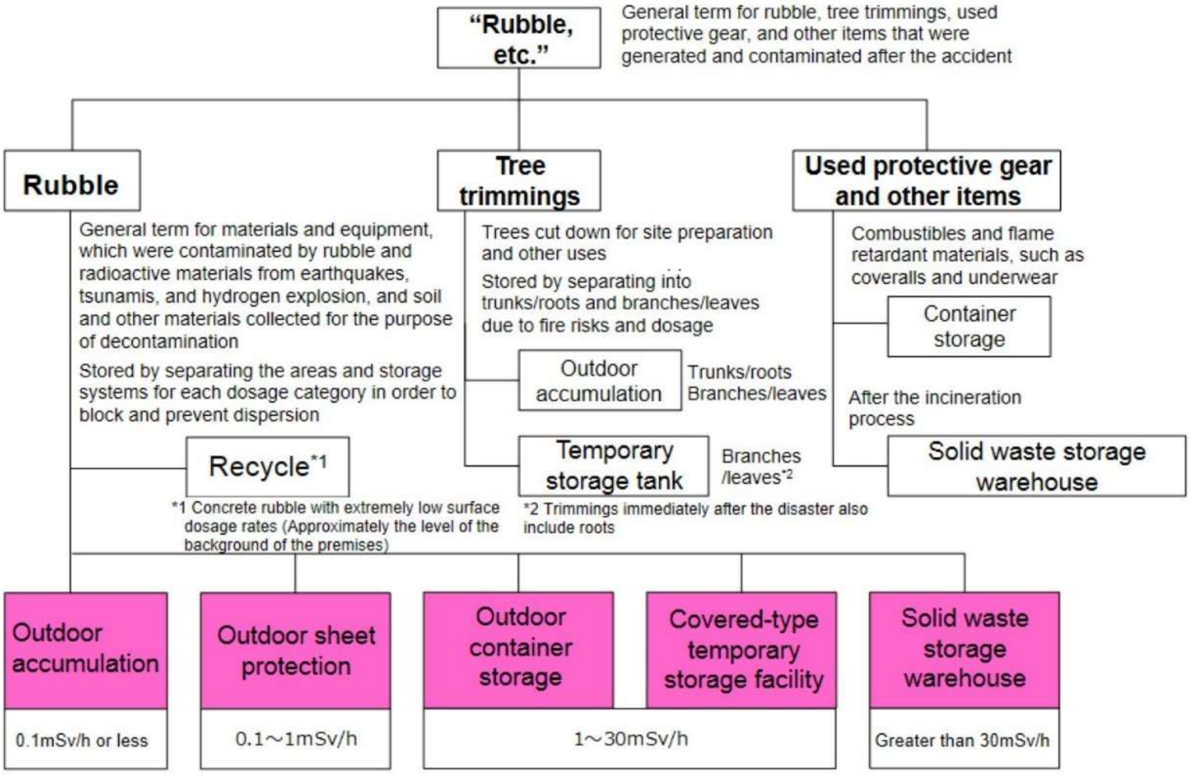

FIG. 1. Diagram showing storage management method for rubble, etc.

FIG. 2. Storage area status.

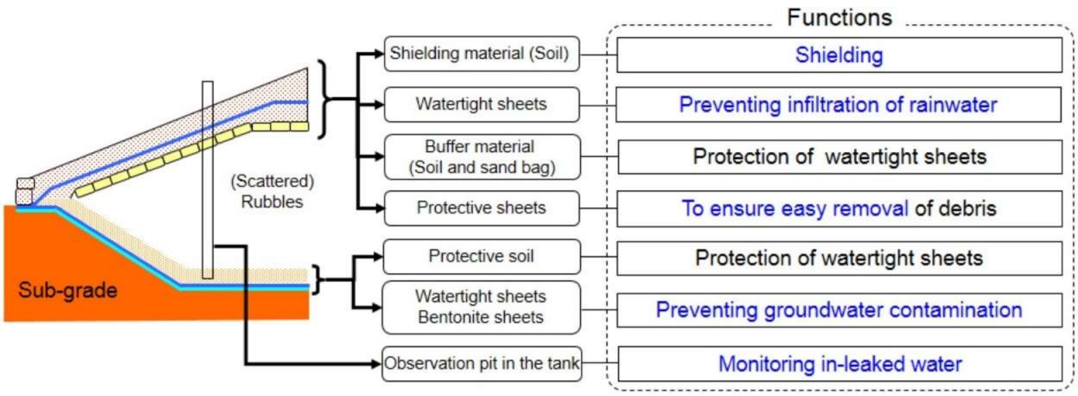

FIG. 3. Sectional view of the structure of 'covered-type' temporary storage facility.

As the decommissioning work has progressed, the amount of waste accumulated has also increased. While the total storage volume of rubble at the end of FY2013 was 95 000 m^3 [7], the total volume of that at the end of 2020 had increased to 311 000 m^3 [5]. Figure 4 shows the status of the waste storage area on the premises.

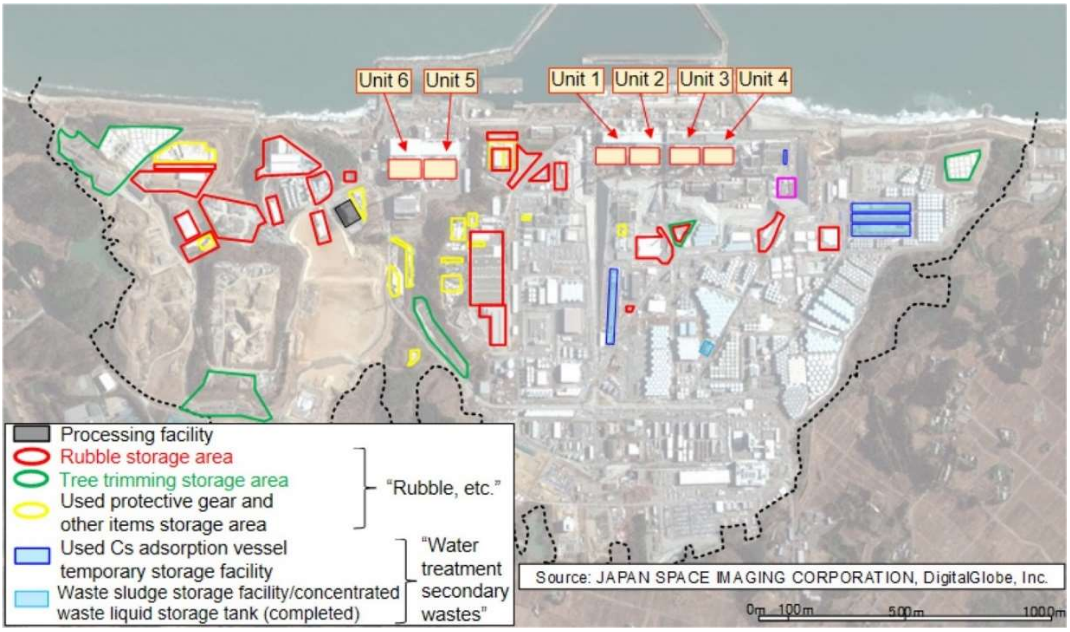

FIG. 4. Diagram showing the status of waste storage area on the premises.

The Fukushima Daiichi NPP has continuously improved its waste management process, including building and operating a miscellaneous solid waste incineration facility for burnable waste in March 2016 [4].

The Fukushima Daiichi NPP Solid Waste Management Plan was also developed in 2016 [4] and is revised annually, with the most recent revision in July 2020 [4]. Its main objective to reduce waste volume as much as possible and then move it into storage warehouses. Based on a waste volume generation forecast for the next 10 years a construction plan for volume reduction facilities and solid waste storage warehouses was formulated. According to the plan, waste storage warehouse No. 9, which can store the solid waste about 33 600 m^3 was built and began operation in February 2018 [4].

3. FUTURE PLANS

Published by the Inter-Ministerial Council, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1 to 4" presents the milestone (main target process) for solid waste management on site [8]. The milestone is as follows:

By FY 2028, TEPCO will eliminate the outdoor temporary storage area for all solid waste (fallen trees, rubble and others, soil, used protective clothing) except for secondary waste from water treatment and waste to be used for reuse or recycling to reduce the workers' risk, such as radiation dose risk from all of the decommissioning works and various generated solid waste types.

The latest Waste Management Plan from 2020 presents the plan for achieving this targeted process.

The plan projects approximately 784 000 m^3 of waste will be generated by end of FY2032 [4], as shown in Fig. 5. Out of this, approximately 203 000 m^3 is estimated to be metals and concrete with a surface dose rate of 5 µSv/h or less [4], which can be reused or recycled. Except for the metals and concrete, approximately 581 000 m^3 of rubble, etc. should be stored as solid waste [4].

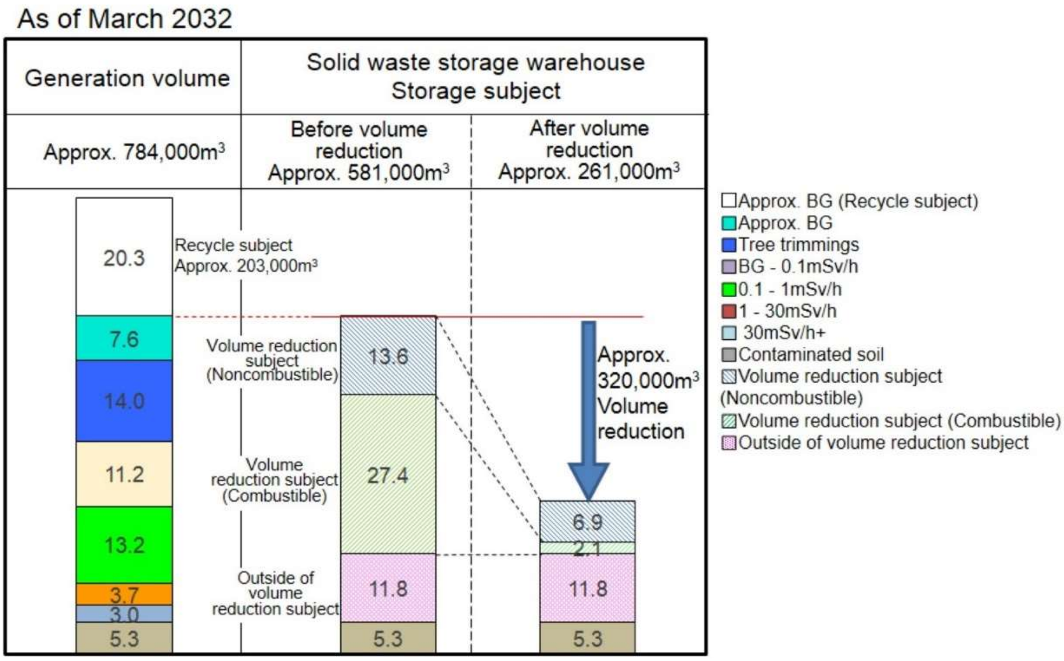

FIG. 5. Diagram showing the result of waste generation forecast at the end of FY2032.

According to the plan, an additional incinerator called "Additional miscellaneous solid waste incineration facility" is under construction and was scheduled to start operation in FY2021 [9]. There is also a plan to install "Volume reduction equipment" for metals and concrete with surface dose rate of 1 mSv/h or less. This facility is under foundation work and scheduled to start operation in FY2022 [4]. These facilities will enable significant volume reduction of combustible materials, metals, and concrete. Consequently, it is estimated that approximately 261 000 m^3 should be stored in solid waste storage buildings at the end of FY2031 (Fig. 5) [4]. Additionally, two more solid waste storage warehouses, No.10 and 11, are being designed and are scheduled to open in FY2022 or later [4]. Figure 6 shows the schematic layout of planned solid waste management-related facilities [10].

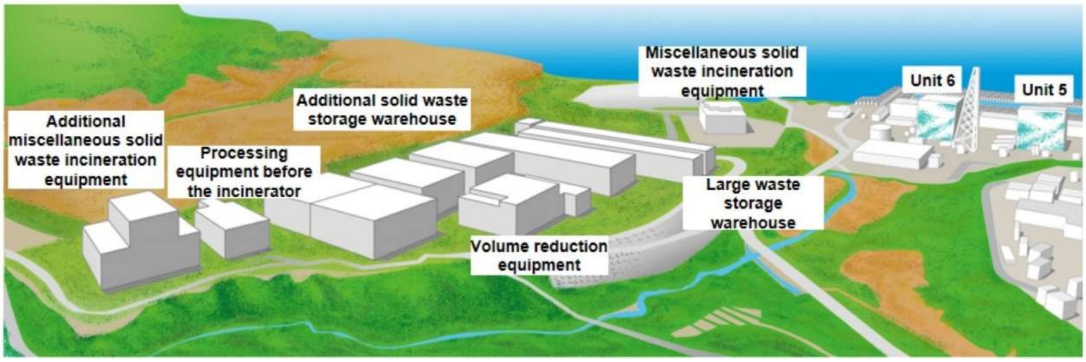

FIG. 6. Schematic layout of planned solid waste management-related facilities.

Figure 7 indicates a 10-year overview of the solid waste management plan [4]. Figure 8 shows the expected solid waste storage conditions on the premises. By implementing this plan, the targeted process described by the Mid-and-Long-Term Roadmap of "eliminating the temporary outdoor storage area within FY 2028" is achievable [4].

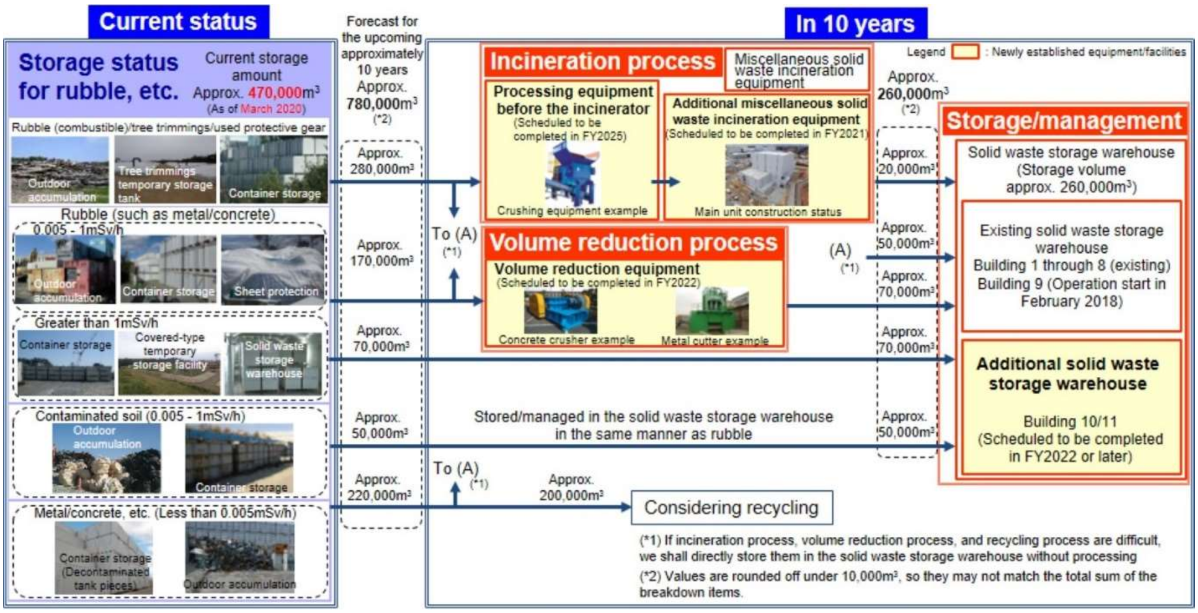

FIG. 7. Overview of Solid Waste Management Plan for Fukushima Daiichi NPP.

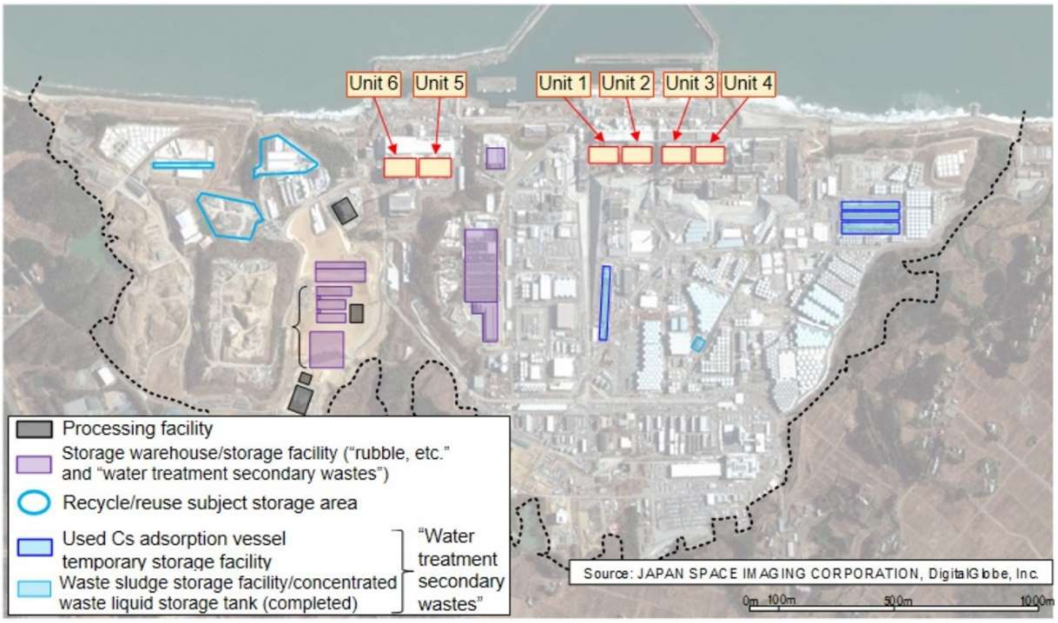

FIG. 8. Map of future solid waste storage conditions on the premises.

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APPLICATION OF GEOPOLYMERS IN MANAGEMENT OF PROBLEMATIC RADIOACTIVE WASTE

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Abstract

In the context of decommissioning of many various nuclear power plants (NPPs) worldwide and a remediation of old legacy sites, it is necessary to process various problematic waste streams, which have been stored for many years, and have properties that are not processible by classic technologies. These include solid and liquid wastes, in varying quantities, sometimes located in a variety of difficult-to-access locations across large sites. The longer these radioactive wastes (RAW) are stored, the harder they can be technically and economically processed. The general trend in the world is therefore gradual replacement of conventional radioactive waste processing technologies by new, more efficient, and more versatile ones. There is a portfolio of methods to safely treat these materials in readiness for long term storage or disposal. The choice of an appropriate method depends on various aspects and influencing factors such as the categorization of the waste to be treated in terms of radioactivity, its chemical and physical properties and homogeneity. The decision making also includes security aspects, economic issues, availability, and sustainability of raw materials. Moreover, the final product processed by this technology has to comply with the waste acceptance criteria (WAC) for disposal or storage and the whole process has to be approved by the competent supervisory authorities. Encapsulation of the waste using geopolymer matrices (e.g. Jacobs' SIAL®) is an example of a new generation waste solidification technology, that offers a safe and cost effective alternative conditioning technique. The process is based on polycondensation reaction of aluminosilicate materials (solid phase) in a basic medium (liquid phase) at room temperature and pressure, producing a crosslinked, inorganic geopolymer which has good physical strength, hardening characteristics, leachability performance, radiation stability, biodegradability, flammability, explosivity and stability in frost. The SIAL geopolymer solidification technology now has a track record of over 20 years which includes on-going research and development. The presentation summarises the most interesting performance records of this technology, the applied mobile devices as well as the characteristics of final products.

1. INTRODUCTION

Recent years, as more and more NPPs are coming to the decommissioning phase, the effective technologies of their systems' and components' characterisation, dismantling, fragmentation, decontamination, measurements, and monitoring are becoming more important.

Treatment, conditioning and disposal of the radioactive waste from decommissioning and especially management of the heavily treated (problematic) waste such as sludge, spent resins, crystalline sediments, organic solutions etc. that have been accumulated in the on-site storage tanks is also important.

In both cases conventional technologies are gradually being replaced by new, more efficient, and more versatile ones.

There is a portfolio of new encapsulation methods to treat these materials using matrices such as various types of cement, various organic polymers and using geopolymers. In this paper, attention is paid to the use of geopolymers in the treatment of radioactive waste.

Geopolymers are inorganic artificial polymeric materials - an alkaline aluminosilicate, in which, depending on the nature of the starting materials and the reaction conditions, the structures are either amorphous (gel) or crystalline. French scientist Joseph Davidovits introduced the term “geopolymerisation” in 1978 to name a newly discovered synthesis that produces inorganic polymeric materials [1]. During more than 40 years since Professor Davidovits' first geopolymer introduction, much laboratory research has been carried out in the world with different chemical systems and various radioactive wastes. The result of this development is that geopolymer matrices seem to be the most promising substitute for cements.

Developed and tested over the last 20 years, Jacobs' SIAL is an example of a new generation waste solidification technology, that offers a safe and cost effective alternative conditioning technique and that was developed to solidify various radioactive waste streams. The technology has been licensed for use by both the Slovakian (UJD SR) and Czech (SUJB) nuclear regulators since 2003 and 2006. In 2016, the CEZ company (Czech Republic) successfully extended its existing license also for the solidification of liquid and solid borates into the SIAL matrix. Up to date, SIAL has been used successfully to immobilize approximately 3000 tons of radioactive waste which includes sludge, resins, crystalline borates, and contaminated organic waste from Jaslovske Bohunice and Mochovce (Slovakia) nuclear power plants (NPP) and approximately 300 m^3 of spent ion exchange resins and sludge from tanks on site at the Dukovany NPP in Czech Republic. The international missions by the World Association of Nuclear Operators (WANO) and the Operational Safety Review Team (OSART) evaluated the SIAL matrix technology at Dukovany NPP as an example of good practice (2010).

This paper provides an insight into the practicality of deploying the SIAL process based upon a technical review of the available information and experience gained in Central Europe.

2. SIAL SOLIDIFICATION TECHNOLOGY PROCEDURE

Various goals were considered in developing and testing of the SIAL matrix, solidification technology and equipment. Firstly, the aim was to convert the quasi-liquid and dangerous waste streams (sludge, spent sorbents, organic materials etc.) into a form safe for transportation, temporary storage or to dispose in a radioactive waste repository. The second aim was to perform the solidification local to the point of retrieval, quickly and with consideration of properties and parameters of the waste streams.

2.1. SIAL technology principle and mechanism

The chemical principles of the SIAL technology have been described in detail in many previous articles and presentations, e.g. [2-4]. This technology is based on polycondensation reaction of inorganic aluminosilicate components in a basic environment at normal temperature and pressure. During the immobilisation process, some radionuclides are physically or chemically bound to a certain part of the SIAL matrix components, the others are mixed into the SIAL volume and encapsulated in 3D structures during the polycondensation process. The three-dimensional network of the SIAL matrix allows comparable compressive strength to cement and moreover improves leachability to standard cement matrix not only for all radionuclides but also for macro components of waste. The resulting stable geopolymer also has good hardening characteristics, good radiation stability, biodegradability, flammability, explosivity, low volatility, posing a low fire risk and excellent physical stability in the presence of frost and water (no distortion or cracking).

The SIAL technology is deployed at room temperature. The polycondensation process during curing is a slightly exothermic reaction with the maximal temperature reached in the middle of the drum being approximately 55°C [2].

2.2. SIAL technology application

As well as the principles of the technology, the procedure of its application, including the equipment used, was described in detail in [3].

There are two 'Baseline' approaches to the application of the SIAL technology – the out drum (pouring) application, and in drum encapsulation of waste.

Generally, in both modes of application, the SIAL solidification process is always adjusted and slightly modified for individual radioactive waste streams with different compositions. To determine the most appropriate composition, the SIAL application technology is laboratory tested on imitating and/or real samples of each individual waste stream. Then an appropriate mixture of aluminosilicate composition and other inorganic compounds is as a given solidification application.

Also, in both methods all application devices are tailor-made; therefore, they also meet the specific requirements of clients. Always with new applications, devices are improved, in terms of safety and efficiency.

2.2.1. Pouring (out drum) application of SIAL technology

LLW and ILW can be stabilized by entombment within a matrix so that the combination of waste form and container providing a suitably robust, multi-barrier waste package that satisfies the requirements for interim storage, transport, and disposal. The most common encapsulation matrix for radioactive materials is a cementitious grout selected due to the cementation process being relatively simple, low cost and low temperature and because cementitious systems have proven durability in high radiation environments, resistance to degradation and provide a beneficial chemistry (high pH) for the disposal environment.

Grouting/encapsulation by geopolymer (e.g. SIAL) can be considered as an alternative technology for encapsulation of heterogeneous solid radioactive materials. The greater fluidity of geopolymers when compared to cementitious grout is a distinct advantage to the process as it can penetrate more easily and readily and does not require the development of superplasticiser which have been suggested over recent years.

Recent research on the advanced SIAL matrix is showing its increasing potential even when applied underwater with a high salt content or under higher temperature water (~ 90°C). SIAL can be also applied to solid surfaces at temperatures close to 300°C. The formed solid layer immobilizes the present radionuclides, which in specific cases, allows the radioactive waste to be processed in a safer manner.

Application of SIAL technology can be used in case of need to improve certain consequences raising from accidents on nuclear facilities.

2.2.2. In drum application of SIAL technology

The solidification of waste in drum or in other approved packages is a classic way of radioactive waste processing [3].

Depending on the amount of waste and site characteristics (e.g. multiple reactors and/or sparsely spaced tanks), waste can be either processed using the mobile equipment (e.g. FIZA S 200) in situ, or a dedicated centralised facility can be installed to service the multiple locations.

The current equipment used to deploy SIAL is modular, flexible, and versatile, and it can encapsulate waste quicker than cementation.

3. CHARACTERIZATION OF THE SIAL FINAL PRODUCT

3.1. Strength and stability

The strength of the SIAL final product in operation is measured by using non-destructive methods. Values of the typical compressive strength for solidified radioactive sludge and resin were ranged in the interval from 15 to 40 MPa.

The standard destructive measurement of compressive strength for solid concrete products proceed according to STN EN 12390-3:2003 guidance “Testing the hardened concrete,” Part 3: The compressive strengths of the test specimens. Years of our experience for solidification of various waste streams into the SIAL matrix shown a very good agreement between the results obtained by destructive compressive strength determination of cube-shaped with unified dimensions of 15 × 15 × 15 cm and operational non-destructive determination of compressive strength measured on the surfaces in 60 litre (L) and 200 L drums in operation using Concrete test Hammer - Digi Schmidt.

Most measured samples reach the same or higher value of compression strength in time. Table 1 shows one of drum's compressive strength measurement's stability in operation.

TABLE 1. LONG-TERM STRENGTH STABILITY OF SIAL WITH FIXED SLUDGE IN 200 LITER DRUMS

Drum No.	Time [days]	28	370	490
14	Compression strength [MPa]	24.0	26.4	27.1
21	Compression strength [MPa]	24.0	27.1	27.8

3.2. Leaching resistance

One of the best features demonstrating strong radionuclide binding in the SIAL matrix is the determination of leachability properties. The leaching test for main radionuclide content is an integral part of radioactive waste treatment process.

The leaching characteristics for individual radionuclides are shown in Table 2 [5].

These below stated leaching characteristics fully confirmed an effective way to capture of radionuclides content safely in the SIAL matrix.

TABLE 2. THE COMPARISON OF LEACHABILITY AND DIFFUSIVITY COEFFICIENT FOR INDIVIDUAL RADIONUCLIDES IN SAMPLES OF SOLIDIFIED REAL MIXTURE OF SLUDGE AND RESINS TO MATRIX SIAL

Radionuclides	Diffusion coefficient [cm^2/s]	Leachability Index Li (7)	Waste type
^{14}C	5×10^{-10} to 10^{-9}	9 to 9,3	sludge
	1.5×10^{-10} to 1.5×10^{-9}	8.8 to 9.8)	resins
^{59}Ni	(1.5 to 3) $\times 10^{-11}$	10.5 to 10.8	resins (Ni)
^{63}Ni	(2 to 3) $\times 10^{-11}$	10.5 to 10.7	sludge (Ni)
	10^{-12} to 3×10^{-11}	10.5 to 12.1	sludge (Co)
	3×10^{-13} to 10^{-12}	12.1 to 12.5	resins (Co)
		9.9 to 12.8	resins 50 to 90%
^{90}Sr	10^{-15} to 1.5×10^{-13}	12.8 to 15	sludge A1
	10^{-12}	12	resins
	3×10^{-13}	12.5	sludge
^{94}Nb		sludge + resins undetectable for low activity	
^{137}Cs	2×10^{-11} to 3×10^{-9}	8.5 to 10.7	sludge A1
	(3 to 4) $\times 10^{-10}$	9.4 to 9.6	sludge + resins
		8.94 to 9.8	resins 50-90 %
^{239}Pu	3×10^{-19} to 6×10^{-13}	12.2 to 18.5	sludge A1
^{241}Am	6×10^{-17} to 4×10^{-13}	12.4 to 16.2	sludge A1 other-low activity

3.3. Heat resistance

From 2016 to 2017, the study for the pouring application of blank (no waste loading) SIAL matrix in conditions of increased temperature has been completed. The possibility of using the SIAL matrix at elevated temperature was tested for its application under hot water (below the water boiling point ~ 90°C), as well as on direct pouring application on hot metallic surfaces (300°C). The course of blank SIAL pouring application under hot water by using peristaltic pump is shown in Figures 1 and 2.

FIG. 1. Pouring application of SIAL under hot water by using water bath set at 90°C.

FIG. 2. View of SIAL final product and its compressive strength test (under hot water application).

3.4. Radiation resistance

The influence of ionising irradiation has been investigated (using a total dose of 10^6 Gy, which approximates the time of irradiation in a typical repository of 300 years). Products (sludge and resin in SIAL matrix) were irradiated by a ^{60}Co source (dose rate ~ 2.5 kGy/hour) for a total dose of 1.027 MGy. No reduction of compression strength was found [2].

3.5. Hydrogen generation

The radiolytic hydrogen generation from SIAL matrix studies were carried out to examine the rate of radiolytic produced hydrogen. The results were obtained in cooperation between Jacobs Slovakia laboratories and Jacobs' laboratories in Harwell (UK).

Crushed blank SIAL samples and crushed SIAL samples with solidified waste streams (sludge and slurry) were irradiated in the Jacobs ^{60}Co irradiation facility at separate dose rates of 1 and 3 kGy hr^{-1} at room temperature to total doses of 40 and 1000 kGy. The G_{H2} values measured for the SIAL/waste simulant samples after irradiation to 40 kGy ranged from 0.01 to 0.14 molecules per 100 eV [5,6].

The G_{H2} data for SIAL are consistent with data from grouts that have the lowest radiolytic hydrogen release rates. Therefore, in terms of hydrogen release, it is suggested that SIAL should be ranked alongside the more stable types of cementitious grout encapsulants.

3.6. Chemical stability

A possible impact of selected chemical agents on SIAL solidification technology has been reviewed. The effects of high concentrations of sodium, sulphate, liquid, and solid borate forms have been investigated and was confirmed that these wastes can be effectively and safely encapsulated into the SIAL matrix.

The SIAL matrix itself can effectively retain not only radionuclides presented in treated radioactive waste, but also most macro components forming a chemical character of the waste as were above mentioned borates, cyanides or sulphates at quite high concentrations. At the same time has been confirmed very low level of these waste macro components presented in leachate solution (e.g., leachability level concentration of 100 ppm for sulphate or 0.120 ppm for cyanide) confirming very high efficiency of SIAL solidification technology.

3.7. Homogeneity of final product

In the case of dry samples, homogeneity is defined as uniform distribution of fine, visible particles (having a size of the order of mm) throughout the volume of SIAL matrix with no apparent signs of sedimentation of these particles in the solid matrix.

A cross section of the SIAL matrix is usually performed after 28 days of matrices maturing by means of semiautomatic band saw BOMAR DG 230. Examples of cross section observation for SIAL samples are shown in Fig. 3 and Fig. 4.

FIG. 3. Cross section observation for series of SIAL samples solidified with different waste streams (resin, sorbents type).

Homogeneity of the final product is also important in the case of pouring (out drum) application. Figure 4 illustrates examples of solid waste distribution in solid matrices. Cross section of final product confirms uniform distribution of solid waste in the SIAL final solid product.

FIG. 4. Cross section observation of final solid product after pouring application.

4. ECONOMIC ASPECTS OF SIAL TECHNOLOGY

There are numerous benefits to using the SIAL geopolymer for waste solidification or encapsulation not only in quality, safety, and economic terms.

In the case of in drum solidification, the technology can be used at room temperature and can incorporate significantly more waste (sludge, resin) as a cement matrix equivalent depending on the waste being treated. One of the economic advantages is, therefore, zero energy consumption (neither cooling nor heating is necessary) except of electricity consumption required for the facility operation (waste and matrix mixing, operation control) which is comparable with cementation facility.

The technology represents a comprehensive solution for processing of various liquid radioactive waste. Based on the adjusted composition of the SIAL matrix, it is possible to fix the radioactive sludge, spent resins, and residues from the contaminated oil and decontamination solutions. Therefore, the SIAL solidification facility can be used largely universally for processing of various waste streams and, in the case of mobile variants, at different locations of these streams' production.

The SIAL solidification facility can be also designed and manufactured for immobilization of liquid waste and for encapsulation–embedding of solid radioactive waste.

An important economic advantage of the SIAL solidification technology is a "higher volume reduction rate" compared to cementation technology. Based on more than 20 years of experience, the loading capacity of the SIAL matrix (volume reduction rate) is significantly higher than in the case of the cement matrix (the values are different for different waste streams).

A method that has been used for many years and one of the great advantages of SIAL technology is its ability to solidify some types of waste together. In this process, the most appropriate of several options is selected based on the current situation and client requirements.

For example, when removing spent ion exchangers from storage tanks, contaminated water containing radioactive sludge is used as a transport medium. It is often several cubic metres of water placed on the surface of the spent ion exchanger, which serves as a shielding medium during storage. This liquid is also radioactive waste and is typically processed by evaporation to the desired salinity concentrate, which is then solidified into a cement or bitumen matrix. SIAL technology, thanks to its technological design and chemical solidification principle, can use this liquid to transport the waste to the pretreatment module and as the technological water needed for solidification process. An excess liquid is removed from the pretreatment module and returned to the waste storage tanks while the other (calculated) part of this radioactive liquid is used as reaction water, which is needed for the polycondensation reaction. In this manner, the entire volume of shielding water containing sludges is usually consumed. A cost savings is realized for converting liquid to a concentrate and processing this concentrate. The technology has been successfully used, for example, in treating spent sorbents at Dukovany NPP [3] and in treating historical waste – sludge and sorbents at the NPP V1, Jaslovske Bohunice, Slovakia [3].

Another efficient combination of different waste streams was used for this NPP V1 historical waste treatment project in which a small amount of liquid borates were added to spent ion exchangers dosed in drums with a calculated amount of sludge, increasing the waste dry matter content in the matrix and reducing the number of solidified drums. The advantage of the SIAL matrix was used that it can solidify also a certain amount of borates which are not processable into the cement matrix (so called "cement poison").

The solidification of combined waste streams – spent sorbents and sludge – is also frequently used in other projects. The spent ion exchangers originating from decontamination of NPP V1 primary circuit were treated together with sludge removed from the bottom of storage tanks within the parallelly realized project of decontamination these tanks. On average, 40% of spent ion exchangers and 10% of sludge were combined and solidified in 200 L drums.

A cost comparison of different technologies and their application has to therefore be complex and be based on a multi-criteria analysis that also accounts for the resulting product quality.

Consideration also has to be given to the fact that future limits and conditions will be more strict, thus the final product quality should not only meet today's values but should be the best and beyond them.

The result of a rough estimation and comparison of waste processing costs for various waste treatment technologies is that SIAL technology significantly reduces the production cost of the final product and the disposal cost in the surface repository.

5. BRIEF COMPARISON OF THE MOST USED WASTE SOLIDIFICATION TECHNOLOGIES

Usually, solidification processes like cementation, bituminization, or solidification into geopolymer (SIAL) alumina-silicate matrix could be applied to process various standard and non-standard waste streams.

Cementation using specially formulated grouts provides the means to immobilize radioactive material on solids and in various forms of sludge. The main disadvantage of the cementation is its low load capacity and relatively high leachability index of final product.

Radioactive elements added to grout typically do not partition into the typical grout phases. For example, ^{137}Cs is thought to reside in the space between solid phases; only ^{90}Sr can substitute for calcium in the various calcium-rich minerals. Accordingly, the radioactive nuclides are more vulnerable to release into aqueous solutions that may enter the solidified waste form outside of the disposal system, causing them to be more easily leached. The inclusion of clay in cement reduces the leaching rates of the radionuclides significantly, however, clay additions greater than 15 wt. % causes a significant decrease in the hydrolytic stability and compressive strength of cement product [7].

Cement is also not always compatible with all wastes – there is a growing group of incompatible wastes types, for example ion exchange resins, high salt content waste (including sulphates, nitrates, phosphates, or various borate forms), and various liquid mixtures with complicated chemical composition (decontamination liquids, mixtures from lab operations etc.). These incompatible wastes, the so-called "problematic" or "non-standard" wastes, can cause various undesirable phenomena e.g. formation of components resulting volume changes of the final product, and/or unsatisfactory leaching, strength, or stability results.

Moreover, waste chemistry and physical properties can limit waste loading, for example when high levels of soluble zinc are present or where waste form viscosity becomes too high (see below). The significantly reduced leaching rate of certain radionuclides has proved a major driver for the use of geopolymer. This has allowed waste loadings to be higher in geopolymer than in cement, while still meeting the required waste acceptance criteria [7].

Bituminization (encapsulation in a bitumen matrix) of radioactive waste is a technology that has been applied and that is still being applied in many countries.

Bitumen has the advantage over cements of higher waste loading, but it also has some disadvantages, the most important being its potential fire hazard. The possibility of combustion in the case of an accidental fire has led to certain restrictions on the use of bitumen as an immobilising matrix and it is not used in the UK or USA. Two significant fire incidents occurred in Belgium in 1981 and in Japan in 1997 in bitumen-containing nitrates from evaporator concentrates. Bituminization facilities have to, therefore, include fire suppression and extinguishing systems.

Anionic ion exchange resins start to decompose around 150°C, resulting in the release of amines. At the conditioning temperature and in contact with bitumen these compounds may give rise to spontaneous exothermic reactions, resulting in fires.

6. CONCLUSIONS

The advanced (SIAL) geopolymer solidification technology offers an alternative route for the treatment of problematic waste streams. Their superior mechanical properties allow for efficient waste loadings, allowing the number of packages to be reduced, while maintaining the integrity of the waste forms. Their resistance to liquids makes them highly durable, and they exhibit excellent radionuclide retention and leach resistance.

For solidification of the real waste streams, it is also important to consider corresponding radioactivity values of waste streams related to required encapsulation. It is important due to lower dose rates from solidified product, which allows safe handling of the product and to meet waste acceptance criteria for subsequent disposal valid in the country concerned.

In its 2014 nuclear technology review, the IAEA cited operational application of proven SIAL solidification technology as:

"Recent favourable construction experience with geopolymer materials suggests their more widespread application to waste conditioning is possible. SIAL geopolymers have demonstrated enhanced compressive strength and low leachability of ^{137}Cs and are licensed for use in the Czech Republic and Slovakia for radioactive sludge and resin solidification. Research in Australia, the Russian Federation, Slovakia and the United Kingdom is likely to generate more knowledge, including information about their long-term durability.” [9]

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AN EFFICIENT AND ENVIRONMENTALLY FRIENDLY GEOPOLYMER PACKAGE FOR ENCAPSULATION OF NUCLEAR GRADE RESINS LOADED WITH ^{134}CS RADIONUCLIDE

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Abstract

Safe disposal of nuclear waste is of great importance with the rapid development of nuclear industries. Although cementation has become the standard radioactive waste treatment strategy, Portland cement-based matrices solidification of nuclear-grade organic resins may result in adverse reactions with ion-exchange resin and an increase in the volume of the packaged waste. The paper explores an efficient and environmentally friendly approach for encapsulating nuclear-grade IERs using a geopolymer package, which was designed via a one-factor-at-a-time concept using different un-calcined phosphate sludge (UPS) content in a Metakaolin (MK) reagent. Various loadings of non-radioactive resin beads ranging from 9, 11, 13, to 15 wt.% within the geopolymer packages were performed. Chemical stability, mechanical properties and leaching rate of Cs+ from the individual MK and MK–UPS binary geopolymer package solidifying radioactive resins were investigated and compared to the conventional Portland cement binder (PCB). The results indicate that the loading ratio of the spent resin beads up to 13 wt.% by geopolymer package was practicable. The compressive strength of the elaborated package was greater than the waste acceptance criteria (31.55 MPa). Leaching results showed that, the leaching rate of Cs+ across 14 days reaches 2.66×10^{-8} cm/s for Portland cement packages, and 1.58×10^{-9} cm/s for UPS-based geopolymer packages, respectively. These values were lower when compared with previously conventional PCB, indicating the excellent solidification performance of the UPS-based geopolymer packages for radioactive resins doping with caesium. The study provides a promising paradigm for the effective solidification of radioactive grade resins and upcycling of phosphate tailings.

1. INTRODUCTION

The management of large volumes of radioactive wastes, generated primarily by the industrial sector and urban activities, is considered to be one of the most important issues today from a global environmental and economic perspective [1]. Radioactive ion-exchange resins (IER$_S$) is an intermediate level waste (ILW) containing radionuclides including caesium (^{134}Cs and ^{137}Cs; half-life of 2.06 and 30.17 years, respectively) and strontium (^{90}Sr; half-life of 29 years) [2, 3]. The radioactive resin beads are a kind of macromolecular copolymer solid material, commonly in the form of strongly acidic (cationic) or weak basic (anionic) spherical beads with various particle size distributions, or both [2]. These beads are used in the most common techniques for the purification of water circuits in nuclear power plants, but their quantities have increased year after year and, therefore, should be properly managed using suitable ways. The Kingdom of Morocco operates a 2 MW MARK-II TRIGA research reactor at Maâmora Nuclear Research Center (CENM), where the use of resin beads has been estimated at 0.1 m^3/year in the purification pool water of the reactor [4]. The IAEA suggests the direct solidification of spent IER through cementation technology, such as using Portland Cement Binder (PCB) to meet the waste criteria for disposal [5]. Throughout literature, while cement-based matrices are already available and at a lower cost, most common PCB-based materials are highly porous, have a tendency for swelling, and are relatively easily cracked under aggressive environmental conditions with poor mechanical and thermal stability [3]. Consequently, the retention of radionuclides does not work well with such a cement matrix.

A few recent studies have found that geopolymer binders may be a better matrix than PCB for the immobilization of radioactive wastes [3, 6, 7]. For instance, Naggar et al. assess the performance of individual, binary, and ternary blends of metakaolin, feldspar, and blast furnace slag based alkali activated binders to immobilize of a nuclear grade cationic resin loaded with ^{134}Cs, ^{60}Co, and $^{152+154}Eu$ radionuclides [8]. Relatedly, Lin et al. and Lee and co-workers solidified radioactive resins from the Taiwan Research Reactor using MK–blast furnace slag-based geopolymer obtaining material composites of good mechanical properties and limited release of Cs^{+} and Sr^{2+} [6, 7]. The superiority of geopolymer binder immobilization is primarily attributed to its main reaction products – as N-A-S-H, (C,N)-A-S-H, C-S-H, and C-A-S-H. These reaction products are of particular interest to radioactive waste solidification owing to their ability to incorporate radionuclide ions and produce fibrous crystal interlocking through their unique amorphous network to semi-crystalline structures [9]. However, the shortage of high quality raw materials for manufacturing geopolymer binders, as well as high production costs, have significantly limited their production and application, especially in nuclear waste treatment.

At the other end of the spectrum, by means of Moroccan phosphorus enrichment, phosphate concentrate production gave rise to 28.1 million metric tons phosphate mine tailings in the process of mineral processing in 2010 [10]. These generated tailings are accumulated in large quantities or discharged into rivers and farmlands and pose a growing threat to environmental security due to lack of effective governance, indicating that innovative phosphate mine tailing upcycling technology is urgently needed. Earlier CENM laboratory work showed the use of phosphate mine tailings can potentially produce a high performance geopolymer binders [11, 12]. However, none of the previous studies have explored the combination of phosphate mine tailings-derived geopolymer package and radioactive resins disposal.

Presented herein is an innovative and technical approach for solidifying radioactive resins using phosphate mine tailings-derived geopolymer packages. The geopolymer packages were first prepared by one-factor-at-a-time method using uncalcined phosphate sludge, which was then employed to directly solidify radioactive resins loaded with a simulated caesium. The performance assessment criteria were based on a combination of mechanical properties (compressive strength) alongside leaching rate of caesium radionuclides of the solidified packages. Collectively, the work showed the coordinated assimilation of phosphate mine tailings and nuclear wastes, which supports current thinking toward to green chemistry and circular economy.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

The geopolymer packages are manufactured from a mixture of commercial soda silicate, adjusted with NaOH and KOH, diluted with demineralised (DI) water, and eventually added with a variable proportion of uncalcined phosphate tailings (UPT) and metakaolin (MK).

The liquid sodium silicate used was used with a composition provided by the manufacturer: 55 wt.% water, 29.69 wt.% SiO_2, and 15.3 wt.% Na_2O. The sodium and potassium hydroxides used are in the form of micro-beads and are 99% and 90% pure, respectively.

Phosphate tailing by-products derived from the beneficiation of phosphate rock (washing and flotation techniques) were sampled from the Moroccan phosphate mine industry (Gantour basin, Morocco). Multiple samples were taken from a large stockpile and mechanically crushed to obtain phosphate tailing powder with a size of less than 0.08 mm. The particle size distribution was measured by a laser particle size analyser and the obtained powder was used in this investigation without thermal activation.

The MK precursor powder was prepared from kaolin by calcination at 750°C in an electric muffle furnace. The compositions and characteristics of the powders and alkaline solution are given in Table 1. The chemical composition of the powders was performed using an X ray fluorescence sequential spectrometer.

TABLE 1. CHEMICAL COMPOSITION AND CHARACTERISTICS OF REAGENTS

	SiO_2	Al_2O_3	CaO	Fe_2O_3	P_2O_5	MgO	Na_2O	K_2O	H_2O	d50 (mm)
UPT	10.44	2.38	42.63	1.32	11.86	3.10	0.03	0.25	0	0.03
MK	52.60	39.07	0.09	0.94	0.05	0.34	—	2.79	0	0.006
Soda silicate	29.69	—	—	—	—	—	15.3	—	55	—
NaOH	<1	<1	<1	<1	<1	<1	99	<1	<1	—
KOH	<1	<1	<1	<1	<1	<1	<1	90	<1	—

2.2. Preparation of simulated resin beads

The examined nuclear grade resins were employed in their unloaded H^+ form cationic resin and OH^- form anionic resin, having a capacity indicated by the provider of 1.8 and 1 eq/L, respectively. The IER wastes are collected from the TRIGA MARK II research reactor located at CENM, during the purification of the water circuits and spent fuel storage pools. They are stored with very high moisture in drums in the storage department. To determine the moisture content, the resin beads are weighted and dried in an oven at 105°C until a constant weight is reached (mf) (in triplicate) [13]. The moisture content is expressed by the following formula:

$$\text{Moisture (wt.\%)} = (\text{mi-mf/mi}) * 100 \tag{1}$$

To complete the study, leaching experiments of ^{134}Cs incorporated into the resin beads before its solidification were undertaken. The caesium activity was prepared with 257.98 Bq/kg in aqueous solutions, which was obtained by dissolving C_SCl in deionized water. IER wastes content were mixed and equilibrated individually – with 10mL of the aqueous solution of ^{134}Cs. After few days, a gamma spectroscopy was utilized to determine the activities of caesium at the end of the ion exchange sorption process.

2.3. Solidification procedure

Geopolymer package elaboration was performed using an alkali dosage of 4.5 wt% Na_2O+K_2O. The soluble silicates in the activator solution were adjusted to achieve a SiO_2/M_2O activators modulus (Ms) of 1.3. This alkaline solution was applied to produce the packages at different liquid–solid ratio of about 0.90 to 1, depending on the raw mixtures. Individual and binary binders were designed according to Table 2 by the blending of different ratios between MK and UPS. These synthesis parameters were chosen based on previous studies [11, 12], which show reliable workability and mechanical performance. Different contents of the non-radioactive resin beads (NR) (9, 11, 13, and 15 wt.%) were added according to the design given in Table 2. All formulations were cast into cylindrical plastic moulds and were subjected to a temperature of 55°C for 28 days.

The binders were designed using the one-factor-at-a-time concept to achieve the main objective of obtaining geopolymer packages with better mechanical performance and lower fractional leached activities for solidification of spent IERs. Thus, the formulations were divided into two main groups, one of which (25Ø × 52 mm) was allocated to the non-radioactive resin (NR) beads compressive strength investigations; while the second (42Ø × 86 mm), noted here radioactive resins (RR) beads, was allocated to investigate the leachability of ^{134}Cs radionuclide matrices. The detailed package ID and proportions are given in Table 2, with the following nomenclature: MK/(content of UPS in wt.%) - (wt.% of non-radioactive resins used) NR/ RR .

TABLE 2. CHEMICAL COMPOSITION OF IERS CONTAINED GEOPOLYMER PACKAGES (WT.%)

Synthesis parameters	Packages ID	Design parameters		Materials			
		Ms modulus	M_2O content	MK	UPS	IERs	^{134}**Cs** activity, Bq/Kg
Control package	MK/42P-0NR	1.3	4.5	58	42	0	0
Use UPS	MK/0PS-13NR	1.3	4.5	100	0	13	0
	MK/30PS-13NR	1.3	4.5	70	30	13	0
	MK/50PS-13NR	1.3	4.5	50	50	13	0
Use of IER wastes	MK/42PS-9NR	1.3	4.5	58	42	9	0
	MK/42PS-11NR	1.3	4.5	58	42	11	0
	MK/42PS-15NR	1.3	4.5	58	42	15	0
Use ^{134}Cs	MK/0PS-13RR	1.3	4.5	100	0	13	257.98
	MK/42PS-13RR	1.3	4.5	58	42	13	257.98

MK=Metakaolin; UPS=Un-calcined phosphate sludge; NR=Non-radioactive Resins; RR=Radioactive Resins.

2.4. Characteristics of geopolymer packages

2.4.1. Chemical stability

After curing for 28 days, IERs contained in geopolymer packages were immersed in deionized water (DI) with 1.5 µS/cm electric conductivity in sealed polyethylene bottles in an indoor ambient environment for 60 days. The volume of de-ionized (DI) water was 10 times the surface area of the package. After immersion, the packages were subjected to compressive strength tests.

2.4.2. Compressive strength test

After 7 to 28 days curing, the package compressive strength measurements were recorded using a compressive machine.

2.4.3. Leaching tests

If the elaborated geopolymer of IERs is to be accepted as a stable and suitable package for eventual disposal it is essential to show that it prevents the flow of radionuclide elements into the biosphere. The most frequently used leaching method was the Toxicity Characteristic Leaching Procedure (TCLP), as a standard toxic leaching method, which is used to test dissolution and migratory aptitude of radioactive wastes in waste packages [14], and it can be used for simulation of extreme environment solutions.

To demonstrate this purpose, leaching of ^{134}Cs, from the examined geopolymer packages into water solution, was performed using the IAEA standard static leaching test [15]. The cylindrical monolith sample (42Ø × 86 mm) was placed into the centre of a leaching vessel and mixed with DI water to maintain a solid-to-solution ratio of 10 ±1 mL of eluant per cm^2 of sample. To track the $^{134}C_S$ leaching rate (R_i), the leachants were replaced and analysed for radioactivity after 1d, 3d, 7d, 14d, 21d, 30d, and 50d of immersion at ambient temperature. Leachates were analysed by gamma-ray spectrometry to calculate the leaching rate (Ri), which was calculated according to the following Eq. (2) [15–17]:

$$R_i = \frac{\sum A_{des} \times V}{A_0 \times S \times \sum t} \tag{2}$$

where R_i is the incremental leaching rate (cm/s), A_{des} is the ^{134}Cs cumulative activities leached during each leaching interval (Bq/Kg), determined from the net peak areas of gamma spectrometer rays (604.7 keV) through the leachates in 175 ml plastic container, V is the geometric volume of the geopolymer package (cm^3), A_0 is the ^{134}Cs activity incorporated initially in the package (Bq/kg), S is the geometric surface area of the package (157.44 cm^2), and t is the leaching time (s).

3. RESULTS AND DISCUSSION

3.1. Characterization of IER wastes

The grain structure characterization of the air-dried resin was performed using an optical microscope. They are an equivalent mix of gel cation and a porous gel anion resins, in the form of yellow translucent and clear amber spherical beads with diameters between 0.465 mm and 0.928 mm (Fig. 1).

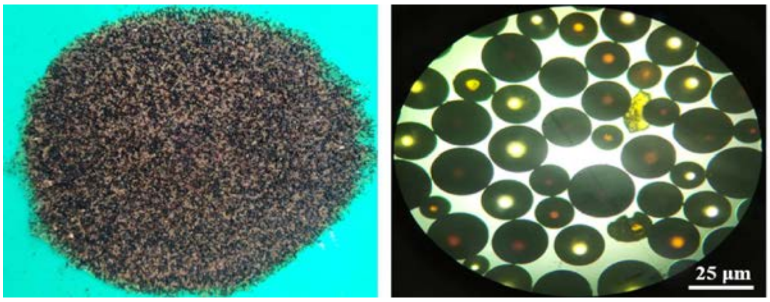

FIG. 1. Polarizing microscope images of used resin beads.

The physical properties of the IER wastes are shown in Table 3. It was noticed that the increase in the percentage of IER wastes resulted in an increase of conductivity due to the total ions leached out. Furthermore, the final pH has stabilized at a value of 4.16 that is suitable to optimal immobilization of the resins. These used resin wastes are also characterized by higher water content (63.54%) suggesting the hydrophilicity of the ionic polymer matrix (IER). Moreover, IERs exhibited a different grain size distribution with high fine content.

TABLE 3. PHYSICAL PROPERTIES OF IER WITH SOME PHYSICAL CHARACTERISTICS

Physical properties of IER wastes	Conductivity (µs/cm)	~ 2.8	~ 21.3	~ 33.2	~ 53.3
	pH	~ 5.74	~ 5.37	~ 4.97	~ 4.16
	Moisture (wt.%)	~ 63.54			
	Grain size (mm)	$D_{0.3}$	0.4		
		$D_{0.4\text{-}1}$	82		
		$D_{1.25}$	5		

3.2. Chemical stability of the elaborated packages

Figure 2 presents the visual appearance of packages immersed under DI water for 3 months. Packages prepared with the un-calcined UPS presented a better performance and desired features of durability after an immersion test, in comparison to the packages prepared with MK (Fig. 2A); this suggests that the presence of UPS particles were favourable for IERs retention under the neutral nature. A possible reason for this could be that the UPS is actively involved in the chemical reactions or it has a lower sensitivity under immersion in DI water associated with its coarser particles. However, for up to 50 wt.% of the un-calcined UPS, the packages exhibiting a higher amount of visual appearance heterogeneity contain relatively larger pores on the exterior surface; this was mostly ascribed to their higher number of impurities and unreacted particles of the UPS.

Reviewing the photograph of the packages with different concentration of the IER wastes, it appears that the addition of the resin beads has a positive influence on the durability indicators, while significant cracks and superficial deterioration were visible on the package with 15 wt.% (Fig. 2B). As expected by visual examination, the introduction of the resin beads with different particle sizes as an addition to the geopolymer formulation allows reducing the apparent porosity of the elaborated package.

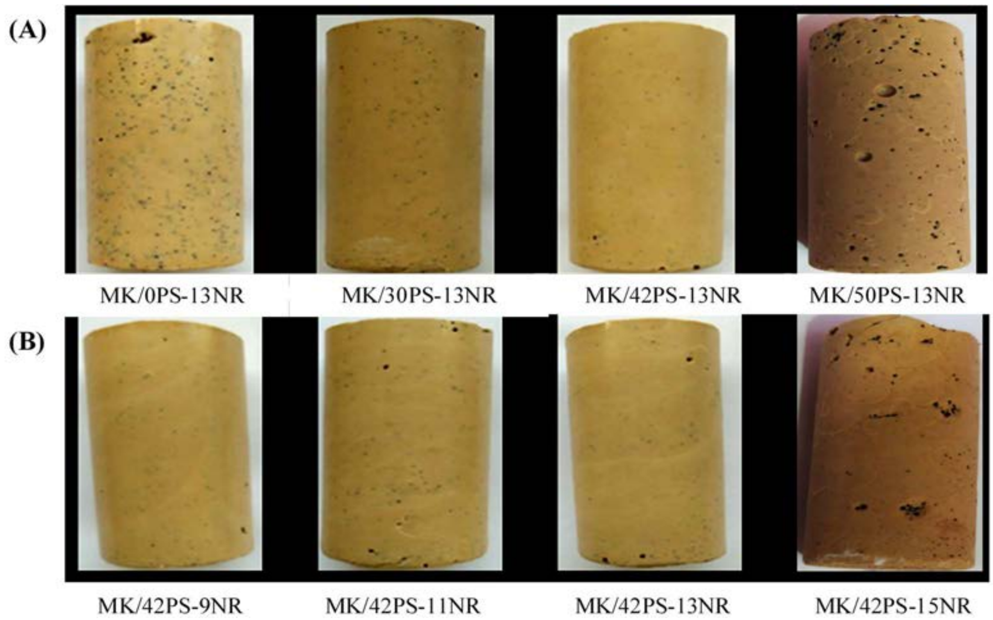

FIG. 2. Geopolymer packages after immersion in DI water for 3 months: (a) effect of un-calcinated phosphate sludge (UPS), (b) effect of non-radioactive resins (NR).

3.3. Compressive strength of solidified geopolymer packages

In order to assess the mechanical integrity of the elaborated packages, compressive strength experiments were performed at 7 days, 28 days, and after immersion in DI water for 3 months (Fig. 3 and Fig 4). Figure 3 shows the compressive strength results for the individual MK and binary MK–UPS geopolymer packages. The addition of un-calcined UPS promotes an increase in compressive strength by approximately 51% after 28 days compared to the reference package (MK/0PS-13RR). The increase of compressive strength is even greater after the immersion in DI water (3 months), (264%), which may be due to dual role of un-dissolved or partially dissolved UPS particles or bonding sites toward the neoformation of new reaction products, such as (C,N,K)-A-S-H, C-S-H, and C-A-S-H [18]. However, the excessive addition of UPS (50 wt.%) reduces the rate of chemical reaction (due to lower bending phases) and compressive strength, especially after immersion in DI water. This behaviour suggests that due to the incorporation of high amounts of UPS (lower amorphous phases), the extent of the geopolymerization reaction is lower. This can suggest an excessive amount of UPS leads to the formation of weak reaction products which can easily be leached out, damaging the chemical durability of packages as observed in Fig. 2A.

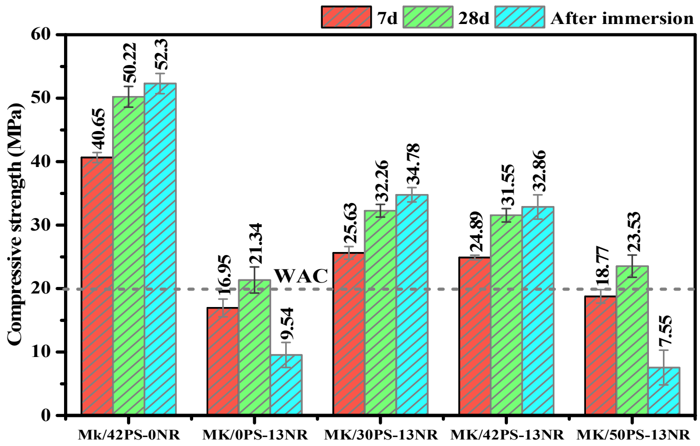

FIG. 3. Compressive strength of different individual and binary geopolymer packages. WAC: waste acceptance criteria.

Although MK/30PS-13NR recorded higher strength (32.26 MPa) than MK/42PS-13NR (31.55MPa), the latter was chosen as the optimal binary binder based on two targets. The first is that replacing MK by UPS directly reduces the consumption of alkaline activator while providing a suitable chemical environment to promote durability and resistance development. While the second target was to obtain higher amounts of reaction products because of an expected partial dissolution of calcite and dolomite when adding the UPS.

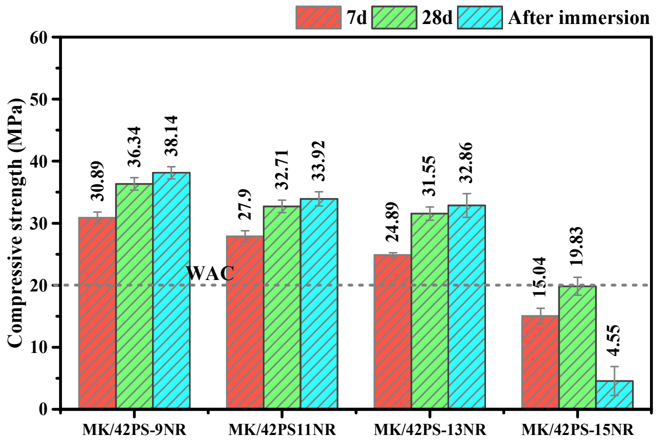

FIG. 4. Effect of non-radioactive resins addition (%) on compressive strength of binary geopolymer packages. WAC: waste acceptance criteria.

Figure 4 shows the compressive strengths of the geopolymer packages with different loading ratio of IER wastes after 7 days, 28 days, and after immersion DI water test. The package in the absence of solidified resin beads (Mk/42PS-0NR) was set as reference in this test (Fig. 3). Generally, the illustrated data revealed the compressive strengths of package recorded a downward trend at different extents when the resin wastes loading were increased, with exception of the loading ratio of 15 wt.% of IER. The highest strength values that met the waste acceptance criteria (WAC, [19]) were 36.14, 32.71, and 31.55 MPa and belonged to loading by 9, 11, and 13 wt.% resin beads. As a result, the 13 wt.% resin beads loading ratio of MK/0PS-13RR and MK/42PS-13RR geopolymer packages were selected for leaching experiments.

3.4. Leaching characteristics

The leaching performance of solidification packages is an essential factor to characterize whether the packages effectively prevent the leaching of nuclide ions into the biosphere. As shown in Fig. 5(a), the leaching of ^{134}Cs mostly occurred over three days, with the leaching rate decreasing quickly over time. However, a small concentration of ^{134}Cs also leached beyond day 7 in the MK/0PS-13RR package without adding UPS. In contrast, a very low amount of caesium leaching was detected after 7 days in the MK/42PS-13RR package; moreover, the leaching rate values were maintained at very low concentrations in any timing of test during the entire leaching experiments.

Although caesium desorption was detected from days 3–7, the total amount of leaching rate remained extremely low. This result indicates that the UPS-based geopolymer package has a good effect on immobilizing caesium, which can satisfy the requirements for industrial applications. Further measurements under various conditions and analysis should be carried out to elucidate the encapsulation mechanisms of caesium.

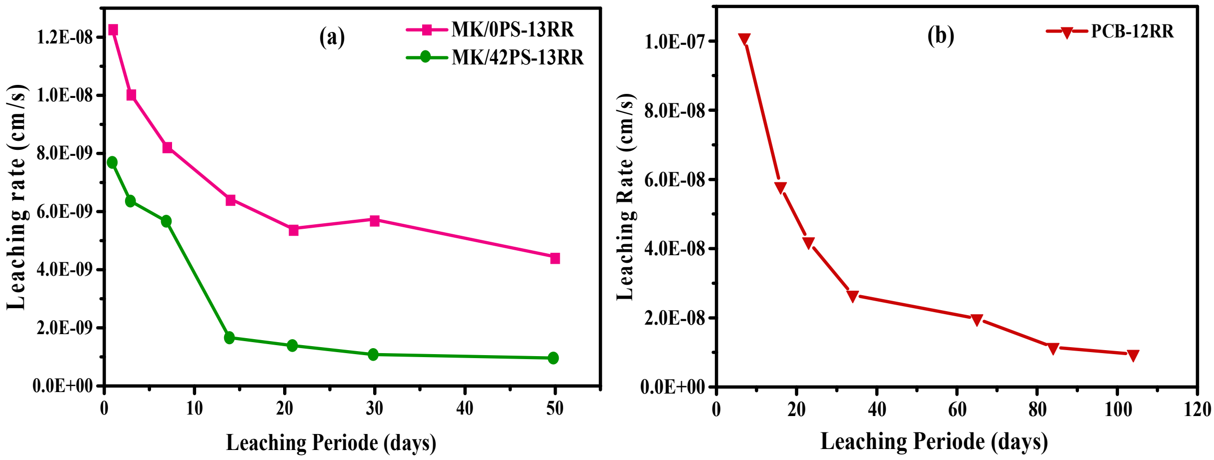

FIG. 5. Effect of binder type on the leaching rate of ^{134}Cs leached from solidified resin beads. (a) individual metakaolin (MK/0PS-13RR) and binary (MK/42PS-13RR) geopolymer packages and (b) Portland cement binder (PCB-12RR).

Previous work from the CENM laboratory has found that the PCB can potentially be used to treat radioactive resins loaded with ^{134}Cs [16]. In the current work, the prepared package had a strength of 8.61 MPa and was effective in encapsulating 12 wt.% of the spent resin over a wide range of caesium concentrations (with initial activity 107.93 Bq/kg). As shown in Fig. 5(b), the highest leaching rate of ^{134}Cs from PC-based packages occur on the 7 days of leaching. The leaching rates of Cs^+ in the PCB decreased over time and dropped significantly before day 65. The leaching rate of Cs^+ across 14 days reaches 2.66×10^{-8} cm/s for Portland cement packages, and 1.58×10^{-09} cm/s for UPS-based geopolymer packages, respectively. This result showed that the immobilization ability of Cs^+ in UPS-based geopolymer packages, with initial activity 257.98 Bq/kg), is better than that of PCB packages. Therefore, the UPS-based geopolymer package has clearly demonstrated its ability to improve the encapsulation performance of nuclear resins loaded with ^{134}Cs as compared with individually MK-based geopolymer package and Portland cement package.

3.5. Environmental implications

The safe use of nuclear energy substantially reduces fossil fuel consumption, reducing energy consumption and ensuring a long term energy supply for human society. However, the safe management of nuclear waste is an issue that the world needs to face and resolve. One solution is to synthesize environmentally-friendly materials by using industrial mining wastes; these materials are then used to solidify nuclear waste. From a circular economy perspective, this approach enables the cost effective and safe disposal of nuclear waste, while also promoting the high value utilization of solid industrial waste. The developed UPS-based geopolymer package in this study demonstrated excellent solidification effects of radioactive grade resins toward large-scale utilization of phosphate industry by-products. Collectively, this paradigm provides an alternative pathway to achieve solidification of nuclear wastes and to treat industrial phosphate solid by-products in moving toward a circular economy model.

4. CONCLUSIONS

The phosphate tailings-derived geopolymer package exhibited very effective encapsulation performance for radioactive grade resins loaded with caesium radionuclides. Non-radioactive resin beads could be solidified into MK/42PS geopolymer package by 9, 11, and 13 wt.% yielding 28 days compressive strength values (36.14, 32.71, and 31.55 MPa, respectively) greater than the WAC. The leaching rate values of caesium were two orders of magnitude lower than individual MK-based geopolymer packages and the conventional Portland cement package, indicating the better retention performance of the phosphate tailings-derived geopolymer package of radionuclide elements toward the biosphere.

The production of a phosphate tailings-derived geopolymer package could achieve environmentally friendly character and large-scale resource use of phosphate industry by-products. This approach of handling nuclear waste with phosphate tailings allows for the cost effective and safe disposal of nuclear waste, while also promoting the high-value utilization of industrial solid wastes.

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3.4. SESSION 4 – ROLE OF SAFETY CASE DEVELOPMENT IN SUPPORTING RADIOACTIVE WASTE MANAGEMENT

IAEA Safety Standards Series No. SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste states that a safety case is “a collection of scientific, technical, administrative and managerial arguments, and evidence in support of the safety of a disposal facility, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the disposal facility.”

In the case of disposal, safety will be provided by a number of barriers, some man-made such as the waste form or the waste container (referred to as engineered barriers) and some natural, such as the host rock or surrounding geology. The objective of the safety case is to describe how these barriers work in concert to provide safety to people and the environment and how this disposal system will perform over the time periods of interest. A successful safety case will demonstrate that the operating organization understands the system and its evolution and will thereby provide confidence to the regulatory body, workers, and other stakeholders.

One of the key components of the safety case is the safety assessment. For a disposal facility, the safety assessment is designed to provide a systematic assessment of radiation hazards as result of normal evolution of the facility and as a result of unplanned intrusion events. The assessment provides quantification of radiation dose and radiation risks that might arise from the facility for comparison with dose and risk criteria published as national and/or international standards. These are used in the safety case in demonstrating understanding of the behaviour of the system under normal conditions and in the event of intrusion and extend to cover all time frames over which the radioactive waste remains hazardous.

It is the safety case and the supporting safety assessment that provides the basis for demonstration of safety and for licensing. This is not a one-off activity. The safety case will be developed and updated in line with the key design, construction and operational phases and is typically assessed by the regulatory body as part of the permitting to progress to the next stage. In any event periodic safety reviews are necessary (usually every 10 years) where the safety case is reviewed and updated to take account of operational experience and learning, new data coming from site characterization or research or to take account of changing legislation or requirements. This is also an opportunity to revisit the supporting research programme to incorporate any new areas of uncertainty identified by the safety case update.

This Session addressed the role of, and development of the safety case, providing examples of safety case structures, inputs, and interfaces from Member State programmes. Safety cases have an essential role in all stages of waste management whether in waste processing, handling, storage or disposal and for all types of waste. The safety case is the key vehicle where safety arguments demonstrating the operating orgaization’s understanding of the performance of waste packages and the disposal system are presented. The session heard about progress in safety case development from low level near surface waste facilities, through to geological disposal facilities for high level waste and spent fuel.

A common theme from all presenters was that safety cases need to be developed in a step-by-step manner, with successive iterations capturing new information and learning. For a disposal facility, the safety case is a living document and may span many decades as the facility is planned, developed, operated and eventually closed. The safety case needs to be accessible to all and be based on international safety standards and best practice so host communities can understand present and potential future impacts and public confidence be strengthened.

The session also discussed the development of waste acceptance criteria, research and development and innovation and the interaction between them and how the safety case and associated documentation is subject to periodic updates to allow learning to be incorporated. In turn the safety case also informs and shapes the research agenda, ensuring its focus on resolving uncertainties and strengthening safety arguments.

Safety case development is a highly collaborative, multi-disciplinary effort involving careful management of interfaces and robust configuration management, such that the safety case evolves in step with the facility. Whilst the preliminary version might be based on expectations of performance, it then progresses to reflect the as-built condition and successive design modifications and behaviours found in practice: the physical facility, design basis and safety case always need to be consistent.

Session Chairs: C. Van Drunen (Canada) and M. Tayyeb (Pakistan)

Session 4 comprised eight papers from France, Brazil, Spain, the Russian Federation, the United Kingdom, the Republic of Korea and China, with an additional paper from one of the conference's Young Professionals Showcase Leads (Canada).

- **Paper ID#188 by S. Voinis (France)** presented an overview of the step-by-step development of the Cigéo geological disposal facility design and associated safety case stages. Safety case development is a multi-discipline and multi-interface process, which need to be continuously refined in iterative cycles and reviewed by experts and the regulatory body. This feedback process is essential as it allows the safety case to be improved based on learning from the previous stage. It may lead to design changes to enhance operational or long term safety. The Cigéo programme was initiated in 1991 and has since undergone four iterative updates. The next update will support the licence application to commence construction.
- **Paper ID#89 by S. D. Santos Cota (Brazil)** described the preliminary safety studies conducted in in support of siting a near surface disposal facility for low and intermediate level waste. In the early stages of safety case development, the safety assessment is a useful tool to explore and identify those aspects of the system that are more significant for safety and which need to be explored in more detail. In this case, the assessment used the unit activity concentration for all listed radionuclides in order to obtain a hierarchy of importance for dose contributors, based on the combined effects of their radioactive, chemical, and exposure characteristics.
- **Paper ID#305 by I. Lopez Diez (Spain)** described the evolution of the safety case supporting the El Cabril disposal facility for low and intermediate level radioactive waste. El Cabril obtained its operational authorization in 1992, along with approval of the Safety Study licensing document. The Safety Study contains all the information required to conduct an analysis of the facility from the perspective of nuclear safety and radiological protection, along with an analysis and evaluation of the risks associated with site operations, both under normal and accident conditions. During nearly 30 years in operation, the facility has been required to adapt to new technological, regulatory and management needs and/or realities. Thus the management arrangements at the facility are constantly changing and the Safety Study has proved an essential tool in this adaptation process through its periodic review and update.
- **Paper ID#111 by S. Utkin (Russian Federation)** described plans for the development of a geological disposal facility for heat generating intermediate level waste and high level waste. A structured and iterative process is being followed with the safety case being developed and refined in stages as information from site characterization and ultimately from URL and facility construction comes forward. An innovation within the project is the establishment of a central digital knowledge management framework (PULSE system) which stores data and metadata and ensures use of a verified and consistent dataset for all assessments. The project has also adopted transparency as a key principle and provides open information to stakeholders through various platforms and fora.

- **Paper ID#191 by A. Huntington (United Kingdom)** presented an overview of the design and safety case improvements that have been implemented at the UK's near surface disposal facility for LLW. A comprehensive design and safety update was issued in 2002 which saw some major changes to the operation of the facility and the way in which safety was presented and demonstrated. The safety case was revisited in 2011 and will again be updated in 2026. The safety case is now an essential management tool, used for instance to guide the R&D programme, to assess new wastes and potential impacts on facility capacity, to address design changes, and to assess options for capping and closure. The safety case is also providing the foundation for studies examining the potential for future expansion of the site.
- **Paper ID#138 by G. Gwak (Republic of Korea)** presented an overview of the waste acceptance criteria developed for the Wolsong low and intermediate level Waste Disposal Center (WLDC). The WAC are directly based on the safety assessments so that the operator has confidence that any packages accepted onto site will be compliant with the needs of the underlying safety case. The WAC development methodology and structures are based on best practice guidance issued by IAEA.
- **Paper ID#302 by P. Zhang (Peoples Republic of China)** presented key features of the design and safety assessments of near surface disposal facilities for low and intermediate level wastes. The safety case for the Feifeng Mountain Disposal Site was presented in some detail and the information management system giving real-time information to operators described. The paper also presented a case study illustrating how the safety assessment had been used to identify areas for the introduction of remote operation which would reduce operator dose and risk, which with design improvement could also increase facility throughput and efficiency.
- **Paper ID#244 by M. Herod (Canada)** described the regulatory review of waste acceptance criteria for the near surface disposal facility. The review was iterative, meaning the review team was provided with draft materials and able to identify areas for clarification or improvement before seeing a final version. If the near surface disposal facility is approved for construction, the regulator will begin compliance verification activities of all aspects of the safety case and the waste acceptance criteria.

Paper ID#188

ROLE OF THE SAFETY CASE DEVELOPMENT IN SUPPORTING RADIOACTIVE WASTE MANAGEMENT- FRENCH ILLUSTRATION ON HIGH LEVEL WASTE AND INTERMEDIATE LEVEL WASTE MANAGEMENT- THE CIGÉO DISPOSAL

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Abstract

Andra is currently in the license application process for a deep geological disposal facility for high level waste (HLW) and intermediate level waste (ILW) in a clay formation, the Callovo-Oxfordian, in the eastern part of France. This process started in 2011 by the development of an industrial design phase that consists of a proposed overall underground architecture for the repository and the definition of the operating principles, and the name given to the project was defined: the “Centre industriel de stockage en milieu géologique” (Cigéo, Industrial Center for Geological Disposal).

The files and in particular the safety case that will support the license application result from a continuous increase in knowledge, project development, and associated safety assessment for several decades. Since the French Act in 1991 on the long term plan for the management of ILW and HLW in France, Andra is running a comprehensive research project including a broad combination of laboratory research, surface and drilling based site investigations, research in the Bure URL and model development. The preparation of the license application is thus the result of a stepwise accumulation of knowledge and iterative process including several safety cases as well as their regulatory review.

The safety case development plays a key role in supporting the development of the technical solutions to manage HLW and ILW. It is based on successive “knowledge/design /safety” iterations. Each iteration involves scientific and technological knowledge acquisition, study of the layout designs consistent with this knowledge and safety assessment.

Each safety case is associated with key milestones (reliability, siting, underground research, industrial design development, safety options, licensing) based on the “knowledge/design /safety” iteration providing lessons learnt.

The successive iterations gradually help to guide the choice toward design solutions, R&D programmes, and safety studies. Andra collects and documents knowledge R&D data and analyses residual uncertainties in the knowledge.

1. INTRODUCTION

In 2011, the French National Radioactive Waste Management Agency (Andra) entered an industrial design development phase for the Centre industriel de stockage en milieu géologique (Cigéo) (Industrial Center for Geological Disposal) and is now completing the overall safety case toward its licensing application. As part of safety options for 2015, namely “Cigéo 2015,” Andra is currently in the licensing application process of the Cigéo for HLW and intermediate level and low level waste (IL-LLW) in the Callovo-Oxfordian clay formation, in the eastern part of France.

Andra is preparing the safety case and in particular is documenting a preliminary safety report to support the licensing application resulting from a sound step by step development of the deep geological repository (DGR) and based on an iterative increase in scientific and technological knowledge, design development, and associated safety assessments since 1991. Andra has already performed many safety, design, and research and development (R&D) iterations, each one responding to a specific objective connected with a key stage in the gradual development of the DGR: basic reference rules and initial options; license for construction and operation of the Underground Research Laboratory (URL) in the Callovo-Oxfordian clay formation on the Meuse/Haute-Marne site in the eastern part of the Paris basin; feasibility demonstration of the DGR in the clay formation within an area about 250 km² around the Bure URL (called “Bure URL”); and precise siting of the underground facility within this area, location of the above-ground facilities, and safety options.

Each iteration has led to a safety assessment addressing operational and long term safety regarding the level of scientific and technological knowledge, the status of the design of the disposal facility, and the description of its performance over time. For each iteration, Andra has endeavoured to verify compliance with safety and protection objectives set by French regulatory texts and safety guidance published by the regulatory body – Autorité de Sûreté Nucléaire (ASN) (as such the basic safety rule RFS.III.2.f in 1991 updated in 2008 namely “Guide de l'ASN n°1 : Stockage définitif des déchets radioactifs en formation géologique profonde”). Each iteration has resulted in preparation of a documentation, issued by Andra, which has been subject to a detailed review by the ASN and sometimes to expert review internationally.

The successive iterations and safety cases have helped to state confidence in the scientific and technological basis, the level of detail of design, and the safety. They also progressively identify the safety and R&D topics early in the process integrate them into the design at each key stage in the development of the DGR. The iterative nature of the approach to design and to acquire scientific and technological knowledge implemented by Andra has allowed the feasibility of the project, and then its development, to be established in a gradual, structured, evaluated, and traced manner, regarding applicable safety requirements.

The successive safety cases led by Andra relied on internationally well-established fundamental objectives, as the objectives evolved, and by building on the successive achievements. This includes fundamental safety functions and related design requirements (such as a maximum temperature less than 100°C, the emplacement of HLW and IL-LLW in separate zones, grouped access to the underground facility, an overall blind underground repository architecture, and a low carbon steel over-pack for HLW, among others). The main principles of uncertainty analysis and of definition of post-closure safety scenarios (expected normal evolution, deviated evolutions, human intrusion, what if) were regularly applied. With the progress of the Cigéo project development, safety cases have integrated more and more precisely the links with the operational safety and advancement in the design of the repository, in particular its progressive optimization. So, detailed requirements for the design were progressively considered and a more enveloping approach was adopted, since the safety options report in 2015, for the expected normal evolution scenario to consider these requirements and underline the robustness of the repository.

- The safety case development plays a key role in supporting the scientific and technological R&D programme, as well as the development of design solutions to support development of deep geological disposal for HLW and ILW.
- The successive safety cases are based on successive “scientific and technological knowledge/design/safety assessment” iterations supporting key milestones (reliability, siting, feasibility, industrial design development, safety options, licensing application) based on the “knowledge–design–safety” iteration providing lessons learned.
- Each iteration involves current scientific and technological knowledge, study of the layout designs consistent with this knowledge and safety assessment.

2. PRESENTATION OF THE DEEP GEOLOGICAL REPOSITORY (DGR) CIGÉO

The deep geological repository (DGR) “Cigéo” will be in Meuse/Haute-Marne departments in the east part of the Paris basin. It consists of an underground area for the disposal facility and surface facilities spread over two areas, as well as ramps and shafts connecting the surface and underground facilities, Waste emplacement will take place for over 100 years and the facility will be expanded as space is needed. DGR will then be closed to ensure the containment of waste over very long periods of time without the need for human action. The disposal system consists of a set of manufactured and natural components including the Callovo-Oxfordian clay formation. The underground facility is in the Callovo-Oxfordian clay layer and is designed to ensure a maximum thickness of undisturbed clay host rock on each side of the disposal cells.

The DGR “Cigéo” consists of a three dimensional “3D” nuclear facility (see Fig. 1):

— A nuclear facility at the surface for receiving, handling and preparing HLW and ILW before being transferred to their respective disposal area;
— an underground nuclear facility in the Callovo-Oxfordian clay host rock formation at a depth of about 500 metres where the HLW and ILW are emplaced in separated zones;
— 5 shafts and 2 access ramps ensuring a continuous link between the surface and underground facilities.

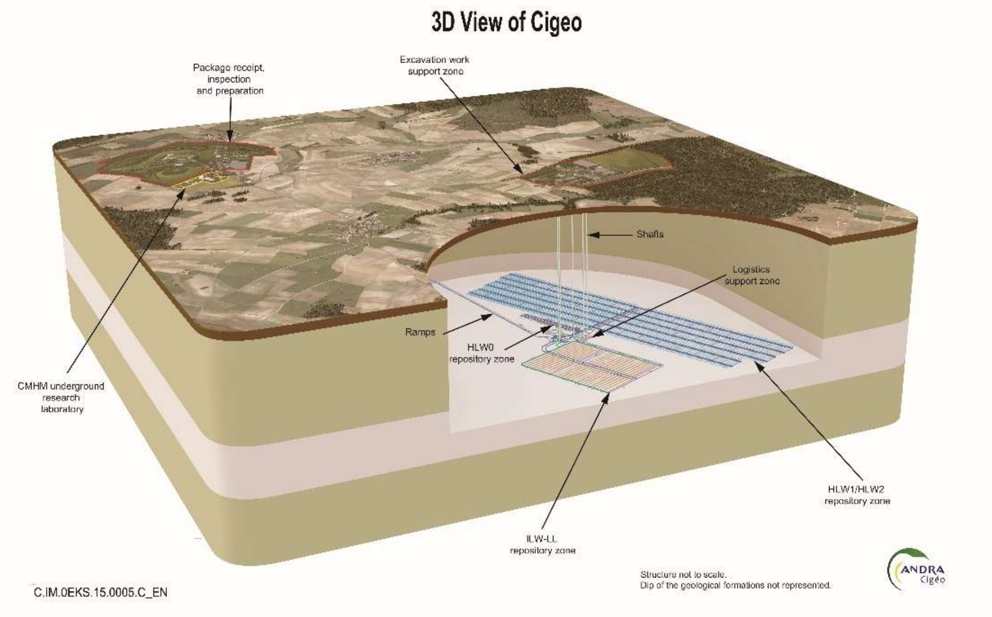

FIG. 1. 3D scheme of DGR Cigéo: the two surface and the underground areas (cf. « Cigéo 2015 » documentation). Courtesy of ANDRA.

Given the specific characteristics of the DGR (its “unique” nature, its underground location, and the fact that it needs to ensure people and the environment are protected in the long term), its gradual development is founded on a very close relationship between three pillars: knowledge (scientific and technological), design, and safety. This close interconnection also incorporates a specific characteristic of the DGR compared to “traditional nuclear facilities,” a coordinated and parallel implementation of two safety approaches (see Fig. 2):

— One is similar to conventional approach as applied for any other type of nuclear facilities, but with consideration of the specific requirements of the underground facility (reception of primary waste packages, conditioning of primary waste packages into disposal packages, handling of waste disposal packages from the nuclear facility at the surface into underground facility), a wide variability between different types of waste, construction work being carried out at the same time as operation of an underground nuclear zone, length of structures, gradual development, operational period of at least one hundred years, etc.);
— The other, specific to the DGR, intended for assessing safety over very large timescales after closure, to estimate its robustness in relation to the double objective of isolation of radioactive waste and of retardation and limitation of radionuclide transfer to the surface. The emphasis is on integration of scientific and technological knowledge and management of residual uncertainties.

3. A GRADUAL DEVELOPMENT OF THE CIGÉO PROJECT BASED SYSTEMATICALLY ON SUCCESSIVE ITERATIONS COMBINING SAFETY, DESIGN, AND SCIENTIFIC AND TECHNOLOGICAL KNOWLEDGE

Since 1991, Andra has integrated safety into the early phases of design development and R&D programme: (1) to provide continuous guidance for the design choices concerning the disposal facility, and (2) to make it more robust by taking account of gradual advances in scientific and technological knowledge and the safety objectives addressed.

Each iteration thus incorporates acquisition of new knowledge and consolidation of existing knowledge, particularly using the results from the R&D programme and advances in disposal facility design, in line with the sum of all this knowledge, and in relation to the safety objectives. The lessons from each “safety–design–knowledge” iteration form the input for the next one and can provide guidance, appropriate to the specific objective concerned, for research to acquire further scientific and technological knowledge, for design studies, and for requirements in terms of more detailed safety studies (Fig. 2).

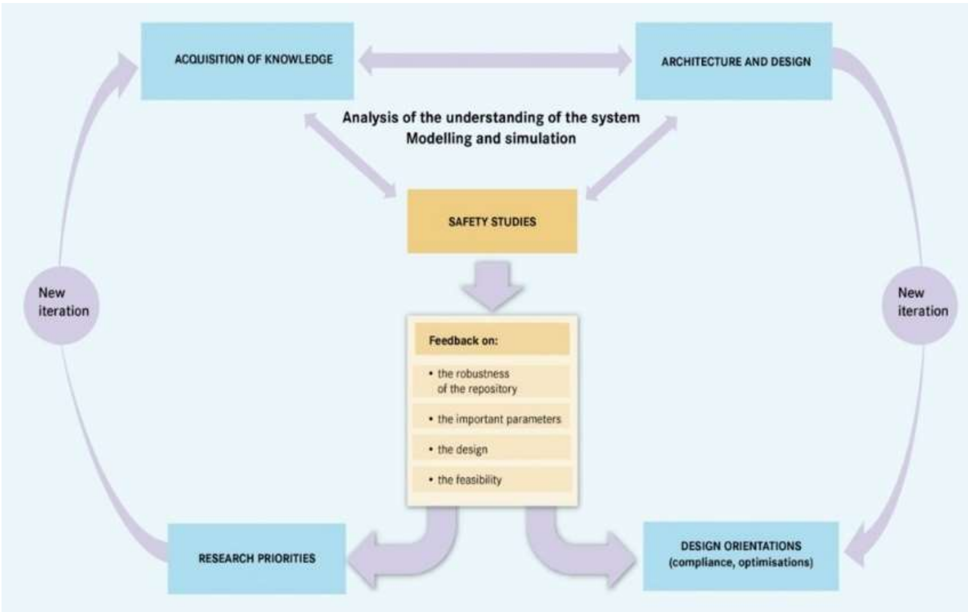

FIG. 2. Illustration of the iterative process.

Each iteration and safety case undertaken by Andra and its reviews by the ASN was carried out in relation to the following objectives to be achieved (Fig. 3):

— To establish the fundamental needed for demonstrating the safety of a DGR, and particularly in the long term after closing;
— To prepare for an underground research laboratory, by assessing site selection criteria and carrying out an initial safety assessment;
— To improve knowledge and preparing the feasibility report;
— To present the feasibility of the disposal facility based on knowledge acquired and applying the safety approach, in response to Law n°. 91-1381 of 30th of December 1991 [1];
— To specify the detailed research for the underground facility within the area where the feasibility of the disposal facility was established in 2005 and the siting areas for surface installations;
— To support gradual development of the design and its evolutions for the licensing application;
— To submit the safety options prior to the licensing application, in accordance with the French regulation.

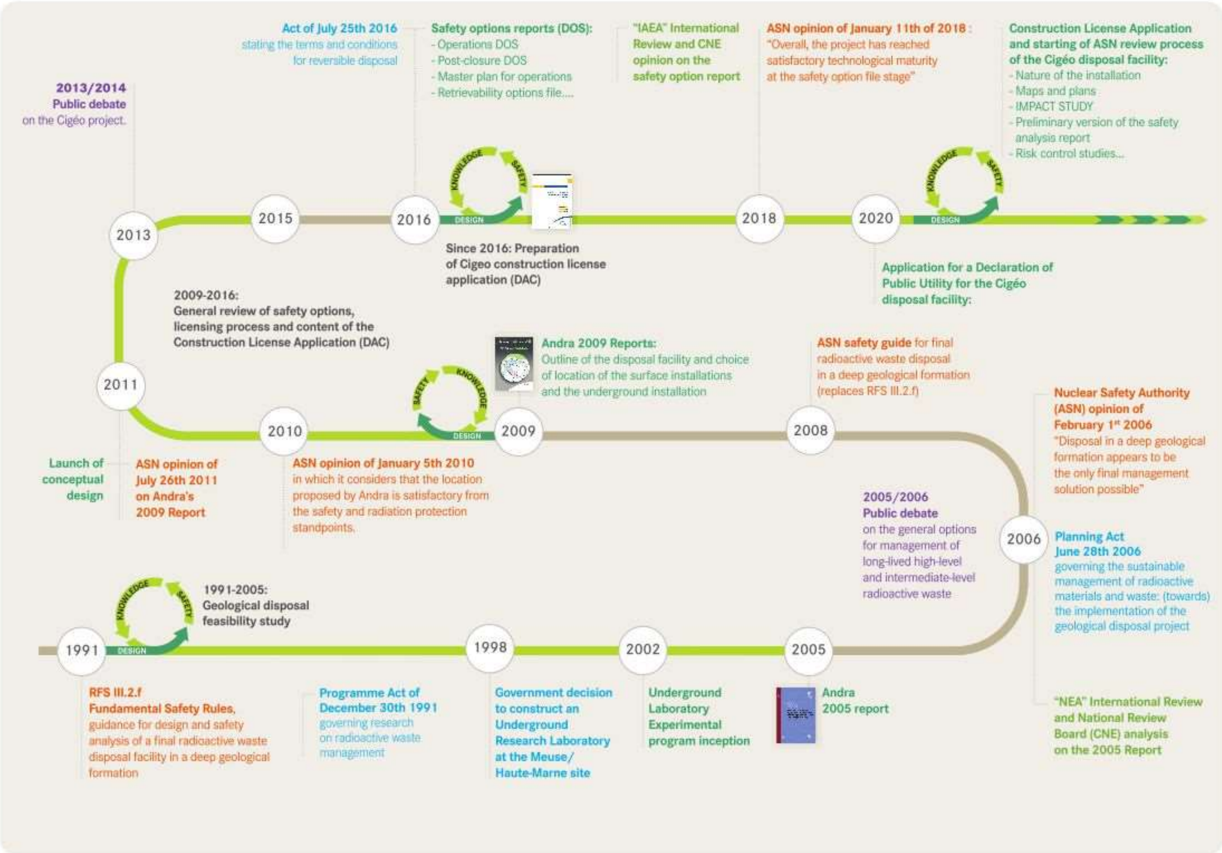

FIG. 3. Safety case iterations among the DGR Cigéo development programme from 1991.

4. THE LONG TERM SAFETY: A FUNDAMENTAL OBJECTIVE OF THE SAFETY DEMONSTRATION SINCE 1991

From the start of the disposal facility project development process, in particular taking account of the fundamental objective of protection in the long term, as mentioned by RFS III.2.f, Andra developed and then implemented a safety approach that meets the following specific requirements (Fig. 4):

— The need to address the safety of the disposal facility as such for the operational, dismantling and closing phases by means of risk analyses (and analyses of safety functions) similar to those applied in nuclear facilities adapting them to the underground nature of the disposal facility (depth, parallel activity of underground construction and nuclear operational work, geometry of underground structures, 100 year operating period with gradual development, among others).
— The central place given to the post-closure period, from the start of the design, based on four areas of research and development:
  - The acquisition of knowledge (characteristics and behaviour of the geological environment, in particular host rock; waste forms and radionuclides; engineered components) to understand the physical and chemical phenomena governing the behaviour of all these aspects, and the changes in them over very long periods.
  - The design of the disposal facility (disposal containers, disposal layout and integration into the geological site, construction and operation methods, waste disposal package management, options for closing the disposal facility) in order to provide a repository architecture, once permanently closed, in line with the state of knowledge and in response to the long term safety objectives.
  - The description (i.e. understanding) of the behaviour of the disposal facility and its geological environment (in particular interactions between the components and geodynamic changes) to

understand the thermal, mechanical, chemical, and hydraulic changes, as well as the release of radionuclides over time and in space, in particular through modelling and computer simulation.

- The safety analyses to assess risks and uncertainties, as well as the performance of the disposal facility in terms of isolation and containment regarding uncertainties or risks.

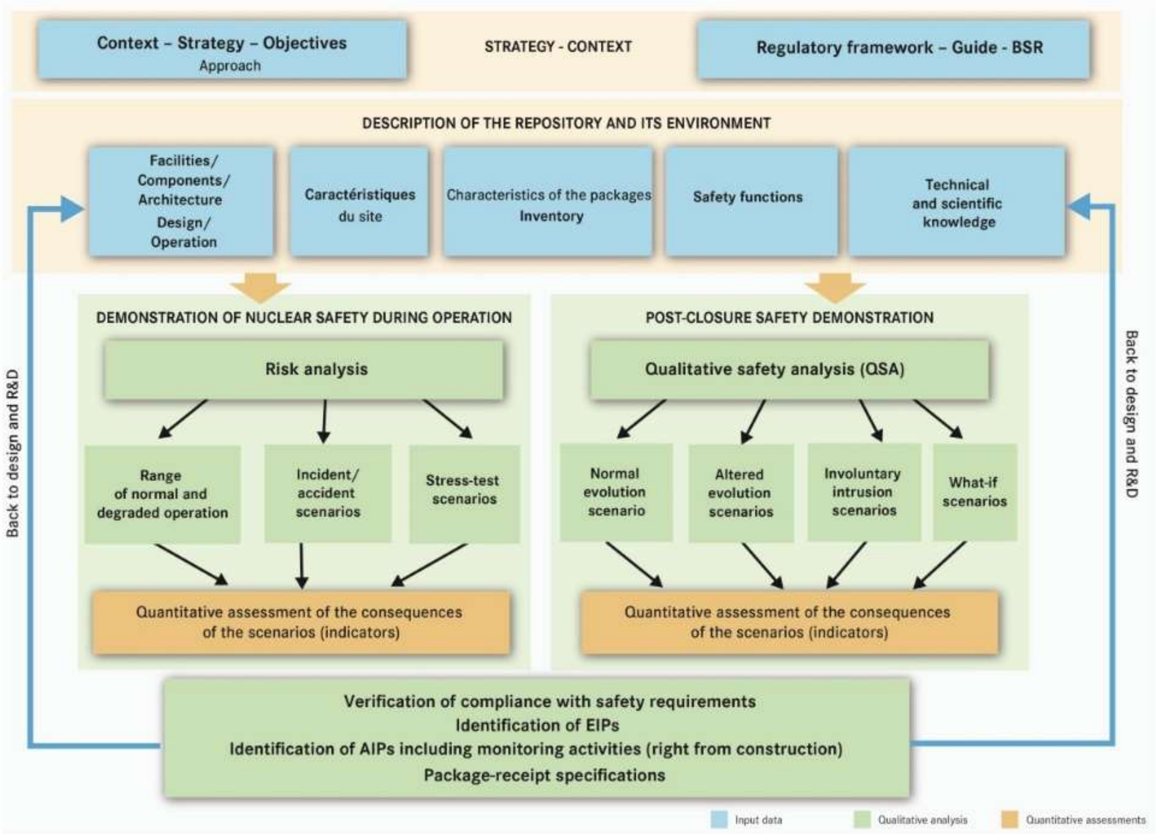

FIG. 4. Diagram illustrating the links safety, design and scientific and technological knowledge as well as coordinated approach to operational safety and post-closure safety

5. AN INITIAL SAFETY CASE IN 1996 TO SUPPORT THE DECISION OF AN UNDERGROUND RESEARCH LABORATORY IN A CLAY FORMATION

From 1994 to 1996, Andra undertook a programme of surveys and characterization to understand the main features of the geological environment of Meuse/Haute-Marne (along with other sites in France that were ultimately not selected), departments, and in particular:

— To confirm the benefit of the Callovo-Oxfordian clay formation envisaged as the host rock for the disposal facility and its geological context over an area of several hundred km^2, located south of the Meuse and north of Haute-Marne;

— To select a precise site for establishing an underground research laboratory in the Callovo-Oxfordian with the aim of potential establishment of a deep radioactive waste disposal facility.

The objective was to create a first characterization of the properties of the geological formations, more specifically the Callovo-Oxfordian host rock, with a widely spaced core sampling grid. Surface geology mapping work has made it possible to specify the existing geological maps.

The characterization, measurements and tests have:

- Confirmed the basic structure of the geological environment (succession of almost flat clay and limestone geological formations, etc.);
- Offered an initial overview of the geo-mechanical, thermal, geochemical and hydrogeological properties of the Callovo-Oxfordian clay host-rock;
- Confirmed its very low permeability;
- Showed its properties presented no prohibitive aspect for the feasibility study for a disposal facility and that at this stage of investigation, with only very minor variations.

These elements allowed the site selection criteria to be verified, in accordance with the recommendations of RFS.III.2.f. All this work resulted in the site being proposed for installation of an URL, as the preliminary study of the mechanical properties of the clay formation also indicated the possibility of implementing the excavation work necessary for the URL. At the same time, Andra undertook disposal concept studies to answer questions highlighted by the first safety analyses.

Andra defined the experimental programme to be implemented in the URL and its appropriate architecture; this work allowed Andra to submit a licensing application for the URL.

Upon review of the application, the publication in August 1999 of the decree authorizing the construction and operation of the Bure URL initiates a new stage in the study and research programme, supporting the development of the deep geological disposal facility project.

6. A SAFETY CASE IN 2005 AFTER 15 YEARS OF RESEARCH TO SUPPORT THE DGR FEASIBILITY REPORT

Following the decree of 3 August 1999, Andra continued to obtain more details in its characterization of the Callovo-Oxfordian at the Meuse/Haute-Marne site, from the surface (3D seismic survey, new boreholes, etc.) and in 2000 started excavating the access shaft and auxiliary shaft of the underground research laboratory. Along with the progress in site characterization, the conceptual design studies were progressively developed to answer the questions that were highlighted by the initial safety case.

At the end of this new stage of acquisition and addition to knowledge from the surface, in 2001, Andra prepared an interim report that reported on the state of knowledge and provided a first safety assessment in order to identify the elements of the disposal facility and the natural phenomena to be focused on, with the aim of establishing in 2005 the feasibility of the deep geological disposal facility in the Callovo-Oxfordian clay formation in Meuse/Haute-Marne.

The overall documentation of this report, like the previous one, was subject to national reviews, as well also, on request from the ministries overseeing Andra, as an international peer review process, organized at the same time between October 2002 and February 2003 to assess the Andra programme in light of international practice. This review, organized by the NEA, the OECD’s nuclear energy agency, was made up of international experts from counterpart organizations of Andra, or from research bodies or technical support organizations of safety authorities. The review issued a general opinion, particularly on the quality of the documentation and the position of the research programme in relation to international standards. It also issued recommendations on a certain number of specific technical points.

The safety assessments undertaken by Andra in 2001 identified the components of the disposal facility and the natural phenomena to be focused on: for example, improved characterization of the geological environment, the study of the seals of the disposal facility access structure. These assessments were subject to detailed examinations by the ASN and the Institute for Radiological Protection and Nuclear Safety (IRSN) as well to an international peer review under the supervision of OECD/NEA, which confirmed or clarified the directions for further studies and research. This led Andra, in particular, to strengthen the interfaces between, on one hand, engineering and safety, and on the other hand, research and safety.

The assessments recommendations were considered in defining the priorities for the study and research programme. They also fed into considerations of the organization of the documentation in 2005 concerning the feasibility of the deep geological disposal facility.

In 2004, the sinking of the main access shaft of URL reached the Callovo-Oxfordian formation. The digging of an experimental tunnel at −445 m made it possible to carry out the first in situ characterizations and experimentations in the Callovo-Oxfordian formation. Subsequently, the sinking of the shafts resumed, and in 2005 reached the level of the underground laboratory in the middle of the Callovo-Oxfordian layer, then work started on digging the horizontal tunnels from the two shafts, which met each other at the end of 2005.

In 2005, after fifteen years of research performed under the law of 30 December 1991, and several safety iterations punctuated by examinations undertaken by ASN, Andra produced overall documentation (so called “Dossier 2005”), that comprised a report on design and operation, a report on phenomenological evolution of DGR and its geological environment from operating period to long term in post closure, and a safety case, to support the feasibility on principle of a reversible disposal facility for high-level radioactive waste and intermediate-level long lived radioactive waste in the Callovo-Oxfordian clay formation, studied using the URL.

This feasibility on principle has been established over an area (called transposition zone, “ZT”) of about 250 km² around the URL and defined as without major fractures and with characteristics of Callovo-Oxfordian clay formation like those observed in the Bure URL. Different representative positions of the DGR within this area were studied without prejudging the choice of its future location.

The purpose of the 2005 documentation was to assess the feasibility of the DGR in the Callovo-Oxfordian geological formation. As such, it obviously dealt with the safety of the DGR, an integral part of the feasibility, first after closure, as a fundamental objective of the geological facility, but also during its operation. It was based on data collected on the site of the URL at Meuse/Haute Marne site.

The objective of demonstrating feasibility and so the supporting safety case in 2005 was to show the existence of technical solutions for construction and operating of a safe disposal facility, but without any optimization of the DGR design at this step. The safety case presented two complementary safety analyses: one concerning the operation of the underground facility, and the other concerning the disposal system in the post-closure phase. It focused on assessing the most significant risks in operation (internal or external origin). For this purpose, accident scenario studies were used to assess the risk of dissemination of radioactivity in the event of a waste package being dropped, a fire in a lorry transporting packages or an explosion caused by release of hydrogen. These studies were supplemented by tests, in some cases.

The post closure performance of the disposal system was also assessed, for the facility as a whole and in terms of individual components. An impact assessment in terms of dose was also carried out for indicating in particular that the impact complied with the long term protection objectives set by the RFS III.2.f. The analysis showed the clay host formation and the seals of access as pillar of the long term safety.

This work contributed, at the stage of the disposal facility feasibility report, to verification of the capacity to reduce risks in operation and to manage the consequences of uncertainties in the long term at the lowest level possible in the current state of knowledge and techniques available at the time. The 2005 feasibility report constitutes the culmination of a cycle of preliminary safety iterations, on one hand, based on acquisition of knowledge based on an important programme of scientific and technological study and research undertaken since 1991 and first acquisitions from the Bure URL, and, on the other hand, on the first design elements and the related safety assessments.

The acquisition of scientific and technological knowledge, including the lessons learned from the Bure URL and the various safety–knowledge–design iterations carried out over 15 years made it possible to show the favourable properties (high thickness, low permeability, low diffusion of elements in solution, high retention capacity, etc.) of the Callovo-Oxfordian clay formation for the containment of radionuclides as for the construction of underground structures.

This knowledge supported the safety assessments that showed the achievement of the fundamental objective of protecting the environment and people, and the robustness of the safety in the long term. The great majority of the radionuclides contained in the waste packages thus remain contained in the disposal facility or in the Callovo-Oxfordian near field of the disposal facility. Only a few of the radionuclides, the long lived mobile ^{129}I and ^{36}Cl, can migrate within the Callovo-Oxfordian and reach its upper and underlying formations.

As for the safety case of 2001, the “dossier 2005” and the safety case was subject to technical examination by IRSN experts at the request of the ASN, as well as an international expert review conducted under supervision by the Organisation for Economic Co-operation and Development–Nuclear Energy Agency (OECD–NEA) at the request of the ministries overseeing Andra. Following examination of the feasibility report in 2005, in its opinion, the nuclear safety authority noted that “These examinations highlighted that major results concerning the feasibility and safety of a disposal facility were obtained for the Bure site” and that “the principles presented by ANDRA, in the short and long term, should fulfil the radiological objectives of RFS III.2.f.”

As the 2005 stage was the start of the route to be followed toward industrial implementation of a disposal facility, at the end of this feasibility stage, Andra identified the information to be explored in greater detail in order to achieve an industrial operation and to continue the experiments in the Bure URL (i.e. mechanical performance of the rock in relation to excavation techniques). Andra also identified the challenging issues on the design and the safety assessments during its operation in relation to the industrial development of the DGR.

7. SUCCESSIVE SAFETY CASES TO SUPPORT THE GRADUAL INDUSTRIAL DEVELOPMENT OF THE DESIGN OF THE CIGÉO DISPOSAL FACILITY TOWARD THE LICENSING APPLICATION

From 2006, Andra continued to develop the design, increase its knowledge of the characteristics and behaviour over time of the components of the DGR and of the geological environment, particularly the Callovo-Oxfordian formation, and undertook related safety assessments. Optimization has then been considered.

Based on government validation of the Andra proposal for the location for the underground installation on an area for detailed reconnaissance (called “Zira”) of about 30 km² within the transposition zone (Fig. 5) and the choice of two locations for the surface installations, one called the ramp zone located in Haute-Marne and the other called shaft zone in Meuse in line with the underground installation location area, and the ASN opinion on the Andra 2009 documentation in 2011, Andra initiated the industrial design phase of the Cigéo project as a whole. It took place in several key stages including a sketch phase, a basic preliminary design phase then a detailed preliminary design phase, for the future construction license application.

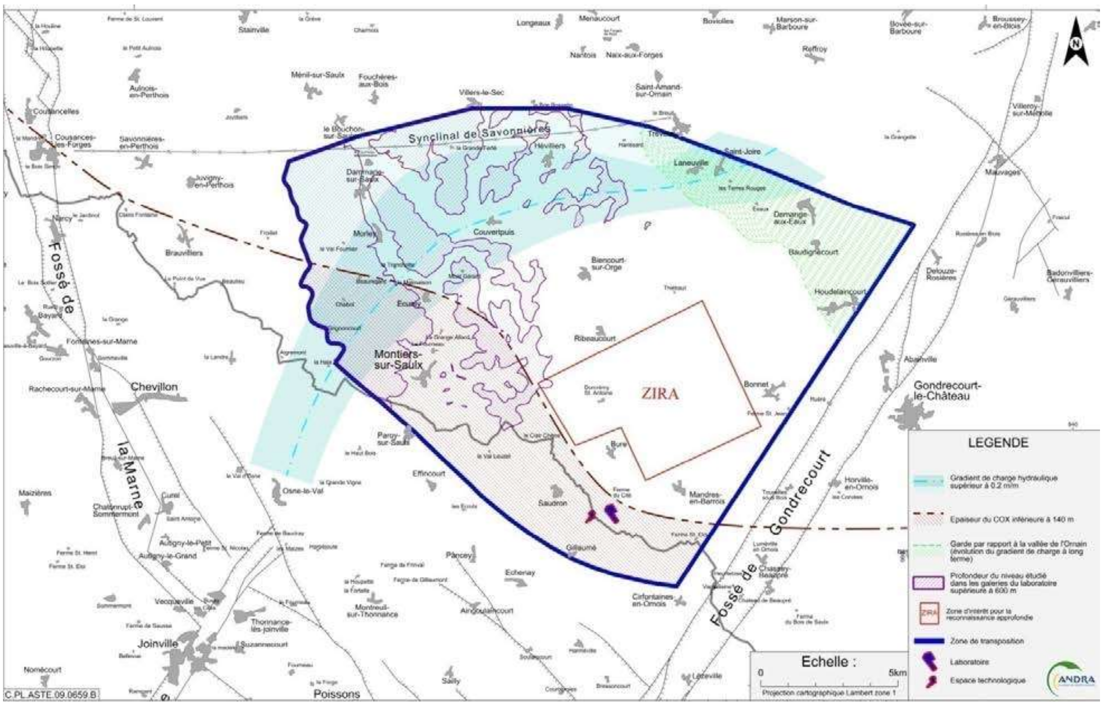

FIG. 5. The detailed reconnaissance area (ZIRA) within the transposition zone (ZT) (see safety options in reference [5]

Between 2011 and 2013, Andra issued intermediate reports that were subject to examinations under ASN oversight through its technical support to the IRSN. The reports focused on the input data and first elements of design and safety in the sketch stage. Following the technical examinations of these reports, between 2013 and 2014, the ASN issued opinions stating a position and expressing additional requirements to Andra in relation to the safety options documentation, as well as for the future construction license application. The safety iterations connected with the progress in industrial development of the design of the Cigéo disposal facility and of studies and research undertaken particularly in the URL have made it possible (i) to develop the disposal facility design, (ii) to consolidate the achievements concerning the Callovo-Oxfordian stratum and the performance of the disposal facility, and (iii) to undertake associated safety assessments. The successive process for design optimization is shown in Fig. 6.

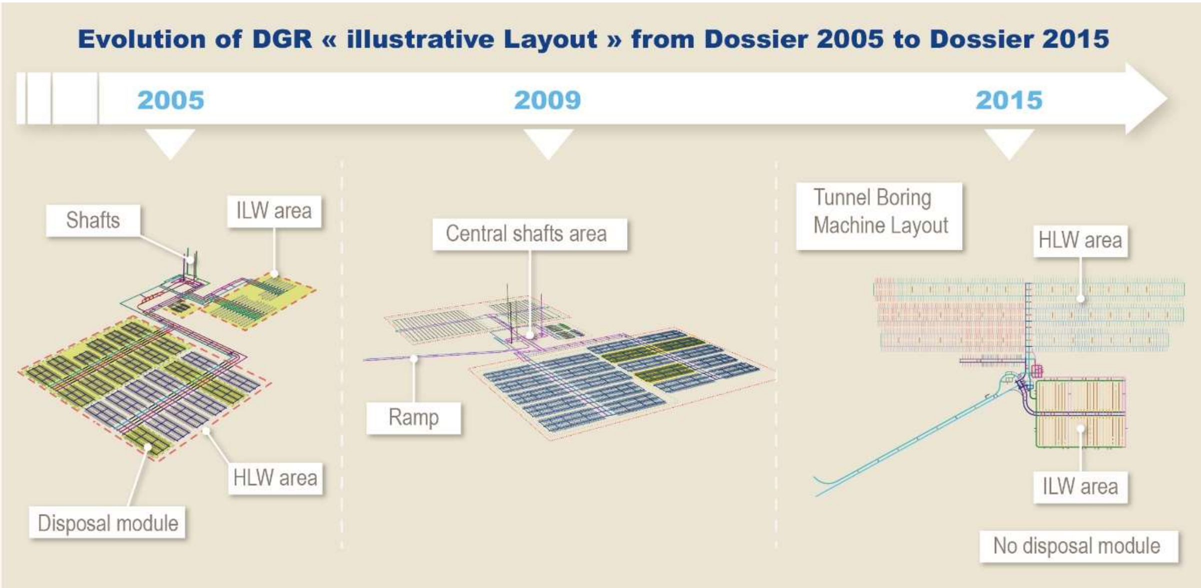

FIG. 6. Illustration of successive optimization of the design of the DGR with development of the Cigéo project and related safety cases.

The establishment of the safety options formed a key stage of the industrial development and construction of the Cigéo project. In April 2016, Andra submitted a safety options document called “Cigéo 2015” to the Nuclear Safety Authority (NSA) considering that this was an important step in the gradual development of the Cigéo design before submitting the construction license application.

According to the French regulatory texts, as safety is at the heart of the project headed by Andra, the safety options documentation was used to stabilize the main principles–requirements, methods, design choices and associated preliminary safety assessments towards the safety case that will support the future demand for the construction license application.

The safety options were subject to a detailed examination on behalf of ASN by IRSN. It was also subject to an international peer review mandated by ASN and on behalf of the IAEA. The ASN opinion on the safety options was published in January 2018 and constitutes the Andra roadmap up to the construction license application.

The ASN opinion, which is generally positive, is indeed an important step forward for the project:

- ASN considered the project had reached an overall satisfactory level of technological maturity at the stage of the safety options documentation
- ASN emphasized that:
  - Andra has acquired detailed knowledge of the Meuse/Haute-Marne site, confirming the suitability of the area selected for installation of the DGR and constitutes a high-quality basis for supporting the safety case;
  - The quality of the studies and the composition of a substantial amount of knowledge about the development of the behaviour of the waste and EBS (HLW metallic disposal container, cementitious and clay-based components);
  - The inventory of waste to be disposed has been defined appropriately.
- ASN has also identified issues requiring special attention in the safety case to support the licensing application:
  - Elements justifying choices of underground architecture layout;
  - Monitoring strategy;
  - Management of post-accident situations;
  - Particular attention to bituminous waste (research on neutralizing the chemical reactivity, studies to modify the design to preclude the risk of runaway exothermal reactions, improvement in characterization, among others).

8. UPCOMING SAFETY ITERATIONS AND THUS UPDATED SAFETY CASES

The licensing application will be based on all information acquired already during previous safety iterations and will endeavour, on one hand, to consolidate the information already acquired and, on the other hand, to answer questions raised in the ASN opinion of 2018 concerning the safety options. The so-called “preliminary safety report,” which constitutes one of the reports supporting the licensing application, will incorporate the elements of a new safety–design–knowledge iteration since the safety options. The level of details will be in line with the gradual development of the Cigéo DGR, particularly its gradual constructions and operations, including an initial industrial pilot phase with a HLW pilot quarter and four IL-LLW disposal cells.

In accordance with the regulations, with the Environment Code (Articles R.593-22 to R.593-26), the licensing application, in particular the preliminary safety report will be subject to an examination by ASN. At the end of the examination process, in accordance with the established principles in the Environment Code, if the licensing application is issued, it will be passed by order of the Board of Directors after ASN opinion. This order will also be able to impose instructions concerning the design, construction, or operation of the facility.

Next, prior to the operational phase (emplacement of the first waste disposal package), Andra will have to compile a new safety case based on feedback from the initial construction phase and technology advances in design. This safety case will be submitted to the French national authority and reviewed again on behalf of ASN to obtain authorization for the facility to begin operation. According to the regulatory framework, every ten years, Andra will have to perform regular re-examination of facility safety, considering the experience acquired during operation and the changes in knowledge and rules applicable to similar installations.

9. CONCLUSION

Andra has acquired 30 years of experience in the development of safety cases for the deep geological disposal of HLW and IL-LLW. While the fundamentals have not changed, the safety case has considered the increasingly precise development of the Cigéo project, including optimization of design and the conservative approach to support the DGR robustness in post-closure.

The safety case that will be included in the future licensing application is the result of these 30 years of development. If the licensing application underlines the high level of maturity of the Cigéo project development, it is only a step. In line with the gradual industrial development of the Cigéo project over more than 100 years, new stages will have to be taken, such as an initial industrial pilot phase before initiating further development. If authorized, the Cigéo project will therefore be the subject of new safety cases (at least every 10 years), taking advantage of operating experience feedback between two iterations, scientific and technological progress, and possible evolution of the design in a logic of continuous progress (to increase safety robustness, etc.). Moreover, the design of Cigeo is considering possible changes in French radioactive waste management, in particular the disposal of spent fuel or graphite. Should such a decision be made, a specific licensing application including an associated safety case would be carried out. Andra has acquired 30 years of experience in the development of safety cases for the deep geological disposal of HLW and IL-LLW. While the fundamentals have not changed, the safety case has considered the increasingly precise development of the Cigéo project, including optimization of design and conservative approach to support the DGR robustness in post-closure.

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Paper ID#89

DEVELOPMENT OF A SAFETY ASSESSMENT FOR THE BRAZILIAN NEAR SURFACE REPOSITORY IN THE SITE SELECTION PHASE

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Abstract

The internationally accepted approach for developing a safety case focuses on the integration of the repository design and site characteristics, associated with the safety demonstration through the elaboration of safety assessments. These tasks may relate to a given stage of the project development. The paper describes a post-closure safety assessment for the Brazilian Near-surface Repository for Low and Intermediate Level Radioactive Waste at the current site selection stage, including the context, assumptions, scenarios, methodology, and analysis of the mathematical simulation results. The analysis was based on the methodology established by the IAEA in the Improvement of Safety Assessment Methodologies (ISAM) reports and employed the code RESRAD-OFFSITE. The reference scenario involving on-site dwelling and farming was developed to reflect the specific data applicable to the Preliminary Areas of Selection Site phase of the project, complemented with generic data from the literature. Due to the lack of isotopic inventory data, reference radionuclides were included in the analysis using a unit activity concentration and the resulting specific dose results showed which radionuclides could be the most significant for the simulated scenario. Three specific peak doses were observed: the first at the beginning of the simulation time, of short duration (due to ^{226}Ra); the second of lower magnitude, around 1000 years (related to ^{129}I), and the third of greater magnitude and duration, between 4000 and 19 000 years (related to the process of erosion of the cover layer). Carried out at the early stages of the development of a repository project, such analysis can be useful to support decision makers to assess needs for further analyses and to build confidence.

1. INTRODUCTION

The internationally accepted approach for developing a safety case focuses on the integration of the repository design and site characteristics, associated with the safety demonstration through the elaboration of safety assessments. These tasks may relate to a given stage of the project development. IAEASafety Standards Series No. SSG-23, The safety case and safety assessment for the disposal of radioactive waste [1] states that the safety case is “a collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety-related work associated with the disposal facility” (Fig. 1). In this context, the safety assessment is a necessary part of the safety case and involves a systematic quantification of the exposure from radiation resulting from the disposal system and the comparison with dose criteria. The safety case is normally developed in a step by step approach, reflecting the progressive increase in the technical understanding and definitions of the disposal system over time, associated with the different phases and contexts of the project development, and the supporting safety assessment needs to be reevaluated to reflect the current level of the safety case.

The paper describes the context, assumptions, scenarios, methodology, and analysis of the mathematical simulation results for the preliminary post-closure safety assessment of the Brazilian Near Surface Repository for Low and Intermediate Level Radioactive Waste, reflecting the current definitions of the conceptual design and site selection phases. Due to the lack of data necessary for the analysis, in terms of isotopic inventory, deposition system details, and the final decision about the site selection process, the output of this analysis can be seen as an indicator of which radionuclides are most significant for the simulated scenario, rather than the end point needed to compare to the criteria defined the Brazilian regulatory body (annual individual effective dose to an adult member of the exposure group, CNEN NN 8.02 [2]). Thus, the paper presents a generic methodological exercise and a basis for the development of future assessments, when more information about the facility and the site will be available and is related to the building confidence process in the long term safety of the facility.

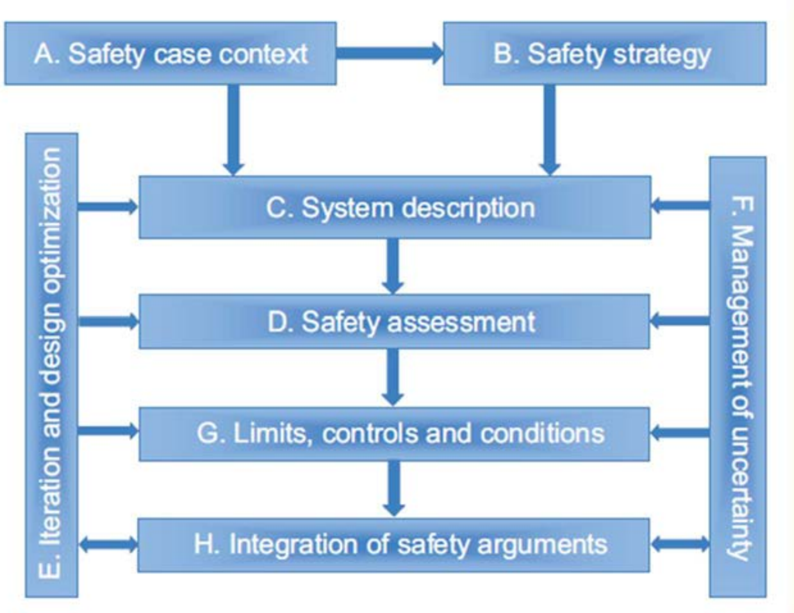

FIG. 1. Components of the safety case and the role of the safety assessment[1].

This analysis was developed based on the methodology established by the IAEA in the ISAM reports (Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities) [3]. The process of defining scenarios for the safety assessment within the ISAM methodology starts with the elaboration of a Features, Events and Processes (FEP) list. FEPs are defined as the characteristics, events and processes that could, directly or indirectly, have an influence on the radionuclide release, transport on the different compartments of the geosphere and exposition of the critical group, among others, and it has to reflect all aspects of the deposition system that were effectively considered in the analysis. The FEP list is a powerful tool for a systematic definition and justification of scenarios and to report these decisions, contributing to the transparency and confidence of the process.

2. SCENARIO DEVELOPMENT AND MODELLING

The main assumptions of this safety assessment are: partial definitions of the project in its conceptual stage; a radionuclides list estimated based on forecasting of radioactive waste from the Brazilian Nuclear Power Plants (Angra 1 and 2) and literature data; radioactive activities given in terms of a unit activity per unit mass of deposited material (called unit activity concentration); use of country-specific data applicable to the Preliminary Areas of Selection Site phase of the project; and use of simple and conservative models, complemented with generic data from the literature, when applicable.

The geosphere data used for this analysis reflect the Preliminary Areas phase of the site selection. Despite the lack of definition of specific candidate sites (with the consequent lack of site-specific data), all definitions during the site selection process, in terms of geology, hydrology, meteorology, and exposure possibilities, were incorporated in this analysis. For some data, Brazilian-specific large-scale data were used, by applying statistics for determining the most frequent values. As an example, for obtaining exposure-related data, demographic databases were used to obtain the most prevalent food habits. In terms of the repository design, the current conceptual project of the disposal system, including the repository dimensions, waste form, and some definition of the engineer barriers (cover and backfill), are also reflected in the present analysis, even with some project-specific definitions still unknown (such as the cover hydraulic properties). To fill these gaps, literature values were used and, if necessary, could be used as references for the next development phases of the project.

A major uncertainty at this stage of the project is the isotopic composition of the waste since only a little information on the radionuclide activities is available for the main source (Nuclear Power Plants [NPP] waste), limited to gamma emitters. The list of these radionuclides was completed using the literature for near surface repositories reference inventory [4]. As for the concentration activity of each radionuclide, few possible approaches were investigated, such as composing a synthetic activity concentration list based on similar repositories published data, scaled for the projected waste volume, or obtaining limiting activities, based on consolidated references [4]. Using the derived concentration guideline levels (DCGLs), provided by the code used for this analysis (RESRAD-OFFSITE [5]), was also considered as an alternative for overcoming this problem. These are limits of concentration for a single radionuclide (and its progeny) to ensure that the predicted dose from this radionuclide alone is within a specified dose limit. However, despite all these approaches are consolidated and can be applied for different purposes during the safety case development, at this stage of the project, they were not considered to be able to provide useful information for the next stages.

Instead, the analysis was carried out applying a unit activity concentration for all radionuclides of the inventory list. As RESRAD-OFFSITE code requires the use of activity per unit of deposited mass, an activity concentration of 1 Bq/g was used for each radionuclide of the original inventory. With this approach, the dose results provided by the code are related to a unit of a radionuclide activity concentration, or, as called here, the specific dose. Having removed the factor related to the total activity of each radionuclide, the results obtained by this approach provide information about the combined actions of the radioactive characteristics (decay and ingrowth of progeny), chemical (for example, distributions coefficients, Kds, in geological media) and exposure (dose conversion factors), in addition to the effect of contaminant transport processes in the repository, geosphere, and biosphere.

The scenario assumed for the analysis, called here a reference scenario, was a generic scenario with a conservative character according to international experiences based on reviews of repository safety analysis and safety cases, as well as on information about possible sites for the facility. It contemplates the long term, post-closure exposure of adult individuals dwelling and farming on the top and the surroundings of the repository deposition area, ignoring the institutional control period after closure. Alternative scenarios were not included in the analysis, but an approach for their development was envisioned for future safety assessments, with the dual purpose of analysing the impact of different FEP configurations and verifying the design safety margins, demonstrating its robustness and verifying the importance of some components of the repository.

The conceptual model assumed for the reference scenario includes: release of radionuclides from the deposition zone (source term) through leaching by infiltration of rainwater and irrigation, radon release and dust suspension; transport of radionuclides through the deposition zone (primary contamination), geosphere (unsaturated and saturated zones) and biosphere (atmosphere and soil); estimation of the dose evolution overtime for a rural resident farmer scenario, considering the pathways for ingestion of groundwater, food produced locally (plant and animal products), inhalation of radon, inhalation of particles containing radioisotopes, and direct external exposure onsite (directly at the deposition site) and offsite (areas out of the deposition site) (Fig. 2).

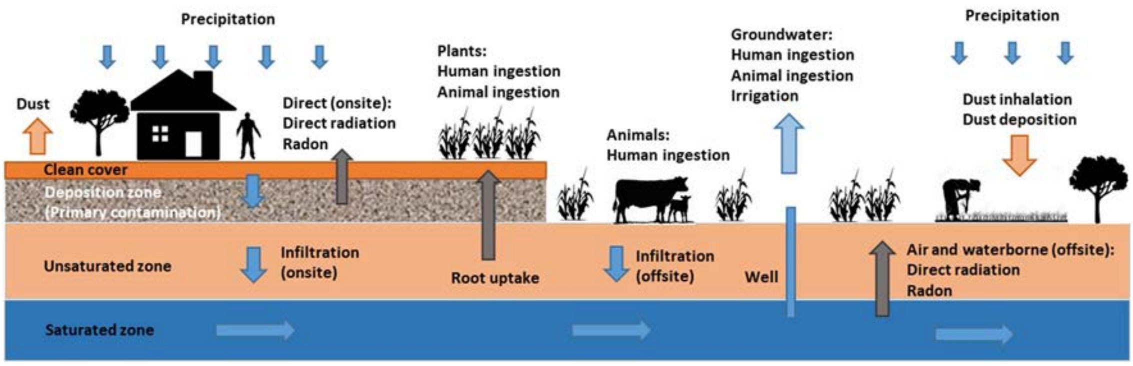

FIG. 2. Exposure pathways considered in the modeling.

RESRAD-OFFSITE code version 4.0, developed by Argonne National Laboratory, was used to implement the assumed conceptual model. This code evaluates radiological doses and excess cancer risks to an individual residing and/or working in onsite or offsite contaminated areas, using models of radionuclide transport in the air and groundwater. The code has built-in tools to study parameter sensitivity and uncertainty of calculated doses and risks. The sensitivity analyses can be carried out considering each parameter separately (single-parameter method) or through probabilistic simulation with multiple parameters. Sensitivity analysis and uncertainty analysis help to understand the effects of input parameters on mathematical model results.

3. SAFETY ASSESSMENT FOR THE REFERENCE SCENARIO

The simulation of dose evolution considering the unit activity concentration (1 Bq/g) for all radionuclides used as isotopic inventory (uniformly distributed in the deposition zone) allowed to obtain the dose per unit of activity concentration (referred here as specific dose) as a function of time, in terms of the total dose (considering all radionuclides), the total dose from exposure pathway and the partial dose for a particular decay chain. The evolution of the total specific dose over time, obtained by simulating the reference scenario (Fig. 3), shows three specific peak doses: the first at the beginning of the simulation (right after the repository closure), of short duration; the second, of lower magnitude, around 1000 years; and the third, of greater magnitude and duration, between 4000 and 19 000 years. To help to identify the main radionuclides responsible for these peaks, Fig. 4 shows the specific dose over time for the different pathways for the reference scenario.

It is possible to assume that the first peak is due to the inhalation of onsite radon, related to the chain of ^{226}Ra in the deposition area. This exposure pathway should not be of concern when the institutional control period is included in the analysis, which is not considered in the present work. The second peak dose, around 1000 years, is due to the ingestion of contaminated water and plants, meat, and milk (all contaminated by water), related to the ^{129}I decay. This exposure occurs due to the leaching and transport of radionuclides dissolved in water through the geosphere, reaching the supply well of the residents, who in the reference scenario use water for domestic use, animal feed, and irrigation of plantations.

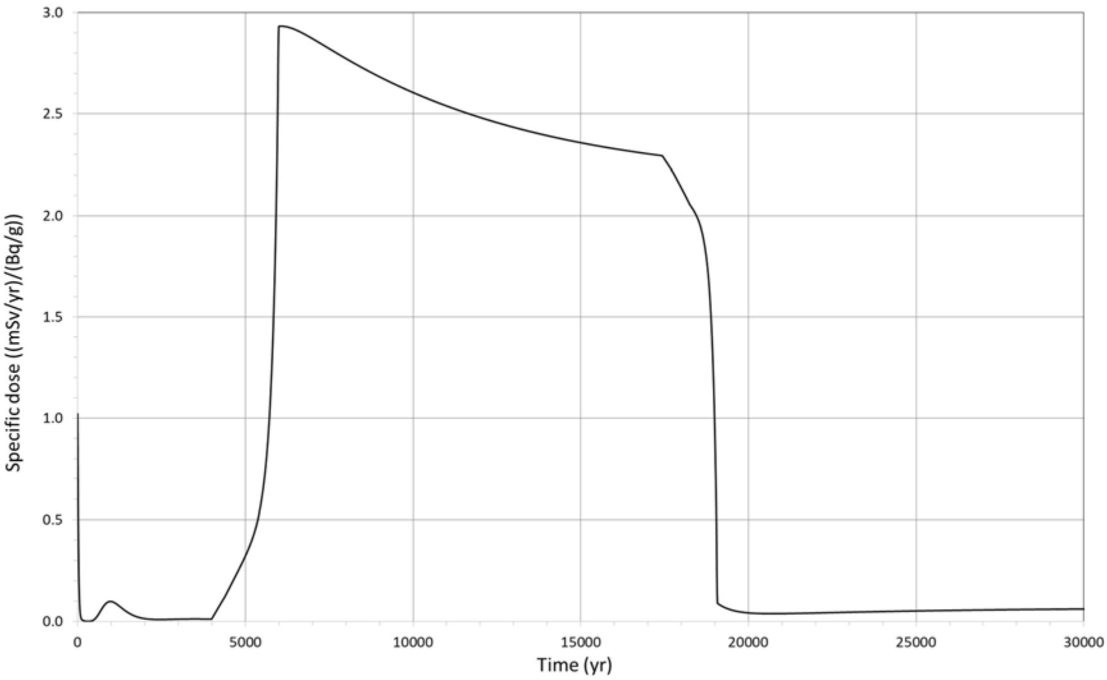

FIG. 3. Evolution of the total specific dose over time for the reference scenario.

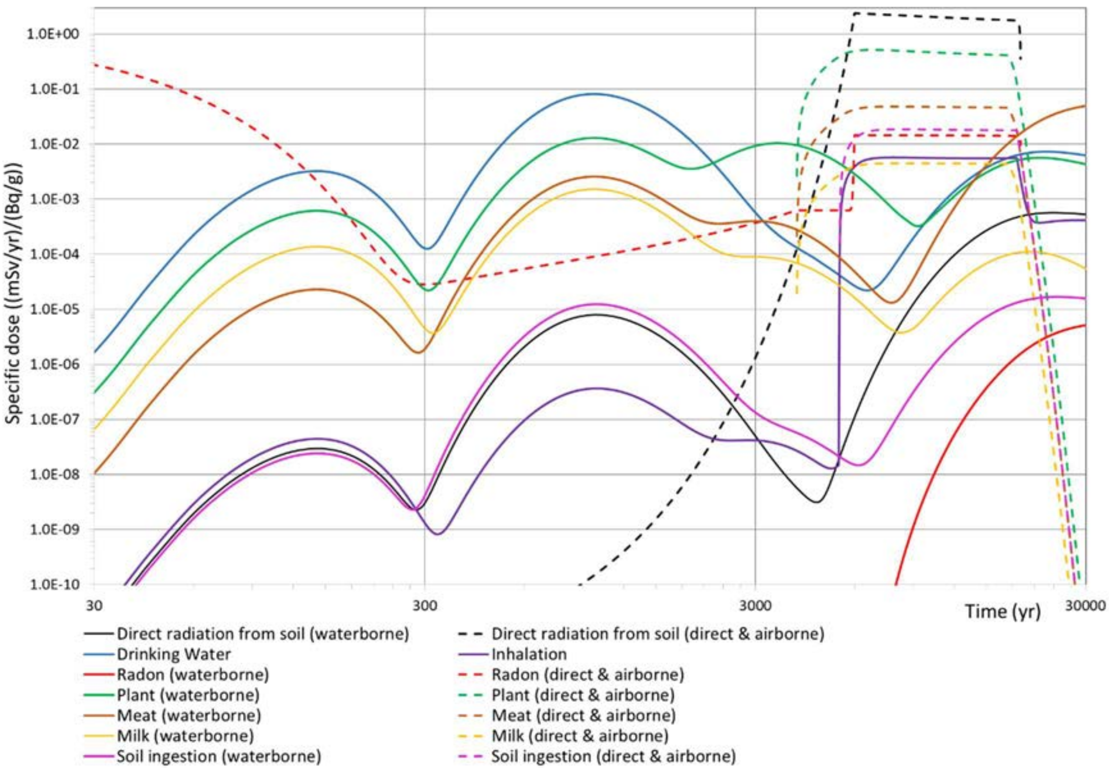

FIG. 4. Evolution of the specific dose over time for the different pathways for the reference scenario (log-log scale).

The third group of peaks, with greater duration and magnitude compared to the previous ones, consists of the sum of peak doses related to different pathways, all of them originating from the deposition area (onsite) or airborne secondary contamination (offsite). The maximum value of the specific dose occurred at 6070 years, related to direct exposition from soil and plant and meat ingestion, mainly due to ^{232}Th, ^{234}U, ^{94}Nb, and ^{137}Np. These peaks are assumed to be related to the process of erosion of the cover layer, leading to the progressive reduction of the thickness of the barrier, ultimately causing the roots of the plants to withdraw their nutrients directly from the deposition area and increasing the external direct exposure of the residents living directly above the deposition zone.

Figure 5 provides an overview of the relative importance of some radionuclides (and their progenies) included in the analysis for the total estimated specific dose, in terms of maximum or peak specific dose, occurring, therefore, at different times of simulation. This figure can be an indicator of the main contributors for the total dose for the reference scenario and provide a preliminary guide of where radionuclide-specific data acquisition should be focused on.

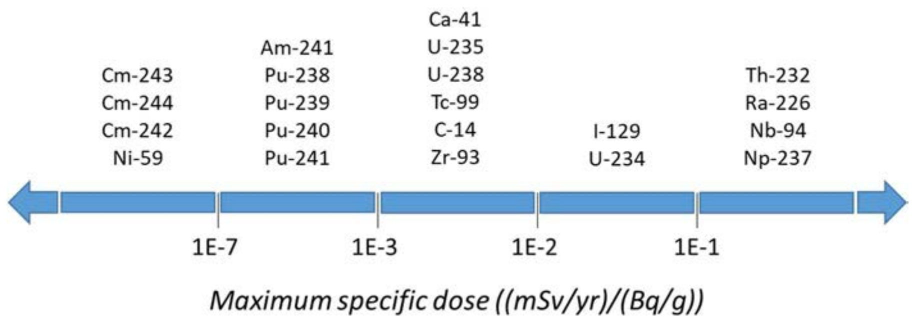

FIG. 5. Maximum specific dose range for different radionuclides and progenies for the reference scenario (cutoff lower value for inclusion was 1E-10 (mSv/ano)/(Bq/g)).

The sensitivity analyses of the input parameters of the model were performed based on the results obtained for the reference scenario, to confirm the relevance of cover layer thickness on the total specific dose, and identifying which are the most sensitive parameters for the following pathways: external irradiation, food intake (onsite), and water and water contaminated food intake. Using the single-parameter method and the probabilistic simulation, the most relevant parameters were those related to the erosion of the cover layer of the deposition area: evapotranspiration coefficient in the primary contamination area, soil erodibility factor of the cover, and rainfall and runoff factor (Fig. 6).

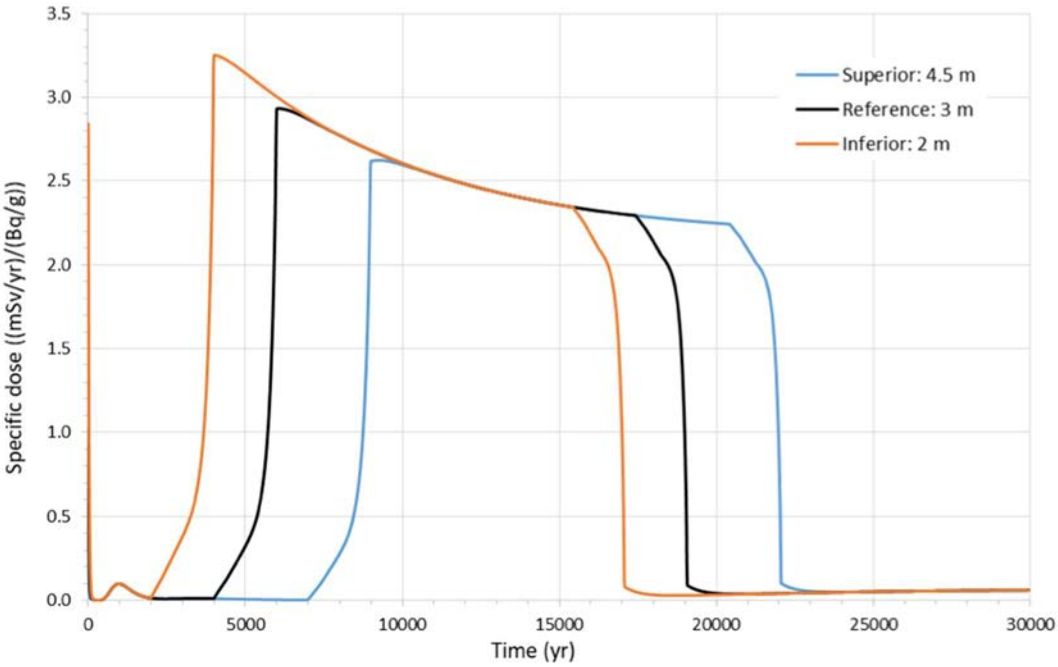

FIG. 6. Sensitivity analysis for the cover depth using the single-parameter method.

As expected, based on the results for the reference scenario, considering all exposure pathways and radionuclides, the concentrations of ^{232}Th, ^{94}Nb, and ^{137}Np in the deposition area were the most relevant parameters for the total specific dose, since these radionuclides are the main contributors to the peak doses that occur between 4000 and 19 000 years (Fig. 7). More comprehensive probabilistic sensitivity analyses were also carried out, addressing a larger number of parameters, and identifying the parameters that, even though were not significant in the analysis considering a specific unitary isotopic inventory, may prove to be more important when using a realistic isotopic inventory for the project.

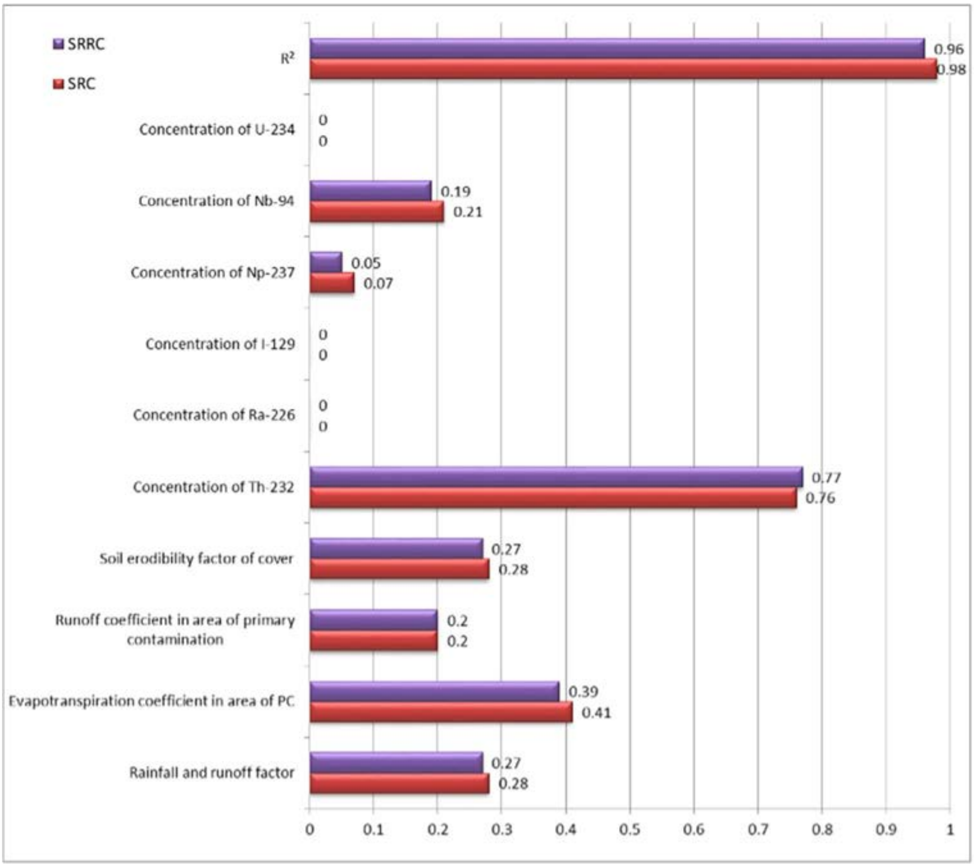

FIG. 7. Importance analysis of parameters influencing the total specific dose.

Among the results from the simulation of the reference scenario and the sensitivity analyses, the following can be highlighted:

— The concentration of deposited ^{226}Ra strongly influences the dose related to the radon inhalation at the deposition area right after the repository closure, by disregarding the institutional control period.
— The doses for the pathways related to the ingestion of contaminated water and food via groundwater transport are mainly due to the presence of ^{129}I and ^{99}Tc in the deposition area, as well as to the parameters related to leaching of these radionuclides and their transport in unsaturated and saturated zones.
— The concentrations of ^{232}Th, ^{94}Nb, ^{237}Np, and ^{234}U in the deposition area are relevant contributing factors for the predicted doses related to the pathways direct exposure and ingestion of plants and meat (onsite), between 4000 and 19 000 years, because of erosion of the cover layer of the deposition area.
— The less relevant radionuclides than the previous ones that contribute to the total specific dose are ^{14}C, ^{41}Ca, ^{235}U, ^{238}U, ^{93}Zr, ^{241}Am, and ^{238}Pu.

4. CONCLUSIONS AND REMARKS

A structured safety analysis was carried out for the near surface repository based on the ISAM methodology, implemented using the RESRAD-OFFSITE code. An approach for modeling the reference scenario, selecting alternative scenarios, evaluating the post-closure radiological impact, and analyzing sensitivity and uncertainty was presented and discussed. The ability of RESRAD-OFFSITE for modeling geometry, radionuclide distribution in the deposition zone and other engineered barriers proved to be adequate for the current phase of the analysis. The use of a unit activity concentration for all listed radionuclides allowed to obtain a hierarchy of importance for the dose contributors, based on the combined effects of their radioactive, chemical, and exposure characteristics added to the effect of contaminant transport processes in the repository, geosphere, and biosphere.

The list of radionuclides from the isotopic inventory used in the simulations does not correspond to the actual situation of the future repository, but rather the information available when preparing this paper. Therefore, it is important to remember that the use of a more realistic isotopic inventory, after the design definitions of the repository, can change the relative importance of radionuclides and the pathways pointed out in this analysis. However, if the trend discussed is verified, attention is recommended in the subsequent phases of the safety assessment with the design parameters related to the design of the cover layer and its erodibility. Therefore, due to the relevant role identified for this engineered barrier, the importance of characterizing phenomena related to its erosion is highlighted, identifying the main parameters of the materials to be used and the hydrological and climatological conditions of the candidate site, for the more advanced phases of the repository project. In addition, it is important to assess the effects on possible deviations from the reference scenario related to this barrier in the alternative scenarios.

All non-included considerations that should be addressed in the future, such as certain meteorological and geological phenomena, as well as non-radiological impacts on the human population and radiological and non-radiological impacts on non-human biota, are clearly stated on the FEP list developed for this analysis. More than a scenario development and justification tool, the FEP list has proven to be a valuable way to organize aspects that were addressed in a particular analysis, the ones already ruled out in previous safety assessment runs and what is still left to be analyzed throughout the development of the safety case. In the future, this FEP list could be used as the base for a new step of scenario development, including the alternative scenarios.

ACKNOWLEDGEMENTS

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THE SAFETY STUDY IN SUPPORT OF THE DEVELOPMENT AND IMPROVEMENT OF WASTE MANAGEMENT AT EL CABRIL DISPOSAL FACILITY

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Abstract

The El Cabril facility, located in the province of Cordoba in southern Spain, is the national disposal site for low and intermediate level radioactive waste. In addition to separate areas for the disposal of very low level and intermediate, and low level waste, the facility is equipped with processing and conditioning capabilities, laboratories to support waste characterization, and acceptance activities, and buildings for the temporary storage of waste to regulate operations. El Cabril obtained its operational authorization in October 1992, along with approval of the Safety Study licensing document. For nearly 30 years, the facility has been required to adapt to new technological, regulatory and management needs or realities, or both, turning the initial project into a project that is constantly changing to handle and optimize the management of such radioactive waste, while maintaining national and international safety standards. The Safety Study has proved an essential tool in this adaptation process to demonstrate compliance with the conditions of the operational licence, and in response to the demands of the regulatory body – the Spanish Nuclear Safety Council.

1. INTRODUCTION

Empresa Nacional de Residuos Radiactivos, S.A., S.M.E. (Enresa), is the entity responsible for the management of radioactive waste in Spain, including spent fuel.

Under Spanish law, low and intermediate level waste (LILW) and very low level radioactive waste (VLLW) is transferred from the producer or holder to Enresa, whatever the form and characteristics of the materials in question. Enresa operates the El Cabril Disposal Facility, located in the province of Cordoba, as an essential part of the national management system to manage radioactive waste. The El Cabril Disposal Facility is equipped with the technological capabilities needed for the processing, conditioning, and definitive disposal of waste under the established safety conditions. The installations include various conventional and radiation buildings, and the structures or vaults used for disposal on what are known as the North and South Platforms for LILW and the East Platform for VLLW (Fig. 1).

The El Cabril Disposal Facility has been in operation since October 1992, with indefinite authorization until the volumetric or radiological disposal capacity is used up, with specific safety and radiation protection limits and conditions issued by the Nuclear Safety Council [1,2].

The conditions and limits are established by the licensing documents on which the authorization is based, including the Safety Study. This document describes first the characteristics of the site, of the waste, and of the facility, and furthermore the organization of operations and the functioning of the facility, as well as a safety analysis in the operational phase and in the long term. In short, it presents the set of arguments and scientific, technical, administrative, and management tests demonstrating the appropriate safety and quality of all activities performed at the facility [3].

This presentation explains how the Safety Study has evolved from generic to more specific considerations in the various stages: design, construction, and operation, and during almost 30 years of the facility being in use, how this has provided support for the new technological, regulatory, and management needs or realities, or both, to which a response has been required, and in short, improvements to the management of radioactive waste.

FIG. 1. Aerial view of El Cabril Disposal Facility.

2. CONTENTS OF THE SAFETY STUDY

The Safety Study needs to, in accordance with the provisions of the Nuclear and Radioactive Facilities Regulation [4], contain the information required to conduct an analysis of the facility from the perspective of nuclear safety and radiological protection, as well as an analysis and evaluation of risks derived from the functioning of the facility, both under the normal regime and under accident conditions. It likewise needs to contain detailed descriptions of the safety functions, of all safety systems and safety-related structures, systems and components, their design specifications, and their functioning under normal operational and accident conditions. It furthermore identifies the regulations, codes, and standards applicable to the facility.

The Safety Study of the El Cabril Disposal Facility covers the following aspects:

— Description of the site and its characteristics, including supplementary data obtained during construction;
— Description of the facility as built, and of the processes that take place there;
— Description of the radioactive waste processed, conditioned and disposal;
— Description of the safety-related systems, structures, and components;
— Description of the design criteria and technical options implemented regarding radiation protection, control, and supervision of the facility;
— Description of the operational environmental radiation monitoring programme, to evaluate the impact derived from the functioning of the facility;
— Safety assessment in the operational phase, covering normal operations and accident situations;
— Long term safety assessment, covering situations of normal and altered evolution.

The Safety Study has periodically been revised to comply with the operational licensing conditions, and in response to the demands of the regulatory body, the Nuclear Safety Council (CSN). These revisions have been linked to modifications to the safety evaluation on the one hand, and design modifications on the other, and all correspond to improvements adopted to address the needs that have arisen over the years of operation of the facility, and the experience and knowledge built up over these years.

3. SAFETY STUDY AND SAFETY ASSESSMENT

It would be fair to say the safety assessment forms an intrinsic part of the Safety Study. The development of the safety evaluation in the different stages of design, construction, and operation has evolved from the application of generic methodologies to bespoke or specific methodologies.

At the design stage prior to construction, the evaluation methodology applied was the result of consideration of the regulations of the country of the reference facility – France – and the specific United States (U.S.) regulations for surface disposal of radioactive waste. In both reference cases, certain generic scenarios were established to be considered in the safety assessment, used to conduct the first safety evaluation of the El Cabril Disposal Facility.

In the construction or pre-operational stage, the long term safety assessment covered data for the site and the disposal design, and presumed data as to the characterisation of waste based on similarities with the waste processed at the reference facility (L'Aube).

In the operational stage, following construction of the facility, actions were taken with a view to improving the analysis of the scenarios evaluated, for better alignment with the reality of the facility and the specific values of the parameters to be used in the mathematical models, drawn from the studies conducted in the various areas involved in the evaluation, such as the characterisation of the materials of the engineering barriers and durability, characterization of the waste and the conditioning matrices, and knowledge of the site, thereby achieving a substantial improvement in the integration of knowledge acquired in each of the aforementioned areas.

Furthermore, from 2001 onward, when the current Operational Authorization was awarded to the facility, the safety evaluation has been supplemented by the presentation of information ordered in a systematic, documented, and accredited manner on the basis of technical and scientific studies, following the international guidelines that have progressively been implemented in this regard, as well as the instructions received from the CSN.

4. SAFETY STUDY AND DESIGN MODIFICATIONS

In order to address new technological, regulatory and management needs or realities, or both, the organization involved in the design of the facility and the organization of El Cabril itself hold periodic meetings at which they establish the working and improvement plans to be followed. This activity is governed by a procedure known as the "Design Modifications Procedure," which establishes the different phases involved in the process, from the design modification proposal, through the safety analysis and presentation, to the supervising ministry for evaluation, and following authorization with a favourable report from the CSN, implementation and commissioning or application, which concludes or closes the modification.

A design modification is understood as any change to operational, construction, or documentation characteristics of structures, systems, and components of the facility, and official operational documents. This means that practically any improvement or a new initiative is guided by this process.

As a result, once a new need or improvement has been detected, the corresponding safety analysis and evaluation is conducted, comprising an examination of the implications for safety, and the radiation protection of the facility in the short and long term. The following circumstances are analysed:

— There may be an increase in the likelihood of occurrence or a worsening in the consequences of an accident or malfunction of a safety-critical component or equipment in the short or long term at the facility, which is covered by the Safety Study.
— The change may result in the possibility of an accident or long term behaviour that is anomalous and different from the conditions analysed in the Safety Study.

In this examination, the Safety Study serves as the essential support tool for the incorporation of design modifications and regulatory changes to demonstrate compliance with the criteria, standards, and conditions on which operational authorization of the facility is based.

By way of example, the following design modifications are the most representative that have been conducted during the years that the facility has been in operation, and where the Safety Study provided the basis for their development.

- Adaptation of systems for the management of wastes arisen from the accidental smelting of ^{137}Cs sources at scrap yards.
- Development and operation of the complementary facility for the disposal of VLLW, including the determination of waste acceptance criteria.
- Capillarity process observed in LILW vaults, with generation of free water inside.
- New configuration of a disposal unit better suited to dismantling needs to optimize the volume available in LILW vaults.
- Disposal of spent sealed sources with a half-life between ^{60}Co and ^{137}Cs in LILW vaults.

Regarding changes resulting from adaptation to new regulations or a revision of the existing regulations, the following changes supported by the Safety Study should be emphasized:

- Modification of the Regulation on Health Protection against Ionizing Radiation in 2001 and 2010.
- Royal Decree on physical protection of nuclear facilities and materials and radioactive sources of 2011.
- Various Safety Instructions and Guides issued by the CSN regarding, among other aspects:
    - Requirements as to the nuclear facility management system, integrating safety, occupational risk prevention, environmental protection, physical protection, quality, and economic aspects, to ensure safety is adequately considered in all the organization's activities (IS-19).
    - Radiation control of waste materials generated at nuclear facilities (IS-31).
    - Quality guarantee at nuclear facilities in operation (GSG-10.07).
    - Content and Criteria for the generation of Radioactive Waste Management Plans of nuclear facilities (GSG-09.03).
    - Long term safety evaluation of definitive surface disposal of LILW (GS-09.04).

The description and safety evaluation of all the stated design modifications and regulatory changes are set out in the Safety Study through the inclusion of the set of arguments and scientific, technical, administrative, and management justifications demonstrating the appropriate quality and safety of the activities associated with the design modifications or regulatory changes.

5. CONCLUSIONS

El Cabril obtained its operational authorization in October 1992, along with approval of the Safety Study licensing document.

The Safety Study contains the information required to conduct an analysis of the facility from the perspective of nuclear safety and radiological protection, along with an analysis and evaluation of the risks derived from the functioning of the facility, under the normal regime and accident conditions. It likewise contains the set of arguments and scientific, technical, administrative, and management justifications demonstrating the appropriate quality and safety of the activities undertaken at the facility.

During nearly 30 years in operation, the facility has been required to adapt to new technological, regulatory, and management needs or realities, or both, turning the initial project into a project which is constantly changing to handle and optimize the management of such radioactive waste, while maintaining national and international safety standards. The Safety Study has proved an essential tool in this adaptation process to demonstrate compliance with the conditions of the operational licence, and in response to the demands of the regulatory body – the Spanish Nuclear Safety Council.

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Paper ID#111

RESEARCH AND DEVELOPMENT PROGRAMME FOR THE DEVELOPMENT OF A DEEP RADIOACTIVE WASTE DISPOSAL FACILITY IN THE RUSSIAN FEDERATION: BASIC PRINCIPLES OF DEVELOPMENT, STRUCTURE, AND SPECIFIC FEATURES OF ITS IMPLEMENTATION

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Abstract

This paper deals with modern treatment of the Safety Case (SC) concept and basic principles of how it should be fulfilled in the Russian Federation. The paper considers the stages of development and elaboration of the research and development (R&D) programme, its structure, scientific features, and implementation as a part of Safety Case development for a deep radioactive waste disposal facility at the Yeniseiskiy site in the Krasnoyarsk Territory. It is also indicated that the main connection between the SC and an R&D programme is by following an iterative approach.

1. INTRODUCTION

The Russian Safety Case (SC) concept is currently being standardized with the internationally recognized concept [1], which considers the following areas:

— The set of safety arguments built up and recurrently verified (iterative approach).
— The set of considered scenarios and factors under each scenario being evaluated to demonstrate its completeness.
— Specific aspects of the long term safety assessment, in particular:
  - Forecasts regarding the processes that can potentially occur in a long term perspective at the site and within its area of influence;
  - Accounting for uncertainties of various origins;
  - Increasing the validity of the results obtained, reducing the conservatism in the estimates along with data accumulation.

The paper seeks to highlight the current understanding of the SC concept and its influence on the plans drawn regarding the development of a deep disposal facility for radioactive waste (DDFRW) at the Yeniseiskiy site in the Krasnoyarsk Territory and on the implementation of relevant activities. In 2016, this site was approved for a site-specific underground research laboratory (URL) construction (the corresponding licence was issued to the National Operator for RW Disposal). The licensing process involved the SC development based on a set of relevant information on the properties of the geological environment, characteristics of the waste inventory accumulated due to past activities, and other information available at the time.

At the same time, the Russian regulator has been developing some new regulations and guidance on the DDFRW long term safety demonstration procedure and on the layout of relevant documents taking into account the experience gained and laid down in International Atomic Energy Agency (IAEA [2] and Nuclear Energy Association (NEA) documents [1].

2. CURRENT UNDERSTANDING OF THE SAFETY CASE CONCEPT IN RUSSIA

The SC concept is currently understood as a collection involving a full range of various safety aspects presented as a series of final documents (Fig. 1). The final document is built upon issue of main topical documents based on reports presenting some specific studies and their findings and accordingly are reviewed as new information is acquired and reconsidered. At the same time, the structure and the content of a particular document (series of documents) depends on the results of certain studies.

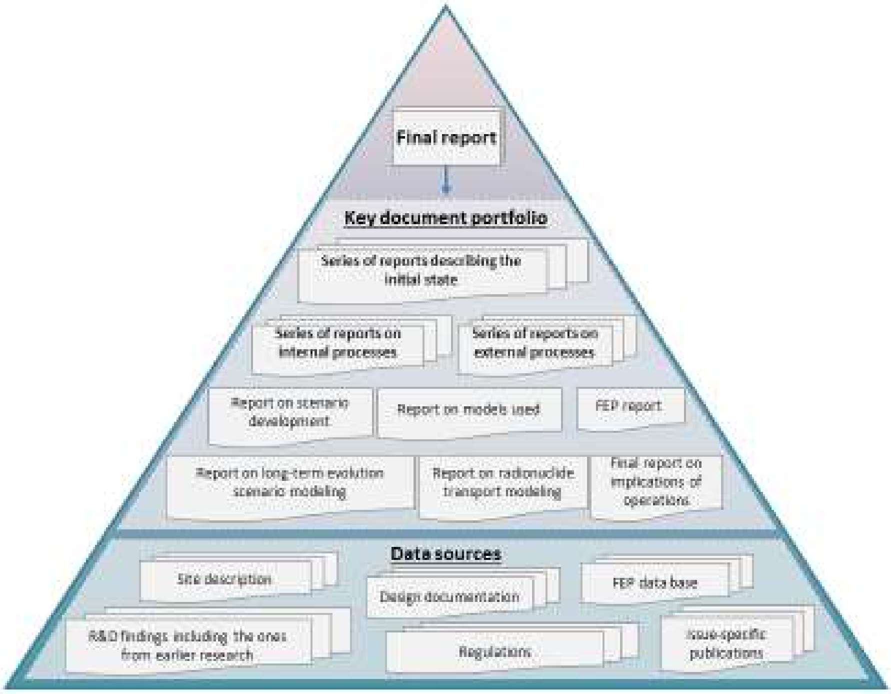

FIG. 1. Safety Case development structure

Development of the SC volumes should be guided by certain principles, including the following:

- Arguments should be developed iteratively;
- System-based approach should be used to arrange for the measures seeking to reduce the uncertainties;
- Requirements of the control system should be met;
- Data, information, knowledge management should be provided.

3. DEVELOPMENT AND ELABORATION OF THE R&D PROGRAM

Development of a consistent R&D programme is considered important for the implementation of the SC development principles which is related to the development of fundamental issue-specific SC volumes being considered as a foundation of the ultimate SC document (Fig. 1). Firstly, the layout of the volumes and the structure of each individual volume was decided upon the international experience. Then, all the information available to the operator at that time was fed into the corresponding SC volumes. Owning to such systematization of information and interpretation of available data, uncertainties associated with relevant needs in the substantiation of predictive model parameters could be identified, which served a basis for the research programme development. The programme also takes into account the requirement framework of the Russian regulator and relevant recommendations of international organizations (IAEA and NEA).

The core of the programme is viewed as a complex multidimensional structure that can be represented in different ways depending on the existing needs. It can be conveniently visualized in the form of a matrix (Fig. 2) with the elements of the disposal system (radioactive waste, engineered barrier system (EBS), geosphere, equipment, biosphere) presented horizontally and the corresponding research methods (monitoring, field research, laboratory, bench and industrial research, technology refinement, analytical estimates, and modeling) plotted vertically. Research areas are attached to matrix cells: these are deemed necessary to study some particular elements of the system and are implemented in the indicated way. Each research area unfolds into an even more detailed structure involving some individual operations and their stages. When relevant plans are drawn, a passport is provided for each activity (stage) with relevant data on its goals, expected results and their further application, required materials and equipment, as well as its reference to some FEPs, contracts, and contractors.

The research programme can also be represented as a diagram showing the interrelationships between studies arranged via the "application of the results" passport cell (Fig. 2).

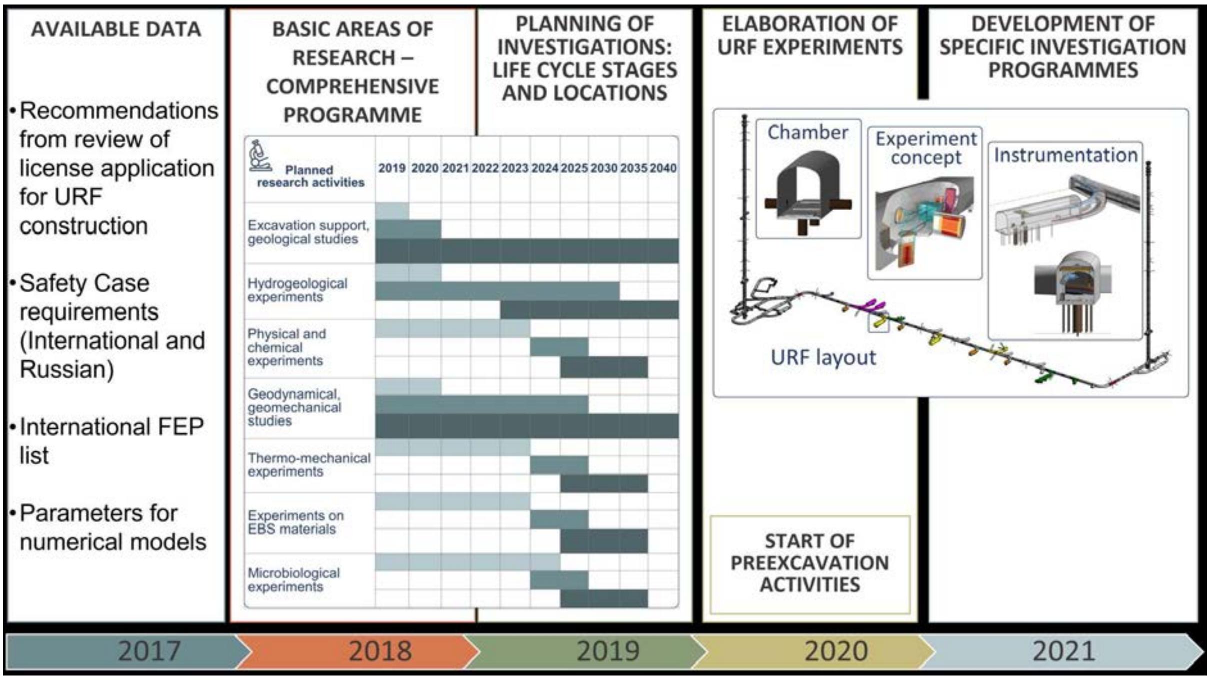

FIG. 2. Stages of R&D programme development

Operations giving rise to the areas of research presented in the programme were categorized according to their location (for example, on the surface, in the URL, in a field or stationary laboratory, computer-based, etc.) and the reference to the stage of the URL life cycle (for example, preparation for mining operations, construction, operation). If operated as expected, URL closure will take place simultaneously with that of the DDFRW.

The next stage in the research programme development, launched in 2020 and currently underway, suggests the activities considered as the highest priority at the URL pre-construction stage should be investigated from the entire framework of research areas and consistently implemented. Also, the designs of some specific studies such as, for example, full-scale URL experiments, are still being refined.

4. R&D PROGRAMME IMPLEMENTATION UNDER THE SAFETY CASE PORTFOLIO DEVELOPMENT

Consistent coordinated efforts have been arranged for to address four priority tasks under the implementation of the priority activities under the Comprehensive Research Program for 2019-2021, namely:

— Development of an information system providing computational support for URL and DDFRW development and operation (PULSE), which is seen as a platform enabling the accumulation of information and coordination of ongoing activities.

- Efforts implemented to refine the geological and hydrogeological characteristics within the URL siting area and necessary preliminary activities with their findings that will be used to update the data fed into the SC volume devoted to the initial conditions of the site, as well as the one on the external processes.
- Computational and experimental studies and necessary preliminary activities addressing various engineered safety barriers systems (EBS) with relevant findings expected to update the SC volumes discussing the internal processes in the disposal system.
- Development of RW predisposal treatment methods. These data will form the basis for the SC volumes discussing the radioactive waste and their packaging.

The PULSE system (Fig. 3) combines such components as [3]:

- A system of models representing facilities and processes intended for the safety assessment;
- Knowledge base intended for long term safety demonstration;
- A baseline database system intended for safety assessment;
- BIM model of the URL.

The sets of models were developed to enable predictive calculations showing the evolution of system elements, radionuclide filtration and migration in the geological environment and EBS considering the current understanding of the facility’s structure and processes given the available knowledge regarding the characteristics of materials.

The information component of the PULSE system enables the aggregation and systematization of various types of information arising along with the implementation of the URL and DDFRW development and operation strategy. The current version of the system allows:

- To maintain the library of information sources (relevant publications) to demonstrate long term safety;
- To systematize the research findings;
- To monitor the implementation of a comprehensive research programme;
- To build connections between different information blocks.

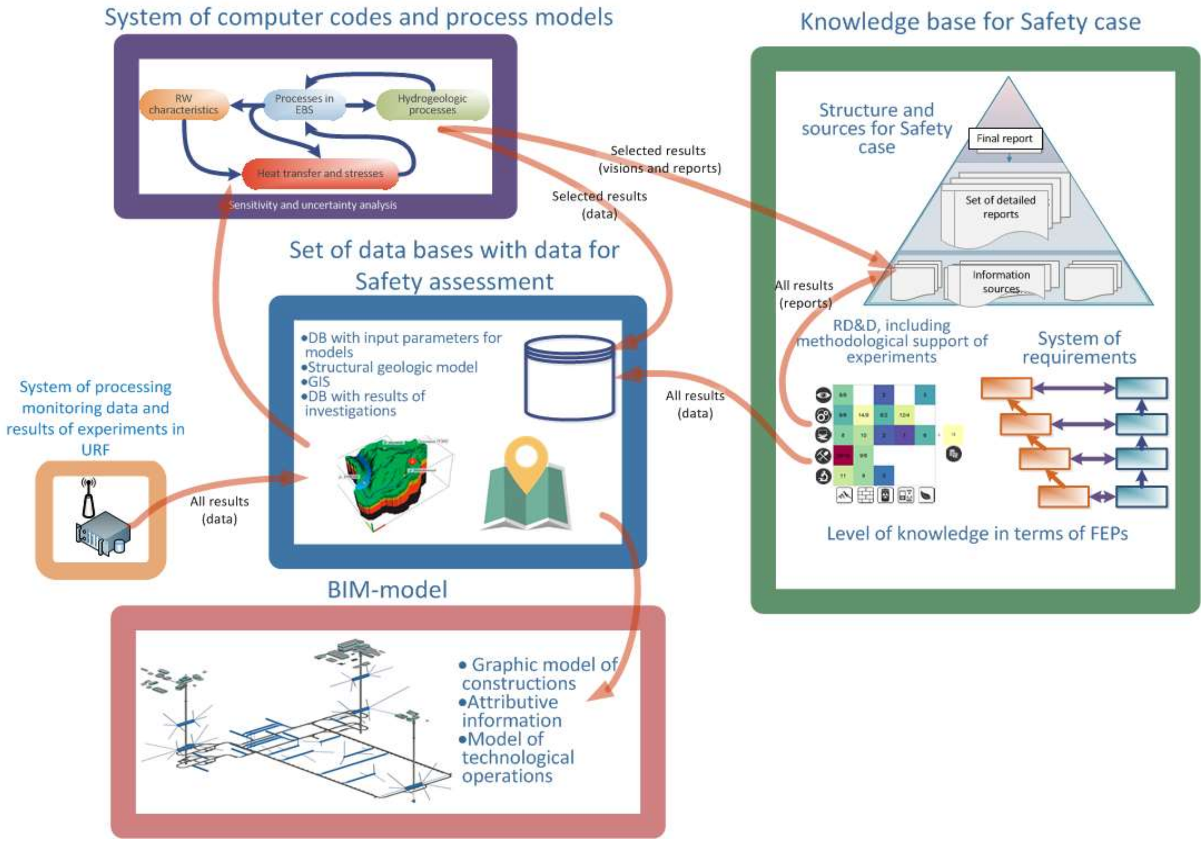

FIG. 3. Structure of the PULSE system

As a preliminary stage of efforts aimed at reducing the uncertainties in the geological and hydrogeological characteristics of the URL siting area, some detailed programmes have been developed, such as:

— A comprehensive programme for further refinement of existing monitoring systems (geodynamic, seismological, hydrological, hydrogeological, geochemical, meteorological, environmental, etc.). The programme development has accounted for the data analysis focused on already deployed monitoring systems. This allowed to identify the needs in an increased number of observation points, equipment maintenance and upgrading; adjusting the observation modes.
— A comprehensive programme focused on additional geological study of the URL site and the DDFRW potential impact area. The activities stated under the programme are aimed at: clarifying the nature of structural rock disturbances, groundwater characteristics, characteristics of tectonic conditions allowing to forecast the future evolution of the territory, as well as to identify the undisturbed rock blocks between tectonic zones.
— A programme providing the scientific support for mining operations seeking to obtain the maximum amount of information about the rock mass while complying with a reasonable excavation mode [4].

Additional study of geological and hydrogeological conditions is already underway involving reconnaissance surveys of the construction site with rock sampling performed to refine the geological map for the URL siting area, studies of near well-bore areas in the existing wells, and some geophysical studies. Detailed experimental groundwater inflow testing has been also started in the existing deep wells. In addition, laboratory analysis of core samples taken at the depth of the target horizon was carried out: their structure and composition were studied (which was done also via the application of such methods as high-resolution X ray tomography and scanning electron microscopy); and relevant thermal and mechanical properties were investigated, including the thermal rock anisotropy.

The study of engineering aspects associated with the development of the EBS and the processes related to the evolution of the EBS materials under DDFRW conditions was focused on:

- The evaluation of potential EBS materials (bentonites, kaolins, mixtures of clay materials) in terms of their basic characteristics (mineral composition, geological conditions in available deposits, waterproofing, physical, mechanical properties) [5].
- Demonstrating the fact that purpose-designed equipment should be developed to enable the evaluation of the waterproofing properties: swelling pressure due to filtration, liquid, and gas diffusion.
- Initial experimental studies and preliminary importance evaluation for the safety assessment purposes regarding:
  - The chemical stability of buffer materials when interacting with underground natural solutions and with each other at elevated temperatures;
  - The corrosion processes and the ways in which they are affected by microbiological processes and mechanical erosion of clay materials;
  - The interaction of EBS contact materials (bentonite-metal canisters, cement-based RW matrix, aluminophosphate glass, borosilicate glass, magnesium potassium phosphate compound);
  - Physical and chemical interaction between radionuclides and clay materials of safety barriers and host rocks after the former ones get leached from glass, namely, considering the identification of its key parameters;
  - Colloid formation processes considering various materials of engineered safety barriers (EBS) assuming the model water being under disposal conditions;
  - Gassing processes in the buffer materials of the DDFRW considering corrosion, water radiolysis and microbiological activity.
- The development of kinetic models demonstrating steel corrosion processes considering the activity of thermophilic microorganisms and the presence of bentonites, colloidal formation, gas formation, and migration (in various forms) of radionuclides in bentonite.

Based on the preliminary analysis, a detailed calculation and experimental programme has been developed involving the study of some fundamental parameters, such as the swelling pressure, filtration and diffusion coefficients at different dry density levels, the effect of the groundwater composition, the evolution of microbiological processes, EBS material transformations at their interfaces, etc., permeability of clay barriers with different densities and their composition under simulated DDFRW conditions.

In addressing the task of the predisposal RW management, the focus was placed on the completeness of the data available on the characteristics being considered important for the long term safety assessment [6], the radioactive waste inventory awaiting disposal and the forecasts regarding waste generation from various sources. A research plan has been drawn for the vitrified high level waste inventory featuring the measurements focused on the content of radionuclides being considered important for the long term safety demonstration, the rate of their leaching, the state of the matrix, etc.

5. CONCLUSION

In 2019, the first versions of the following SC volumes considered as the baseline documents of the SC were developed (these will be updated along with the implementation of the comprehensive programme), namely: quality control system description, report on radioactive waste, report on the site properties, report on the radionuclide migration paths, report on the long term evolution of the geosphere (for scenario development purposes), report on models and data. Data required for the development of the remaining main SC volumes was missing at that time, even to compile the most preliminary versions. For this reason, they were replaced by additional documents: URL layout, report on bentonites, physical and chemical processes during the interaction of radioactive waste matrices, EBS materials and enclosing DDFRW bedrocks affecting the long term safety of the repository, information support for demonstration of safety (PULSE system), description of the monitoring system.

Efforts performed to date have required updating the following report subjects: radioactive waste, the site properties, the radionuclide migration paths, and the models and data. In addition, primary versions of the volume can be developed based on the available basic documents, in particular: the FEP report, the report on processes occurring in RW and the RW matrix, and the report on EBS processes.

ACKNOWLEDGEMENTS

The paper is based on results obtained by a set of organizations providing the scientific support for the construction of the for deep radioactive waste disposal facility at the Yeniseiskiy site in the Krasnoyarsk Territory, among them: IGEM RAS, Geophysical center RAS, Kranoyarskgeology, ScolTech, Sankt-Petersburg department of IGE RAS.

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Paper ID#191

THE BENEFITS OF A TARGETED RESEARCH AND DEVELOPMENT PROGRAMME TO ADDRESS KEY QUESTIONS

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Abstract

Operational since 1959, the Low Level Waste Repository (LLWR) is the United Kingdom's (UK) national low level waste disposal facility. The LLWR operates under an Environmental Permit granted by the Environment Agency, which requires the operator to develop, maintain, and submit updates to an Environmental Safety Case (ESC). As the regulator did not fully accept the submission made by a previous operator in 2002, the Environment Agency required the LLWR to submit a revised ESC by 2011 to address the criticisms of the previous safety case. A research and development (R&D) work programme was developed to address these key problems. Since then, the ESC has been maintained as a 'live' safety case, supported by an ongoing R&D programme. The safety case and associated R&D programme is a tool to assess new information against and allows the exploration of key questions and proposed developments. This has enabled new wastes to be considered and accepted for disposal and the design of the closure engineering to be radiologically optimized. The ESC is now being used to support a programme of work to assess the potential to dispose of a wider range of wastes using a risk-based approach. The R&D programme developed to support this work is designed to enable the optimization of any such facilities.

1. THE LOW LEVEL WASTE REPOSITORY

The Low Level Waste Repository (LLWR) is the United Kingdom's (UK) principal facility for the disposal of solid low level radioactive waste (LLW). The LLWR is owned by the Nuclear Decommissioning Authority (NDA) and operated on behalf of the NDA by a Site Licence Company (SLC) – LLW Repository Ltd. The LLWR is located on the coastal plain of West Cumbria about 0.5 km from the Irish Sea coast (see Fig. 1). It is about 3 km from the Ravenglass Estuary where the Rivers Irt, Mite, and Esk join. The Rivers Irt and Mite flow roughly southwest from the hills inland in the Lake District. The River Esk is separated from the other rivers by the prominent bedrock ridge of Muncaster Fell. To the east, the site is bounded by the Carlisle to Barrow-in-Furness railway line.

The geology of the area consists of Quaternary deposits overlying older sandstone bedrock. In the vicinity of the LLWR site, groundwater generally flows from the Lake District hills towards the coast. The Upper Groundwater is present within the upper Quaternary deposits and overlies the Regional Groundwater. It is most evident in the northwest and central parts of the site. In the Upper Groundwater, the majority of groundwater moves vertically downward. The Regional Groundwater is observed in the Quaternary drift deposits and in the underlying sandstone. The groundwater flow direction in the Regional Groundwater at the LLWR is generally toward the coast, discharging to the inter-tidal zone and off-shore.

The LLWR receives LLW from across the UK. The arising mainly come from fuel fabrication and power generation, fuel reprocessing and decommissioning. Low level waste is defined as radioactive waste having a radioactive content not exceeding four GBq/t alpha or twelve GBq/t beta–gamma activity. The wastes are packaged into half-height ISO freight containers and grouted on receipt at the site. The majority of the wastes are brought to the site via the railway line.

FIG. 1. The location of the LLWR site.

The site was originally developed as a Royal Ordnance Factory (ROF) during World War II. Trench disposals commenced in July 1959, starting in one of the former ROF railway cuttings re-engineered for the purpose. The trenches were either constructed within an underlying clay layer or had bentonite rotovated into the base to create a low hydraulic conductivity base. During operation, the trenches were progressively filled by tipping loose wastes from the top of the previously filled area into the excavated trench. Trench disposal began to be phased out in 1988 with construction of Vault 8. The design solution for the vaults is based on containerised waste being emplaced into a concrete vault, with a water management system to ensure an unsaturated system. The most recent vault, Vault 9, was commissioned in 2010 and is used to the present day, see Fig. 2. Approximately 1 million m^3 of LLW has been disposed to the site. The trenches are currently covered by an interim cap and a final cap will be progressively constructed down the site, over the filled vaults and adjacent trench area. Eventually the whole disposal area will be covered by a vegetated engineered cap designed to minimize water ingress and deter intrusion.

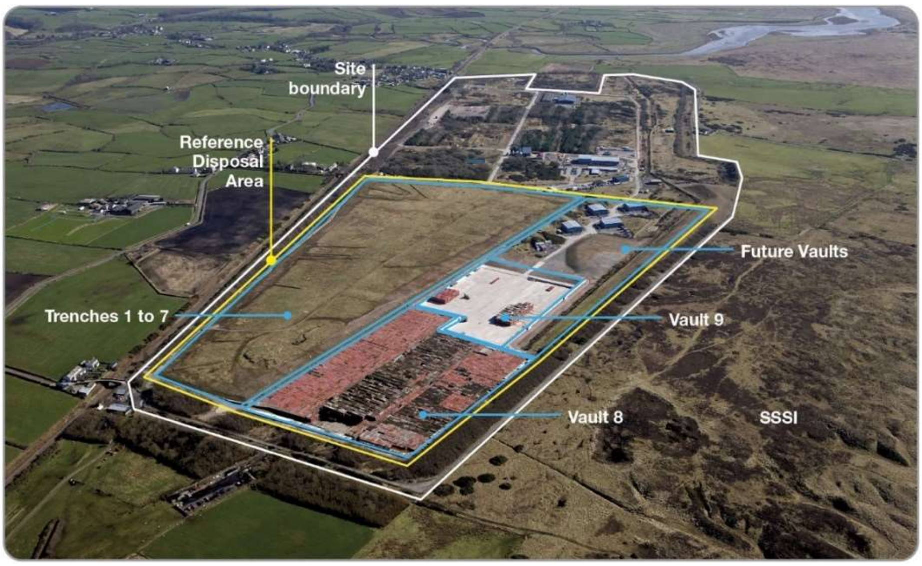

FIG. 2. An aerial view of the LLWR site.

2. THE ENVIRONMENTAL SAFETY CASE

The LLWR operates under an Environmental Permit issued by the Environment Agency under the Environmental Permitting (England and Wales) Regulations 2010. One of the conditions in the permit is that the operator has to develop, maintain, and submit updates to an Environmental Safety Case (ESC). The previous operator of LLWR submitted an ESC in line with such requirements in 2002. The regulator reviewed that submission and in 2006 issued a restricted authorization (now termed permit) that only allowed for storage of waste in Vault 9 pending the submission of an updated ESC demonstrating the safety and appropriateness of continued disposals. The regulator gave three main reasons for not not fully accepting the case: it had not adequately addressed radiological optimization; it had not addressed coastal erosion; and doses and risks to the public exceeded regulatory guidance. Work then began on a revised ESC for submission by 1 May 2011. One of the main aspects the 2011 ESC aimed to address were the criticisms of the previous case. An R&D programme was developed to address these challenges strongly focussing on optimization and the use of assessment models to support the development of an optimized design for the facility, particularly on closure engineering. One of the key successes was the definition of capacities for the site. Radiological capacities based on the sum of fractions methodology were derived as were capacities for some non-radiological substances that require control. Using this capacity approach, the LLWR was demonstrated to capable of accepting all LLW in the UK that requires disposal in an engineered vault. Crucially, it was also demonstrated that the LLWR site has a greater capacity than the LLW requires. This raises the possibility that new wastes can be considered for disposal.

The 2011 ESC was successfully delivered [1] and a revised permit, allowing the resumption of disposals to the site and permitting the installation of the closure engineering, was granted in 2015. The permit requires a Major Review of the ESC to be submitted to the regulators by the 1 May 2026. The ESC has been implemented on site and the requirements from the ESC have been integrated into the site procedures. This ensures the site is operated in line with the assumptions in the ESC and any changes have to be submitted to a formal process of evaluation to ensure they are consistent with the safety envelope of the ESC. The ESC is also the basis for most of the conditions in the LLWR waste acceptance criteria (WAC). The WAC ensure only wastes consistent with the ESC are accepted for disposal.

The ESC is a ‘live’ safety case supported by an ongoing R&D programme [2], with new information and data assessed and considered. The R&D programme is about continuous improvement and refinement of the ESC, especially with regards to reducing uncertainty. The ESC can be considered to have two main functions: regulatory compliance and site management. The safety case and associated R&D programme becomes a tool to assess new information that allows the exploration of key questions and proposed developments. Using the ESC, the LLWR can assess new wastes to determine their suitability for disposal. The ability to be able to accept such wastes supports the UK decommissioning mission and the high hazard reduction programme. The ESC is also used to assess proposed changes to the design of the closure engineering but, crucially, ensures such changes are radiologically optimized. The ESC is now being used to support an NDA programme of work to assess the potential to dispose of a wider range of wastes using a risk-based approach. The R&D programme developed to support this work is designed to enable the optimization of any such facilities.

3. NEW WASTES

The ESC is based on an assumed forward inventory. Performance assessment calculations demonstrate this inventory is safe for disposal at the LLWR site and there is the radiological and volumetric capacity to receive them. Proposals to dispose of new waste streams, not included in the assumed forward inventory, have to be assessed against the ESC. These waste streams are streams previously declared as higher activity wastes but due to decay or improved characterisation are now LLW. An assessment of their suitability is required to ensure their disposal at the LLWR is consistent with the ESC and to ensure disposal would not constitute a disproportionate use of radiological and volumetric capacity. The ESC has been used to assess several such proposals and successfully shown that disposal to the LLWR is safe and appropriate. The acceptance of these streams has enabled other sites to preserve storage capacity, allowing decommissioning to continue to support the high hazard reduction programme. It has also provided a final disposal solution for these wastes sooner than anticipated and, in one case, supported a site to reach its required end state.

4. CLOSURE ENGINEERING

Our Repository Development Programme is responsible for delivering future disposal capacity at the LLWR site and optimization and installation of the closure engineering. The first stage of works is the capping of Vault 8 and the adjacent trenches. The ESC defined a set of requirements that were used in the design phase to ensure design decisions were optimized and compatible with the ESC. During this design phase it became apparent that it would not be possible to install the closure engineering in the way described in the ESC without damaging the containers. A programme of work to understand the anticipated deformation of the containers was undertaken. This included physical testing and Finite Element Analysis of containers to understand the mode and magnitude of the deformation, see Fig 3. This work demonstrated that the stacks of containers already disposed in Vault 8 will not be able to withstand the mass of the capping material. The corner elements of the containers will undergo deflections beyond their yield point with the final load path going through the grout and waste within the container. Any voidage within the containers will be expressed and the lids on the top containers will be damaged.

FIG. 3. Container testing and associated FEA model.

The ESC was used to consider this new information and assess the implications of the changed assumption. This new understanding means that containers will be damaged at an earlier stage than assumed in the ESC; during the process of closure rather than over a longer time period due to more general corrosion mechanisms. This has implications for the multi-barrier concept assumed in the ESC, although the damaged containers will still provide some barrier function against water ingress. The unsaturated conditions will be maintained in the vault as the container stacks will largely remain in place such that the preferential vertical drainage paths between stacks to the vault floor will remain. Our understanding of repository evolution is largely unaffected, and the overall chemical evolution is not expected to vary significantly. As no quantitative credit is taken for the containers in our performance assessment calculations, the new information does not lead to an increase in calculated impacts.

5. DIFFERENT DISPOSAL CONCEPTS

The current UK government policy for disposal of LLW is disposal to the LLWR, and for higher activity wastes to a geological facility. The policy also requires the NDA to consider alternative disposal options for higher activity wastes. Currently, the NDA are undertaking exploratory work to look at alternative options for some higher activity wastes. LLWR are supporting this work by considering what the capacity of the site could be if enhanced facilities were to be constructed. The LLWR is considering a modified surface vault concept and a silo some tens of metres below the ground surface. It has developed an R&D programme to support this work, to deliver optimized designs for any such facility to the level of detail they can underpin an ESC. This work is fully integrated into the wider R&D programme to deliver the next Major Review of the ESC such that, if the NDA require, any such new facilities will form the assumed design on which the Major Review is based. It should be noted that the NDA would make any decision to dispose of higher activity wastes at the LLWR site in conjunction with the Department for Business, Energy, and Industrial Strategy (BEIS). Such a decision would require a change in government policy and an associated public consultation. Near surface disposal of higher activity waste would be in addition to the geological disposal facility, which will always be required for wastes that are not suitable for near surface disposal.

The R&D programme covers not only the optimization of any new facilities for higher activity waste but also optimization of the current LLW concept in response to the new information uncovered under the Repository Development Programme.

It is expected that the near field conditions in an enhanced disposal facility will differ from the conditions in the current LLWR vaults (or trenches). This will require the development of new conceptual models and understanding of how such facilities will evolve over time. It will also necessitate changes to the assessment models used to determine the doses and risks to members of the public. Initial models will be produced to support the optimization and design choices by providing information on the expected evolution and potential radiological capacity of such facilities. These models will be refined throughout the process such that they could then be used to undertake final assessment calculations in support of the next Major Review of the ESC. Importantly, the models would also be used to define the radiological capacity for any final design. Definition of a facility or site capacity is a key aspect of the work programme and would be the overall indication of the optimal use of the LLWR site. The LLWR's understanding of the ESC and the implications of changing the assumptions that underpin it is crucial to being able to undertake the work to consider alternative facilities.

6. SUMMARY

The LLWR maintains a live safety case supported by an ongoing R&D programme. The safety case and associated R&D programme are a tool used to assess new information and allow the exploration of key questions and proposed developments. It enables new information to be assessed to ensure any changes, new wastes or new concepts are consistent with the assumptions of the ESC and to ensure radiological optimization. Use of the ESC in this way has enabled the disposal of new wastes that has helped to support the decommissioning mission in the UK. The ESC also been used to consider and inform a proposed design change to the closure engineering. This design is currently being implemented. Using the ESC, the LLWR now supports an NDA programme of work to assess the potential to dispose of a wider range of wastes using a risk-based approach. The R&D programme developed to support this work is designed to enable the optimization of any such facilities.

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WASTE ACCEPTANCE CRITERIA FOR UNDERGROUND RADIOACTIVE WASTE REPOSITORY IN REPUBLIC OF KOREA

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Abstract

A radioactive waste management organization oversees developing the waste acceptance criteria (WAC) and providing radioactive waste producers with the WAC for safe, effective, and efficient disposal of radioactive waste. The WAC needs to be developed in the framework of a safety case and is interconnected with other key components of the safety case to ensure the operational and post-closure safety of the disposal facility. The Korea Radioactive Waste Agency (KORAD) received permission for the operation of the first radioactive waste repository in the Republic of Korea, Wolsong Low- and Intermediate-Level Waste Disposal Center (WLDC), in 2015. The first phase of the WLDC is operational, and the second phase is in the licensing process for construction. The KORAD prepares the comprehensive WAC in accordance with legal and regulatory requirements. The WAC for the WLDC consists of technical requirements (general, solidification, radiological, physical, chemical and biological requirements) and administrative requirements. The KORAD has successfully developed the WAC provided to waste producers. The WAC is periodically reviewed and updated in response of meeting any changes of legal and regulatory requirements and stakeholder expectations.

1. INTRODUCTION

Radioactive wastes are referred to as radioactive material or materials contaminated by radioactive substances to be disposed [1], and they are generated from the operation of various nuclear facilities and other applications of radiation. The major source of radioactive wastes in Korea is nuclear power plants (NPPs). Kori unit 1 started operation in April 1978, and as of March 2020, 24 NPPs are in operation. According to the Korean 7th National Report [2], as of March 2020, 108 927 200 L drums of solid radioactive wastes are generated in NPPs, 18 269 drums were transported to the disposal facility, and 90 658 drums are stored at the on-site storage facilities in NPPs. Radioactive wastes arise from a research reactor and a nuclear fuel fabrication facility. In addition, medical, research, and industrial fields using radioisotopes and radiation generating devices generate various types of radioactive waste.

In Korea, radioactive wastes are managed based on the Radioactive Waste Management Act, which provides the system and framework of radioactive waste management. The Korea Radioactive Waste Agency (KORAD) was created in January 2009 to manage radioactive wastes safely, securely, and effectively, as a dedicated radioactive waste management organization. Also, the Regulations and Notices of the Nuclear Safety and Security Commission (NSSC) stipulate detailed technical criteria and guidelines for managing radioactive wastes.

Radioactive wastes are classified based on heat generation and radioactivity: high level waste (HLW), intermediate level waste (ILW), low level waste (LLW), and very low level waste (VLLW). Details of the waste classification scheme are summarized in Table 1.

TABLE 1. CLASSIFICATION OF RADIOACTIVE WASTES

Classification	Criteria	Related notices of the NSSC
High level waste (HLW)	– Radioactivity concentration: $\geq$ 4000 Bq/g for α-emitting radionuclide having a half-life longer than 20 years – Heat generation rate: $\geq$ 2 kW/m^3	Standards for Radiation Protection, etc. (No. 2019-10)
Intermediate level waste (ILW)	More than concentration criteria of LLW	Regulations on the Criteria for the Classification and Clearance of Radioactive Wastes (No. 2020-6)
Low level waste (LLW)	Between concentration criteria of LLW and 100 × CL	
Very low level waste (VLLW)	Between 1 × CL and 100 × CL	
Exempt waste	Below clearance level (CL)	

2. WOLSONG LOW AND INTERMEDIATE LEVEL WASTE DISPOSAL CENTER (WLDC)

KORAD began construction of the first phase of Korea's first repository for low and intermediate level waste (LILW), the Wolsong Low and Intermediate Level Waste Disposal Center (WLDC), in 2007, and the Korean government granted the operation licence of the 1st phase in 2015. The second phase is under the licensing process for construction, and KORAD is undertaking the conceptual design of the third phase. In the first phase, six underground silos were built in granite approximately 80 to 130 m below sea level. The size of each silo is 23.6 m (diameter) × 50 m (height), and 16 700 drums of the radioactive wastes can be disposed of in the first phase.

A unique feature of the WLDC is that different disposal concepts are incorporated in a disposal site for effective and efficient management of the radioactive waste:

— The first phase is an underground silo-type repository for the disposal of ILW including some LLW;
— The second phase is an engineered vault-type repository for the disposal of LLW; and
— The third phase is a near surface trench-type repository for the disposal of VLLW.

The WLDC is the first radioactive waste disposal facility across the globe that has been developed to host three different repository types in a site. The KORAD's strategy requires each repository to be designed commensurate with the radioactive waste hazards.

3. WASTE ACCEPTANCE CRITERIA IN THE FRAMEWORK OF THE SAFETY CASE

A radioactive waste disposal programme could last over several decades from siting to post-closure activities no matter how the disposal programme matures. It is practical to subdivide the programme into several phases: initiation, siting, construction and operation, and closure. An important decision needs to be made whether to begin the disposal programme or proceed to next phase. The safety case provides the technical basis of a decision making process in developing the radioactive waste disposal programme. As the disposal programme evolves, the safety case needs to be revised and updated to reflect new information and knowledge collected and gained from various aspects of the disposal programme including a disposal facility design, site investigations, and waste inventory.

IAEA Safety Standards Series No. SSG-23 [3] provides recommendations on the components and application of the safety case in the radioactive waste disposal programme , and states that "The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the disposal facility.” The safety case has been used as useful tool for integrating all components and activities necessary for the radioactive waste disposal programme.

As such, the WAC is also one of key components of the safety case. The WAC takes into account other components of the safety case: waste inventory, safety assessment, the disposal facility design, and legal and regulatory requirements.

The hierarchy and main elements of the WAC for the WLDC are summarized in Table 2 [4]: technical requirements and administrative requirements, including how to characterize and how to verify WAC compliance. They have, in principle, been developed based on the legal and regulatory requirements. Site specific considerations, the safety assessment, the waste inventory, and the facility design provide the sound basis of technical requirements of the WAC. In the WLDC, three different disposal concepts will be integrated in a site for the pragmatic management of radioactive waste. Each disposal concept has not necessarily different technical requirements of the WAC; however, the design concept of each repository is one of key factors influencing the WAC. In an underground silo-type repository of the WLDC, waste packages are placed in a disposal canister and then disposed of in a silo; however, waste packages are placed in a disposal vault without a disposal canister in an engineered vault-type repository. Accordingly, there are differences in the some technical requirements of the WAC between the silo-type repository and the engineered vault-type repository: the waste inventory, dose rate, voidage, etc.

The operational and post-closure safety assessments provide the technical basis of the WAC. The WAC also provides inputs for the operational and post-closure safety assessments. As the WAC and safety assessment are strongly linked to each other, there should be effective integration and cooperation between a safety assessment group and a WAC group.

It is worthy to note that the WAC needs to be periodically reviewed and revised to incorporate any changes of legal and regulatory requirements and new research and development (R&D) results. For instance, cellulosic material has been reported to be degraded into isosaccharinic acids under high pH conditions that have complexation potential. A specific technical requirement for the cellulosic material is expected to be elaborated based on R&D results on its degradation characteristics under the WLDC conditions.

TABLE 2. WASTE ACCEPTANCE CRITERIA FOR THE FIRST PHASE OF THE WLDC

Level 1	Level 2	Criteria
Technical requirements	General requirements	Only solid type and physico-chemically stable form of wastes can be accepted.
		Waste packages have to be explicitly marked on the outside with main information, and standardized.
		Weight of waste packages has to be limited to less than 10 t for concrete packaging and less than 1 t for steel drum packaging. The size of waste packages has to be limited to at least above 0.5 m (L) × 0.5 m (W) × 0.8 m (H), 0.5 m (D) × 0.8m (H) and at most up below 1.5 m (L) × 1.5 m (W) × 1.5 m (H), 1.5 m (D) × 1.5m (H).
	Solidification requirements	Homogeneous wastes (concentrated wastes, waste resin, sludge, etc.) have to be solidified. Solidified waste matrix has to satisfy test requirements. Heterogeneous wastes (waste filters, general solid wastes, etc.) above 74 000 Bq/g (2 μCi/g) of total radioactivity concentration with a half-life of 20 years have to be stabilized.
	Radiological requirements	More than 95% of all radionuclides in the waste has to be identified, and the concentrations of the following radionuclides have to be measured: H-3, C-14, Fe-55, Co-58, Co-60, Ni-59, Ni-63, Sr-90, Nb-94, Tc-99, I-129, Cs-137, Ce-144, and gross-alpha.

Level 1	Level 2	Criteria
		Concentrations of radionuclides have to be limited as follows: Nuclides / Limitation (Bq/g) / Nuclides / Limitation (Bq/g) H-3 / 1.11E+06 / Nb-94 / 1.11E+02 C-14 / 2.22E+05 / Tc-99 / 1.11E+03 Co-60 / 3.70E+07 / I-129 / 3.70E+01 Ni-59 / 7.40E+04 / Cs-137 / 1.11E+06 Ni-63 / 1.11E+07 / Gross-alpha / 3.70E+03 Sr-90 / 7.40E+04
		Maximum surface dose rate of waste packages may not be above 10 mSv/hr.
		Fissile species in waste packages have to be limited so that criticallity conditions can not occur.
		Average measured radioactivity concentration on the surface of waste packages may not be above 4 Bq/cm^2 (beta, gamma, low-toxic alpha emitter) and 0.4 Bq/cm^2 (other alpha emitter) in arbitrary surface over 300 cm^2.
	Physical requirements	Wastes containing particulate materials has to be treated to non-dispersible.
		Voidage in waste packages has to be less than 15% in the container
		Free standing water may not exceed 0.5% by volume of wastes to be disposed. (in case of high-integrity container, not exceed 1%)
	Chemical requirements	Chelating agents exceeding 0.1% of the waste have to be identified and described: their names and amounts. Waste containing chelating agents exceeding 1% of waste volume have to be solidified. Total chelating agents may not exceed 8% of waste volume.
		Corrosive materials have to be removed or corrosivity has to be reduced to the extent practical before packaging.
		Waste packages may not contain explosives and materials causing reaction with water. Flammable materials have to be removed or flammability has to be reduced. Pyrophoric materials in waste packages have to be treated to non-pyrophoricity and then packaged.
		Gas generation in waste packages may not deteriorate the stability of the package or the performance of disposal facility.
		Toxic materials may not be contained or generated.
	Biological requirement	Living organism, pathogen and infectious materials have to be removed.
Level 1	Level 2	Contents
Administrative requirements	Wastes characterization	Wastes characterization methods and documentation for waste producers

Level 1	Level 2	Criteria
	Methods for verifying compliance with WAC	Methods for verifying compliance with WAC through sampling, inspection, documentation, and measurements
	QA planning	Methods and process of QA
	Consignment process	Overall process for wastes shipment
	Documentation	Types and formats of documents
	Management of Non-compliance radioactive wastes	Process of return and/or treatment for non-compliance radioactive wastes

4. CHALLENGES AND ISSUES

The WAC for the first phase is in place, and the preliminary WAC for the second phase is prepared and under review: however, some challenges and issues have remained, including challenging wastes, cellulosic material, and the characterization of toxic and harmful substances contained in the radioactive wastes:

— Challenging wastes include resins, sludge, reactive metals with water and solidification material, historic wastes improperly solidified, etc.
— Cellulosic material remains as a controversial issue. It has been reported for the cellulosic material to be degraded to complexing substances. The KORAD undertaken a R&D activity to justify and prove how much of the cellulosic material is converted to the complexing substances in the WLDC environments.
— The identification and characterization of toxic and harmful substances contained in the radioactive wastes have been considered one of arduous issues and challenges.

As far as we know, many Member States are struggling to get through the challenges and issues [5]. International cooperation and collaboration could provide the Member States with decisive opportunities to properly manage the challenges and issues through information, experiences, and knowledge exchange.

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Paper ID#302

CURRENT STATUS AND CHALLENGES OF CHINA'S LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE DISPOSAL

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Abstract

Based on the safe disposal goal, China implements classified radioactive waste management according to the potential hazards of radioactive waste and the degree of containment and isolation required for disposal. Low and intermediate level radioactive waste (LILW) needs to be disposed in near surface or intermediate-depth disposal facilities in compliance with requirements of nuclear safety stipulated by the State. Currently China has three LILW near surface disposal sites in operation, which has disposed approximately 57,000 cubic metres LILW in total. This effectively guaranteed the nuclear industry development. With the rapid development of nuclear energy and nuclear technology applications, the disposal of LILW and disused sealed radioactive sources (DSRS) has put forward new requirements and brought new challenges. By studying the multi-channel disposal of LILW from NPPs, we implement the strategy of "Combination of Centralized disposal and Regional disposal", which can reasonably respond to these challenges. China is now constructing Longhe near surface disposal site for the centralized disposal of NPP waste, and organizing the site selection of LILW disposal facilities in provinces where NPPs are relatively concentrated. Research and exploration on the intermediate depth disposal of radioactive waste, as well as the strategy for DSRS disposal and the acceptance criteria for near surface disposal, is being carried out in China so as to speed up the implementation of ILW intermediate depth disposal and DSRS near surface disposal in China.

This presentation is provided verbatim as deliviered by P. Zhang in Session 4 – Role of the Safety Case.

1. INTRODUCTION

CNNC Everclean Environmental Engineering Cooperation has more than 20 years of development and experience and we are currently the largest professional company in Radioactive Waste Disposal and Radioactive Material Transportation in China. Our business is mainly in three fields, which are:

- Disposal of Radioactive Waste;
- Transport of Radioactive Materials;
- Decommissioning and Waste Treatment.

2. NEAR SURFACE DISPOSAL FACILITIES IN CHINA

How many near surface disposal facilities are now in China and how they are working? I will introduce all 4 of them in the sequence they were built. The first one is Northwest Repository in Gansu Province. This one has been operating since 1999 and the first stage was designed to build 200 000 m^3 and we have already done 29 000 m^3 with 90 000 m^3 under construction. All of the disposal units are underground.

The second one is the Beilong Repository in Guangdong Province, the southeast part of China. It has been operating since 2011, whose capacity is 8800 m^3 and all the units are underground.

The third one is Mount Feifeng Repository in Sichuan Province, southwest of China. It has been operating since 2016, the designed capacity is 180 000 m^3 and we have already constructed 36 000 m^3 and all the units are underground.

The last one, which is now under construction, is named Longhe Near-surface Repository. Longhe Repository is designed to solve the problem of concentrated disposal of radioactive waste in China, including that from Nuclear Power Plants and other radioactive waste. Its designed capacity is 1 million m^3 and we are now constructing 40 000 m^3. The disposal units in Longhe Repository are half underground.

3. SCIENTIFIC RESEARCH PROGRAMMES TO IMPROVE THE DISPOSAL PROCESS

After knowing the situation of all four repositories in China, now I would like to share with you some of our scientific research programmes and our results.

The first one is remote numerical control and multi-drum grapple. In the past we used truck cranes and human assistance to dispose our waste, which means there would be relatively high radiation risks for personnel; because of human involvement the pattern efficiency is relatively high. The advantage of a remote numerical control system is that it lowers the radiation risks for personnel, but unfortunately it has also relatively low pattern efficiency. And here comes the problem: How to combine a relatively low personnel radiation risk and a relatively high pattern efficiency? Here comes our programme:

To this end we combined remote numerical control and multi-drum grapple at the same time.

We use high-quality rare earth magnetic material as magnetic core of modularized electromagnetic chuck.. After our test, the lifting force of the electromagnetic sling and single chuck load lifting capability meet our requirements. For the bottom, we use concave ring design, which enhances suction by eliminating the void between flange bolts and rings and the alternatingly arranging magnetic permeability module. Also, we consider the power loss condition: when the power is cut off, the hold is still reliable.

The magnetic core is made of rare earth magnetic material and we use 32 alternatingly arranged magnetic permeability modules, and a power loss reliability system.

Also, the sling bottom is rotatable to meet the requirements of special conditions. We also designed a special stretching mechanism between the chuck and rack with an 80 mm vertical free path for the four drums. Also, the stretching structure and chuck are flexibly connected, enabling the chuck to incline to an extreme of five degrees.

Also, to improve our efficiency of spacing the drums, in our design the four grapples for drums are flexible, which means the formations can change from the left-side square to the right-side parallelogram, reducing the drum spacing from 40 mm to 20 mm. This helps improve the efficiency of our spacing.

We are also taking into consideration the following points:

The first one is power loss protection, where we use double pulse magnetization and demagnetization to ensure hoisting safety. The contact check system adds three contact pickoffs for remote real time detection. The remote numerical control lowers the personnel radiation risk. The application takes into account special conditions such as the need for hosting only two drums a single time under consideration.

The result of the process improvement is very interesting. For the 4-drum grapple we developed in the past to hoist one single drum we needed an average of 28 minutes per drum, but now for the 4-drum grapple system the average time is about 9 minutes per drum. This means we not only reduced the frequency greatly, but also increased the efficiency more than 200%. This system is to be applied to the Mount Feifeng and Longhe Repository. We believe by applying this system, the disposing efficiency can be improved dramatically.

Another programme we are doing is for the Mount Feifeng Repository Site and it is the safety case analysis. By doing this programme we wish to ensure the safety of the Mount Feifeng Repository Site for a very long period. Not only during its operation, but also including the closure and post-closure period. In this programme, we first collect and integrate our data into the work plan to make sure which special subject we need to handle in this programme and we get our safety case system established. After that we get the safety case report system, which we will use in the future to optimize our disposal facility.

Now we come to the first step to establish a Features, Events and Processes (FEPs) list. Based on NEA IFEP list ver. 3, we established our own selection criteria. After the first round selection, we get an FEPs list for LLW and ILW near surface disposal. Based on the special factors and characteristics of the Mount Feifeng Repository Site we select for the second round and get a general FEPs list for the Mount Feifeng Repository, taking into consideration the special conditions like slide slope and other characteristics lists, we get the final characteristic list for the site.

Let us see how we establish our FEPs list. The external factors we take into consideration can be divided into four aspects: disposal facility, geology, climate, and future human activity and how they will influence our system.

For the operation period, we mainly take into consideration three aspects:

— Waste – Is the package intact or damaged?;
— Engineering, including disposal unit and if it is in a good condition, the covering layer and slide slope;
— Operation situation – Is it well operating or is there any accident?

Based on this, we got a list of scenarios that could happen in the period of operation. We marked them according to the probability of happening and nuclide migration.

We also developed different scenarios for the after-closing period. We take three aspects into consideration:

— Barrier – is the barrier in good shape, partly damaged or totally disappeared?;
— Waste and container – Is it intact or damaged?;
— Supervision – Is it under supervision by the government?

Also, after collecting them, we sort them out and consider the probability of happening or nuclide migration, we finally got six scenarios we are interested in:

— Natural infiltration;
— Downstream drilling;
— On-site drilling;
— Sprinkle after drilling;
— On-site drilling;
— Slope instability.

After doing this programme, we get as a result the possible scenarios that will have a relatively large impact on the safety of the Mount Feifeng Repository Site and this helps us ensure its safety in a longer period, during its operation, closure and post-closure period. These two projects are only a part of our scientific research programmes. They all help improve our management capability of radioactive waste. In the future we hope to push forward radioactive waste management with high quality.

4. FUTURE PLANS

What do we plan to do to improve this ability? We plan to establish a digital disposal system and here we can see the concept map. You can see that with the digital disposal system, we try to establish a platform system for the management of radioactive waste information. First, we receive the radioactive waste from our clients, which includes NPP, research institutes, universities and urban DSRS repositories, and so on. We dispose of such waste and during our operation and management, we are under the supervision of government agencies like NNSA, SASTIND, and MEE. In the system we will build a database for levelling and staging management. This system can also help balancing traffic stream, material stream and human stream and help monitoring environment, individual dose and it will also have an OA office system and we hope to establish a 3D visible monitoring system. You can see that by doing this system, by establishing this platform, we can get the real time information of the radioactive waste that we are handling.

This is everything for today's presentation. Thank you everyone for listening and if you have any questions or interest, you can contact us. We look forward to future cooperation and communication with you.

Paper ID#244

CANADIAN REGULATORY REVIEW OF WASTE ACCEPTANCE CRITERIA FOR A LOW-LEVEL NEAR SURFACE DISPOSAL FACILITY

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Abstract

The Canadian Nuclear Safety Commission (CNSC) is reviewing the licensing submission for a proposed near surface disposal facility (NSDF) for low level radioactive waste (LLW) at Chalk River Laboratories in Deep River, Ontario, Canada. A crucial part of the application is the waste acceptance criteria (WAC). The NSDF WAC defines the criteria for the acceptance of LLW and ensures all waste received for disposal complies with the facility design and licensing basis. The CNSC's review of the NSDF WAC was an iterative process conducted using Canadian regulatory requirements and guidance and IAEA safety requirements, recommendations and guidance. Specifically, CNSC regulatory document REGDOC-2.11.1, Waste Management, Volume I: Management of Radioactive Waste requires a licensee receiving waste for storage or disposal to develop waste acceptance criteria consistent with, and derived from, the site-specific safety case. From this requirement, the CNSC uses the results of the operational and post-closure safety analysis to inform its regulatory assessment of the WAC. Key topics of regulatory interest were:

— The WAC development;
— Waste inventory and the identification of "key radionuclides";
— The evaluation of compliance with the WAC, acceptance of waste and the waste assurance programme;
— The roles and responsibilities for waste generators and the facility operator;
— Non-compliant waste and the "infrequently performed operations" process;
— The disposal of mixed waste.

The WAC also plays a key role in the assessment of post-closure safety. This was a particular area of regulatory attention from the perspective of the development of WAC and the role of the WAC in ensuring safety during the 10 000 year assessment timeframe. Using the CNSC technical assessment process, comments and requests for clarification or additional information were communicated to the licensee. In response, the WAC were revised and responses were prepared for each information request.

1. INTRODUCTION

1.1. CNL's proposed near surface disposal facility

Canadian Nuclear Laboratories (CNL) is proposing to construct a near surface disposal facility (NSDF) at the Chalk River Laboratories (CRL) site for the disposal of low level radioactive waste (LLW). The Canadian Nuclear Safety Commission (CNSC), Canada's independent nuclear regulator, is reviewing this proposal. To date, the NSDF project has not been approved by the CNSC.

The NSDF facility, if approved, will be located on the CRL site, which is owned by Atomic Energy of Canada (AECL) and operated by CNL. It is located on the southern shore of the Ottawa River, approximately 185 km northwest of Ottawa. The CRL site has a long history of nuclear activities beginning in 1944 when the site opened, and has since been at the centre of much of Canada's nuclear research activities and a source of a significant portion of the global medical isotope supply. The activities at CRL have led to the generation of radioactive wastes, all of which is currently in safe interim or long term storage. The NSDF project aims to create a disposal facility for LLW, generated through past activities at CRL and the decommissioning of many old structures located at the site.

The NSDF is proposed to contain 1 000 000 m^3 of LLW in an engineered containment mound (ECM) with a 50 year operational lifetime and 550 year design life. The ECM is a double-lined engineered containment, designed for the disposal of LLW in 10 disposal cells that meet the NSDF waste acceptance criteria. A multi-layer cover system will be installed over the waste upon completion of disposal operations in each cell [1].

All waste entering the NSDF has to comply with the WAC for the facility, which constitutes a key component of the NSDF safety case.

1.2. Canada's nuclear regulator – Canadian nuclear safety commission

The CNSC is Canada's independent nuclear regulatory body, created by the Governor in Council under the Nuclear Safety and Control Act (NSCA) [2]. The CNSC's mandate is to "regulate the use of nuclear energy and materials to protect health, safety, security, and the environment; to implement Canada's international commitments on the peaceful use of nuclear energy; and to disseminate objective scientific, technical and regulatory information to the public." [3]. The CNSC is "an independent entity and this independence is critical so the CNSC can maintain an arm's length relationship with government when making legally binding regulatory decisions. The CNSC is not an advocate for nuclear science or technology. To serve Canadians, the ultimate outcome of the CNSC's work has to be to establish safe and secure nuclear installations and processes solely for peaceful purposes and to instill public confidence in the nuclear regulatory regime's effectiveness"[3].

1.3. Overview of the licensing process

Once a license application is submitted, CNSC will evaluate the proposed safety and control measures contained in the documentation against the applicable regulatory requirements. Canadian safety fundamentals state that "Information submitted in support of an application has to demonstrate that the proposed safety and control measures will meet or exceed CNSC expectations. All submissions have to be supported by appropriate analytical, experimental, or other suitable evidence" [3].

To support the licence application, regulatory documents as well as industry standards may be used by the applicant. These documents become part of the licensing basis when directly referenced in the license or supporting documentation [3].

Technical assessments are conducted by CNSC staff to support licensing, compliance, and regulatory decision making (Fig. 1). Based on a thorough technical assessment, CNCS will confirm if the submitted documentation has a sound technical basis evaluated against the regulatory framework. These technical assessments will also check for the completeness of the provided materils, their comprehensiveness and the validity of the rationale in the technical justifications provided in the license submittal [3].

In addition to reviewing the information described above, section 24(4) of the NSCA places the onus on the CNSC to ensure the applicant [3]:

- Is qualified to carry on the activity that the licence will authorize the licensee to carry on;
- Will, in carrying on that activity, make adequate provision for the protection of the environment, the health and safety of persons and the maintenance of national security, and the measures required to implement the international obligations to which Canada has agreed.

The comprehensive assessment that takes place during the licensing process may define additional programmes and criteria as conditions of the licence. Once they are satisfied all requirements of the NSCA and its associated regulations have been met and the applicant's documentation is complete and acceptable, CNSC staff prepare a licence recommendation for submission to the Commission. The recommended licence may include any conditions identified as necessary during the assessment, including the documentation references submitted in support of the application. Ultimately, the Commission is responsible for the decision to issue a licence and the conditions that are included in the licence. Each decision to license is based on information that demonstrates that the activity or facility operation can be carried out safely and that the environment is protected [3].

FIG. 1. Overview of the CNSC technical assessment process for review of licensing submissions.

1.4. Canadian regulatory framework

The CNSC maintains an effective and flexible regulatory framework inorder to safely regulate an evolving nuclear sector. Figure 2 below depicts the main elements of Canada's nuclear regulatory framework, which consists of laws passed by the Candian parliament governing the regulation of Canada's nuclear industry, as well as the applicable regulations, licences, and documents, which CNSC uses to regulate the industry.

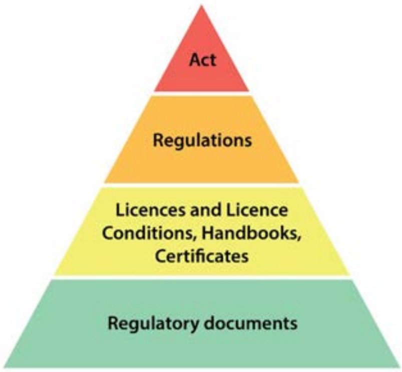

FIG 2. Elements of the Canadian nuclear regulatory framework [3]

The NSCA and its associated regulations set out requirements, while regulatory documents provide more detailed regulatory requirements and guidance, expectations, and decisions. Regulatory documents explain to licensees and applicants what they have to achieve to meet the requirements set out in the NSCA and its regulations.

The CNSC regulatory documents related to radioactive waste management and decommissioning, specifically for disposal and WAC, are as follows:

— REGDOC-1.2.1, Guidance on Deep Geological Repository Site Characterization;
— REGDOC-2.11, Framework for Radioactive Waste Management and Decommissioning in Canada,;
— REGDOC-2.11.1, Waste Management, Volume I: Management of Radioactive Waste 2;
— REGDOC-2.11.1, Waste Management, Volume II: Management of Uranium Mine Waste Rock and Mill Tailings;
— REGDOC-2.11.1, Waste Management, Volume III: Safety Case for the Disposal of Radioactive Waste, Version 2.

2. REGULATORY REVIEW OF THE NSDF WASTE ACCEPTANCE CRITERIA

As a key part of the NSDF licensing application, the WAC was subject to extensive regulatory review by the CSNC following the licensing and technical assessment processes [4]. CNSC staff submitted numerous comments to CNL for disposition and reviewed multiple revisions of the WAC prior to reaching the now final version. In addition, several detailed technical meetings were held between CNSC staff and CNL on the WAC, waste inventory and long term safety to ensure clarity for both the proponent and regulator about the WAC and the regulatory issues being raised. CNSC staff's assessment of the WAC and all other aspects of the NSDF licence application will be presented to the Commission in an upcoming public hearing for their decision on the project.

In the course of CNSC staff's review, several technical themes emerged on particular aspects of the WAC, as described in the following sections.

2.1. Long term safety and the WAC development process

The development of the NSDF WAC was an iterative process that was closely linked to the results of the operational and post-closure safety assessments (PostSA) for NSDF which analyses the impact of the facility on people and the environment during the post-closure period to ensure isolation and containment of the waste is maintained and acceptance criteria continue to be met for the 10,000 year assessment timeframe [5]. The PostSA is assessed against CNSC REGDOC-2.11.1, Waste Management, Volume III: Safety Case for the Disposal of Radioactive Waste, Version 2 and IAEA safety requirements and recommendations such as IAEA Safety Standards Series Nos SSR-5, Disposal of Radioactive Waste, and SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste. In the iterative development process estimated radionuclide inventories and concentrations were used to assess the potential dose during the post-closure period against acceptance criteria (1 mSv) and dose constraints for the facility (0.3 mSv) to ensure there are sufficient safety margins to account for uncertainties or assumptions in input data. The inventory was then adjusted to obtain new PostSA results and revised in the WAC. This allows the derivation of specific activity limits for radionuclides in the NSDF. These limits provide a safety envelope for the acceptable inventory of the facility as the PostSA analysis showed an inventory composed of these limits resulted in doses that meet acceptance criteria and dose constraints.

The limits, along with Canada's radioactive waste classification for LLW, were then used to determine the waste streams that may be accepted into the NSDF [6]. On this basis, specific activity limits were defined for any waste accepted for disposal at the NSDF for:

— α-emitting radionuclides;
— Long-lived β and γ emitting radionuclides;
— Short-lived β- and γ-emitting radionuclides.

The inventory was further developed by extrapolating existing waste packages, environmental remediation projects and decommissioning projects data for the Chalk River Lab site to an assumed total volume of the NSDF at time of closure (i.e., end of operations phase in ~2070). CNL developed the projected waste volumes and inventory of significant radionuclides (activities) in bulk and packaged waste using the following main steps and as illustrated in Fig. 3 [1]:

— Assemble characterization data obtained or derived from waste package records, facility decommissioning and environmental remediation projects.
— Assess the data against the WAC and report total radioactivity and radionuclide concentrations.
— Evaluating the Reference Inventory against the long term safety criteria to confirm the radiological inventory provides acceptable results in the PostSA.
— Produce the Licensed Inventory, representing a maximum radiological inventory limit for the NSDF.

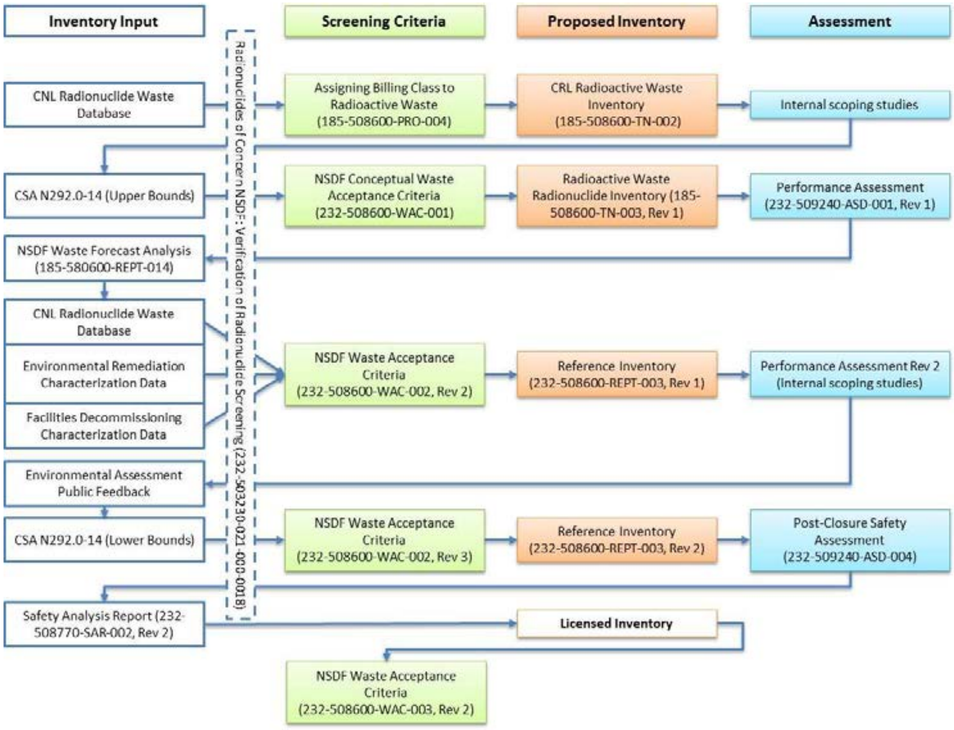

FIG. 3. Flowchart showing the inputs and steps in the development of the NSDF WAC. Copied from [1] with permission.

The initial proposal for the NSDF in 2017 envisioned it would contain LLW and ILW. However, in response to PostSA results and public and regulatory comments, the NSDF WAC was revised to accept only LLW. As a result, the inventory of the NSDF at closure would now contain 1% of the activity that had been initially planned if a licence is issued. Indeed, to provide more confidence that the NSDF waste inventory contains only LLW, the WAC was adjusted to align with the lower bounds of the IAEA, CNSC, and CSA Group guidelines for LLW. Previous to this adjustment, the WAC reflected the upper bounds of these documents.

CNSC's role throughout the WAC development was to ensure the resulting WAC comply with Canadian requirements and guidance. Specifically, REGDOC 2.11.1 Volume I requires that the WAC have to be developed "consistent with, and derived from, the site-specific safety case." In addition, REGDOC 2.11.1 Volume III requires "The limits, controls and conditions derived from the safety assessment for the waste shall include the waste acceptance criteria for individual packages as well as for the entire facility, and the acceptable waste inventory and/or the allowable concentration levels of radionuclides in the waste."

CNSC staff had many comments and questions on drafts of the WAC throughout its development concerning the integration of the PostSA results into the WAC. Specifically, CNSC staff requested that this link be clearly explained within the safety case and PostSA to enable regulatory assessment of how the WAC and bounding waste inventory were developed. It is important to understand how the bounding inventory, limited by the WAC, translates to receptor doses in the operational and post-closure periods. The WAC, as the document that controls and limits the waste entering the disposal facility, is the ultimate control on the volume and inventory of waste accepted to NSDF. As a result, predictions of long term safety, which are sensitive to the waste inventory, are highly correlated to the limitations imposed by the WAC. This makes it of the utmost regulatory importance that the WAC be examined in the context of the post-closure safety assessment. A specific example of this relationship is illustrated by the results for one of the NSDF human intrusion scenarios in which doses were above 1 mSv/yr. In this case, the doses were due to the mobile and long-lived radionuclides ^{129}I and ^{239}Pu being transported in groundwater from a hypothetical well drilled directly in a hypothetical contaminant plume. In response to this result, CNL reduced the allowable activity of both radionuclides in the WAC inventory to ensure doses would remain well below acceptance criteria in the unlikely event this, or a similar scenario, occurs in the future.

2.2. Roles and responsibilities of the waste generator and waste receiver

2.2.1. Waste certification and verification

CNSC staff requested clarification on the roles and responsibilities of the waste generator and waste receiver in the WAC during the regulatory review process as early drafts of the WAC contained little detail on how waste generators would be certified, and waste would be verified. Specifically, these comments raised the fact that as the licensee and owner of the WAC it is the sole responsibility of CNL to evaluate and verify waste for acceptance to the NSDF and not the waste generator. In addition, relying on waste generators to evaluate the acceptance of waste is a conflict of interest as they desire their waste to be accepted into the NSDF.

In response, CNL revised the WAC to state "conformance of the waste with the WAC and its acceptance for emplacement at the NSDF, is the responsibility of CNL as the licensee". CNL also stated that compliance with WAC criteria is enhanced by qualification of users such that they have demonstrated competence in both understanding and implementing the NSDF WAC. This doesn't transfer responsibility of licence compliance but ensures users are aware of the requirements and are competent to comply with them.

Furthermore, CNL also developed an internal process document for the waste certification programme as part of their management system that has to be adhered to. This document has been reviewed by the CNSC.

2.2.2. Infrequently performed operations process

The infrequently performed operations process (IPO) enables the waste receiver to accept waste into the NSDF that may not meet all of the criteria listed in the WAC, such as oversized debris. The IPO process enables CNL to consider the disposal of this waste on a "case by case basis" [4].

CNSC staff requested that additional detail regarding the WAC variance process, now called the IPO process, be added to the WAC. This request required that the section include reference to the CNL internal documents used to carry out the process but also include a summary of the process and its use in the WAC itself to provide greater clarity to users.

CNSC staff also commented that if waste does not meet the WAC, and is therefore outside the NSDF safety criteria, then it should not be accepted. CNL agreed that the WAC provides the limitations on acceptable waste. CNL further responded that conservatism has been built into the NSDF safety criteria and reference inventory to allow the infrequently performed operations process to function and enable the disposal of legacy LLW at CNL. Specifically, CNL states in the WAC that "The Infrequently Performed Operations Process is available as an option when a specific waste package or waste stream meets most, but not all of the requirements of the WAC. The Infrequently Performed Operations process is limited by the safety basis provided in the Design Requirements, the Environmental Impact Statement, the Post-Closure Safety Assessment, and the Safety Analysis Report as there is safety margin between the safety basis and the WAC" [4].

In addition, CNL revised the WAC to state that for waste to be accepted under the IPO process it has to include "the documented authorization from the NSDF Facility Authority following the Infrequently Performed Operations process document. Authorization must comply with the Facility Authorization for the Operation of the Near Surface Disposal Facility at the Chalk River Laboratories. This may be supported by the Operational Decision Making process or Problem Validation & Technical Operability Evaluation as applicable" [4]. The facility authorization, operation decision making process and technical operability evaluation are CNL internal process documents that support the IPO process.

2.3. Significant radionuclides and the reference inventory

2.3.1. Reporting requirements

CNSC staff requested additional clarity and revision on several aspects of the minimum reporting requirements in earlier drafts of the WAC. Specifically, CNSC staff asked how CNL would ensure that limits for significant radionuclides would not be exceeded during NSDF operations. In response, CNL has now included the reference inventory as part of the WAC as well as the requirement that waste generators report the activity and identity of radionuclides in the waste to enable tracking against the reference inventory. This addition ensures that waste tracking is embedded in the WAC directly linking it to the post-closure safety case through the use of the reference inventory and the need to track significant radionuclides, which were identified through the PostSA modelling scenarios [5].

In addition, earlier drafts of the WAC only required that only the activity of the significant radionuclides be reported, however, in response to CNSC comments the WAC now requires the identity of the significant radionuclides in the waste be reported to explicitly enable tracking against the reference inventory. This is crucial information as the concentration limits for acceptable waste in the WAC are provided according to their emission type as opposed to radionuclide specific concentration limits.

The final NSDF WAC requires that "waste characterization plans be developed to provide radionuclide concentrations that are representative of the waste streams in question. As a result, the waste generator has to report at a minimum:

- The activity and identity of radionuclides that contribute to 95 % of the total activity and the uncertainty of those radionuclides;
- For significant radionuclides (Section 5.4):
  - The activity and identity of the significant radionuclides and the uncertainty of the activity of those radionuclides; or
  - When a significant radionuclide was not detected in the waste, the detection limit for the analysis; or
  - When the activity of a significant radionuclide was added using scaling factors, justification of the scaling factors; or
  - When a significant radionuclide was not analysed, justification is required; and
- The activity of radionuclides with half-lives greater than five years that were identified during the waste characterization process also have to be reported along with their uncertainties. This is particularly important for radionuclides that decay to significant radionuclides (e.g., ^{244}Cm, ^{238}Pu, ^{236}U)." [4]

2.3.2. Concentration limits

The NSDF WAC requires that radionuclide concentrations in waste streams be reported, however it does not specify concentration limits on an individual basis for each radionuclide, rather the WAC limits radionuclides according to emission type (Table 1) [4].

CNSC staff requested that CNL clarify why radionuclide concentration limits were established according to emission type as opposed to for specific radionuclides considering that many other facilities around the world used nuclide specific concentration limits in their respective WAC's, particularly for those radionuclides identified as "significant radionuclides". CNL responded that the method of developing the NSDF reference inventory, using site-specific waste forecasts and the iterative input of the reference inventory in the PostSA, ensures that there are radionuclide specific limits for the NSDF as a whole that are intended to ensure safety criteria for the facility are met and the reporting requirements ensure radionuclides are tracked individually. The concentration limits presented are related to the Canadian framework for the classification of LLW and ensure that all waste accepted at the NSDF is indeed LLW [4, 6].

In addition, the original proposal for the NSDF envisioned that it would accept ILW for disposal (1% of the NSDF by volume) and as a result significantly higher concentration limits and a total inventory was initially proposed. CNSC staff recommended that CNL reassess the inclusion of ILW in the NSDF due to the difficulty in achieving long term safety and safety margins for near surface disposal as well as IAEA and Canadian regulatory guidance on the disposal of ILW. Specifically, predicted doses from some human intrusion scenarios exceeded the 20 mSv/yr stipulated in section 2.15 (d) of SSR-5. As a result, CNL removed all ILW from the proposed NSDF inventory and modified the WAC to allow only LLW.

TABLE 1. RADIONUCLIDE CONCENTRATION LIMITS IN NSDF WASTE

Limits for Bulk Waste and Non-Leachate Controlled Packaged Waste	100 Bq/g for α emitting radionuclides 1000 Bq/g for long lived βϒ emitting radionuclides (t1/2 > Cs-137) 10 000 Bq/g for short lived βϒ emitting radionuclides (t1/2 ≤ Cs-137) 100 000 Bq/g for H-3
Limits for Leachate Controlled Packaged Waste	400 Bq/g for α emitting radionuclides 10 000 Bq/g for long-lived βϒ emitting radionuclides (t1/2 >Cs-137) 10 000 Bq/g for Cs-137 10 000 Bq/g for Sr-90 10 000 000 Bq/g for H-3

Note: Table 1 has been modified from the NSDF WAC document [4]

2.3.3. Shielding and dose rates

The NSDF WAC specifies "the dose rate limits and the means of handling and transferring that shall be applied to the bulk and packaged waste at the NSDF" [4]. These are presented in Table 2 and are derived from the operational safety analysis.

TABLE 2. DOSE RATE LIMITS AND MEANS OF HANDLING AND TRANSFERRING

Radiation Type	Dose Rates	Means of Handling and Transferring
Total gamma and neutron	≤0.5 mSv/h near contact and ≤0.01 mSv/h at a distance of 1 metre (m)	Manual handling or mechanical means
Total gamma and neutron	>0.5 mSv/h to ≤2 mSv/h near contact and >0.01 mSv/h to ≤0.1 mSv/h at a distance of 1 m	Mechanical means
Total gamma and neutron	>2 mSv/h near contact or >0.1 mSv/h at a distance of 1 m	Handling and transferring is subject to Radiation Protection Programs controls, Infrequently Performed Operations and assessment approval by the NSDF Facility Authority.
Beta	<10 mSv/h near contact	Based on total gamma and neutron dose rates

CNSC staff commented about a lack of alignment between the dose limitations presented in the WAC with those found in the operational safety analysis [7]. In response, CNL revised the WAC and the safety analysis to ensure full alignment and integration of the WAC and safety analysis which are key safety and licensing documents.

2.4. Physical properties of waste

2.4.1. Waste types

The waste envisaged for emplacement in the NSDF has been categorized into six types by CNL (Table 3) [4].

TABLE 3. NSDF EMPLACED WASTE CANDIDATE CATEGORIZATIONS

Type	Physical Properties
1	Soil and soil-like wastes. Includes contaminated soils and other waste materials with characteristics similar to soil that can be placed within the mound with what would be required for the disposal of soil.
2	Comingled radioactive waste, debris, refuse, soil, and soil-like waste. Includes wastes anticipated to be at least 50% soil or soil-like in nature.
3	Non-soil-like waste. Includes materials that can be excavated and handled as bulk materials but do not have the physical characteristics of soil and soil-like materials. These include process wastes, highly organic wastes, highly compressible wastes, flowing wastes, and similar waste types.
4	Decommissioning and Demolition (D&D) waste. Includes typical materials used in construction, such as: concrete, asphalt, brick, lumber, structural steel, process equipment, piping, wood, and other building materials produced by D&D activities.
5	Packaged Waste, refers to wastes contained in rigid packages. There are two types of rigid waste packages: Non-Leachate Controlled Waste Packages and Leachate Controlled Waste Packages. Liners and soft-sided packages are not considered Type 5 Waste.
6	Oversized debris, includes waste that does not fall within the definition of waste Types 1 through 5, primarily by its size or shape. The Infrequently Performed Operations process (Section 6.4), is used to approve placement of Type 6 wastes.

Earlier versions of the NSDF WAC had a very broad definition for Type 6 waste such that it appeared almost any waste that did not fit in the other five types could be classified as Type 6. At the request of the CNSC, CNL revised the definition to clarify that Type 6 has to meet all chemical and radiological requirements of the WAC and is only to be considered for oversized waste. The statement that other wastes falling outside these types may only be considered for acceptance in the NSDF through the infrequently performed operations process was added to address this concern.

2.4.2. Packaged waste

Earlier versions of the NSDF WAC had vague and limited information on the requirements on lead used as shielding in waste packages and its acceptance for emplacement in the NSDF for disposal. CNSC staff requested CNL to be more specific and include requirements applicable to the use of lead as shielding and for disposal. The final WAC, along with the NSDF As Low As Reasonably Achievable (ALARA) Assessment [8], states shielded waste packages are used to limit external exposure rates and protect workers during waste emplacement and has to comply with the dose rate limits outlined in Table 2. For disposal of waste packages bearing lead material, they are subject to the Land Disposal Requirements of Ontario Provincial Regulations 347, which contains the regulations on the disposal of hazardous materials in landfills.

2.5. Disused sources

CNSC staff noted there was little discussion of disused sources in earlier drafts of the WAC and requested that CNL add information regarding the acceptability of disused sources in the WAC and ensure alignment with

IAEA publications, such as “Disposal Options for Disused Radioactive Sources,” TRS-436, IAEA, July 2005, and “Safety considerations in the disposal of disused sealed radioactive sources in borehole facilities,” TECDOC-1368, IAEA, August 2003. In response, CNL revised the WAC to include a section specifically dealing with the disposal of disused sources in the NSDF. The WAC now states “The NSDF requires that all disused sources being considered for disposal at NSDF are evaluated through the Infrequently Performed Operations process. The evaluation have to follow the applicable International Atomic Energy Agency (IAEA) requirements and guidance” [4].

2.6. CNSC compliance oversight

If the Commission grants CNL a licence to proceed with the construction and operation of the NSDF, CNSC’s role will expand to include compliance oversight of the NSDF. While the licensee is responsible for the safe operation of its site, the CNSC also undertakes compliance oversight to ensure ongoing compliance with the licensing basis and regulations. To evaluate compliance the CNSC conducts desktop reviews and field verification, which are primarily inspections. CNSC inspections are led by trained inspectors which are planned and executed according the CNSC’s conduct of inspections processes. If deficiencies are identified via ongoing compliance, the licensee is expected to correct the situation promptly. If necessary, the CNSC may also compel the licensee to return to compliance using a variety of enforcement tools [3].

In the case of the NSDF, the WAC, which has been submitted as part of the licensing application for the facility, will become a part of the NSDF licensing basis if the Commission grants a licence. If this occurs, the WAC will form a key part of CNSC’s compliance verification activities for the NSDF to verify that waste accepted for disposal does indeed comply with the WAC, has been characterized to the level required in the WAC and supporting documents, and that sufficient information is provided and retained for tracking of waste disposed of in the NSDF. Planned future inspections of the NSDF include waste characterization inspections on the different waste streams, such as the legacy waste, facilities decommissioning, environmental remediation, and operational wastes and their compliance with the WAC.

3. CONCLUSIONS

The regulatory review of the NSDF waste acceptance criteria was a rigorous, iterative process. In carrying out this review, the CNSC:

— Followed the established technical assessment and licensing processes to identify regulatory concerns and submit comments to CNL;
— Reviewed responses from CNL and participated in several detailed meetings regarding the WAC development through iteration with the post-closure and operational safety assessments and content;
— Reaffirmed its commitment to ongoing compliance verification of the NSDF, and the WAC specifically, if the NSDF obtains a licence from the Commission.

CNSC staff identified a number of areas for clarification and improvement in early drafts of the NSDF WAC prior to it reaching its final version. Key topic areas for CNSC comments included:

— The development of the WAC and its linkage to ensuring long term safety for the NSDF during the post-closure period.
— How waste generator certification and waste verification against the WAC are performed and the application of the infrequently performed operations process.
— Reporting requirements for significant radionuclides and concentration limits for NSDF and why radionuclides are limited according to emission type as opposed to radionuclide specific limits.
— Ensuring consistency for shielding and dose rates in the WAC and the NSDF operational safety analysis.

— The physical properties of the different waste types. In particular Type 6 waste and ensuring that this waste type would be screened appropriately using the WAC and the infrequently performed operations process.
— The acceptability of lead shielding for disposal in the NSDF.
— The acceptability of disused sealed radioactive sources.

If the Commission grants CNL a licence for the NSDF, CNSC staff will begin to engage in compliance verification activities of all aspects of the NSDF, including the WAC. These activities will include desktop reviews and onsite inspections. The implementation of the NSDF WAC and compliance with its criteria will be key points that CNSC inspectors will verify during on-site inspections.

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3.5. SESSION 5 – SOCIOECONOMIC ASPECTS OF RADIOACTIVE WASTE MANAGEMENT PROGRAMMES

There is a growing awareness that an open and transparent dialogue with stakeholders is important in the decision making process for radioactive waste management programmes and that meaningful engagement is as important as safety case and technical aspects of the project. This Session provided a forum for the sharing of experiences of socioeconomic considerations and how they have been reflected in Member State's waste management programmes.

In some Member States, good progress has been achieved towards siting and implementing disposal facilities with the consent of the local community. In other Member States, and even on other disposal projects within a same Member State, continuing concerns and opposition among the public have slowed down or so far prevented the implementation of the specific radioactive waste disposal programme. Public understanding and acceptance of a consent-based disposal programme requires adequate information to the public at large on the associated programme as well as proper involvement of the relevant stakeholders in the different stages of its development and implementation. The strategy and methods to be used for communication and stakeholder involvement need to be established, taking due note of challenges and lessons learned in similar programmes around the world, and building upon the specific national, social, political, and institutional situation.

To initiate and develop a radioactive waste disposal programme, a Member State needs to establish a legal and institutional framework, and to ensure sustained political support, suitable funding, and the provision of competent resources to carry out the responsibilities assigned to the organizations within the national framework. The Member State also needs to elicit and establish a clear, understandable, and acceptable decision making process. Sound communication and stakeholder involvement are key components of such a process.

It is now widely accepted that societal and political acceptance can be a deciding factor for implementation of radioactive waste management programmes. The focus of many operators is now on social acceptability as the priority, as they realise that technical issues usually have a more straightforward solution. Successful programmes today are those that start thinking about their stakeholders from the very start.

The Session heard from a number of these programmes, some more successful than others, but all recognising the truth that enhancing the level of stakeholder participation will result in a relationship of trust, thus supporting sustainable decision making. Several different approaches are described, which could be adopted by other programmes, but be aware, whatever approach is adopted it needs to be adapted to suit local circumstances and culture.

In general, there is consensus that the successful radioactive waste management programme is the one that promotes, creates, and feeds networks with stakeholders and is actively part of the community in which it sits.

Session Chairs: S. Ali (Pakistan) and L. Payne (United Kingdom)

Session 5 comprised eight papers from Netherlands, Ethiopia, Switzerland, Germany, Canada, United States of America, Japan, with an additional paper from one of the conference's Young Professionals Showcase Leads (Brazil).

- **Paper ID#312 by E. Verhoef (Netherlands)** discussed the importance of communication, engagement and emotion, for successful relationship building between waste management organizations and the communities that they are part of. Some organizations will consider ‘invisibility’ as a mark of their success, but this paper argues the opposite. Whilst all waste management facilities will be visible, if not highly visible, it is important to maintain that visibility, otherwise how can you engage with the community if you become invisible? The paper explains the steps that COVRA have taken to maintain their visibility: by designing their high level waste storage facility to be dual purpose and opening it up as a community space, displaying works of art in the storage halls and presenting the externals of the buildings as works of art themselves.

- **Paper ID#106 by A. Tiruneh (Ethiopia)** described research into public attitudes to a waste management facility in Addis Ababa. The research concluded that whilst some members of the public had positive attitudes to the facility, the overriding perception was negative, with waste and radiation having negative connotations. The reason for the negative perception was attributed to knowledge gaps and unfounded narrations, which should be addressed by information provision and a strategically designed public awareness campaign.
- **Paper ID#284 by C. Bolli (Switzerland)** described the process being followed in Switzerland to site a geological disposal facility with particular emphasis on the socioeconomic impacts on affected communities. Three areas within the country are now being investigated for technical suitability and the paper describes socioeconomic baseline studies and trends identified as a result of long term monitoring.
- **Paper ID#172 by J. Ottmann (Germany)** described the approach adopted in Germany to encourage public participation in the re-launched site selection procedure for a planned geological repository. This is a multi-stage selection process with clearly defined scientific siting criteria and transparency and public involvement as key principles. Public involvement has been promoted by use of conferences, which have facilitated broad open discussion before decisions are made, and which the implementer will have to take into account. These conferences were self-organized, with agenda and working modes set by the participants. This approach was found to promote involvement and strengthen participation and commitment. It did tend to attract already organized or interested stakeholders who were not necessarily representative of the general public.
- **Paper ID#257 by M. Phaneuf (Canada)** presented the role that the regulator can play in building public trust and confidence in a site selection process. First of all, the public needs to have trust and confidence in the regulator as a source of independent and trustworthy information. Consultation and engagement with stakeholders has always been a key part of the regulatory function and expectations are increasing, where meaningful engagement is as important as safety case and technical aspects of a project. The classic spectrum of stakeholder engagement moves from inform, to consult, to involve, to collaborate, and then empower. Canadian experience has shown that moving through the stages does result in a relationship of trust thus supporting sustainable decision making.
- **Paper ID#215 by C. Mendez Cruz (USA)** presented an approach being developed to assist with siting of geological disposal facilities which recognises that the challenges are not only technical, but also political and social. The approach is based on the application of sociotechnical systems theory which recognises the interaction and dependencies between people and technology. Use of ‘concurrent engineering’ requires early input from stakeholders and aims to find an optimized and balanced solution which supports both the technology and community standpoints.
- **Paper ID#304 by S. Kondo (Japan)** presented an overview of the consent-based and step wise approach in the site selection process for a geological disposal facility in Japan. Recognising that this involves not only technological but also socioeconomic problems and solutions, the Government and developer have been pursuing an active information and consultation process to keep the disposal agenda alive and effective. The accident at the Fukushima Daiichi nuclear power plant has had a major impact on public opinion which has had to be reflected in the communications and outreach programmes.
- **Paper ID#110 by R. Soares Souza Pimenta de Almeida (Brazil)** presented a study that uses geospacial techniques to apply the site selection methodology for radioactive waste disposal. The project demonstrated that this is a robust and feasible approach and provided

outcomes that were in line with appropriate legislation. The study identified a number of potentially suitable sites which could then be considered from a public acceptability viewpoint.

Paper ID#312

OPEN, TRANSPARENT, BUT NOT INVISIBLE

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Abstract

Over past decades, there has been a growing social awareness of the need for transparency, openness, and dialogue with stakeholders in decision making processes throughout the life cycle of radioactive waste facilities. Member States approach the dialogue on long term radioactive waste management in different ways depending on cultural, political, institutional, and economic factors. The planning of the radioactive waste programme determines when, how, and with whom dialogues need to take place. In the Netherlands, the factor of time plays a decisive role in the dialogue about radioactive waste. As the Netherlands has an interim storage period of at least a hundred years, communicating time is a specific challenge for the Central Organization for Radioactive Waste (COVRA), the national organization for the management of radioactive waste. The paper explains how COVRA’s communication activities evolved over time to meet that challenge. Like many other (nuclear) organizations, the objective first was to be as transparent, factual, and objective as possible. But if one is too transparent, one becomes invisible to its stakeholders and the public, which is not a good basis to start a dialogue. To create opportunities for dialogue, people need to notice you: you have to show yourself, stand out, be proud of what you do, show that radioactive waste management can be done in not only a safe, effective and efficient manner but also with beauty. Therefore, COVRA started using its buildings as communication instruments. COVRA’s communication became not only factually and objectively, but also based on emotion, art, and cultural heritage.

1. INTRODUCTION

Over the past decades, there has been a growing social awareness of the need for transparency and openness, and the dialogue with stakeholders in decision making processes throughout the life cycle of radioactive waste facilities [1]. Dialogue processes can enhance public awareness, trust, risk perception, and understanding, as well as produce socioeconomic strategies for best addressing these. Dialogue processes consist of interactions between waste management organizations, local municipalities, regulatory bodies, members of the public, and environmental and civil society organizations. In some Member States, the dialogue between the institutional actors and communities take place or will take place in the form of partnerships, while in others the specific arrangements to consult and engage the local and regional levels is done through regional conferences or other participatory models. Member States approach the dialogue on long term radioactive waste management in different ways, depending on cultural, political, institutional, and economic factors. Another important factor is time. The planning of the radioactive waste programme determines when, how, and with whom dialogues need to take place. In the Netherlands, the time factor plays a decisive role in the dialogue about radioactive waste.

The Dutch policy is that radioactive waste and spent fuel are stored above ground for a period of at least 100 years. Geological disposal is envisaged in around 2130. Radioactive waste and spent fuel are managed by the Central Organisation for Radioactive Waste (COVRA) [2]. For the management, COVRA has realized storage and processing facilities in the southwestern part of the Netherlands. At the COVRA site, the waste is stored aboveground in specially designed buildings. COVRA takes all necessary steps for the longer term. This means that a period of at least 100 years was considered in the design of the waste packaging and storage buildings. But how can one maintain a dialogue over such a long period? What role can storage facilities fulfil to start and maintain a dialogue and build public confidence in future disposal? How can they help explain the long term aspect of radioactive waste management in a way people can relate to? Considering the interim storage period of at least a hundred years, this is a specific challenge for COVRA. This paper explains how COVRA's communication activities evolved over time to meet that challenge.

2. SEEKING THE DIALOGUE

2.1. Open and transparent

Established in 1982, COVRA was temporarily located until a new location could be found. In 1986, the choice of an industrial area near Borsele, a municipality in the southwestern of the Netherlands, received strong local resistance. This resistance was well illustrated in three cartoons by a local villager [Fig. 1]. Even though COVRA's activities would pose no risk to the municipality, the fear and, therefore, negative attitude among citizens was real. Something more than a purely rational attitude would be necessary to bridge the gap between COVRA and Borsele residents. A relationship had to be built and, as ultimately COVRA would be established there for many generations, it had to be built for a very long term. Most successful relationships are not built on rational motives, rather they are built on emotions. Therefore, COVRA started to take emotional values into account in the actual implementation of the building plans and site layout. The objective for the design was primarily aimed at safety and security, but openness and transparency were also set as objectives. The site was designed to show visitors "everything" and make a visit an effective way to have a dialogue with the local communities.

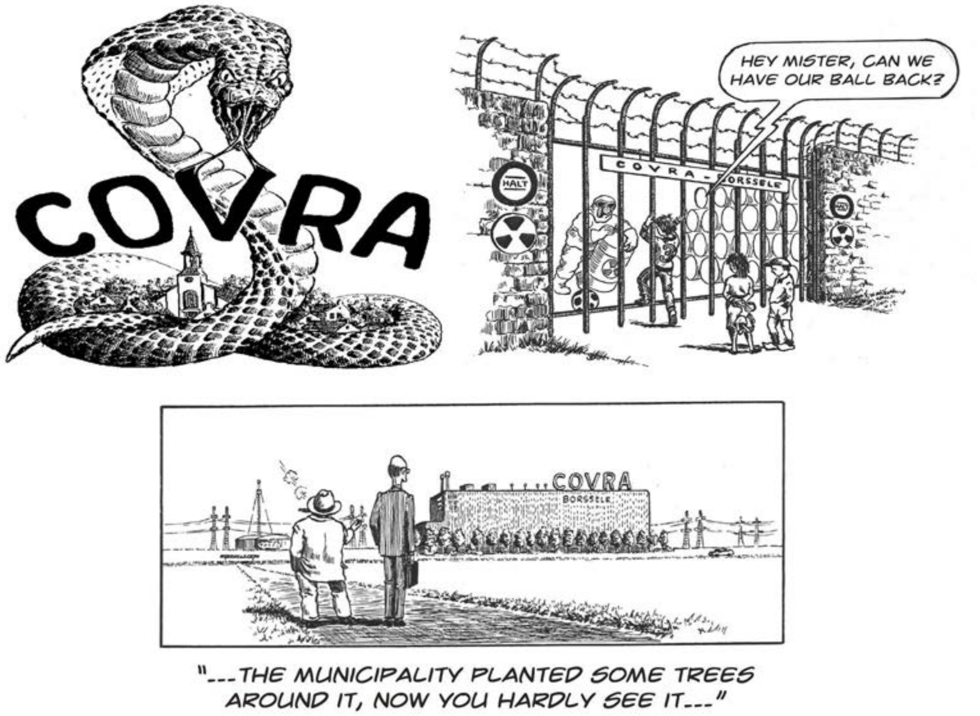

FIG. 1. Cartoons by a villager from Borsele about COVRA (text translated into English). Courtesy of COVRA.

A typical visit began with an explanation of what radioactivity is, of the uses and dangers of radioactive material, and included a guided tour of the facilities. The first impression visitors get from the site is its demarcation, which is required for both safety and security. Although a barbed wire fence meets security requirements, it does not appear open or hospitable. For this reason, the main gate is always open during working hours and the reception hall and information room are freely accessible. They form part of the barrier to the radiologically controlled area. The terrain is open and transparent. Everything that happens on site is visible. The forecourt has plenty of vegetation and an almost park-like structure that one rarely encounters in an industrial area. A pond (moat) has been chosen at the entrance to the site. This also has a safety function as an extinguishing water reservoir.

The reception hall is open and transparent, but the facade finish of the processing building and the storage sheds for low and medium level radioactive waste is made of concrete with marble stone supplement in a light neutral colour and is, therefore, robust, and solid. The walls and doors are thick and heavy, providing radiation shielding and a barrier against intruders. Nevertheless, the buildings are accessible to all visitors under supervision. The processing building has a central corridor along which various processing or buffer storage areas are located. Depending on the activities and current radiation level, these areas can also be entered by visitors. In the storage buildings, waste is sorted into various radiation levels; in the final stacking, the higher radiating waste barrels are shielded by barrels with a lower radiation level. The result is that a low radiation level prevails in the storage areas, so maintenance and inspection work are not under time pressure (safety), and visitors can also walk between the waste drums. Site visits are an effective way to facilitate the dialogue about radioactive waste, as visitors can form an opinion of the storage based on their own experience. After the visit, visitors generally have a more positive attitude toward COVRA. This does not automatically mean they are also in favour of nuclear power production, but it takes some of the emotion away from that discussion. However, it turned out to be a challenge to keep attracting a substantial number of visitors over time.

A dialogue about an operational waste management facility is different than a dialogue during decision making about a site for a disposal facility. While site selection attracts the direct attention and involvement of local communities in the decision making, it requires a significant effort keep local communities and other stakeholders involved in an operational storage facility. The normal operation of the COVRA facility yields little real news: few changes in activities or buildings occur and, due to high safety standards, there are fortunately no incidents. Consequently, after the siting, establishment, and commissioning, the attention of the media, local community, and other stakeholders had faded. There was no opposition to COVRA, but COVRA was not visible either. Like in the cartoon, COVRA became invisible (“you can hardly see it”), but not because it was surrounded by trees; it was hidden in plain sight due to a lack of interest to look at it. For COVRA, openness and transparency were necessary, but not sufficient conditions for maintaining an effective dialogue. To create opportunities for dialogue, people need to notice you and, therefore, the communication policy of COVRA had to change. Instead of the modest non-provocative and somewhat silent attitude showed during the first years of its existence, COVRA is now actively present: we are proud of our work, and we like to show that. Our work is necessary and useful for society. We will certainly not hide our activities but show them and look for opportunities to start and maintain the dialogue. COVRA uses its buildings as canvasses to tell stories about radioactive waste and its long term of involved management. The subsequent section discuss three examples to illustrate this strategy.

2.2. Metamorphosis

During construction of the high level waste storage building, the HABOG facility, the idea was born to do something special. Discussions with a local artist, William Verstraeten, resulted in a provocative, and as it turned out, brilliant idea to integrate the building as an art concept appropriately named ‘Metamorphosis 2103–2103 (Fig. 2).

The building itself is now a piece of art; it is a statement by itself. The building is an orange object because orange relates the transition between dangerous (red) and safe (green). To make a link with the activities on the inside, on the outside wall three formulas are painted in green. The ‘Einstein formula,’ written in the well-known form as $E = mc^2$, as well as $m = E/c^2$ and ‘Planck’s formula,’ $E = h\nu$ — metamorphosis from mass to energy. The building is repainted every 20 years, each time done slightly lighter in colour than the previous. After about 100 years the colour will be white instead of orange. In this way, you can see on the outside of the building what is going on inside: the decrease in heat production of the high level waste.

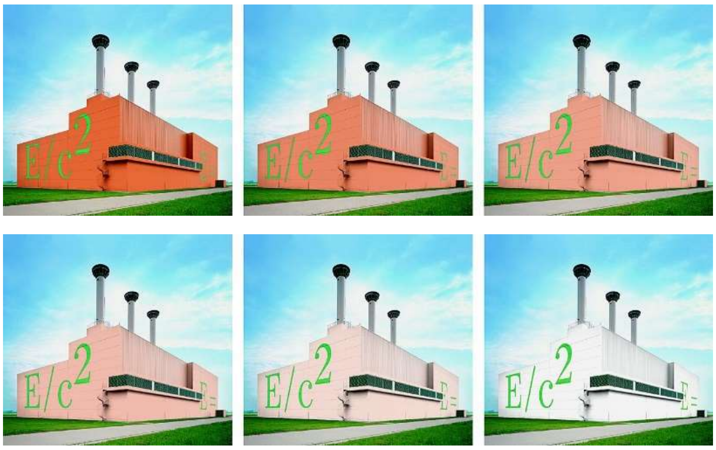

FIG. 2. The artwork Metamorphosis shows how high level waste is cooling down by repainting the outside in a lighter shade of orange every 20 years. Courtesy of COVRA.

Verstraeten wanted visitors to look outside from the inside through the 1.7 metre concrete walls. For the HABOG interior, he made a series of light boxes with a photo-collage of a 500-year-old dike that was built around a 'wheel,' a small lake resulting from dike breach. In the collage, he mounted the outline of the canisters in which the high level radioactive waste is stored as spots of light. In this way, he made the connection between the waste storage and the surrounding landscape visible. Time and the slow disappearance of the heat radiation took shape in the decay of the colour of the images. The last compilation in black and white hangs in the room where the waste is stored. Not in a lightbox but printed on a layer of gold leaf, which symbolizes the value of time and decay for waste management (Fig. 3).

FIG. 3. The colour decay of the photographic images of the Valdijk. Courtesy of COVRA..

There are many more relations between the art concept and the waste management concept. Both are mixed and related and can no longer be separated. The strictly rational scientific world and the emotional artistic world have become one. COVRA offered to the Borsele community one of the largest artworks of the Netherlands combined with a radioactive waste storage facility. 'Metamorphosis' is very often the start of a dialogue with people much more than radioactive waste.

2.3. Art of storage

With HABOG the dialogue can begin concerning how to safely store radioactive waste. Often questions concern the long timespans involved: how can waste be managed for 100 years and even longer. How can the long term aspect of radioactive waste management be explained in a way people can relate to? The answer is surprisingly simple. By showing people we have a very long history of storing things, often things that are far more difficult to store than immobilized waste. The long timescales involved in managing nuclear waste can be hard for people to understand, and this contrasts with their easy understanding of some similar timescales involved in preserving great works of art. Ask people how long art should be stored – take paintings of Rembrandt and Van Gogh for example – and they often respond, “forever.” Does this mean more than hundreds or even thousands of years? The link between the storage of works of art and of radioactive waste helps people to visualize and trust the concept of long term storage.

Interestingly, not only COVRA sees this parallel. Museums in the region where COVRA is situated have endured shortage of storage space for the artifacts not being exhibited. This represents some 90% of their stock. Looking for suitable storage space, the museums and COVRA found each other. The COVRA storage buildings have enough unused space to store the museum artifacts, as shown in Fig. 4. This space is the result of the robust building construction that cannot be used for the radioactive waste. A pilot project with the museums showed the conditions in the low- and intermediate level waste buidling were suitable for a museum depot. COVRA has been a regional depot for museums since 2009.

FIG. 4. The storage of museum collections in the building for low and intermediate level waste. Courtesy of COVRA.

Stored between the drums with radioactive waste one can find many remarkable objects of the museums from within and outside the region. There is, for example, a display case with very special contents that belonged to the French Nobel prize winner Marie Curie. She took two tubes with radium, that she discovered in 1898, to the city of Leiden and there, together with another Nobel prize winner, Heike Kamerlingh Onnes, she instigated the effect of very low temperature on the new phenomenon of radioactivity. Curie left the radium tubes in Leiden for further research, but never returned. One of the tubes – the other is missing – is now part of the collection of national museum Boerhaave in Leiden. The tube is kept at COVRA for safety. There it helps not only remembering our history of more than 100 years but also explaining the future of our radioactive waste.

2.4. The shadow of time

During the construction of the second building for storing depleted uranium (VOG-2), COVRA again collaborated with artist William Verstraeten again. Radioactivity decays to zero with the passage of time, a very long time. For example, the time in which ^{238}U halves in radioactive value is no less than four and a half billion years. The fissile ^{235}U has a much shorter half-life, namely 704 million years. Because the uranium stored in the VOG-2 is a clock that slowly counts down, Verstraeten designed VOG-2 to become the largest sundial in Europe, upon which the sun will cast the shadow of huge protracting needles over the building as a sign of advancing time (Fig. 5). The sundial also shows the relationship with the largest nuclear reactor in our vicinity: the sun.

This building is painted bright blue because uranium was named after the blue planet that was discovered eight years earlier than the metal. The chemical formula of uranium oxide, U_3O_8, is prominently displayed on the facade and on top there is an enormous grass roof. Positioning the 'ground level' on the roof gives the impression that the storage space has been erected from the ground. The building looks like a blue column rising from the earth: the link to the fact that uranium is a mineral mined from the earth that eventually will return there in a geological disposal facility.

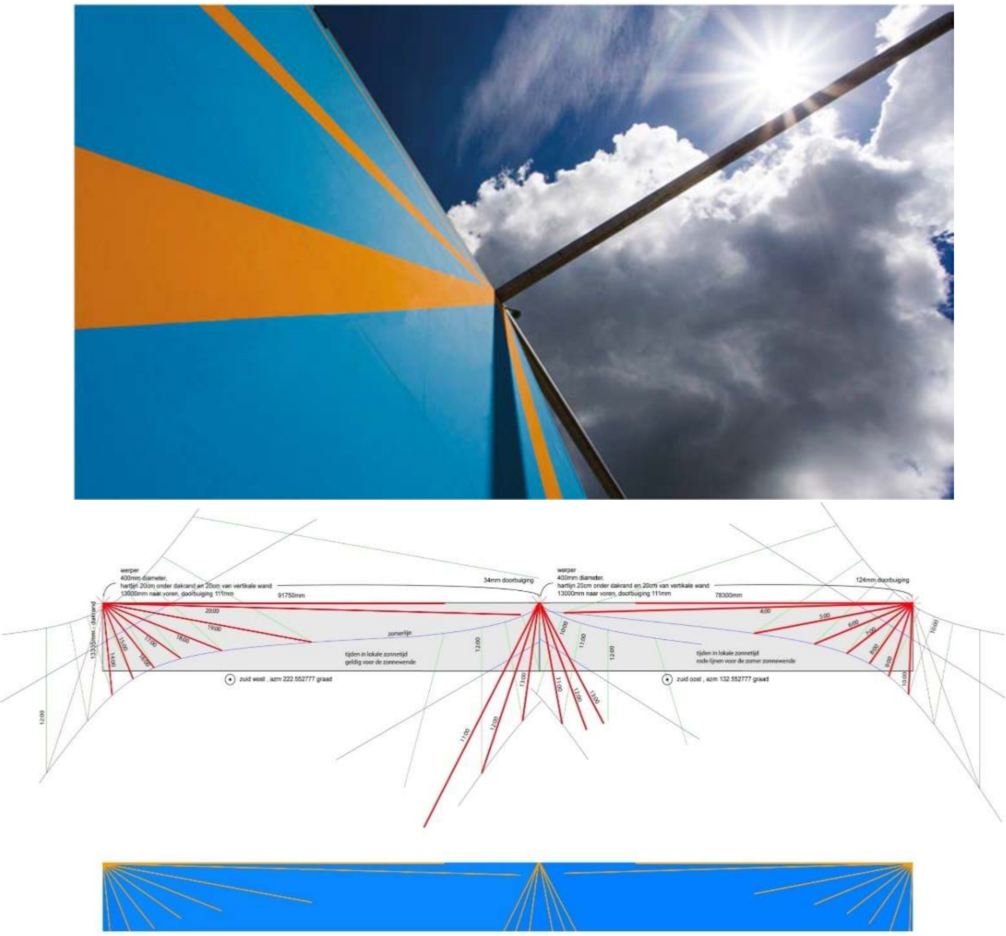

Figure 5. The artwork 'The shadow of the time': orange lines show the hours on the longest day of the year. Courtesy of COVRA.

3. SHOW TIME, BE VISIBLE

Dialogue with stakeholders can enhance awareness, trust, risk perception, and understanding, as well as produce socioeconomic strategies for best addressing these. Member States approach the dialogue on long term radioactive waste management in different ways, depending on cultural, political, institutional, and economic factors. Another important factor to maintain a dialogue is time. In the Netherlands, with a policy on long term storage, COVRA has to maintain a dialogue with the local community and other stakeholders for over a century. Maintaining a long term dialogue around an operational waste facility is different than during a siting process. Important lessons learned include:

— Be open and transparent. Like many other (nuclear) organizations, COVRA first started to communicate as transparently, factually, and objectively as possible. COVRA started with the distribution of newsletters, but the impact was very limited. Sending out a lot of information does not mean that it will be read or understood. It is better to invite people to your facility. Make sure people can visit and see ‘everything’ and implement this in the design of your facilities. The closer you can look at things the better. Our experience is that being open and transparent is more than being factual and objective as radioactive waste is an emotionally charged issue. In the design of the COVRA facilities and site, therefore, we paid attention to psychological and emotional factors. We felt that a good-looking exterior could help to establish a good relationship.

— Be visible. Being open and transparent alone is not enough, when you are in a community for a very long term. When you are too transparent, you are invisible to your stakeholders or the public and this is not a good basis to start a dialogue. To create opportunities for dialogue, people need to notice you: you have to show yourself, stand out, be proud of what you do, show that radioactive waste management can be something beautiful. Looking for opportunities to communicate requires creativity, thinking outside the box and sometimes even outside the nuclear field. Art can create opportunities as it can connect divergent worlds. Using art you can reach the non-technical part of the population, which is by far the majority. The design of the buildings aims to bring the work done at COVRA closer to the people. It shows that safe can be beautiful. This is also apparent from the visitor numbers that have more than doubled since commissioning of the HABOG and from royal support – Queen Beatrix opened HABOG in 2003 and returned as Princess Beatrix to open VOG-2 in 2017.
— Show time. A good topic for a dialogue on radioactive waste management is time. It seems so obvious, but if you ask someone to explain what “time” actually is, not many people are able to answer. Yet showing time is the key to confidence in radioactive waste management, as it is the only thing that renders radioactive waste harmless. The powerful image VOG-2 evokes with its bright blue colour and giant sundial is easier to understand than the physical story of the radioactive decay of the depleted uranium that takes place inside. When we show museum collections in the building for low and intermediate level radioactive waste, we place our activities and our time in daily life: people realize that they often have objects in their home that are older than a hundred years. Museums explain about long term storage of waste and, because it is so safe, they have chosen to store their collections along with it. Such a vote of confidence of very institutions we entrusted with the safeguarding of our cultural heritage may be more effective than any statement of COVRA.

An important element in the dialogue with stakeholders is inviting people to the facility. Because of the measures to contain COVID-19, making site visits impossible, we had to look for new ways of seeking dialogue. The use of social media and other online communication tools offer new opportunities for building relationships with stakeholders. It enables targeted communication and measuring the results almost directly. And that – in combination with the flexibility of online – provides the opportunity to continuously optimize the use of communication. The storytelling using our buildings also helps online to convey our messages.

Construction of the expansion of the HABOG facility started in 2018 to provide additional storage capacity for heat-generating high level radioactive waste. The extension is necessary because the nuclear power plant and the two research reactors in the Netherlands will remain open for longer. At the same time, the new part of the HABOG forms a wonderful addition to the existing art concept. William Verstraeten was once again inspired by the play of light, shadow, time, and geometry. The result is a modern temple of the sun that will be revealed with the building commissioning on 19 May 2022. The current plan is that opening is a combination of live event at the COVRA site and a streaming event, supported by a social media campaign.

The examples presented in the paper can be seen as unique examples to obtain better public acceptance for the waste in society and for the organizations dealing with it. The stories the storage buildings tell attract interest of people in a positive way and makes COVRA visible; since the opening of the HABOG facility, the number of visitors has doubled. The stories also help explain the long term aspects of waste management and building acceptance of geological disposal at a national level. Perhaps showing time may help develop acceptance for multinational solutions. Showing that state boundaries are only temporary lines drawn by man. Sustainability and security should not be controlled by temporary situations, they should be controlled by supranational structures. Although time will result in the total decay of radioactive waste, the long term solutions we create should be as independent of time as possible.

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Paper ID#106

STUDY OF ATTITUDINAL SOCIAL IMPACTS ON RADIOACTIVE WASTE MANAGEMENT PROGRAMS AND PRACTICES

A Case Review of Ethiopian Radiation Protection Authority Radioactive Waste Management Center Activities

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Abstract

The paper describes a study that explored the formidable social attitudinal problems encountering the Radioactive Waste Management (RWM) processing facility located in Addis Ababa, Ethiopia. A qualitative approach was purposefully applied to provide respondents opportunities to express their feelings, beliefs, and attitudes exhaustively and freely toward the waste facility programmes and activities. The data collection instruments employed for this study were questionnaires and interviews. Study participants were selected from the Ethiopian Radiation Protection Authority (ERPA), citizens who either work or live near the waste facility, and randomly selected people in Addis Ababa. Fourteen questionnaire respondents and six interviewees participated as informants of the study. Secondary data was appraised through a literature review. The results of the study showed the local community and the public at large have perceived, rather than actual, radioactive waste risks based on the knowledge gap and low understanding the public has concerning radioactive waste. The findings indicate that a strategically designed public sensitization and awareness programme is crucial to reversing current diverse social attitudes. Correspondingly, the result confirmed that stakeholder engagement, which is key to attaining facility objectives, is a missing component and needs due attention. Socioeconomic impacts were found to be host community and public concerns the likely cause of which may be perceived risks driven by low understanding about radiation and radioactive waste.

1. INTRODUCTION

The radioactive waste processing facility of Ethiopia, which was opened in 2014, is located within the heart of Addis Ababa, the capital, and stores an estimated 137 sources. The adjacent surrounding area to the facility site is owned by private industries and business firms with some urban residential houses. While the facility shares similar social attitudinal problems experienced by other global facilities, differences are appreciated contextually.

Despite the potential benefits nuclear technologies can provide to humans, negative perspectives, news of actual harmful incidents, and the possibility of terrorist actions have made many people believe that radioactive waste poses an unacceptable risk to people and the environment.

The present generation has a responsibility to prevent future generations from an undue burden of radiation harm. Although people are aware of the beneficial uses of nuclear technologies, they are also aware of the harmful effects of radiation exposure that have occurred elsewhere on earth from a variety of sources. Radioactive waste creates a diverse public social attitude towards the use of the use of technologies which generate these wastes and their related risks. This needs to be amicably mitigated by devising strategies to address public awareness programmes, socioeconomic issues, and a broad cross-section of stakeholder participation for collaborative synergy between facilities and affected communities. Examining the attitudinal social impacts toward possible risks from radioactive waste exposure from the facility to the host community, public perceptions, and awareness level of radioactive waste management are very important considerations in furthering facility goals.

1.1. Statement of the Problem

Social attitudes on radioactive waste processing facility programmes and practices are a key factor in the effective performance of waste management. The following are some of the challenges that contribute to the diverse social attitudes toward radioactive waste management and which might affect the success of the waste management and the expectations of stakeholders such as the public.

- Attitudinal misperceptions;
- mistunderstandingsof the facility goals and activities held by the public;
- A weak cooperative relationship between the radioactive waste management facility and stakeholders;
- Lack of communication and public awareness on the goals of the radioactive waste management programmes;

1.2. Aim of the study

The study aims at exploring the social attitudinal problems posed in relation to the overall performance of the Ethiopian Radiation Protection Authority's (ERPA) radioactive waste management facility.

1.3. Objectives of the study

The study was tasked with following objectives:

- To examine the social attitudes about radioactive waste management programmes and practices;
- To study the contribution of stakeholder participation for radioactive waste management success;
- To explore the risk perceptions and related public awareness level of radioactive waste;
- To identify the benefits the host community receives from facility waste management programmes.

1.4. Research questions

The following questions were included in the research:

- What social attitudes are there toward radioactive waste management activities?
- Does stakeholder participation contribute to radioactive waste management programme success?
- What risk perceptions and level of awareness does the public have of waste management activities?
- Are there benefits the host community can secure from waste management programmes?

1.5. Significance of the study

The study will serve as a springboard for those who intend to further examine the impacts of social attitudes on radioactive waste management facilities. It still could be supportive for understanding the 'why' of the radioactive waste management facility, the interdependence between socioeconomic activities and waste management, importance of stakeholder participation, implications of public awareness programmes, and the likely benefits waste management programmes bring to the host community.

1.6. Scope of the study

The scope of the study was confined to investigating the social attitudes toward the Addis Ababa facility radioactive waste management activities.

2. LITERATURE REVIEW

The social aspect of radioactive waste management could involve identifying the attitudes, values, and views of the community living around the waste facility. The IAEA has stated that "Public attitudes and expectations in relation to potential construction of radioactive waste management facilities should be understood and addressed" [1]. The socioeconomic undertakings of the host communities near radioactive waste management facilities need to be carefully considered and the picture of the people residing in the neighbouring facilities need to be studied in clear terms. "Hosting a facility does raise concerns over potential detrimental impacts on land prices; agricultural market access and prices as well as tourism impacts" [2]. Explicit knowledge of the host community's needs, interests, and concerns will help develop national radioactive waste management strategies to improve the quality of governance process and decision making. A careful identification of mechanisms that assist a viable relationship between the waste management facility and the host community remains crucial. The knowledge, radioactive waste risk perception, and the overall awareness level of the public about the radioactive waste management strategies, programmes, and practices should also be a point of concern for facility operators to build a maintainable relation and rewarding accomplishment of waste management goals.

2.1. Why do we need a radioactive waste management facility?

Radioactive waste management facilities are established for the safe handling, processing, and temporary storage of conditioned waste. The IAEA [3] defines six classes of waste: exempt waste, very short-lived waste, very low level waste, low level waste, intermediate level waste, and high level waste [4]. Waste facilities may be designed to finally dispose of low level waste and potentially store intermediate level waste on a transitory basis [5]. Facilities can also be places where radioactive material is produced, processed, used, handled, stored, or disposed of [6]. Facilities often serve as transitory storage of radioactive waste in a location with the intention of moving the waste to a final disposal site. The period of storage may be different depending on the waste and the type of facility [5]. Radioactive waste facilities help ensure the protection of the health, safety, and security of the public and the environment, and are designed to serve a definite purpose. They could contain several waste treatment plants, storage tanks, a waste repository, analytical instruments for examining chemical properties, and measuring radioactivity, etc. [7]. The siting of radioactive wastes poses a significant planning challenge to many countries. "The public is generally extremely apprehensive about radioactive waste, and this has led to substantial delays in siting much needed waste facilities" [8]. The facility in Ethiopia serves to store disused radioactive sources from different industries and abandoned orphan sources, which the host community and the public consider to be potential health and environment threats.

2.2. Social attitudes toward radioactive waste management facilities

Community attitudes could be positive but often public anxieties on radioactive waste are dominant. The distress arises from a fundamental worry about radioactivity, lack of knowledge about radioactive waste and its management [9]. Public and political beliefs can be inhibitions for countries to host regional or multinational facilities [9]. Public attitudes toward nuclear waste may spring in part from concerns over nuclear weapons. Nuclear establishments in quite a lot of countries were founded under the "defense secrecy" model that gave freedom of choice in decision making to small group of technological experts as Jasper cited in 1990 [10]. Storing wastes on site could lead to problematic social and political issues. The first check of public reaction or sentiment toward nuclear waste came in a 1960 survey of attitudes on the siting of the Indian Point reactor as cited in Rankin and Nealey [11]. On the other hand, over time public care driven by leaking of radioactive wastes from storage tanks shifted from environmental to safety matters. Waste topics became more frequent and placed at the top of public worries over nuclear power during the latter half of the 1970s, and local governments inaugurated laws that help control the use of their areas for disposal. As high level of concern about radioactive wastes comes into scene, public approval remains a challenge to achieving a waste management programme. Siting of facilities, as cited in Roger E. Kasperson [12], could initiate public distrust on institutions responsible for risk management in their effort to ensure equity through the fair distribution of risks and benefits among those affected [13]. Organizations involved in handling nuclear waste are not often trusted by members of the public [14]. Local hostility in many sites suggest that the public may consider that waste management poses local, highlevel risks. Public attitudes and expectations of radioactive waste management facilities should be understood and addressed [2].

2.3. The need for host community and stakeholder participation

Facilities will have mechanisms that allow them to conduct a discourse between operators of the facility and stakeholders, be they staff, local community leaders or others [15]. Stakeholder is defined as "any actor –

institution, group or individual – with an interest or a role to play in the radioactive waste management process" [4]. Host community or stakeholder participation is crucial to enable the public to have say on waste management activities. The local public and authorities can be involved in waste management development plans or projects focusing on social and environmental issues [16]. A successful and constructive or optimistic relationship needs to be established with those residing there right from the start to the long term [17]. Consultation with stakeholders on facility goals, activities, and issues of safety, environmental protection is quite important to both the facility and the affected social groups. The facility should be responsive to public concerns. Involving the host community in waste management decision making can both avoid distraction and promote the sustainability of the host environment through building projected social relationships [17]. A range of partnering arrangements with stakeholders can be practical the usual ones being government organizations such as local and regional units and non-governmental agencies [17]. Local communities may not be familiar with scientific technicalities, administrative difficulties and inadequacies that persist in waste management activities. Although interested and affected citizens may not have the technical expertise or capability, they do have strong, legitimate views regarding what they want [18]. An extensive stakeholders' participation can help resolve issues of common interest. Allocation of specific monitoring activities to the community is a key issue to ensure safety, guarantee transparency and build public confidence. This ensures an enduring link with the community and helps build sustainable relationship with relevant stakeholders and social groups. The public participation style underlines the relevance and influence of all affected parties by facility activities [13]. Benefits and risks can fairly be shared when sustainable relationship is built with common understanding.

2.4. Significance of Public Awareness Programmes on Waste Management

One of the concerns of waste management is that the public does not fully understand the technical issues related to radioactive waste which makes public acceptance of facility programmes difficult. This can adversely impact the public not to fully trust the scientifically proven standpoints of the subject [19]. "Members of the public usually have incomplete knowledge and a great deal of uncertainty when it comes to issues involving nuclear and radiation safety" [20]. Public viewpoints proved that distrust in the waste domain is multilateral. Institutional representatives or agents may lose confidence or distrust the public as much as members of the public distrust them [18]. "Communication can help reduce the risk of misunderstanding fed by fear and rumor and consequently increase safety" [21]. The regulatory body has a duty to communicate in a way that anticipates problems and needs and initiate dialogue with the public while demonstrating a willingness to listen and respond to a broad variety of concerns [20]. This may also seek to empower citizens and other stakeholders to make more informed decisions. There is a widely held image, in the rhetoric of decision makers, of lay people as unfamiliar, unaware, and fearful of the unknown. This image suggests that if the level of information is raised, lay people will accept the proposals from decision makers [19]. In countries where radioactive waste management has turned out to be a major public concern, extensive information and public participation programmes have been undertaken [9]. A variety of communication tools should be employed the purpose of which need to be creating an informed community and public about waste management objectives and minimize distrust between the host community and the facility which eventually promote mutually beneficial relationships between actors.

2.5. Benefits of waste management facility activities to the host community

Radioactive waste management programmes can bring different benefits to the host community and many social groups in the public. They can minimize or avoid radiation exposure to people, or any pollution. Waste management activities protect human health and the environment, now and in the future, without imposing an undue burden on future generations. The activities and programmes of radioactive waste management help boost the use of the clean environmental technology of nuclear energy [9]. Technology transfer, enhancement of quality and safety aspects and security against terroristic attacks are benefits that can be reaped from radioactive waste management programmes run by facilities. Similarly, economic benefits can be gained from customer funds, local taxes to host community, employment opportunities and development of local infrastructure. Creation of an international framework and implementation of relevant environmental and social programmes at the site are also returns the community can get from waste management programmes [22]). Training opportunities that build sufficient expertise and improve personal skills will be available locally. The community can also have chances to volunteer and participate with facility owners, often governments, to work together on social, safety and environmental issues for common good.

2.6. Conclusion

The literature review suggests that radioactive waste management facilities are key for safe handling, processing, and temporary storage of conditioned waste. Social attitudes toward radioactive waste management are diverse and could be positive or negative. The interdependence between socioeconomic activities of the host community and waste management facility activities have to be clearly identified. The host community and stakeholder participation is crucial to enable the public to have say on waste management activities of the facility. Members of the public usually have incomplete knowledge and a great deal of uncertainty, thus, public awareness raising programmes on radioactive waste management and facility activities are important strategies in preparing the public for a voluntary and cooperative action between the public and waste management facilities. Studies confirm that host communities near or adjacent to radioactive waste management facilities can reap some benefits despite the anticipated risks in place. Economic benefits can be gained from customer funds, local taxes to host community, employment opportunities and development of local infrastructure. Public attitude is diverse which consists of lack of trust and uncertainty on facility programmes, fear that radiation is harmful to health and environment and can jeopardize socioeconomic activities of the host community.

3. METHODOLOGY

The method applied for this brief study is a qualitative approach. The qualitative approach has been applied for the study purposefully to give respondents opportunities to express their feelings, beliefs, and attitudes exhaustively and freely toward waste facility programmes and activities. The issue being more of an opinion and experience the qualitative approach best suits for the study. Data collection instruments employed for this study are questionnaires and interviews. Open ended questionnaires have been distributed to relevant responders and some interviewees have also been invited as participants. Respondents of the study are staff members from the Ethiopian Radiation Protection Authority, citizens from the public and relevant customers. Supportive secondary documents that discuss social attitudes about radioactive waste management facility programmes, activities, and practices have also been reviewed. Data analysis was conducted through set steps. Raw data was generated from questionnaire and interview respondents and organized as text data. Themes, attitudes, and behaviours were identified from text data and amalgamated into core issues. The core issues (themes) were interpreted to meanings which detail the social attitudes present toward radioactive waste facility and its programmes.

4. DISCUSSION AND RESULTS

4.1. Established public attitudes and misconceptions

Some participants of the study pointed out that the local community and public have built trust, and positive attitudes on facility programmes. Few citizens around the facility show belongingness and responsibility. They believe that facility programmes need to be accepted for they create job opportunities, keep the environment clean from pollution, and help control malicious act, sabotage, theft, and terrorist attacks involving the use of sources. It is underscored that facility programmes can protect the public from radiation exposure and harms it entails and ensure safety of the public and the environment. Some respondents believe that radioactive accidents, unauthorized use of sources and storage of radioactive materials can meaningfully be reduced by the waste management programme efforts. Through discussions held with the host community on facility issues, some people have started considering the facility to be important for storing waste. Most respondents, however, had pessimistic views toward radioactive waste, its management programmes and facility activities. Participants disclosed that radiation waste can affect health of the community causing cancer and other problems. They recognized that socioeconomic activities of the local community can be affected by waste stored in the facility. Fear by the local community of radiation accidents and hazards are all around [9]. It was stated that public resistance, lack of trust on facility programmes and uncertainty are norms among the host community and public. The local community was once said to have raised its concern to the authority on fear of radiation exposure from facility waste. It was highlighted that the public does not clearly understand what radioactive waste is and it often associates waste to risks of nuclear weapons and sees it to be a burden or curse. There is an irrational belief that the facility area is contaminated, dangerous, and a risk to health, the environment and property. It is said some won't enter the facility compound and the community thinks that it is not safe to be around the facility because of the risk of exposure to radiation. Respondents emphasized that wrong interpretation of information by the public and the negative image created on facility waste management activities has brought a lack of confidence on the public. The public has no means to know about waste management, and as a result does not recognize problems related to waste. This has led to failure to accommodate changes in waste management objectives. Psychological stress and inaccurate belief about radioactive waste were said to be source of fear and unconstructive attitude formation. The respondents mentioned that radiation 'protection' can imply the connotation of 'defence' in the name ERPA itself has. The Amharic equivalent word for 'protection' is 'መከላከያ,' which translates to 'defence' and has made the public believe that the facility has a connection to weapons issues. Fear over nuclear weapons looks to have contributed to the formation of wrong perceptions and attitudes toward facility programmes. Mistrust, perception of threat, and confidentiality tendencies by facility managers that keep the public at a distance are inputs for unconstructive attitude formation. Respondents raised the concern of the possibility of a conflict of interest between the operator (waste facility) and the regulatory body because the authority grants the operation license and regulates facility activities, as well. It should also be clear that some respondents expressed they knew little or nothing about the facility programmes or activities.

4.2. Socioeconomic effects

Analysis of socioeconomic effects requires a closer look focusing on adverse effects and inclusive changes that occurred after the establishment of the facility. This study, though there has not been an institutionalized body that oversee the socioeconomic effects of locally affected community around the facility earlier, has come up with stated socioeconomic impacts that could happen to the facility locality. The typical socioeconomic activities of the local community around the facility are diverse, including different industries, stores, construction works, hotels, farm, health centres, groceries, supermarkets, shops and schools (kindergartens). Participants reflected that facility being around factories if waste is not properly managed it can affect factory products quality and create negative image and distrust on companies [8]. The fear the facility waste affects health, environment, water, land pollution and economic activities of the community, and could initiate public resistance. Some informants mentioned the facility should not have been located there and have forwarded their concern that it can be source of conflict leading the public to unfounded doubts on facility programmes and becoming uncooperative. Participants highlighted concerns of impacts to local businesses including limiting market area, industry, and hospital construction. Additionally, future health of the community will be at risk which impacts the socioeconomic undertakings of the local community. There is also a diverging view that though some respondents encourage facility programmes others denounce its relevance which could be source of resistance to public cooperation and interaction.

4.3. Relevance of stakeholder engagement

Most participants favoured public and stakeholder engagement to initiate a sustainable relationship with potential collaborators and radioactive waste management success. Others also reflected that it could contribute much toward building confidence among the host community and the public. A concerted effort that facilitates public participation is crucial to devising agreed solutions to public concerns and challenges over facility waste management programmes. Participants likewise proposed views that public and stakeholder engagement should involve the identification of complex issues and areas of cooperation properly which will help meet the needs of the stakeholders and facility programme objectives [16]. The participants favourably pointed out that the areas of public and stakeholder engagement should be implemented using a variety of methods that effectively ensure collaborative action and mutual gains [15]. The areas of cooperation, as reflected by the respondents, should focus on safety and security, waste policy development, decision making and consultancy, community empowerment, communication, and networking for collective action [17]. Benefits of infrastructure development in the facility area, observed inequalities in the distribution of benefits and costs in the waste management process, economic compensation (if any), and political incentives for the host community need also be topics of public and facility concerns. Emergency preparedness and response activities and public awareness raising programmes were still noted as shared responsibilities of actors to research. Stakeholders and the public, as specified by participants of the study, have shared roles to play in the waste management efforts. They are required, through consensus, to implement the rules of the facility, be cooperative for facility programmes success, negotiate on issues that affect collaborators, and build a sense of ownership. The relation between the community and facility should be integrated to enhance collaborative action [17]. Collaborative intervention on facility management activities was credited by respondents to be supportive for policy makers, effective waste management programmes and facilitation of information exchange. Stakeholders' roles and responsibilities should be clearly stated through a binding and signed memorandum of understanding the performance of which will be regularly evaluated. Periodic group discussions, roundtables, and meetings with relevant stakeholders, local community principals, and sector agencies were all noted by participants to be helpful for waste management programmes success. Participants indicated when the regulatory authority works in connection with stakeholders it can effectively and efficiently discharge its responsibilities of protecting the people and environment from undue radiation exposure.

4.4. Facility programme benefits

Despite the challenges of radioactive waste management raised by participants of this study, it was also indicated that there are local benefits that can be drawn from facility activities and programmes. The first benefit noted by informants is the protection of the public, property, and environment from adverse effects of radioactive waste, malicious use of disused sources and related threats [4]. Knowledge transfer, access to information, collaborative research undertakings with university students and research centres and the economic diversification in the locality were also noted benefits mentioned by participants. The host community is said to have benefited from facility establishment. Employment opportunities during facility construction and operation and access to facility water, electricity, and road infrastructure are mentionable benefits appreciated by respondents. Anticipated hosting fees, socioeconomic development packages, and establishment of an integrated programme with the local community, as indicated by respondents, were also suggested benefits obtainable from the facility in the future [22]. Some of the social groups and citizens, if involved, think they can make a difference on waste management programmes of the facility is valued to be an important progress benefiting the public, local community, and facility. The principal benefits of facility establishment were stated to be the public's safety and security and protection of environment from radiation exposure.

4.5. Significance of public awareness

In the Ethiopian context, as indicated by respondents, the level of understanding about radiation and radioactive waste remains low among the host community, stakeholders, and the public at large [20]. It was pointed out that the potential benefits of radiation technologies, radioactive waste management, and related risks are not clearly understood by people. This challenge was said to be increasing public concern on facility programmes and affects the active involvement of residents and community in the waste management activities [19]. Respondents articulated that improved public understanding of waste management programmes is crucial for the community and facility goals attainment [21]. It was also mentioned that awareness programmes can help stakeholders easily learn facility missions and programmes [21]. Awareness raising programmes, as reasoned by participants, can allow the stakeholders and public to dynamically participate in waste management activities and protect them from radiation risk. It was further detailed that the community’s knowledge gap on the purposes of radioactive waste management and related radiation risks will, to a great extent, be resolved by strategically tailored community empowerment and sensitization programmes [19]. Awareness creation can help avoid irrational fear of radiation waste by the public and creates understanding on why waste is stored in the facility and how the public is protected. Interviewees reasoned that through awareness programmes the public and stakeholders can more effectively interpret information [9], solve problems, make reasonable decisions, accommodate change, and develop balanced attitudinal view on waste management programmes. They also expressed that one of the primary goals of waste management is to prepare the public and local community to effectively manage radioactive waste, debris, and materials generated by homeland facilities or industries in collaboration with facility operators. The younger generation in the host community appeared to possess a relatively better, but neither detailed nor perfect, understanding than previous generations about radiation and waste. Study participants believe discussions concerning radioactive waste issues with community representatives, members, and the public provide relevant information and knowledge about radioactive waste management programmes and objectives [20]. Continued discussions with potential stakeholders can reduce public resistance, build trust, and ensure a sustainable relationship between the facility and the local community.

4.6. Conclusion

Although some members of the local community were said to have benefited from facility activities and built trust and positive attitudes toward facility programmes, the results of the study confirm most people in the community have pessimistic views on waste facility programmes and activities. Public resistance and the belief held by the local citizens that radiation accidents and hazards are everywhere, not trusting and being uncertain about facility results, and having an irrational belief that the facility area is contaminated are reflections of the attitudes of the host community and the larger public to some degree. The terms ‘radiation’ and ‘waste’ stir public frustration. Likewise, the word ‘protection’ can imply the connotation of ‘defence’ in the name Ethiopian Radiation Protection Authority and the Amharic equivalent word for ‘protection’ ‘መከላከያ’ meaning ‘defence’ has made the public believe the facility has connection to nuclear weapons. Fear over nuclear weapons has possibly contributed to the formation of wrong perceptions and attitudes toward facility programmes. Mistrust, perception of threat, and confidentiality tendencies by facility managers who distance the public are inputs for unconstructive attitude formation. The attitude of the community that facility activities can jeopardize socioeconomic activities of the local people is said to be a concern. Stakeholder engagement and public input is said to be crucial for social acceptance of facility programmes. The level of understanding about radiation and radioactive waste remains low among the host community, stakeholders, and the public at large. There seems to be a growing awareness of building public confidence and transparency of the waste management decision making process and this could be realized through strategically designed public sensitization and awareness programmes.

4.7. Recommendation

— Initiate strategically designed public awareness and sensitization programmes to address the incorrect perception held by the host community and public jeopardizing waste management programme objectives and socioeconomic activities
— Prioritize promoting stakeholder engagement, as it is the missing element to waste management facility programme success.

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SOCIOECONOMIC EFFECTS OF DEEP GEOLOGICAL REPOSITORIES: OPPORTUNITIES OR THREATS? THE SWISS CASE.

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Abstract

The Swiss site selection procedure for deep geological repositories (DGR) for low and intermediate level waste (L/ILW) and high level waste (HLW) is regulated by a federal spatial planning instrument under the auspices of the Swiss Federal Office of Energy (SFOE). The procedure was started in 2008 and consists of three stages. The SFOE established specific participation bodies (regional conferences) to incorporate the local stakeholders' interests into the planning process governed by national law. With the reduction to three potential siting regions in 2018, the final stage was initiated and will be terminated with the siting decision in 2029. The consideration of potential future socioeconomic effects caused by a repository has enjoyed a high priority since the beginning of the procedure. Extensive socioeconomic baseline studies to assess social, demographic, ecologic and economic effects of a DGR were conducted in the six initial potential siting regions. They involved a four-stage benefit analysis comprising over 40 indicators in the dimensions society, environment and economy. Additional studies were conducted in fields where stakeholders demanded further clarifications.

Until the siting decision, the activities relating to socioeconomic aspects are concentrated on long term monitoring of socioeconomic indicators, so-called in-depth studies, and regional development. Concerning monitoring of socioeconomic indicators, a pilot study has demonstrated the methodology and feasibility of a comprehensive long term surveying. The in-depth studies deal with specific questions of concern. So far, a methodology has been proposed to assess potential causal effects of a DGR on a siting region as a residential and business location and an analysis on leveraging positive economic effects of a DGR on the regional economy has been completed. The paper summarizes the results of the studies completed so far and presents an outlook on the SFOE's planned activities in the field of socioeconomic aspects.

1. THE SWISS SITE SELECTION PROCEDURE: STRONG EMPHASIS ON CITIZEN PARTICIPATION

The Swiss site selection procedure for deep geological repositories (DGR) for low and intermediate level waste (L/ILW) and high level waste (HLW) is regulated by a sectoral plan, a comprehensive federal spatial planning instrument. The Swiss Federal Office of Energy (SFOE) is responsible for its implementation. The procedure was started in 2008 with the adoption of the initial conceptual document by the federal council (national government) and consists of three stages [1]. According to this conceptual document, socioeconomic aspects of a DGR need to be analysed in the site selection procedure to optimize its economic effects. Nevertheless, they will not be considered for the siting decision, which will be taken based on a set of 13 purely security-oriented criteria. The procedure consists of three stages. Stage 1 was concluded in 2011, resulting in six potential siting regions [2]. In 2018, stage 2 was concluded by a reduction to the three remaining potential siting regions depicted in Fig. 1 and the final stage was initiated [3]. It is to be terminated with the siting decision by the national government in 2029 for a L/ILW and a HLW repository[1]. The decision is subject to ratification by the national parliament and possibly by a national popular referendum. However, it is planned that the implementer will announce in 2022, which region (or regions) they intend to choose for the submission of general licence applications.

[1] The two repositories can either be combined or separated. All socioeconomic analyses have been accomplished for both cases. The paper considers only a combined repository.

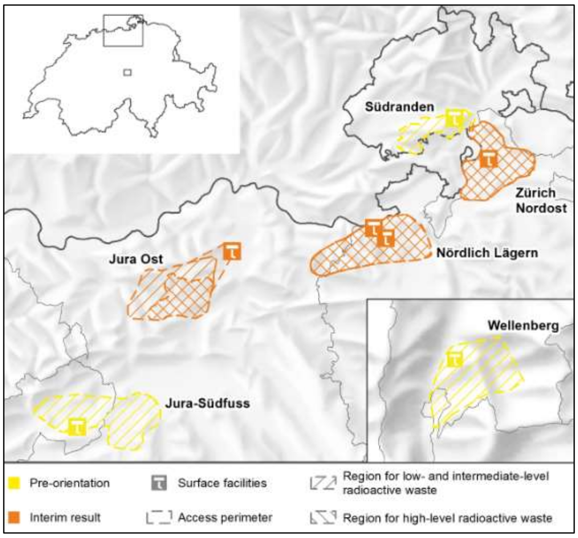

FIG. 1. Status of the site selection procedure after stage 2: with three regions still under consideration. Courtesy of Swisstopo.

The SFOE established specific participation bodies (regional conferences) to incorporate the local stakeholders' interests into the planning process governed by national law. They consist of four categories of members: representatives of local municipal authorities, regional planning agencies, NGOs, and the civil society. The regional conferences' bodies are shown in Fig. 2. The subject area of surface infrastructure placement is where participation is most extensive. The Surface Infrastructure working groups are assigned the task of elaborating the regional conferences' statements on behalf of the federal authorities about where – regarding the local context – to place the DGR's surface infrastructure. The Regional Development working groups are the regional conferences' bodies dealing with socioeconomic aspects. They are involved in the steering committees of all the studies analysing socioeconomic aspects commissioned by SFOE, and their general task is to elaborate ideas on fostering regional development. The SFOE has, together with the regional stakeholders, developed and published a guideline on this [4], and the regional working groups are currently elaborating ideas for regional development projects, as suggested by the guideline.

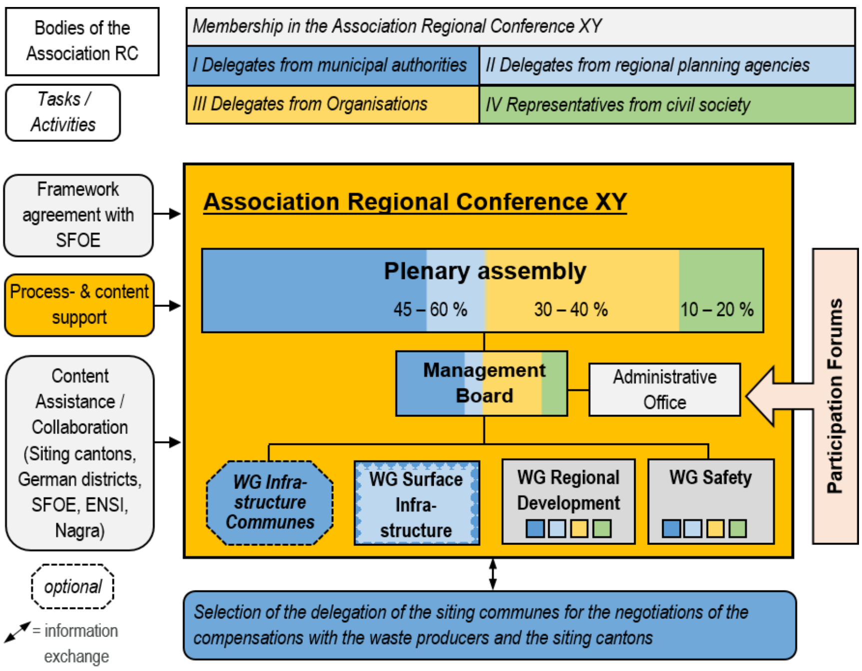

FIG. 2. Organization chart of regional conferences.

2. SOCIOECONOMIC BASELINE STUDIES

During stage 2, extensive socioeconomic baseline studies to assess social, demographic, ecologic and economic effects of a DGR were conducted in the six initial potential siting regions [5]. The underlying methodology for a comprehensive impact analysis was developed in stage 1 in a participatory approach involving relevant regional stakeholders. It consisted of four stages: first, the three dimensions of sustainability (social, economic, environmental) were taken as a basis. Second, for each of them, two main goals were defined (see Fig. 3. Third, the main goals were divided into several subgoals and fourth, these subgoals were operationalised and measured by sets of indicators on a scale of –5 (negative effects) to +5 (positive effects), resulting in a total of more than 40 individually weighted indicators.

The impact analysis concluded that some effects were to be expected in all potential siting regions, but that they would be mostly moderate from an overall perspective. Figure 3 presents an overview of the results. With regard to the economic dimension, overall positive effects were identified, mainly due to compensation payments expected to be disbursed and due to the added value created by construction and operation of a DGR, with hardly any differences between the potential siting regions. In the environmental dimension, the studies predicted moderate negative effects with minor differences between siting regions, mainly due to land usage, excavation, and disruption of wildlife corridors. In the societal dimension, slightly more pronounced negative effects than in the environmental dimension were estimated and pronounced differences between siting regions were identified. These results were influenced mainly by the proximity of the planned surface infrastructure to residential areas, which differs between siting regions, and the direction of the respective spatial planning strategy.

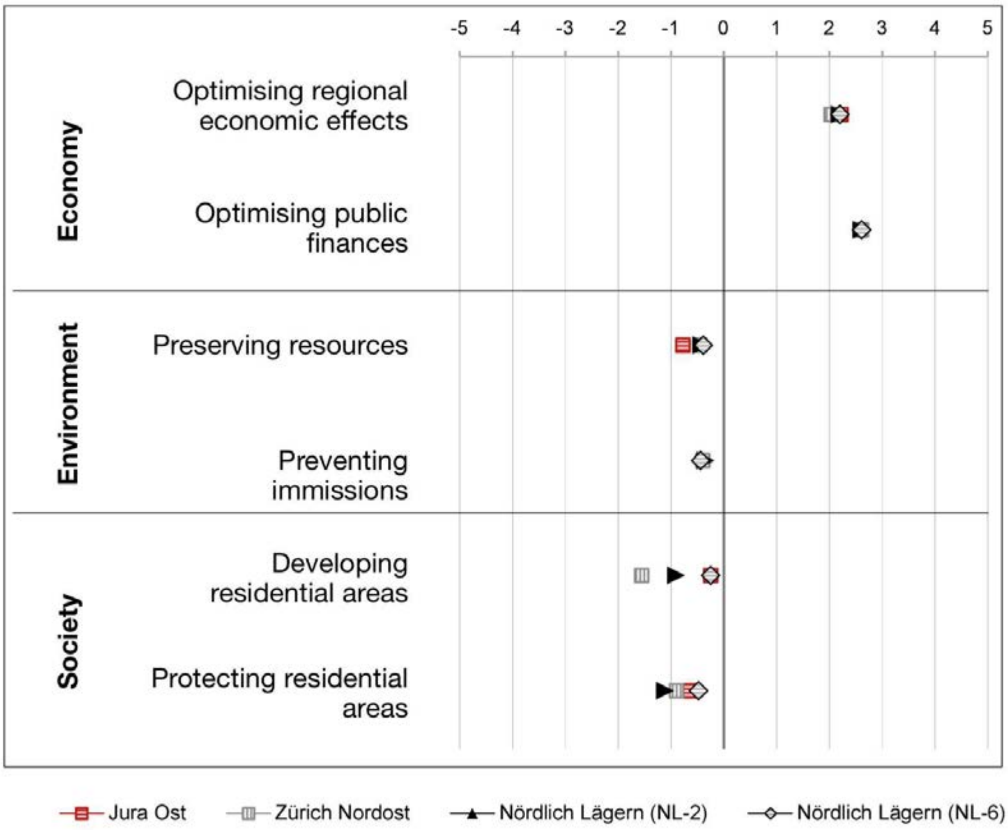

FIG. 3. Overview of results of socioeconomic baseline studies.

The impact analysis study was criticised by some of the regional stakeholders. One of the most prominent criticisms was that the potential effects of a DGR on the image of a region and on social cohesion had been excluded. Therefore, an additional extensive study covering these topics was conducted under the auspices of the affected Cantons and in cooperation with the SFOE in the remaining three siting regions [6], [7], [8]. It comprised two modules: The first module consisted of quantitative, representative population surveys in the siting regions, whereas the second module contained a qualitative analysis of so-called affectedness dynamics within the respective regions. The overall results of the surveys were that the siting regions generally have a positive image with their inhabitants and with the inhabitants of neighbouring regions and that there is neither evidence for emigration tendencies nor for societal conflicts. However, the study also suggested there are some differences between proponents and opponents of a DGR and there are differences in attitude between neighbouring German regions and Swiss regions, with the Germans generally being more sceptical. The results were similar in all three evaluated regions. Nevertheless, they should be interpreted with caution, as there are considerable statistical uncertainties and methodological difficulties associated with them. The study, dealing with a hypothetical situation in the far distant future, certainly revealed the limits of survey-based analyses.

3. LONG TERM MONITORING OF SOCIOECONOMIC INDICATORS AND IN-DEPTH STUDIES

In order to assess the potential – positive or negative – impact of the selection procedure, construction and operation of a DGR on a siting region, SFOE is establishing a long term monitoring programme of socioeconomic indicators. This will provide a basis for mitigating undesirable developments and exploiting opportunities for positive developments. The monitoring programme will systematically record regional developments and thus help to objectify the discussions. At the same time, it can identify areas in which specific projects can and should be initiated in the regions so that sustainable development can be ensured despite or with a DGR. The monitoring results can provide a basis for planning, initiating, and implementing measures for the desired development. Regarding the implementation of the monitoring programme, the SFOE developed a concept in collaboration with the siting regions and cantons [9]. The concept was tested in a pilot implementation in 2018 and 2019. The monitoring pilot report [10] presents the initial situation, the procedure, and the results of the monitoring for the areas "activities," "media coverage," and "socioeconomic indicators." It has been shown the implementation of the concept is feasible and the desired information can be obtained and presented. Figure 4 shows some results for the siting region Nördlich Lägern, as an example.

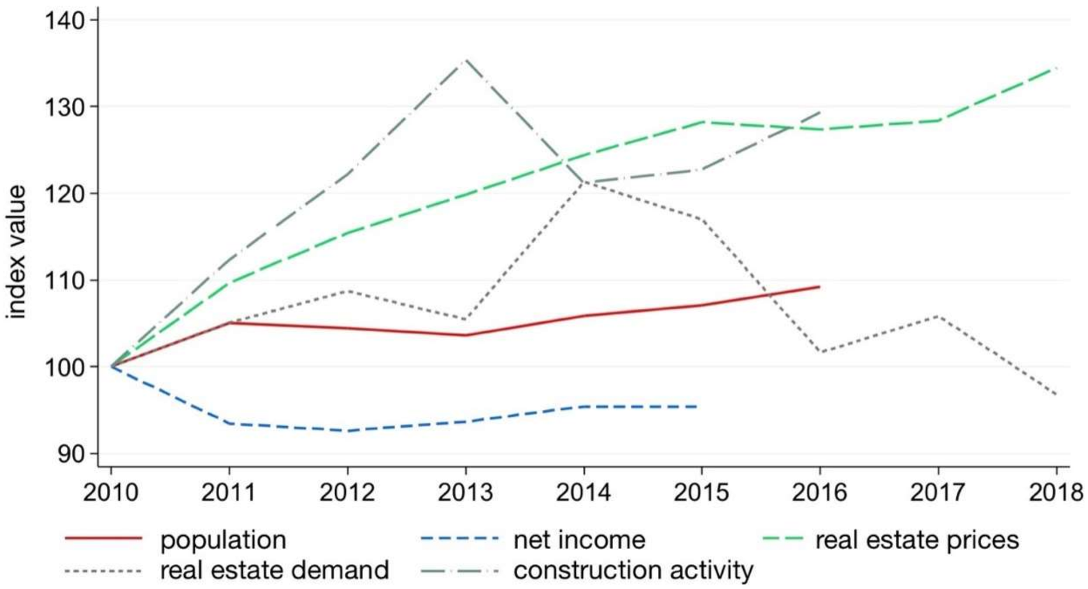

FIG. 4. Development of some socioeconomic indicators covered by the monitoring in the siting region "Nördlich Lägern" (indexed; 100 = 2010).

The developments presented in the pilot report do not deviate significantly from the development of neighbouring regions or from the Swiss or Southern German average. This is not a surprise, as the location of the repository has not yet been determined and only few activities related to the repository have taken place in the regions so far. Therefore, it is important to build up a longer time series to be able to compare the future monitoring results during construction and operation of a DGR against the “zero measurement” taken in the pilot. Thus, the underlying data for measuring the indicators defined in the monitoring are continuously being collected. The next full monitoring report is scheduled for 2023.

Monitoring alone cannot usually explain whether the observed developments are a causal consequence of a repository. This requires more in-depth investigations. Therefore, SFOE has set up a framework for so-called in-depth studies that examine individual issues in greater depth and assess selected future impacts by means of scenarios or forecasts [12]. The focus is on forecasting potential effects and developments and on causalities. It is also conceivable that the in-depth studies will examine in greater depth effects that have already occurred (e.g. changes in the real estate market) and they should answer additional questions that are still open or may arise. As such, they should also serve as a “catch-all,” especially if questions arise that are not sufficiently covered by the environmental impact assessment or other studies. For stage 3, in-depth studies are planned in the following fields:

- Residential location and economy;
- Public finances;
- Different perimeters and time periods;
- Economic effects of the impacts on transport and traffic;
- Procurement and regional economy.

On the topic of residential location and economy, a preliminary methodological study was carried out [12]. It demonstrated the possibilities and limits of a potential full study and outlined a possible methodology for its implementation. The authors of the preliminary study concluded that predicting the effects of a DGR on the decisions of people and companies ex-ante is very difficult and also associated with great uncertainties and methodological difficulties. As there are hardly any existing infrastructures worldwide comparable to a DGR for HLW, no conclusions could be drawn for Switzerland based on existing experience. The expected gain in knowledge of a full study on this topic would therefore presumably be limited.

The first full study that has been completed was on the topic of procurement and regional economy [13]. The main aim of the study was to analyse to what extent the regional economy can benefit from new jobs, orders, and secondary effects in the context of the DGR project and to draw up recommendations on how to maximise these benefits. The study assumes, compared to the overall economy, a small possible order volume for construction and manufacturing industries, as well as some potential for additional demand for services in the areas of transport, cleaning, green maintenance, winter services, and conventional technical maintenance. The recommendations developed are directed at the future operating company, the regional economy, and the siting region. The operating company is recommended to involve the business community and the local authorities in the project at an early stage. It should also strive to ensure public tenders are SME-friendly. On the part of the regional economy, it is important to prepare at an early stage for the special requirements of contracts in connection with a DGR. It should also create appropriate information and advisory services. In addition, the authors advise the siting region to work towards a siting agreement with the operating company. Such a contract would define the framework under which the operating company and the communes would work together. Finally, the siting region is advised to invest in the empowerment of the regional economy: Until construction begins, local businesses have to be able to offer the services that will be in demand during construction or operation by the operating company to benefit from contracts. As a sequel to this study, the institutional foundations for a future cross-border organization in the siting region dealing with regional development are currently being examined. Such an organization also has to be capable of allocating funds resulting from compensation payments expected to be disbursed after a general licence will have been issued to support regional development projects.

4. CONCLUSION

Assessing and quantifying the socioeconomic effects of a DGR is not trivial, especially ex-ante. Therefore, neither is their handling in the context of a site selection procedure with a strong emphasis on citizen participation, such as the Swiss. The first section of the paper has touched upon the institutional cornerstones of the Swiss selection procedure and has pointed out how the activities regarding socioeconomic effects are embedded in the procedure. Section two has looked at the socioeconomic baseline studies carried out in stage two of the selection procedure, indicating only minor differences between siting regions with predicted minor overall positive effects in the economic dimension and moderate overall negative effects in the environmental and societal dimensions. In addition, the methodological difficulties involved in survey-based analyses of hypothetical situations in the far distant future were mentioned. The third section shed light on SFOE’s current and future activities dealing with socioeconomic aspects that focus on data-based long term monitoring of socioeconomic indicators on one hand and on in-depth studies analysing specific questions, especially regarding cause-and-effect relationships, on the other. While at this point, no significant deviation of any socioeconomic indicator in any of the potential siting regions from the general trend has been identified, this cannot be interpreted as a DGR having zero negative socioeconomic effects, since the project is still in an early phase of implementation. Therefore, complete and continuous long term collection of data underlying the indicators defined to be monitored will be crucial in order to take well-informed, evidence-based decisions in the further course of the whole DGR project. In addition, close and trustful collaboration of the federal authorities with regional stakeholders in the siting regions and the transfer of ownership of regional development projects mitigating potential negative and leveraging positive effects of a DGR to the regional level will be pivotal for embedding a DGR into the local economy and society.

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FOSTERING STAKEHOLDER ENGAGEMENT: SELF-ORGANIZATION AS A NEW APPROACH TO PUBLIC PARTICIPATION IN THE CONTEXT OF THE GERMAN SITE SELECTION PROCEDURE

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Abstract

In 2017, Germany started the search for a final disposal site for high level radioactive waste. Viewing transparency and public participation as essential prerequisites for creating credibility and legitimacy, the law stipulates extensive participation opportunities for the public during the complete procedure. Following the publication of first interim results in autumn 2020, the first formal participation format has started – the “sub-areas conference.” With the aim of enabling a broad societal discussion process, legislators have introduced a completely new form of organization for this participation format: self-organization. This means the participants can determine the agenda, their way of working, and the main topics for discussion. The goal is to promote the involvement of the general public by enabling them to take on responsibility and shape the process. As the competent authority for public participation, the Federal Office for the Safety of Nuclear Waste Management (BASE) was responsible for implementing the conference. The paper provides first insights into the perspective and learnings of BASE regarding the concept of self-organization from a practical point of view. A central finding of the paper is that the concept of self-organization reinforces individual responsibility and therefore the involvement of the participants and creates well-functioning working structures and results. During the course of the discussions, the conference increasingly became an independently acting alliance of interested stakeholders with its own decision making structures and content priorities. However, it also became clear that self-organization involves a great deal of effort by those involved in it and that it requires time. Also, it should be recognized that individual interest groups, which can strongly affect the process, can particularly emerge in formats that are self-organized. The format, at best, represents only a part of all societal interests.

1. INTRODUCTION

Germany started looking for a disposal site for high level radioactive waste in 2017. The goal is to find a permanently safe site for the waste accruing from the use of nuclear power. Transparency and public participation are essential requirements in this process and are stipulated by law. Extensive participation opportunities for the public are, therefore, envisaged during the complete procedure. The actors in charge of the procedure are also required to organize additional participation opportunities, if needed.

The implementer commissioned to perform the search, Bundesgesellschaft für Endlagerung mbH (the Federal Company for Radioactive Waste Disposal), published the first interim report on its work in the autumn of 2020. The report has also formed the basis for the first participation format stipulated in the law – the sub-areas conference.

The conference represents a new kind of participation format in three different ways: it starts at an early stage in the procedure, even before any decisions have been made. It is open to all interested parties across Germany and it organizes itself according to the law. The last point in particular represents an innovation in German participation. The concept of self-organization aims at enabling the public to have the freedom to shape the process and work independently. The goal is to deliberately strengthen public involvement, particularly during this early phase in the procedure, where no specific areas are yet affected and the willingness to participate will be low.

The public reacted to this new format with a great deal of scepticism. How can a self-organized discussion process succeed with an unlimited number of participants with very differing preliminary knowledge, interests, and needs? What opportunities and what restrictions for public involvement does the self-organization concept provide? The paper reports recently collected practical experience and presents the initial findings from the sub-areas conference from the point of view of the Federal Office for the Safety of Nuclear Waste Management (BASE); the latter has been responsible for implementing the format as the body in charge of public participation in the site selection procedure and supported the idea of self-organization from the outset.

Starting with a presentation of the origins and basic principles of the German site selection procedure (chapter 2), the sub-areas conference and the concept of self-organization are viewed in greater detail (chapter 3). This is followed by an initial assessment of self-organization based on its specific use at the conference (chapter 4). The results gained so far about the opportunities and limits of the concept of self-organization are then considered in the conclusion (chapter 5).

2. THE SITE SELECTION PROCEDURE – A PARADIGM SHIFT IN SEARCHING FOR A DISPOSAL SITE IN GERMANY

Decades of major social conflict have characterized the history of using nuclear power and disposing of radioactive waste in Germany. One of the focal points has been the northern German town of Gorleben, where the German government decided to establish a nuclear disposal centre in 1977. A parliamentary investigating committee, which was appointed from 2010 until 2013, was unable to precisely explain the reasons why the salt mine there should be explored for disposal purposes. The local population believed that its concerns and fears had been disregarded and responded with resistance. About 100 000 people, including numerous farmers from Gorleben, made their way to the state capital of Hanover to protest the plans. Massive protests throughout Germany decried the use of nuclear power in general and the exploration of the site over the decades, partly because the work on a disposal site was viewed as the basis for operating nuclear power stations.

The German parliament decided in 2011 to finally phase out nuclear power by 2022 – based on the reactor accident at Fukushima Daiichi. This decision and the associated phase-out of nuclear power created a central prerequisite for relaunching the search for a disposal site in Germany. As a result of abandoning nuclear power, the amounts of radioactive waste are limited. The disposal site issue is no longer coupled to ongoing operations at nuclear power stations, Although the permanent social conflict focal point previously centred on the pros and cons of using nuclear power, now the focus is on finding viable solutions for disposing of the remaining radioactive waste, which can be accepted by society as a whole.

The Federal Parliament decided by a large majority to relaunch the search for a disposal site for high level radioactive waste in 2013. It appointed a broadly structured disposal site committee and commissioned it to investigate fundamental issues related to disposing of radioactive waste and draw up recommendations for action for a new selection procedure. The committee started its work in 2014 and presented its final report in 2016. The parliament adopted the Site Selection Act the following year based on the committee's recommendations. This forms the basis and yardstick for the search procedure that has been continuing since then.

The Site Selection Act represents a paradigm shift in several respects. First, it aims to find the site with the best possible safety for a period of one million years in a comparative and open-ended procedure. The law envisages a multi-stage selection process using scientific criteria, which have been clearly defined in advance. Using the principle of a "blank map," all German federal states and regions are included in the search. As no prior decision has been made about a specific host rock, salt, clay and crystalline rocks are being equally considered in the procedure.

On the other hand, the Site Selection Act marks a paradigm shift regarding public participation, because it views transparency and public involvement as essential prerequisites for creating credibility and legitimacy [1]. The public should be able to participate during all procedural stages. This is the only way of ensuring people in the region where the disposal site will be located will be able to understand the site is suitable for safety considerations. Public participation is, therefore, also viewed as an opportunity to recognise and correct errors. This approach is fundamentally different from earlier concepts of searching for a disposal site. The disposal site committee realized here, "the opportunities for democratic participation will also determine the success of the search process. This is not to replace, but to supplement parliamentary democracy by adopting a new learning policy" [2]. The Federal parliament will, in the public interest, decide the disposal site and the stages leading up to it.

The fresh start to the procedure has also created a new structure of actors in charge of the procedure and it implements a multilateral system of checks and balances [3]. The BASE is the controlling and supervisory authority, as well as the responsible actor for handling public participation, as enshrined by law. Bundesgesellschaft für Endlagerung (BGE) mbH, on the other hand, is performing the exploratory work as the implementer and suggests regions and sites for exploration. Finally, the National Civil Society Board is accompanying the procedure as an independent societal body with the aim of mediating in the procedure. It is composed of renowned personalities from public life and citizens selected randomly

3. SELF-ORGANIZATION AS A NEW CONCEPT TO PROMOTE PUBLIC INVOLVEMENT AT AN EARLY STAGE IN THE PROCEDURE

The selection process has now reached the first important point in the multi-stage procedure: the implementer, BGE mbH, published its first interim report in the autumn of 2020. Based on an initial, purely geoscientific consideration by the Federal Republic of Germany, the implementer has named the regions it believes can be excluded from the procedure. The remaining part, which will be further restricted at later stages, accounts for about 54% of the surface area of Germany. The paper represents an initial progress report by the implementer and does not contain decisions about potential siting regions. It is rather geared toward transparently presenting the initial substantive principles for searching for a disposal site and ensuring comprehensibility, even before final results are available and the first decisions in the process have been made. The law, therefore, does not envisage any review by the nuclear supervisory body, BASE, at this interim stage.

The first participation format prescribed in the law – the sub-areas conference – was launched when the interim report was published. Its goal is to enable an in-depth understanding and public discussions about the interim report and the approach adopted by the implementer. Initial feedback, questions, and criticism from the general public were also to form part of the procedure at this early stage. BGE mbH needs to consider the results of the discussions at the conference in its ongoing work. The sub-areas conference is an open discussion format, which is geared toward members of the public, representatives of local authorities, scientists, and social organizations. It is, therefore, directed at all interested parties across Germany, regardless of their previous knowledge. According to the law, the conference should communicate the findings of its discussions to the implementer within six months after holding no more than three discussion meetings.

The sub-areas conference is a direct response to a phenomenon that is well-known in participation research: the participation paradox. According to this, the readiness to participate at the beginning of planning processes is normally very low, because there is not yet any specifically affected area. However, the most far-reaching scope of action and opportunities for organizing matters are precisely available at the start of such procedures [4]. The sub-areas conference should counter this participation paradox and enable public discussions, before regional aspects tend to dominate the discussions, once the suggestion for site regions has been made during the next stage of the procedure. The idea is to develop skills in the course of discussions and to generate interest in shaping the process.

How is it possible to resolve this need for discussions about a very complex and sophisticated report with multiple perspectives? The law prescribes a further specific issue here and no blueprint for this has ever existed in Germany before. To enable the participants at the conference to work independently, legislators have introduced a completely new form of organization: self-organization. This means the participants can determine the agenda, their way of working, and the main topics for discussion. Organizing the discussions and even the mechanisms of decision making processes have, therefore, been placed in the hands of conference participants. Legislators deliberately opted to create a new type of participation facility during this first stage of the search for a disposal site and in the light of the specific general conditions for this phase, where the course and the content have not been planned in advance and managed. The goal is to promote the involvement of the general public by enabling them to take on responsibility and shape the process.

The concept of self-organization within the framework of the conference is therefore meant to help create an important foundation for the further participation steps in the procedure. Those affected will only be able to understand at the end why their region is suitable as the site for safety considerations if the public has been involved in the procedure from the outset. From the point of view of BASE, therefore, an essential element of self-organization is that interested members of the public have the possibility of determining the major points of the report that need to be understood and discussing prospects without any controlling intervention by BASE and BGE mbH. Assuming responsibility is a desired effect of self-organization. It implies a change of role for the participants at the conference, but also for BASE as the party responsible for holding the conference. As the authority in charge of public participation, BASE assumes the role of an enabler for the conference to make available resources and provide support with organizational tasks. The conference itself can make decisions about the content and results, BASE only makes sure that the conference acts within the framework outlined in the law and that fairness and justice characterize the procedure. According to the law, the implementer needs to then consider the conference's comments and results related to the interim report. BASE therefore becomes an enabler for a social dialogue process that is self-organized.

Independently working participation formats are also envisaged for further stages in the procedure. For example, the regional conferences that will be organized in all the siting regions, which the implementer suggests for further exploration during the next stage in the procedure are also self-organized.

4. SELF-ORGANIZATION IN PRACTICE

The sub-areas conference closed in August 2021. Three discussion meetings took place in February, June, and August 2021 at the conference as stipulated in the law. The conference submitted its results to the implementer in September 2021, one month after the last discussion meeting, and then disbanded. As the authority responsible for public participation, BASE consistently implemented the requirements specified in the law to enable a discussion process that organized itself.

One key finding was the concept of self-organization reinforces individual responsibility and, therefore, participant involvement and creates well-functioning working structures and results. This is particularly noticeable regarding differences between the perspectives of the stakeholder groups who are evaluating their arguments here: elected officials from local authorities, scientists, representatives of social organizations, and interested members of the public. This is also remarkable in view of the complexity and demanding content in the sub-areas interim report – not just for lay people – and the fact that the entire conference has had to be held in a digital format because of the Covid-19 pandemic.

In addition, the concept of self-organization provided room to flexibly address framework conditions: As the interim report by BGE mbH, contrary to expectations, earmarks very extensive areas, which make up about 54% of the surface area of the Federal Republic of Germany, correspondingly, the participant interest has expanded to topics beyond the statutory mandate of the conference. In addition to the content of the interim report, attention shifted to questions concerning the further process of narrowing of sub-areas by BGE mbH and further opportunities for participation. But how were the structures for self-organization specifically created?

BASE initially had the challenge of having to create a foundation and a starting point for an equitable discussion and organization process with an unknown and varying number of participants from throughout Germany with very different levels of knowledge, interests, and backgrounds. BASE, therefore, introduced a kick-off event before the three legally prescribed discussion meetings that took place immediately after the publication of the report by BGE mbH in October 2020. The kick-off event, firstly, helped to explain the content of the report in a generally comprehensible manner. And, secondly, it allowed the approximately 800 participants to hold initial discussions about their future way of working. The discussion focus was partly on developing rules of procedure, for which an initial draft had been prepared in advance for consultation purposes, as well as questions of possible operating modes for the conference. In the end, the conference participants elected a preparatory group, which was mandated to prepare the content and organization of the discussion meetings. All interested participants were able to stand as candidates for the preparatory group. The group equally represented the participant groups mentioned in the law and consisted of four members each from the public, representatives of local authorities, representatives of social organizations, and scientists. Experience has shown that group cohesion takes time. Dissent and conflicts have to be identified and resolved. By introducing the kick-off meeting, the aim of BASE was to keep the legally limited consulting period of six months as free as possible from lengthy group-finding processes.

During the course of the following discussion meetings, for which between 1000 and 1600 participants registered, the conference increasingly developed its own momentum and working structures. The preparatory group emerged as the central steering committee for the conference. It was responsible for developing the programme and managing the conference. It was supported by a moderation firm commissioned by BASE and a business office, which BASE set up to guide and support the organization of the conference. The preparatory group met regularly between the conference meetings and, therefore, guaranteed the continuity of the conference. It examined, for example, suggestions for topics, discussed proposals, and consulted with the participants. At the end of each discussion meeting, the mandate of the preparatory group was renewed by a voting process and interested parties were able to stand as candidates. This assumption of responsibility ensured the preparatory group could largely view itself as the guarantor of the cohesion and workability of the conference, for example, by mediating between different points of view, expressing recommendations for decisions, and actively steering discussions. Enabling the conference to adopt a successful course, therefore, increasingly became a major goal for the preparatory group.

The conference also developed its own momentum with regard to major topics which was reflected in the variety of topics and discussions at the conference. More than 20 topic sessions took place at the first discussion meeting, which had previously been suggested by participants and selected by the preparatory group. Working groups quickly formed around some of these particularly important topics and they independently assumed responsibility for discussions on these matters. These included, for example, spatial planning considerations, host rocks or safety requirements and safety investigations, but also more general topics like participation and transparency in the procedure. It was therefore decided that some of these working groups should continue their work between the conference meetings. As a result, the conference managed to set its own priorities in line with the participants' interests and needs. The topics and major items reflected the interests and diversity of the participants, but also seized on the fact that the interim report was significantly less specific in its degree of detail than it had been expected. In the light of this, many topics not only dealt with the discussion matter stipulated in the law, i.e. the content of the interim report, but also aspects beyond this such as the upcoming stages in the procedure to further narrow down the sub-areas and participation opportunities. The results of the discussions have been documented and form the basis for the results that will be handed to the implementer at the end.

Proposals for decisions, which participants were able to suggest for each discussion meeting during set time frames, served as another element of self-organization. If they attracted a particular minimum number of supporters, they were submitted to the plenary session for discussion and voting. This mechanism developed during the course of the discussion meetings to a means of organizing majorities on contentious issues from the heterogeneous participants and promoting the decision making process at the conference. This, firstly, involved substantive issues like setting up working groups or prioritizing special areas of focus. However, this facility also helped the conference to develop its own internal momentum beyond its statutory mission. The means of making decisions was increasingly used to articulate demands for fundamental procedural issues, for example, issues of financial compensation for participants' voluntary involvement or how participation could continue to be organized after the end of the conference. It should be noted here that BGE mbH is legally obliged to take into account the discussions about the sub-areas interim report. BASE examines demands going beyond the legally prescribes subject of discussions and takes them up as suggestions for organizing the further process of participation.

During the course of the conference, however, it became clear that self-organization involves a great deal of effort by those involved in it. Membership of the preparatory group in particular required an enormous amount of commitment and time, which can barely be provided on a voluntary basis.[1] In line with this, people who also had the necessary time resources particularly became involved in the preparatory group. This caused increasing consolidation in the structures. Hence, the interests of those who are able to invest the most time prevail, also because a working mode that is considered ‘good’ is usually continued in the sense of "never change a winning team". As a result, these structures only represent a part of the interests in the process and cannot claim to be representative. In addition to the time resource factor, stakeholders, who were pursuing particular interests in the procedure, also became involved.[2] It was much harder to attract members of the public, who had not had any connection with issues related to disposal in the past, to be actively involved in the procedure. As a representative survey commissioned by BASE shows, general citizens are more interested in information about the current status of the procedure than in active participation [5]. Local authorities in Germany were particularly strongly represented, with a strikingly high number from Bavaria and Lower Saxony.[3]

It is also necessary to state that any purposeful self-organization work requires either a strong use of resources or time. This is particularly relevant for formats like the sub-areas conference, where time is limited. In order to efficiently extract results from the variety of topics, feedback comments, information sources and questions, working structures, which can only develop over a fairly long period of time, are required. Obtaining a coordinated summary as a result is only possible with a great deal of work in the context of three meetings and requires tight organization, which can normally not be placed in the hands of volunteers. At the same time, experience has shown that processes in which many issues need to be resolved in a short time are prone to conflict if the time for mutual understanding and debate is limited.

5. CONCLUSION

Overall, about 4900 registrations were made for all the meetings at the sub-areas conference. At peak times, more than 1000 people were discussing the search for a disposal site at the same time. Working independently enabled many perspectives to be included in the discussions about the interim report and participants developed a deeper understanding of the content and the way the implementer was working according to their own priorities. During the course of the discussions, the conference increasingly became an independently acting alliance of interested stakeholders with its own decision making structures and content priorities. This result is remarkable, particularly in the light of the considerable scepticism expressed by the public about self-organization in the run-up to the conference. At times, the discussions reflected the needs of the public to understand the content and the transparency of the procedure – also in the light of the unexpectedly large areas mentioned in the interim report.

As a result, the conference drew up extensive comments on the interim report and the way that BGE mbH is operating. They are due to be handed over to the company by September 2021. This involvement has also shown where the implementer needs to take further action within the procedure: it has become clear the local authorities in Germany want the areas indicated so far to be narrowed down so the specific regional and far-reaching participation facilities in the procedure can be used as soon as possible, as envisaged in the law.

Thanks to having the opportunity to set their own content priorities and include expertise and experiences, the participants were also able to develop responsibility for the success of the conference and thus for the search

[1] The preparatory group had to devote a working time of approx. 150 hours in addition to the three discussion meetings (approx. 135 hours) and various working group sessions (approx. 50 hours).

[2] Throughout the three discussion meetings, representatives of the local authority bodies accounted for the lion’s share of the registered participants (more than 35%) and this figure increased significantly over the three discussion meetings. Members of the public accounted for 22% of the registrations, but this figure declined during the course of the discussion meetings. Scientists and representatives of social organizations were stable at about 10% and 8% of the registered participants, respectively. The remaining percentage shares of registrations were spread among observers, who could not be assigned to any of the four categories of participants envisaged in the law. They were able to follow the discussions at the conference, but did not have any voting rights.

[3] In order to ensure no voices went unheard beyond the self-organized meetings, BASE also organized an online consultation platform, which will be made available to the implementer after the conference. The participants and particularly the members of the preparatory group used this digital tool to prepare their appointments during the course of the conference.

procedure as a whole – and this is an important prerequisite for a procedure that is relevant to society as a whole and across generations. This also became clear from the demand to establish a participation format after the end of the sub-areas conference in order to continue monitoring the implementer's work. The conference not only issued a request, but also developed a concrete, solution-oriented suggestion. Discussions were held with BASE during the third discussion meeting on how participation can be continued in specific terms and this will be organized in a joint dialog between the stakeholders involved during the next few months.

However, it should be recognized that individual interest groups, which can strongly affect the process and the course of events, can particularly emerge in formats that are self-organized. The format at best only maps some of the interests. For BASE as the body responsible for the procedure, this means having to particularly ensure fairness and justice are safeguarded and the interests of those, who possibly wish to become involved in the procedure at a later date, are also considered.

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TOOLS AND METHODOLOGIES FOR ENGAGEMENT WITH THE PUBLIC AND AFFECTED COMMUNITIES FOR REGULATION OF RADIOACTIVE WASTE MANAGEMENT PROJECTS

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Abstract

The Canadian Nuclear Safety Commission's (CNSC) regulates all nuclear facilities and activities throughout their life cycle. The CNSC decisions are evidence-based and presented in the context of an open and transparent hearing process. Public and Indigenous engagement allows the CNSC to obtain valuable information and to hear and address concerns about proposed projects, during environmental review (ER) and licensing processes. This strengthens the quality of reviews and informs the Commission's decisions in the regulation of new radioactive waste management projects. The CNSC facilitates public and Indigenous participation throughout the ER and licensing processes in several ways, including written, virtual, and live opportunities, which the paper will explain in more detail. The CNSC provides financial assistance to participate in many of these opportunities. The CNSC also engages with local Indigenous communities over a project's lifetime. In Canada, Indigenous and Treaty rights are protected under the Canadian Constitution, and the Government is legally required to meaningfully consult potentially affected Indigenous groups when making decisions that could impact them. The CNSC is committed to going beyond the legal bare minimum. The CNSC ensures Indigenous groups have opportunities to participate throughout the regulatory life cycle, to ensure all issues and concerns are considered, and that information gathered, including Indigenous Knowledge, is used to inform the Commission's decisions. During the pandemic, the CNSC has adapted how it interacts with the public and Indigenous groups, responding to in-person limitations and the technological availabilities of the other parties. The CNSC's transparent and collaborative approach to consultation and engagement in Canada helps contribute to the CNSC's strategic goal of being a trusted regulator and enhancing the CNSC's regulatory oversight of the nuclear industry.

1. INTRODUCTION

The Canadian Nuclear Safety Commission (CNSC) is Canada's sole nuclear regulator responsible for overseeing all nuclear facilities and activities throughout their life cycle, to protect health, safety, security, and the environment. The Commission's decisions are evidence based and presented in the context of an open and transparent hearing process. Public and Indigenous engagement allows the CNSC to obtain valuable information and to hear and address concerns about proposed projects. This strengthens the quality of reviews and informs the Commission's decisions in the regulation of new radioactive waste management projects and all nuclear projects under the Commission's jurisdiction and mandate. This regulation includes an environmental review and a licensing process.

The CNSC requires the environmental effects of all nuclear facilities or activities be considered or evaluated when licensing decisions are made. Environmental reviews are conducted for all licence applications that demonstrate potential interactions with the environment. The type and scale of the environmental review is commensurate with the scale and complexity of the environmental risks associated with the facility or activity.

Environmental assessments (EA) are one type of environmental review; they are planning tools that are carried out early in the process prior to granting a licence, yet consider the entire life cycle of a project, i.e. from cradle to grave. In Canada, EA was formally introduced in 1973 with the Environmental Assessment and Review Process. This legislation was followed by the Canadian Environmental Assessment Act (CEAA) (1992) and CEAA 2012. CEAA and CEAA 2012 outlined the process and requirements for projects where the federal government had decision making authority. The scope of CEAA EAs is the assessment of adverse environmental effects due to a project as proposed by the potential licensee. In August 2019, the federal Impact Assessment Act (IAA) came into force, repealing CEAA 2012. Impact assessments are conducted for projects that have been identified as having the greatest potential for adverse environmental effects in areas of federal jurisdiction. Through implementation of the IAA, the scope of federal impact assessments has broadened compared to previous EA legislation and includes environmental, health, social and economic effects – positive and negative – of a proposed project.

The transitional provision in the IAA (section 182) states that projects with EAs already started under CEAA 2012 and that are led by the CNSC will continue under the current process. Under CEAA 2012, the CNSC is the sole federal Responsible Authority for conducting EAs for nuclear designated projects. A designated project is defined in the Regulations Designating Physical Activities. There are currently six (6) CNSC-led EAs which are being carried out under CEAA 2012 as per this provision. Of the six EAs, three (3) are being carried out for proposed radioactive waste management projects.

Engagement and consultation with the public and Indigenous groups is a key aspect of the CEAA 2012 EA process (Fig. 1). As per CEAA 2012, the CNSC, as the Responsible Authority, has to ensure there are opportunities for public participation for designated projects.

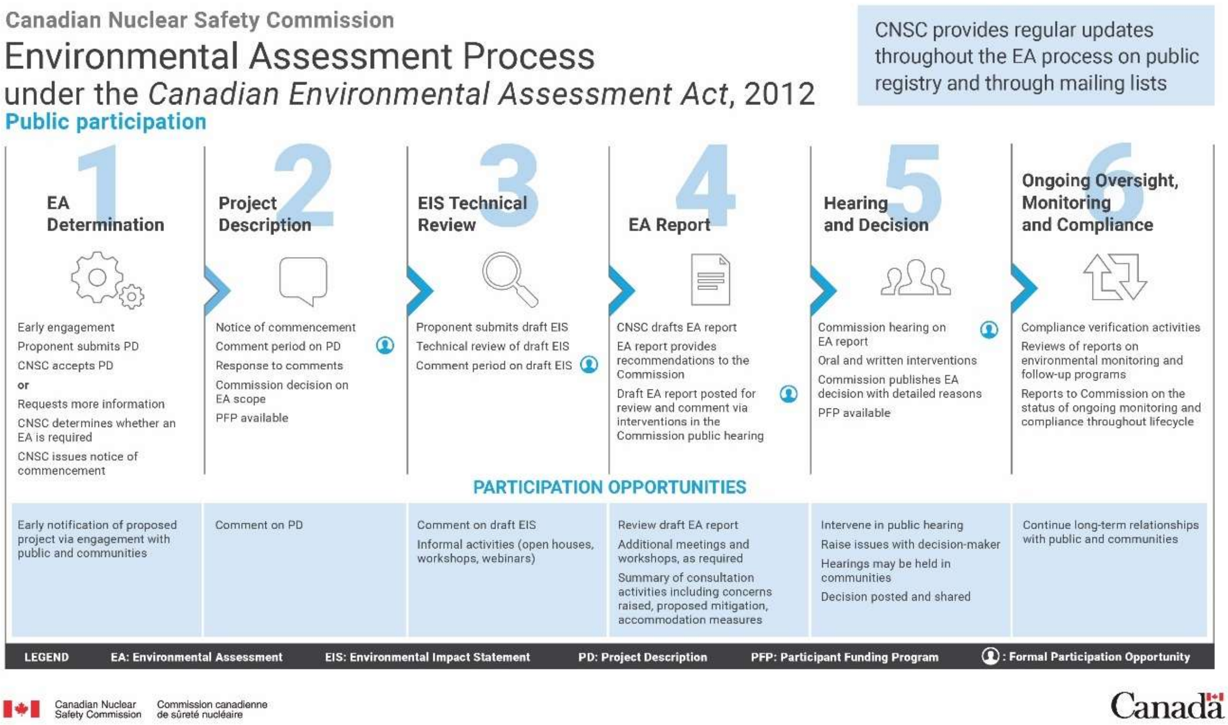

FIG. 1. Opportunities for public engagement and Indigenous consultation within the CNSC's environmental assessment process under CEAA 2012 (with permission from Canadian Nuclear Safety Commission).

Additionally, federal EA legislation requires the CNSC must ensure records and information relating to the EA of a nuclear designated project are posted on the Canadian Impact Assessment Registry (CIAR) (formerly the Canadian Environmental Assessment Registry or CEAR). Relevant information is also posted on the CNSC's website as well as distributed to project-specific distribution lists and to potentially interested Indigenous groups. The CNSC's own regulatory framework also requires each project's proponent engage early and throughout the regulatory review process with the communities and Indigenous groups that would be most impacted by the proposed project.

In Canada, Indigenous and Treaty rights are protected under the Canadian Constitution, and the Government is legally required to meaningfully consult potentially affected Indigenous groups when making decisions that could impact them and their rights. The CNSC, as Canada's nuclear regulator and an agent of the Government of Canada, is committed to going beyond the legal bare minimum for meeting the Duty to Consult as established by the Supreme Court of Canada. By providing funding, constant dialogue, formalized agreements, and regular information sharing, the CNSC ensures interested Indigenous groups have opportunities to participate throughout the regulatory life cycle, in order to ensure all issues and concerns are considered, and that information gathered, including Indigenous Knowledge, is used to inform the Commission's decisions.

The CNSC's Participant Funding Program (PFP), established in 2011, provides financial assistance to members of the public, Environmental, Non-Governmental Organizations (ENGOs) and Indigenous groups to participate and provide information to the Commission through topic-specific interventions related to EAs and other licensing processes. The PFP may be provided at various stages of the EA process including for public review of the project description, the draft Environmental Impact Statement, CNSC staff's EA report and licensing Commission Member Document; as well as for preparing written and/or oral interventions for Commission proceedings.

The paper discusses the evolution of the CNSC's approach for providing opportunities for public engagement and Indigenous consultation as it relates to the EA of major waste management projects. The different opportunities will be discussed in relation to the Spectrum of Public Engagement and Indigenous Consultation (Fig. 2). The Spectrum outlines five different levels for engagement and consultation and was developed to assist with selecting the level of participation in any public or Indigenous participation process. To illustrate the evolution of CNSC's public engagement and Indigenous consultation approaches, the paper describes the engagement and consultation tools used for a previous CNSC-led CEAA 2012 EA (e.g., the Gunnar Remediation Project) and outline how the CNSC is working to adapt its approach in conducting EAs for ongoing major projects, which has been informed and influenced by some of the best practices from a number of different major projects and processes, including the EA for Ontario Power Generation's proposed Deep Geological Repository for Low and Intermediate Level radioactive wastes. As per the Spectrum in Fig. 2, the CNSC's approach for the Gunnar Remediation Project was based on consultation and striving for involvement. Our current enhanced approach is based on involvement and striving for collaboration.

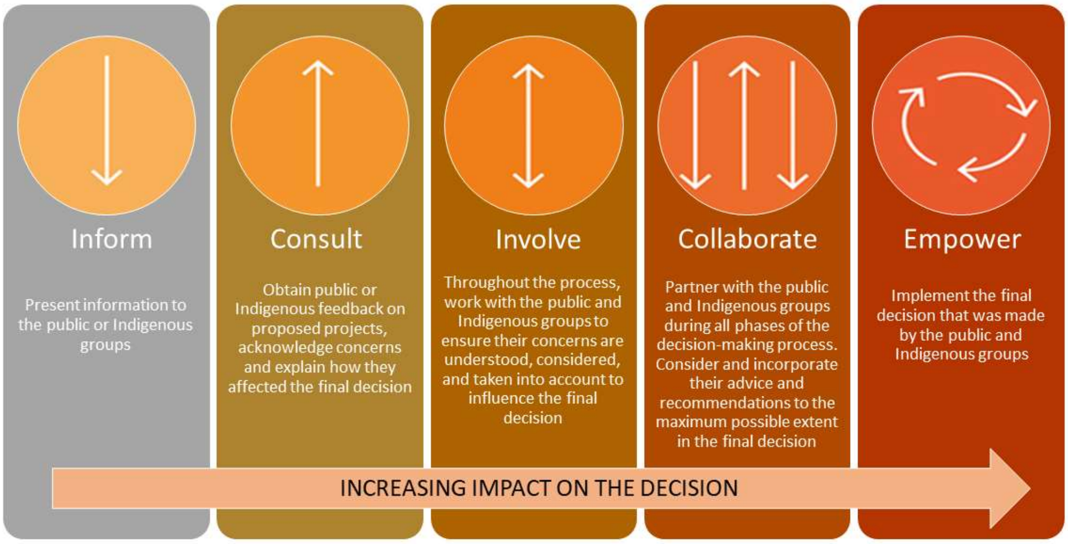

FIG. 2. Spectrum of public engagement and indigenous consultation (adapted from IAP2 2018[1]).

2. TOOLS AND METHODOLOGIES FOR ENGAGEMENT AND CONSULTATION WITHIN A PROJECT

2.1. Overview of the Gunnar remediation project – a case study

The Gunnar Remediation Project (the Project) was a project that underwent a CNSC-led EA. It began in 2007, and was completed under CEAA 2012 in January 2015. The CNSC was the federal Responsible Authority that led the EA in consultation with other federal departments with specialist and expert information or knowledge. The Project was also required to undergo a provincial EA under the Saskatchewan Environmental Assessment Act; resulting in a joint federal-provincial EA process. Under an agreement between the CNSC and the Saskatchewan Ministry of the Environment (SE), the Project EA requirements (including public engagement) of the federal and provincial processes were standardized to the greatest extent possible.

The Gunnar uranium deposit was discovered in 1952, with production starting in 1955. Uranium ore was mined from an open pit from 1955 to 1961, followed by underground operations from 1957 to 1963. The mine officially closed in 1964, with little or no decommissioning of its facilities. The Project involved the long term mitigation of residual public safety and environmental health risks posed by the abandoned Gunnar uranium mine and mill site. The Gunnar Site is located approximately 25 kilometres southwest of Uranium City in the northwest corner of Saskatchewan, Canada.

2.2. Engagement with the public

As the project was undergoing EAs at the provincial and Federal levels, a coordinated approach was used to align EA and regulatory review processes where possible. The CNSC and SE also coordinated and collaborated on where possible for public and Indigenous participation activities to fulfil requirements of the federal and provincial EA processes and reduce duplication and engagement fatigue. A public registry was established on the CEAR (https://www.ceaa-acee.gc.ca/050/evaluations/proj/30100). Information on the project was also provided on the CNSC's website (www.nuclearsafety.gc.ca) and the SE website (www.saskatchewan.ca/environment).

Public comment periods on specific project documents were advertised on the CNSC, Canadian Environmental Assessment Agency (CEAA) and provincial websites, as well as through radio broadcasts and newspaper advertisements. Hard copies and electronic copies of the EA documents were also mailed to interested individuals, organizations, communities, and Indigenous groups for their review. In addition, a public information meeting was held in some local communities to seek public input on project documents and provide information on the EA process.

During the EA process, comments received from the public and Indigenous groups focussed on EA methodology and specific environmental concerns. The CNSC, SE, and the other federal departments worked to address the concerns raised by members of the public and Indigenous groups throughout the EA process. For example, the federal and provincial government representatives met with Indigenous groups and other organizations to provide information on the Project, discuss the potential environmental effects, and encourage participation in the EA review, as well as to seek input on remedial options and to request information as to how the Project, as proposed, could cause adverse impacts to potential or established Indigenous and/or Treaty rights. Further, all comments received on the EA Report were considered by the Commission prior to deciding on the EA and on whether the duty to consult Indigenous peoples, regarding potential impacts on their rights and interests, was met.

2.3. Evolution of public engagement since the Gunnar Remediation Project

The tools and approach described above for seeking feedback from members of the public for the Gunnar Remediation Project were focussed on the Consultation level of the Spectrum of Public Engagement and Indigenous Consultation (Fig. 2). The public comment periods and the engagement sessions were aimed at seeking feedback from participants. The issues and concerns heard throughout the process were documented in the EA Report that was presented to the Commission. The CNSC's EA Report demonstrated how the comments from the public were considered in the development of the report and ultimately considered as part of the final decision. This illustration of how comments received were considered in the decision making process demonstrates how the CNSC was striving for the Involvement level of the engagement Spectrum.

Since the approval of the Gunnar Remediation Project by the CNSC's Commission Tribunal in 2015, CNSC has been building upon its approach to move from Involvement to Collaboration. In this regard, the CNSC is aiming to partner with various non-governmental participants in the EA process to seek their advice and recommendations. Currently, the CNSC is developing a Trust Strategy to help the CNSC reach its strategic goal of being a trusted regulator and generate confidence with its key audiences and stakeholders. Section 3 provides further details including the tools and approaches that the CNSC is developing and considering for implementing this strategy.

2.4. Consultation with indigenous peoples

For the Gunnar Remediation Project, the involvement of potentially impacted Indigenous groups included activities such as annual community tours of the 5 remote communities in Northern Saskatchewan with a direct interest in the remediation Project, relationship building, attending community events, as well as providing funding through the CNSC's PFP to host multiple workshops and participate in the EA process. These workshops were attended by key community leaders and representatives to provide direct input to the proponent and regulator/government representatives regarding the remediation options and approaches.

The workshops provided opportunities for potentially affected communities to not only learn about the remediation approaches for the Project, but also provide their feedback, local/Indigenous knowledge, priorities and preferences directly into the decision making process. Many of the communities' recommendations and priorities were accounted for in the final design of the remediation options, collaborative environmental monitoring activities and protection of their rights and interests.

2.5. Evolution of indigenous consultation since the Gunnar Remediation Project

As part of the Gunnar Remediation Project EA and licensing process, the CNSC has continued to move its consultation processes with Indigenous groups potentially affected by the Project beyond consultation, along the Spectrum of Public Engagement and Indigenous Consultation (Fig. 2), toward involvement.

The CNSC has continued to enhance its approach to consultation and engagement with Indigenous peoples. Since 2016, the political, legal, policy and social expectations surrounding consultation and engagement activities performed by the Government of Canada have evolved significantly. The Government of Canada is committed to achieving reconciliation with Indigenous peoples and is working to facilitate the implementation of rights acknowledged and affirmed in the Canadian Constitution and align federal policies with the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). In 2021, Canada passed the United Nations Declaration on the Rights of Indigenous Peoples Act, which enshrines the principles of UNDRIP into Canadian law.

In light of the shifting legal and policy environment, the CNSC has established several effective processes to support its duty to consult obligations. For more recent major projects, including the three proposed radioactive waste management projects currently undergoing EAs under CEAA 2012, the CNSC has worked diligently to continue to move its approach to consultation engagement further along the Spectrum of Public Engagement and Indigenous Consultation from involvement toward collaboration. For the CNSC, collaboration includes further opening up our assessment and decision making processes to potentially impacted Indigenous groups. For example, the CNSC has signed multiple consultation agreements with Indigenous groups that create a framework for how the CNSC and the Indigenous group will be consulted and involved in the regulatory process. Examples include the collaborative drafting of key sections of CNSC staff's assessment reports and recommendations to the Commission, participation in technical review teams and Rights Impact Assessment processes, and the incorporation of Indigenous Knowledge and Traditional Land Use data.

These measures ensure Indigenous groups continue to be treated with respect and as another order of government who is directly involved in the CNSC's review and assessment process. This is a partnership approach that aims to achieve the principles outlined in UNDRIP, including addressing the concerns identified by Indigenous groups regarding nuclear projects, such as potential impacts on their rights, culture, and way of life in a collaborative and ongoing way with the CNSC. These approaches are helping the CNSC to build trust and achieve positive, sustainable results. However, these collaborative consultation activities are resource intensive for the CNSC and Indigenous groups, and push the CNSC to the limits of what its current regulatory/legal framework and decision making process allows.

Moving forward, the CNSC is committed to continuing to explore ways to enhance its approach to consultation and engagement for major nuclear projects in Canada. Most Indigenous groups that the CNSC works with have clearly stated that while they appreciate the CNSC's current collaborative approach to consultation, they would ultimately like to move the work accomplished together toward the empowerment level of the Spectrum of Public Engagement and Indigenous Consultation.

3. TOOLS AND METHODOLOGIES FOR ONGOING ENGAGEMENT

3.1. Moving forward

The empowerment level of the Spectrum of Public Engagement and Indigenous Consultation (Fig. 2) means the effective joint planning and shared decision making that satisfies all parties. For the CNSC, working toward this desired state starts with the building of long term mutually beneficial relationships with Indigenous groups, the public and key stakeholders.

The CNSC is a lifecycle regulator and has a mandate to disseminate objective, scientific, and regulatory information to the public, including continued and ongoing engagement outside of regulatory review processes for nuclear projects. For the public, the CNSC already possesses a robust approach for ongoing engagement and outreach including a strong social media presence and web content, webinars, "Meet the Nuclear Regulator" events, school outreach, community outreach, fact sheets and community open houses. Building off these approaches and tools, the CNSC is setting a new course around public engagement and is developing a public trust strategy. This strategy will help the CNSC ensure it is engaging with a variety of audiences and stakeholders, including stakeholders and organizations that the CNSC has not previously engaged with, to have meaningful, open and honest two-way dialogue that fosters relationships, confidence and trust. For example, the CNSC is taking steps at reframing and re-establishing a forum for on-going engagement with key Environmental, Non-Governmental Organizations (ENGOs). The purpose is for ENGOs who regularly participate in the CNSC's regulatory processes, including its Commission proceedings, to work together to address their common concerns and questions and improve transparency, accountability, and open and honest two-way dialogue. The CNSC-ENGO forum is still in the early phase of establishment; however, all parties are committed to making the forum a success moving forward.

In addition, the CNSC has developed an Indigenous Reconciliation Strategy that builds off the CNSC's strong track record and efforts in consultation and engagement to date and sets out a vision and key actions to enhance the CNSC's approach to building and strengthening trust with Indigenous groups to positively contribute to the Government of Canada's priority of advancing reconciliation. Part of this work includes formalizing its long term engagement relationships with Indigenous groups that have multiple existing or proposed nuclear facilities within their territories. The CNSC has signed multiple formal agreements with Indigenous groups for long term engagement to date. These agreements lay out a clear framework of how the CNSC and its Indigenous partners collaborate on areas including environmental monitoring, engagement on CNSC regulatory activities, information sharing with their community members and leadership, as well as reporting to the Commission on updates regarding the engagement and relationship building activities.

For example, the CNSC and the Saugeen Ojibway Nation (SON) signed a long term engagement relationship agreement in 2019. The SON's traditional and treaty territories include the Bruce Nuclear Site, which is one of the world's largest and most complex nuclear sites. As part of the agreement the CNSC and the SON jointly established an engagement action plan that includes, the assessment of additional mitigation measures for the protection of Lake Huron fish species and aquatic life, collaborative environmental monitoring activities, regular review and updates regarding CNSC regulatory oversight and compliance activities and joint reporting to the Commission. This agreement and action plan has helped the CNSC and the SON to jointly enhance the relationship, build trust and help ensure effective communication and regulatory oversight of the Bruce nuclear facility.

3.2. Adaptation to the pandemic and post-pandemic

CNSC's engagement activities have not slowed down because of the COVID-19 pandemic. The CNSC and our public and Indigenous partners have been able to adapt to the pandemic context and have found effective means of maintaining and building the important relationships and work accomplished together. The CNSC has taken many lessons learned from conducting engagement and consultation during the pandemic and is beginning the process of envisioning what these activities and processes will look like in a post-pandemic world.

Prior to the pandemic, most meetings with the public and Indigenous groups were held in person and would often require CNSC staff to travel to remote locations, which was resource and cost intensive. Previously, regular meetings were not possible due to these costs and travel requirements. However, videoconferencing platforms have opened new possibilities for regular, sustained, and meaningful collaboration with communities, leadership, and stakeholders virtually. For example, videoconferencing has allowed for more schedule flexibility for CNSC staff, the public, and Indigenous participants, as well as the possibility of participation in multi-party meetings. The CNSC recognizes the limitations of this use of videoconferencing: Canada is a large country, and there are remote locations where the hardware and technology are inappropriate or totally lacking to support this means of communication.

In addition, prior to the pandemic, Commission hearings were open to the public and included interventions in person. Some of those public hearings would have been held in the community closest to a proposed project. During the pandemic, while the hearings have remained public and interventions are still encouraged and supported, they have been required to be fully virtual. However, in the post pandemic world, the CNSC's plan is to return to holding Commission proceedings in person in the communities closest to the projects, as well as continuing to offer the ability to participate virtually to ensure the Commission's proceedings continue to be as accessible and meaningful as possible.

Finally, the pandemic has limited the CNSC's ability to engage directly with the broader community; webinars haven't fully replaced the value of in person open houses and meetings where CNSC staff are able to talk one on one with community members, or large groups. The pandemic has also limited our ability to participate in meaningful activities like walking the land together and conducting environmental monitoring and sampling activities together in person.

Once public health restrictions are eased, the CNSC envisions moving forward with a hybrid approach to consultation and engagement with the public, Indigenous groups, and key stakeholders. This will include the ongoing use of videoconferencing and webinar platforms for the broad dissemination of information and regular update and engagement meetings with key audiences. These technologies and platforms have proved to be a useful and cost effective means of conducting engagement and outreach with audiences from across the country.

CNSC staff are eager to travel again to communities with interests in CNSC regulated facilities, projects, and activities to engage again in person. Through a combination of approaches for regular, sustained dialogue using virtual platforms, along with targeted in-person engagement and relationship building activities, the CNSC believes it will be able to increase mutual trust with our key partners and stakeholders and move to the highest levels of public and Indigenous engagement and involvement.

4. CONCLUSIONS

Meaningful and ongoing engagement and consultation with the public, stakeholders and Indigenous groups has become pivotal for the long term success of any major nuclear project in Canada. In many respects public consultation and trust have become as important for these projects and initiatives as the technical and safety aspects and also require the same level of effort, expertise and resources from industry, government and regulators. As Canada's nuclear regulator, the CNSC, has been evolving the way it conducts engagement and builds trust with the public and Indigenous groups, aiming to ensure the CNSC's approaches are in line with best practices and the growing expectations of key audiences and stakeholders across Canada and within the scope of our mandate.

As discussed in the paper, the emerging trend is that the public expects Governments, regulators, and industry proponents to work toward the collaboration and empowerment levels of engagement and partnership for decisions on projects and initiatives that may impact them. This level of engagement and partnership with key affected parties and stakeholders can lead to real, sustainable support and confidence in regulatory decisions for nuclear projects, including the long term management of radioactive wastes. The nuclear sector, and the world, will not be able to achieve sustainability without this confidence and support. Transparency, openness and partnerships can lead to real trust amongst all affected parties and to better long term outcomes for all.

REFERENCES

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Paper ID#215

SOCIOTECHNICAL SYSTEMS DESIGN FOR CONSENT-BASED SITING OF NUCLEAR WASTE FACILITIES

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Abstract

Successfully executed radioactive waste management projects are critical to the sustainability of the nuclear industry. While there's a tendency to think the challenges to successfully siting radioactive waste management facilities are technical, public acceptance is perhaps the biggest challenge. The social aspects of nuclear waste storage, transportation and disposal cannot be understated; hence the growing emphasis on consent-based siting. While there are examples of successful and unsuccessful siting efforts there is no single "roadmap" or "framework" to describe how to secure community consent. One such potential roadmap or framework could be Sociotechnical Systems Design, which recognizes the interaction between people and technology and considers social and technical factors that influence the functionality, practicability, acceptability, and usage of a system. A holistic analysis of any system considers five work system elements (people, technology–tools, tasks, policies-organization, and the environment) and identifies where requirements or conditions of these elements have consequences triggering changes on the others. Concurrent Engineering is a systematic approach that enables designers to consider all system elements and their interfaces throughout the life cycle by incorporating stakeholders early in the pre-design stages. The paper describes how to use a sociotechnical system that relies on a Concurrent Engineering process to achieve consent-based siting of a nuclear waste management facility. The resulting framework addresses the socioeconomic requirements of communities while facilitating communication and interaction opportunities between technical, political, and social stakeholders. This will allow communities to access information and raise concerns about nuclear waste management locally, while letting technical specialists factor these concerns into the waste management facility design, providing information where needed, and reducing the need for rework and retrofitting. Staged implementation of sociotechnical systems design supported by concurrent engineering can be key to consent-based siting and a successful nuclear waste management programme.

1. PROBLEM STATEMENT AND OVERVIEW

The challenge to addressing nuclear waste management is identifying a facility site. Within the United States this is complicated further by current law that prevents pursuing a government owned consolidated interim storage facility until a permanent repository receives a license. [1] The creation of a consolidated interim storage facility is controversial as waste would be transported twice in the process of getting to a permanent geologic repository. It could be argued that the current process of storing spent nuclear fuel onsite at the commercial nuclear power plant where it was generated eliminates the need for consolidated interim storage. [2] The other argument is "a centralised store would offer cost and efficiency benefits – especially for the Department of Energy, which has to reimburse utilities for the full cost of the temporary storage." [3] Consolidated interim storage and long term geologic repository facilities have to be safe, technically sound, and address transportation considerations. The most important factor is the host community as it needs to become an advocate of the facility: more than just willing; the community needs to be committed. Only a committed community will be able to sustain the effort of gaining approval from the Nuclear Regulatory Commission (NRC), the US Department of Energy (DOE), the community's state government, the neighbouring communities, and so on. The list of social stakeholders for a nuclear waste facility could be potentially very long.

A potential first step to solve America's nuclear waste problem is to develop a consent-based siting approach to site a nuclear waste management facility, whether it be consolidated interim storage or a geologic repository. Consent-based siting cannot stop at the host community level. It has to, at a minimum, pursue the agreement of state government, federal government, and communities potentially impacted by the transportation of the nuclear waste. Site selection for spent nuclear fuel has historically been technology-driven but has failed to secure consent among all the levels of stakeholders. The theory described here introduces a potential framework for science-led, consent-based siting.

2. SOCIOTECHNICAL SYSTEMS AND CONCURRENT ENGINEERING – BACKGROUND

Sociotechnical Systems (STS) is a theory of work systems design that recognizes the interaction and dependencies between people and technology. "The concept… is derived from the premise that any production system requires both a technology, a process of transforming raw materials into output, and a social structure linking the human operators both with the technology and to each other." [6] As such, STS theory aims to achieve joint optimization of the social and technical aspects of the system within the environment in which the system performs. "Joint optimization" suggests social and technical subsystems can be balanced to optimize the outcome of the system. [7] Sociotechnical systems recognize there is an external subsystem, the environment (including the political influences), moderating the balance between social and technical system requirements.

Sociotechnical systems are defined by boundaries and can range from job-specific work systems to fully integrated communities. Community Ergonomics asserts that people perform differently if work system designers "plan new community systems which consider the purpose, motivations, interest, and characteristics of residents." [8] Community Ergonomics aims to "improve human interactions, evolution, law, and planning for positive organization to support self-regulation and control of community resources." [8] This is relevant for consent-based siting for nuclear waste management, identifying locations and planning infrastructure to ensure compatibility with the host community goals, capabilities, and expectations while allowing communities to actively manage their role in the siting process.

The Balance Theory [9], taken from the industrial engineering field of human factors, identifies 5 system elements to any work system. These elements are the people, the technology and/or tools, the tasks, the policies and organization, and the environment. The theory was originally developed to conceptualize the loads that working conditions can exert on worker stress and was used to develop strategies for stress reduction. Since then, the theory has become a generalized tool in the human factors field, providing a way to visualize the interfaces of any work system and identify opportunities for managing system changes. A revisit of the theory [10] twenty years from its first publication highlights four emerging areas of application of the Balance Theory: (a) multilevel analysis of the work system, (b) understanding the non-work sphere, (c) impact of the work system on worker performance, and (d) application to health care and patient safety. Application to consent-based siting for nuclear waste management falls within the first two emerging areas.

Balance Theory posits that every work system is formed by five core elements and a change in any of the elements will affect the others. The five elements of the work system essentially define a sociotechnical system:

— **Tools and technologies that define the technical subsystem.** The "technology" refers to all the tools and technologies (micro and macro) needed to complete each of the tasks required by the system, including the degree of automation and reliability in the technology, the tools that an operator would need to perform the task, and the availability, complexity, performance, and maintenance through the life cycle.
— **Tasks and activities (work) generated in the technical subsystem.** The "task" element defines any activities or operations generating work through the system.
— **People that act and interact with the system.** The "people" element considers all community personas, demographics, values, personnel and staffing needs, and their intrinsic characteristics.
— **Organizations and norms that define and control the social subsystem and its interactions with the technical subsystem**. The "organization" details the policies and procedures that regulate the system, whether directly or indirectly, including organizational structure, communication pathways, and any procedures: escalation, maintenance, emergency response, etc. and
— **The complex environment within which the system operates.** The "environment", an external subsystem, describes the environmental variables within which the work system operates. These variables are normally defined for physical climatology and geographical environments, but can also

relate to the economic, social, and political environments that affect the system (i.e. the STS external subsystem).

Balance Theory advocates for the assessment of changes in any system element, which allows designers to identify the consequent changes on other elements and generate adjustments or propose solutions to balance and mitigate adverse effects. Those adjustments and solutions can be identified from any of the five system elements to support the stability of the system. Figure 1 illustrates the five elements of the Balance Theory within the STS framework.

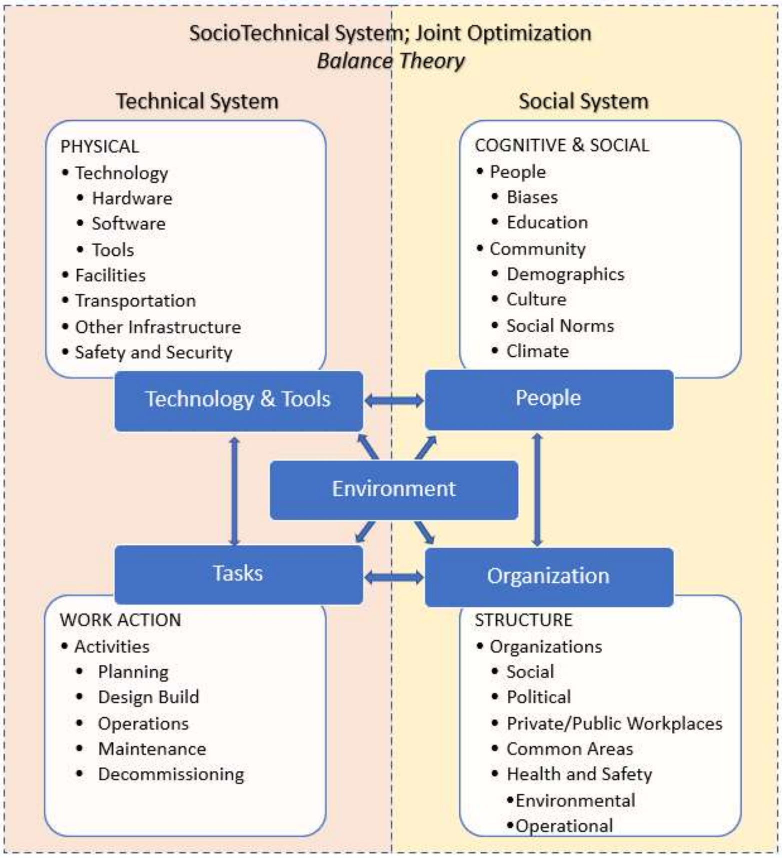

FIG. 1. STS balance theory model for conceptualizing the elements of a work system, where each element interfaces with other elements.

Concurrent Engineering (CE) is a non-linear, systematic approach to product and process design that requires the input and contribution of representatives from all system stakeholders early in the requirements gathering stages and through the design process. It is intended to cause the developers to consider all elements of the product life cycle from the outset, from conception to disposal. [11] While design changes can be applied at any time, they are easiest and less expensive to implement in the earliest stages of development. Concurrent Engineering aims to address this by including representatives from the entire product life cycle during the early stages of requirements definition. Since CE was originally envisioned for short life cycle products, it provided limited consideration for operation and continued maintenance of the final product. However, these factors, along with decommissioning of the system, have to be considered in the life cycle analysis for nuclear waste management. Figure 2 summarizes four guidelines common to CE models and provides the starting point for the application of STS and CE to support consent-based siting for nuclear waste management [12].

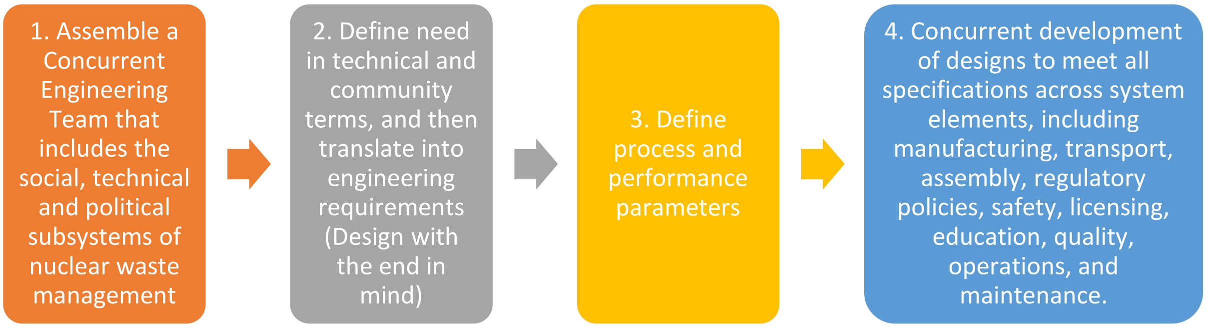

FIG. 2. Concurrent engineering guidelines applied to nuclear waste management.

3. A SOCIOTECHNICAL SYSTEMS DESIGN FRAMEWORK FOR NUCLEAR WASTE MANAGEMENT

Applying STS and CE principles to nuclear waste management provides a “roadmap” or “framework” to pursue community consent for siting of nuclear waste facilities. STS supports the design process from the technology and the community standpoint, enabling communication channels and creating opportunities to integrate community and technical needs into the decision making process on both ends. Figure 3 introduces the Concurrent Engineering and Sociotechnical System Design Framework for Nuclear Waste Management.

3.1. Problem definition stage

The problem definition stage outlines the need for a nuclear waste management facility with pre-defined technical characteristics. It should include a description of the need and minimum criteria for success, with host community, state, and federal consent and support being part of such criteria. It should also include an overview of external influences that may interface and moderate potential solutions.

The problem definition also outlines the siting alternatives and stakeholder definition for each site. The multi-functional team advocated by concurrent engineering principles calls for collaborative partners that work together towards a shared outcome. To the extent possible, the membership of that team should be identified at this stage, developing a comprehensive communication plan for the site that includes all stakeholders at different levels. A RACI (Responsible, Accountable, Consulted, Informed) chart could be used to define the roles and responsibilities of the stakeholders. [13] CE team members are representatives from stakeholder groups. Ultimately, the CE team has to have the ability to successfully address the inherent uncertainties and to represent a broad range of professional skills, including engineering, science, manufacturing, operations, emergency preparedness, industry regulations, policy, marketing, and communications. A CE team has to be identified for each host site candidate.

In general, for a nuclear waste management effort, the CE team membership has to be defined early in the problem definition based on needs and relevant factors of the various host communities. The CE team membership could include representatives from DOE, nuclear power generators, unions, policy makers, transportation, facility designers, builders, managers, manufacturers and suppliers, operations, and stakeholder representatives from the host community, among many others. The team will partner in designing a facility that meets technical needs, and a social system that addresses community concerns, to achieve consent while defining goals and priorities for successful lasting operations.

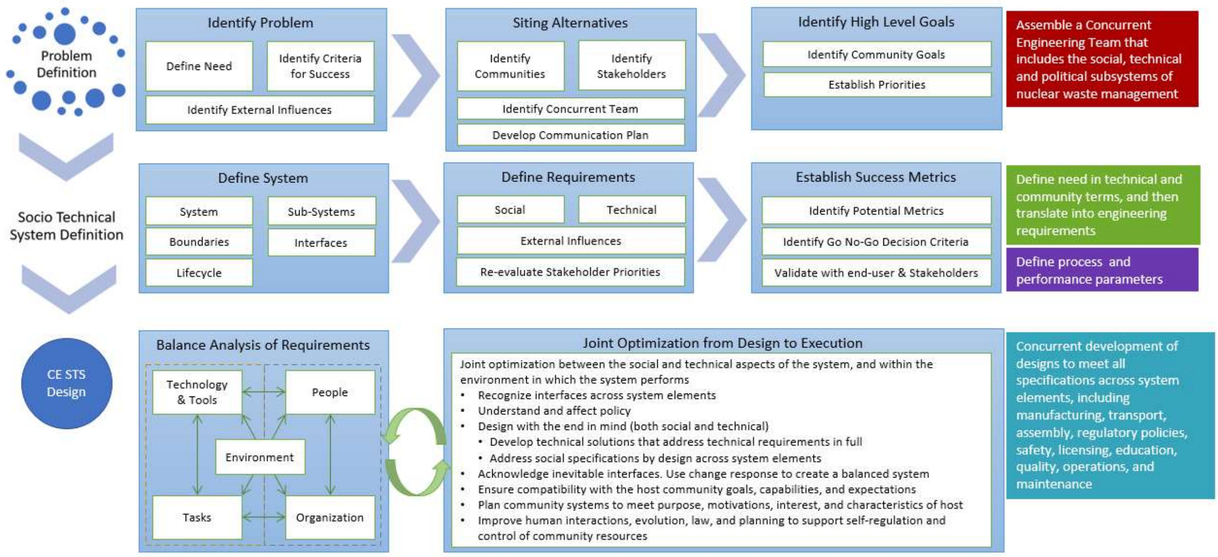

FIG. 3. Concurrent engineering and sociotechnical system framework for nuclear waste management consent-based siting.

4. SOCIOTECHNICAL SYSTEM DEFINITION STAGE

The STS definition stage defines the technical and social system and subsystems, including the boundaries and interfaces between them. This stage clearly identifies the functional and technical requirements of the system. Requirements include:

— Social – to be identified and defined by stakeholders, weighted, and discussed within the CE team;
— Technical – expected life cycle of the facility, description of the waste, logistics and operations (such as transportation, storage, and disposal) and decommissioning at the end of the facility life time;
— External influences – In a consent-based siting process, policy is a critical subsystem moderating the social and technical subsystems.

Figure 4 illustrates the key questions that guide subsystem definition for a nuclear waste management STS. Addressing these questions will define key requirements of each subsystem. This stage also requires making decisions regarding decision factors, metrics, and tools that will be used to evaluate performance parameters and facility success.

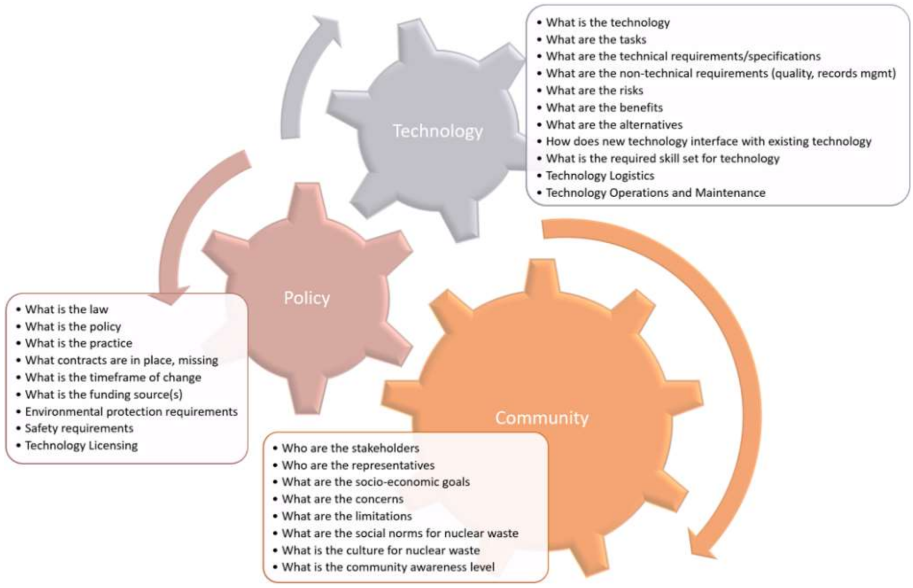

FIG. 4. Key questions to support STS system definition of a nuclear waste management facility.

4.1. Concurrent engineering and sociotechnical system design stage

The CE STS design stage is an iterative process. The social (community, people) and technical (technology, tasks) systems are examined, including their interfaces in contemplation of the environment, to generate a baseline analysis of the current state of the community and the changes the new nuclear waste management facility would bring. A technical design will evaluate social concerns that may be addressed in the design of the facility. A social analysis will ensure that the community is enabled to provide the infrastructure and support needed for successful technology operations. The interfaces between the five elements are managed to ensure congruency and balance.

Joint optimization considers the impact the holistic system, including the community, economics, environmental impact, job market and education requirements, etc. A transition impact analysis may be needed to support the transition while the facility is being built. A few principles to follow during joint optimization of a nuclear waste management facility, its community, and the environment include:

- Recognize interfaces across system elements.
- Understand policy and build in time for change (if needed).
- Design with the end in mind (both social and technical):
    - Develop technical solutions that address technical requirements in full;
    - Address social specifications by design across system elements.
- Acknowledge inevitable interfaces. Use change response to create a balanced system.
- Ensure compatibility with the host community goals, capabilities, and expectations.
- Plan community systems to meet purpose, motivations, interest, and characteristics of the host.
- Improve human interactions, evolution, law, and planning to support self-regulation and control of community resources.

5. CONCLUSIONS

The science and engineering communities have traditionally led nuclear waste storage facility siting efforts. This is likely to continue due to the obvious technical needs associated with storage of nuclear waste regardless of the nature of the facility: interim storage, permanent disposal repository, etc. However, STS recognizes that the facility cannot be sited and operated in a vacuum, and the social component needs to be addressed at the micro (i.e. facility workers), meso (i.e. host community), and macro (i.e. regional and state-level stakeholders) levels. CE provides an early opportunity to communicate and clarify expectations regarding the type of support the facility would require from the community (an educated workforce, infrastructure changes, etc.) and what the community can expect in return (new jobs to be filled by a local, educated workforce, modifications to transportation infrastructure, monetary compensation, etc.) A clear understanding of the needs and demands arising from the technical system helps build confidence within the community that it can fulfil those needs or helps the community choose to opt out with clear understanding of the facts.

Perhaps more importantly, the two-way conversation enables the technical community to understand the concerns from potential hosts and gives an opportunity to address early misconceptions regarding the efforts and deployment, removing biases, and collecting relevant and valid concerns.

The inclusion of stakeholders will identify the social system requirements early in the nuclear waste storage/disposal infrastructure design process, including siting, to ensure community concerns and goals are identified and addressed by design. This avoids retrofitting solutions into the system (which could be costly), or having social requirements negotiated out due to technical limitations that could have been addressed in design. The latter could result in lack of trust, community rejection, political barriers, or delays and denial of permits/license to operate. The CE and STS Design process, while time-consuming when engaging all the necessary stakeholders, has the benefit of inclusion and transparent communications resulting in a greater likelihood of successful siting and long term operations of a nuclear waste management facility.

6. FURTHER INFORMATION

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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STRATEGIES AND PRACTICES TO ENHANCE PUBLIC AWARENESS FOR IMPLEMENTING RADIOACTIVE WASTE MANAGEMENT PROGRAMMES IN JAPAN

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Abstract

The paper summarizes the key activities the Nuclear Waste Management Organization of Japan (NUMO), an organization authorized by the Government, is executing to implement the geological disposal of higher activity radioactive waste in Japan, keeping in mind the dynamics of democratic political process at local as well as national level in cooperation with the Government. In Japan, the Designated Radioactive Waste Final Disposal Act enacted in 2000 prescribed that high level radioactive waste from the reprocessing of spent nuclear fuel should be disposed of in a deep geological repository (DGR) by NUMO based on the fee collected for this purpose as a part of electricity bill. The Act specifies the three-stage consent-based process for the determination of one site for the DGR, in which NUMO can start each stage only when approved by the mayor of the municipality where the area to be studied is located. To maintain these policy decisions, it should be remembered that Japan's democratic political process is essentially a chain of decisions, implementations, and changes accompanying various forms of public consultation and involvement at each juncture. Therefore, in 2002, NUMO announced the open solicitation for the acceptance of the Literature Survey (LS) to all municipalities in Japan. In the first stage of the process, NUMO has been holding seminars on a nationwide scale to communicate with the public on the safety of the DGR and the importance of implementing it, while simultaneously paying respect and expressing gratitude to the participating municipalities. Since last November, NUMO began the LS process at two municipalities advising them of the importance and the safety of the project and what participation means for the area during the site investigation, facility construction, and operation periods if the area is selected as the site of the DGR.

1. INTRODUCTION

Based on the Japan Atomic Energy Commission's (JAEC) decision in 1998, the Government enacted in 2000 the Designated Radioactive Waste Final Disposal Act that prescribed high level radioactive waste (HLW) generated from the reprocessing of spent nuclear fuel SNF) should be disposed of in the deep geological repository (DGR) by the Nuclear Waste Management Organization of Japan (NUMO), an organization to be authorized by the Government, based on the fee levied on electricity bills to consumers for this purpose. Later, the intermediate level waste (ILW) generated from the reprocessing of SNF and mixed-oxide fuel fabrication, which is termed as TRU wastes in Japan, were also added to the waste to be disposed of by NUMO. Hereinafter, HLW and TRU wastes are collectively referred to as higher activity radioactive waste (HARW).

To define the policy agendas that involve technological and socioeconomic issues, problems, and solutions, the Government and the JAEC made significant efforts for obtaining public input on the definition of these issues, problems, and solutions by holding a series of public meetings and seeking public comments on the drafted definition. However, every public policy in Japan's society is under democratic political process that is essentially a chain of settings, implementations, and changes of such decision agenda, accompanying various forms of public consultation and involvement at each step. To move the policy agenda forward, therefore, the Government and NUMO should make every effort for sustaining the agenda and maintaining effective consultations with the public. The paper discusses some of the key issues NUMO is struggling to resolve in carrying out its mission of implementing the deep geological disposal (DGD) of HARW.

2. ESTABLISHMENT OF THE RADIOACTIVE WASTE MANAGEMENT FUNDING SCHEME

To properly and fairly establish the fee to be levied on electrical bills, costs for DGD of HARW include not only the business environment for technological development, site characterization and evaluation, and required project facilities construction, but also costs for measures such as repository operation, closure, and monitoring after closure. Considering economies of scale, the capacity of the DGR was set at 40 000 canisters of vitrified HLW, which was the smallest capacity beyond which the unit cost of disposal did not depend on the capacity. As for the disposal schedule, it was assumed NUMO would begin operating the DGR in 2035, closing it in 2095, and then implementing post-closure measures, such as monitoring, for 300 years. Based on these assumptions and the progress of technological studies on the DGR related to optimizing its design specifications, the most rational design specifications of DGR for a typical sedimentary rock site and a granite site were narrowed. while considering the safety margin as much as reasonable and the average of cost estimates based on these two cases, 3040 billion yen was set as the cost of DGD of 40 000 canisters of vitrified HLW in Japan.

At the start of the funding system in 2000, NUMO calculated the actual fee for disposal of one canister of HLW as 36 million yen by translating future costs into today's required levels of assets using a discount rate of 2%. This asset collected by NUMO was managed by an organization independent from NUMO and the organization was required to invest this fund only into low-risk assets such as government bonds.

The specific fee amount for HLW and TRU waste has been determined by the Ministry of Economy, Trade, and Industry (METI) for each year, taking into consideration various factors that influence the fee. Considering the long-time lag between current decision making and eventual implementation of DGD, it is a challenge to maintain the robustness of funding systems in the circumstances where several framework conditions are changing significantly, including macroeconomic conditions, the knowledge basis for geological environment relevant to DGD, technologies for DGR, the structure of electricity markets, among others. To cope with suddenly extremely low level market interest rates, for example, in 2005 METI decided the annual fee review should refer to the ten-year average of government bond interest rates. In 2020, the discount rate used to determine the disposal fee was 0.1% and the fee for HLW was 129 million yen per canister.

Furthermore, the Nuclear Reprocessing Organisation (NURO) was established in 2016 in response to increased public concern around future nuclear fuel cycle activities owing to the emerging business environment for nuclear power generation, such increased competition due to the electricity market liberalization and safety regulation reform introduced by the Nuclear Regulation Authority (NRA). The regulation reform was based on lessons learned from the accident at the Fukushima Daiichi NPP. which caused sudden reduction of nuclear power generation for refurbishment and even early retirement of several older nuclear power plants. NURO's mission is to develop a master plan of overall nuclear reprocessing projects to ensure sustainability of NUMO's business environment. NURO is also tasked with collecting reprocessing fees based on the amount of SNF produced annually by nuclear power plant operators. Reprocessing is to be carried out under the JAEC principle of do-not-have-plutonium-without-plan-to-use. NURO calculates the unit cost of reprocessing based on estimations of a reprocessing plant's lifetime expense, annually charges this fee to SNF producers, and securely manages the collected SNF reprocessing fund [1].

3. DGR SITING ACTIVITIES

3.1. Activities before the occurrence of the severe accident at the TEPCO Fukushima Daiichi NPS

The Act specifies a three-stage, consent-based process for determining a site for the DGR and each stage can be started by NUMO only after approval by the mayor of the municipality where the area to be evaluated is located. Therefore, in 2002, NUMO informed Japan municipalities of an open solicitation to accept the Literature Survey (LS), the first stage of the siting process, and has held nationwide seminars to communicate with the public on the safety of the DGD, the importance of implementing the final disposal, and to pay respect and gratitude to the municipalities participating in the process. In addition, Government established a plan to provide an area-development subsidy in appreciation to municipalities accepting the LS.

In 2007, Toyo-town in Kochi Prefecture officially submitted its acceptance of the LS to NUMO. However, a strong opposition campaign spread in the municipality (population of about 3400) and an ensuing mayoral election resulted in the defeat of the incumbent who had previously accepted the LS. As a result, the town subsequently withdrew its submission. The strong opposition against the mayor's action among residents was based on the claims of the danger posed by the waste in a DGR that seemed fragile to earthquakes, the undemocratic character of the mayor's acceptance of the LS, and antipathy to the subsidy for community development, regarding it as a disturbance to democratic deliberation.

Acknowledging the difficulty for municipalities to submit the acceptance of the LS, the METI started to explore the way to reduce the difficulty. JAEC also deliberated the issue and requested the opinion of the Science Council of Japan (SCJ) on the effective approaches of public outreach. But neither could come to concrete conclusions before the Great East Japan Earthquake and the major nuclear accident at the Fukushima Daiichi NPS triggered by it in March 2011.

After the accident that completely changed the public opinion about nuclear power, SCJ recommended the Government should pursue social consensus on the nuclear energy policy before discussing the site selection for DGD of HARW; rebuild a policy framework for radioactive waste management (RWM) centred on temporary storage of SNF and control of the total amount thereof; and explore socially acceptable procedures for RWM that should be based on fair burden sharing among people through a multi-step process of building consensus among the public by establishing arenas for discussion, recognizing the need for long term efforts to solve the problems [2]. In response, the JAEC recommended the Government (a) once again review the safety of DGD of HARW in Japan based on the latest knowledge of science, technology, and geology; (b) clearly promote step-by step efforts to realize DGD of HARW, assuring reversibility and retrievability to enable modifying a course of action based on the result of public consensus and emerging risk assessments; and (c) to initiate sharing the information and exchanging opinions with the public through regular meetings with citizens and municipalities.

3.2. Revitalization of DGR siting activities under new nuclear energy policy

In April 2014, the Government announced a new Strategic Energy Plan [3] based on extensive public consultation over several years. As for nuclear energy, the plan said (a) nuclear power should continue to be used as an important base-load power source operating based on a safety-first principle, maintaining the existing nuclear fuel cycle programme, though the nuclear dependence of energy supply should be reduced as low as practicable; (b) as it was concluded by the expert group that the DGD of HARW could be implemented safely in Japan based on the latest geoscientific knowledge accumulated after the Great Earthquake [4], the DGD of HARW and used fuel if necessary is the issue that the current generation who has benefitted from nuclear power generation should address regardless of the future programme of nuclear power generation; (c) the action to implement it should not be postponed, while ensuring the reversibility of the process and the retrievability of waste disposed of so that the future generation can select a better solution if desired; and (d) considering much of the public now have a feeling of antipathy to nuclear power, the nuclear community should sincerely communicate with the public about their resolve of never betraying the nation's right to be safe from nuclear accidents by making full use of lessons learned from the accident at Fukushima.

In May 2015, the Government revised the Basic Policy on the Final Disposal of the Specified Radioactive Waste established (Basic Policy), emphasizing the importance of (1) providing the public with information about potentially suitable areas for siting a DGR in Japan; (2) communicating with the public as well as diverse voluntary groups of peoples who want to learn more about the safety of DGD of HARW and the importance of implementing the DGD; (3) paying the public's respect and gratitude to the municipalities that volunteer to participate in the process for the siting of a DGR in order to help society solve the problem; (4) supporting the municipalities that accept the site investigation to learn about the DGD of HARW and what the acceptance of DGR means for the sustainable development of the region, by establishing the "place for dialogue" among the resident to deliberate them and providing information and financial support to do so; and (5) reviewing the progress of R&D activities promoted by NUMO and other relevant organizations regularly by the JAEC [5].

In accordance with the first point, in July 2017 the Government published the Nationwide Map of Scientific Features Relevant for Geological Disposal[1] defining all areas in Japan into four categories based on the following nationwide scientific screening assumptions:

(a) Unfavourable from the viewpoint of long term stability of the deep geological environment;
(b) Unfavourable from the viewpoint of risk of future inadvertent human intrusion;
(c) Favourable;
(d) Favourable also from the viewpoint of safe waste transportation (potentially more favorable areas among the former as the areas are within 20 km from the coast).

The objective of the publication of this map is to inform the public that a significant part of Japan is in the category of potentially favourable areas and inform municipalities across the country on their potential to host the DGR.

Since then, NUMO has held public information meetings that include small group discussion in various cities of the country, in cooperation with the Government. At the meetings, NUMO explained (a) the importance and safety of DGD of HARW, (b) the information on the geological characteristics of the area using the aforementioned map, (c) the meaning of consent-based siting approach with NUMO's expectation for municipalities to voluntarily accept the LS for the benefit of society, and (d) NUMO's plan to learn and respect the municipality's future vision and its priorities through the "place of dialogue" to be jointly set up in the region with the municipality when it accepts the survey. Regarding the environmental impact, NUMO explained the excavated rock soil from the disposal tunnels will be stored as a pile several metres high above the ground in the area and that the waste transportation cask loaded with HARW will be regularly transported by car from the nearby port to the site. Finally, NUMO promised that the organization will settle there as a local company and contribute to the sustainable development of the area if the DGR is accepted. After the explanation the participants were divided into small groups, gathered around tables for a question-and-answer dialogue with NUMO personnel for about an hour.

Over the past two years, the critical comments and opinions excluding those related to geological disposal technology (about 20%) NUMO received from about 460 tables can be summarized into following points:

— Nuclear power suppliers, NUMO, and the Government cannot be trusted as they betrayed public trust by causing the severe accident at Fukushima Daichi NPS; it is not permissible to continue to use nuclear power as they generate HARW that is difficult to dispose.
— Why geological disposal? Safe geological disposal of HARW seems impossible in Japan as active faults are located everywhere and tsunamis, earthquakes, and volcanic activity occur frequently; don't repeat to impose us "nuclear safety myth" again; it is safer to manage and store dangerous goods on the ground and wait for better technology; it is arrogant to claim the safety of DGD of HARW for hundred thousand years.
— Why does NUMO stick to realize only one disposal site? DGRs should be in each prefecture where nuclear power plants are located, or in the underground of major cities with many electricity consumers from the viewpoint of burden sharing–inequity reduction.
— Why does NUMO hold the meeting here? Why is the number of young participants and or local government officials so small? Considering such low enthusiasm on the side of local government at present, can NUMO maintain the schedule specified by the Government consistent with the time limit nuclear operators set for HLW removal stored at Rokkasho from Aomori Prefecture?

In parallel with holding this type of public information meetings, NUMO has promoted various information dissemination activities to make available to the public various pamphlets, video images, FAQs, etc. containing information on NUMO's plan for DGD of HARW and the safety strategy for this endeavour. Today, websites, SNS, and e-mail newsletters provide an important way of increasing awareness of the NUMO's activities and

[1] https://www.enecho.meti.go.jp/en/category/electricity_and_gas/nuclear/rwm/pdf/map_en.pdf

generating interest in them. The NUMO website publishes not only the contents of these pamphlets, FAQs, and videos but also the plan and programme of nationwide public meetings and their post facto reports. It also makes available all documents, including technical research reports, engagement reports, newsletters and news releases, and minutes of NUMO Advisory Council meetings.

Furthermore, as it is very important to understand the next generation, NUMO explores every opportunity to give lectures in relevant classes of universities and K-12 education systems. In addition, NUMO is dispatching an exhibition vehicle, Geo-Mirai, where people gather, such as event venues of science museums, roadside rests, shopping areas, and university campus open house events. The Geo-Mirai attracts many children and parents, as it offers 3D images of a DGR and a publicity booth with panels and models, and opportunities for children to enjoy simple scientific experiments on the water-sealing property of bentonite clay. NUMO provides funds and information through local voluntary group efforts in municipalities that want to learn about the importance and safety of DGD of HARW and its implementation plan by NUMO in cooperation with residents. Currently supporting about 100 such organizations, they organize meetings by inviting lecturers and tours to related research facilities. NUMO entertains an annual gathering of the volunteers to exchange their experiences and opinions for furthering their activities among them. Finally, the news media provides another way of increasing awareness of NUMO's activities. Therefore, in addition to responding to reporters' inquiries concerning public information meetings, NUMO meets with editorial boards of community and regional media, taking the opportunity to hold public meetings in that region. As a result, NUMO's public meetings are often reported in the local newspapers and in the local TV news.

3.3. Public outreach activities results

As mentioned earlier, the Fukushima Daiichi NPS accident has significantly changed public opinion about nuclear power. As such, since 2014, the Government has made it basic policy to reduce the dependence on nuclear energy as low as practicable, though temporarily using it as a base-load power source, as it does not emit greenhouse effect gas and contributes to strengthening energy security [3]. According to the 2020 opinion survey by the Japan Atomic Energy Relations Organization (JAERO) [6], about a half of the people support the opinion that nuclear power should be gradually abolished, though it may be used for the time being, and 10% of the people agree with the immediate abolition. Although this fraction once was 17%, it has reduced to this level in the last few years. Those who answer "I do not know what to do" has increased to 28%. Half of the respondents who chose a gradual abolition policy can't decide whether nuclear power is effective as a measure against global warming.

Although many experts blame the ambiguity of the Government's basic policy about nuclear energy: but considering the fact that only about 4% of the respondents are of the opinion that the public approves the restart of non-operating nuclear power plants once they improve their safety features against severe external hazards in accordance with new regulatory position of the NRA. while half of the respondents are the opinion that the public's understanding of it has not been obtained, the ambiguity should be understood as a result of deeply troubled choice of the Government faced with antinomy between the public opinion and the responsibility to pursue an energy policy that should satisfy the requirement of economy, security, and environmental protection.

As for RWM issues, the survey reveals 40% of the respondents who had heard about the site for DGD of HARW are undecided, though the fraction of people who have heard about the background of the DGD is approximately 20%. This situation has not changed in the last few years, but when asked if they knew about the progress of the site survey in 2020, 24% percent said yes. This is most likely attributed to widespread mass media efforts in reporting site survey progress. JAERO asked the public opinions on several issues related to the DGD of HARW. The following summarizes the inquiry results and provides some perspective on the public's risk perception of the DGD of HARW, though it should be remembered that the level of their knowledge about the issue is low, as mentioned earlier.

— It is the responsibility of our generation to dispose HARW in DGR:
  - I agree: 41.7%: I disagree: 2.8%.
  - Should proceed irrespective of nuclear energy policy: 38.3%
  - Stop generating HARW before deliberating the DGD: 7.0%
— On DGD of HARW: In favor: 19.8%: Against: 14.8%.
— Safety assurance of DGD of HARW
  - Think it's possible; 11.9%: Don't think it's possible: 24.4%.
— A major accident at DGR
  - Will not occur: 2.3%: Will occur: 52.2%.
— Will you oppose if a DGR is planned in your neighbourhood?
  - Will not oppose the plan: 5.4%: Will oppose the plan: 51.7%.
— Are you interested in the MAP?
  - Yes, I am: 21.8%: No, I am not: 6.5%

It should be added that the result of the opinion survey taken at the public information meetings mentioned before has indicated, especially in the case of those taken after the meetings, most participants favour the policy to pursue the DGD of HARW (though margins are small in most cases) and agree with the claim that the public should pay its respect and gratitude to communities volunteering to participate in the process as a service to society for the siting of a DGR.

3.4. Start of the LS

Last November, NUMO initiated the LS process at two municipalities in Hokkaido, Suttu-cho and Kamoenai-mura. As specified by the Act, the applying municipality can leave the siting process at any stage. As such, NUMO should, in parallel with studying the geological environment of applied areas based on documents, advise municipal residents of the importance and the safety of the project and what participation means for the area during the site investigation, facility construction, and operation periods if the area is selected as the site of the DGR. NUMO is opening Information Centres in each municipality and is supporting jointly with municipal office the operation of Community Dialogue Committee that is comprised of 20 or so municipal residents. The Committee in each municipality is starting to help community members learn about the DGD of HARW and the social and environmental impact of siting the DGR. NUMO will continue diverse efforts for sincerely communicating with the public in this endeavour to be recognized as a competent, caring, and faithful organization.

Whether residents can coexist with the NUMO's DGD project in the future, taking into consideration its impact on the life and the livelihood of the area, including the prospect of its impact on social and cultural norms, should be deliberated exclusively by the local community. NUMO's role at this stage should be limited to providing information for their deliberation on its policy of pursuing harmony between the life and the livelihood of the community and NUMO's business development. In other words, NUMO should strictly refrain from being involved in the deliberation, though it is important for NUMO to keep it in mind that its behaviour in providing such information affects the community's perception of relations between the community and NUMO, which NUMO believes should be based on an enduring regard for each other's interests and the willingness to solidarity on both sides.

4. CONCLUSION

To promote the DGD of HARW in Japan, the Government selected a consent-based stepwise approach to proactively select a DGR site, publishing the map to identify potentially favourable areas to promote municipalities in such areas to deliberate volunteering to accept the LS, the first stage of the siting process, for the benefit of society and establishing a scheme of providing area developing subsidy to municipalities that accept the LS.

It has become difficult to discuss the benefits of nuclear power and radioactive waste disposal when the public expresses strong concern about the possibility of major accidents at nuclear power facilities after the severe consequences caused by the Fukushima Daiichi NPS accident. Fully aware of the local and national level democratic political process dynamics, NUMO is executing various public outreach activities as a responsive organization, with the Government cooperation, to implement the DGD of HARW in Japan. At present NUMO is executing the LS in two municipalities. NUMO believes that a very humble attitude is essential to communicate understand, and carefully consider the opinions and judgements of the municipalities' residents. NUMO is determined to make every effort to be recognized as a competent, caring, and faithful organization, continuing diverse activities to communicate with the public about the safety and the importance of the DGR in parallel with promoting R&D activities essential for the DGD implementer.

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Paper ID#110

SITE SELECTION METHODOLOGY FOR THE BRAZILIAN REPOSITORY FOR LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE TROUGH GEOSPATIAL ANALYSIS

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Abstract

The implementation of a radioactive waste repository will be an important milestone for the Brazilian nuclear sector as it will enable the correct management of a large amount of radioactive waste generated in the country. The site selection process for repositories of low and intermediate level radioactive waste is guided by Comissão Nacional de Energia Nuclear – CNEN (Brazilian regulator for nuclear field) in its Standard NE 6.06. Accordingly, the site selection process is divided into four distinct stages and, for the current scenario geospatial analysis, procedures were applied in each stage, mostly by means of the ESRI ArcGIS Software: Region of Interest, Preliminary Areas, Potential Areas and, finally, Candidate Locations. For each stage of the standard, thematic criteria and numerical parameters for the inclusion or exclusion of areas were considered, covering all standardized topics. The Region of Interest was defined as the area that a truck leaving the main production site – Angra Nuclear Power Plants – can travel in six hours on a two-day journey. Preliminary Areas were defined by the application of the following criteria for inclusion and exclusion process: Environmental Protected Areas; Indigenous Reserves; Rural or Quilombola (Slave-descendant) Settlements; Urban Areas; Hydrogeological Studies; Average Annual Rainfall, Flood Records and Vulnerability to Flooding; Relief Study; Geological Faults, Lineaments and Fractures; Climatological Scenarios; and Mining Areas. The choice of Potential Areas proceeded in a very similar and complementary way to the previous step, covering the following themes: Evaluation of the Road Network; Distances to Airports with Regular Flights; Distance Ranking to Radioactive Waste Generators; Local Lithology; Vulnerability to Flooding Areas, with a better geographic base, and Swamps; Analysis of the Ownership of the Lands; Areas with Archaeological, Historical, Artistical or Cultural Heritage; Environmental Protected Areas. For Candidate Locations, a visual analysis was carried out using high resolution satellite images to exclude areas with evidence of relevant rural activities, water bodies, and native forest. Appropriately, 32 areas suitable for receiving the repository were selected.

1. INTRODUCTION

An implementation of a low and intermediate level radioactive waste (LILW) repository is a vital solution for the Brazilian nuclear sector and will provide a final and safe definition for the radioactive waste management. This repository will receive the low and intermediate level waste of the two nuclear plants already operating in Brazil, Angra 1 and 2, four research reactors, as well as the planned Angra 3, and the new Brazilian Multipurpose Reactor. Wastes from the decommissioning of relevant nuclear facilities will also be disposed of in the planned repository.

Low and intermediate level radioactive waste are short lived radioactive wastes with activities that decay to acceptable levels in 300 years or less, containing predominantly beta and gamma emitters and an insignificant amount of alpha emitters, presenting low or medium radiotoxicity and whose heat generation rates are low or insignificant [1].

According to Mourão [2], the repository will receive short lived low and intermediate level and very low specific activities wastes generated by radioactive and nuclear decommissioning facilities and site remediation. The facility is a near surface repository, similar to the Centre de l'Aube repository in France and El Cabril in Spain, with 60 years of expected operation and 300 years of institutional control. After this period, the areas can be released for the public use, following Safety Analysis requirements.

To ensure a process of site selection that meets the international safety requirements, the National Nuclear Energy Commission (CNEN), Brazilian regulator of the nuclear field, released in 1990 CNEN Standard NE 6.06 [1]. This standard establishes the minimum requirements for site selection for LILW deposition, to guarantee a safe confinement for these materials for the time needed to ensure environmental and society safety. Accordingly, the site selection process is divided into four distinct stages and geographic scales: Region of Interest, Preliminary Areas, Potential Areas and Candidate Locations. For each stage, several criteria were pre-defined by CNEN Standard NE 6.06, as shown in Table 1.

TABLE 1. STAGES, CARTOGRAPHIC SCALE AND CRITERIA FOR SITE SELECTION

Stage	Cartographic Scale	Criteria
Region of Interest	< 1:100.000	Bibliographic research; Survey of environmental protection areas and indigenous reserves; Demographic, water, physiographic, morphological, geotectonic, seismological, climatological, vegetation and mineral extraction studies.
Preliminary Areas	> 1:100.000	Geological, pedological, hydrographic, climatological and demographic studies; Assessment of access roads; Delimitation of the distance strips from the banks of rivers and water reservoirs, from the road network and around urban regions.
Potential Areas	Between 1:10.000 and 1:100.000	Planimetry detail for geology geophysical studies, geotechnical studies; Hydrological, hydrogeological and climatological studies; Socioeconomic studies; Geological survey; Ecological studies; Ownership, occupation and destination of land.
Candidate Locations	>1:10.000	Planialtimetric survey; Radiometric survey; Pedological survey; Meteorological measurements; Opening of wells; Geotechnical/Drilling surveys; Geophysical surveys; Laboratory analysis; Survey of critical radiation exposure pathways; Geochemistry; Ecological studies; Detailing of hydrological and hydrogeological studies.

As shown in Table 1, it is possible to perceive, although still from the 1990s, the proposed approach already offered a visionary principle of an integrated study of wide technical and crucial themes, many of which were not even available at the time. On the other hand, an effective application of the established methodology would entail today an almost impossible form of technical execution due to the complexity inherent to such a diverse and simultaneous assessments.

The CNEN NE 6.06 text could, therefore, be considered very modern at the time but hardly achievable today. Fortunately, technological and computational advances reached in the last two decades have enabled the development and application of multiple geospatial analysis tools. Geospatial technology can be described as an integration of photogrammetry, remote sensing, the Global Positioning System (GPS) and the Cartography and Geographical Information System (GIS). This area of knowledge has passed to an incredible revolution in recent years by the advances in computer science and engineering, leading to an improvement of the software and hardware used in Geospatial Analysis [3]. So, since the creation of CNEN NE 6.06 and the current demands on the geospatial analysis, both software technology or the variety and precision of georeferenced data and satellite images could be ensured.

Despite this auspicious scenario, another and unpredictable side effect also emerged – there is no longer sense in using georeferenced databases with increasing degrees of detail. A more detailed basis could already be used from the beginning of the processes, dispensing the redundant sequential approaches. Thus, in addition to the inherent challenge of raising the most up-to-date digital data, there was also care in applying technological modernities without compromising the legal robustness of all CNEN 6.06 procedures.

2. GEOSPATIAL ANALYSIS FOR THE BRAZILIAN REPOSITORY

For the subject of this work, the site selection team had to develop a methodology that considers all the standard topics and adversities of a Cartesian procedure for the task. It is known that the pure Cartesian approach for waste disposal sites has not been successfully worked: the Not In My Backyard (NIMBY) syndrome is something that can be foreseen for landfill projects, as mentioned by Yannis [4] and it is more than reasonable to anticipate to happen in radioactive waste disposal facilities, as well. According to IAEA [5], international experience indicates that obtaining public acceptance in the planning and siting phase is vital to the project approval. So, if the site selection process does not consider public approval instead of pure Cartesian technical studies, the chances to succeed at a repository in the chosen area are minimal. In fact, the capability of adapting the project and the site selection's methods to a location more likely to accept the repository could be the key milestone for a successful project.

An emblematic example of prioritization of public acceptance in site selection process is the Hungarian repository of Bátaapáti. The Hungarian government had tried unsuccessfully from the 1970s to 1990s to define a repository by a single technocrat top-down approach. After that, in 1993 they started a brand new and audacious process of site selection taking account on the public opinion primarily [6], and with this methodology they were able not only to solve the repository issue by finding a technically suitable site but also one completely accepted by the local population and public authorities.

If it was not possible to adapt the CNEN NE 6.06 standard to these modern concerns and policies, the proposal in the Brazilian project was to use the geospatial analysis as the screening process, followed by a hierarchization of the parameters by technical criteria. In a next stage, several locations have to be chosen and pass through a severe and transparent process of public consultation.

For this work, some adjustments in CNEN NE 6.06 procedures were proposed to enhance the site selection performance by means of geospatial analysis.

2.1. Region of Interest

For the definition of a Region of Interest, a regional level territory, according to CNEN NE 6.06 [1], the single parameter proposed is a two-day truck trip, starting at the Angra Nuclear Power Plant's Complex, driving for six hours a day at 60 km per hour, in all directions. This resulted in a linear distance of 720 km, forming a region like a curved hang glider and with an approximate extension of 466 000 km², as shown in Fig. 1.

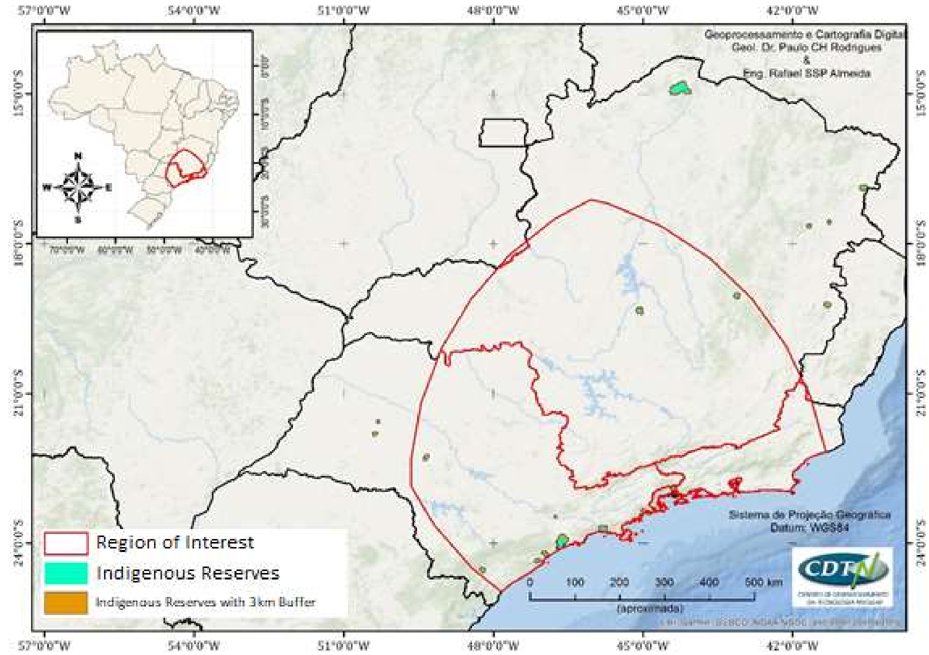

FIG. 1. Map of Brazilian southeast region with the region of interest in red (plotted together with indigenous reserves).

The parameters meant for the Region of Interest, shown in Table 1 were moved to the other topics and studied in a more detailed scale. The only exception is the Bibliographic Research because it is a very subjective matter and difficult to be converted into geospatialized data, especially when considering the area extension and the huge difference between local characteristics throughout the country.

2.2. Preliminary Areas

The Preliminary Areas is a regional level analysis as the Region of Interest itself, and obviously has to be contained inside the later. In this phase most of the Region of Interest parameters of Table 1 were moved on and analysed together, as they have the same scale. A particularly important issue to consider at this point is how the scale of the available georeferenced bases fits, or is at least similarly, in the scales requested in CNEN NE 6.06.

Table 2 shows the result of the scale analysis of the georeferenced bases available in Brazilian governmental public sources for the CNEN NE 6.06 requests in Region of Interest and Preliminary Areas. Clearly, some topics repeat in both stages, so they were considered only once. Some other topics were considered according to the following steps; usually the scale of the related georeferenced bases is too detailed to use in a regional analysis. In other situations, the topic Vegetal Extraction, for example, was driven for a future field survey because there is no suitable georeferenced database, that is, it makes more sense to do in specific and later chosen regions. Likewise, for highly specific topics like seismologic and geotectonic studies, if there was no specialist in the site selection team, for safety reasons, it was better to hire a specialist as soon as all other criteria were already applied and a small quantity of the site selected. Even for countries known for not having strong seismologic and geotectonic events, like Brazil, this is an overly complex topic, and a geospatial analysis is not enough to cover all requirements needed for the study.

Among all criteria and numerical parameters, the assessment of the aquifers, for the hydrogeological studies, represented the most complex judgment, as their geodata included more than 10 relevant spatial attributes.

TABLE 2. CRITERIA AND PARAMETERS FOR PRELIMINARY AREAS STAGE

Stage	Criteria	Parameters for exclusion
Preliminary Areas	Environmental Protected Areas	3 km buffer
	Indigenous Reserves	3 km buffer
	Rural or Quilombola Settlements	3 km buffer
	Urban Areas	Variable buffer according to city's size
	Hydrogeological Studies	Classes 1 to 4 of National Aquifers; sedimentary basins of the Hydrogeological Domains
	Average Annual Rainfall	Isohyets above 1,200 mm
	Flood Records	3 km buffer around county´s limits
	Vulnerability to Flooding	3 km buffer around county´s limits
	Geomorphological Study	Coastal plains
	Climatological Scenarios	super humid climate
	Mining Areas	specific mining demands

For each topic related to Table 2, several parameters of exclusion had to be defined by the site selection team and subjected to the regulatory agency review group. At this point, due to the excess of subjectiveness of the standard, the dialogue with the regulatory agency was necessary to achieve the best results at an acceptable term. Figure 2 shows an example of the result of the Preliminary Areas stage. The shrinkage of the Region of Interest domain due to the application of the parameters was remarkable.

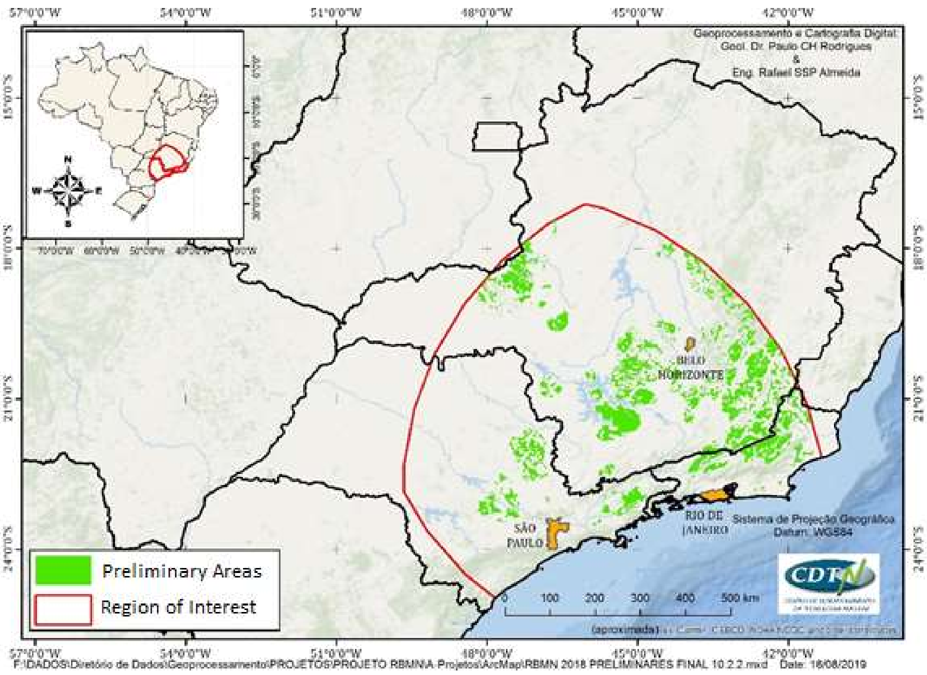

FIG. 2. Map of Preliminary Areas inside the Region of Interest.

2.3. Potential Areas

Once the methodology of previous stages had been developed, the Potential Areas level could be started in the same way as the Preliminary Areas: analyse the georeferenced databases available in the requested scale and apply on the criteria for the Potential Areas phase and the criteria remained from the previous phases.

Table 3 presents the criteria treated for the Potential Areas Stage. Some criteria like Geotechnical and Geophysical Surveys had no corresponding georeferenced data available and field work in this stage was still impossible to consider. Also, for the scale demanded by the Potential Areas Stage, Geological data would remain scalarly unbalanced and technical surveys would be economically and temporally unfeasible, due to the extension of the land proposed. These two criteria sets were then moved to the later local studies.

After sequential exclusion procedures, in the same way of Preliminary Areas Stage, there was a new noticeable reduction of the areas due to the precision and detail of the scale at this stage. The criteria for exclusion analysis were Distances to Airports with Regular Flights; Local Lithology; Vulnerability to Flooding Areas, with a better geographic base, and Swamps; Analysis of the Ownership of the Lands; Areas with Archaeological, Historical, Artistical or Cultural Interest/Heritage; and Environmental Protected Areas.

The step after this exclusion procedure was a ranking procedure with the remaining areas, considering the criteria in Table 4: Evaluation of the Road Network, Geomorphology (slope analysis), and Distance to Radioactive Waste Generators.

TABLE 3. CRITERIA AND PARAMETERS FOR POTENTIAL AREAS STAGE

Stage	Criteria	Parameters for exclusion
Potential Areas	Distances to Airports with Regular Flights	20 km buffer
	Local Lithology	Lithic soils, neo soil and rocky outcrops
	Vulnerability to Flooding	3 km buffer
	Swamps	3 km buffer
	Analysis of the Ownership of the Lands	Private areas
	Areas with Archaeological, Historical, Artistical or Cultural Interest/Heritage	Variable buffer depending on area's relevance. High relevance: 3km buffer Medium relevance: 2 km buffer Low relevance: 1 km buffer
	Environmental Protected Areas	Slope > 100% (45º)

TABLE 4. CRITERIA AND RANKING PARAMETERS FOR POTENTIAL AREAS STAGE

Stage	Criteria	Ranking Parameters
Potential Areas - Ranking	Evaluation of the Road Network	0-2 km - Very good 2-5 km – Good 5-10 km - Acceptable
	Slope Analysis	0-2 km - Very good 2-5 km – Good 5-10 km - Unsuitable
	Distance to Radioactive Waste Generators	Weighted and overlapped concentric buffers

The result of the combination of the exclusion and ranking processes is shown in Fig. 3. The extension from the Preliminary Areas toward Potential Areas decreased enormously and this step completes the limit of the analysis with high objectivity of a Cartesian approach. In the following steps, the subjective and accuracy of the analysis started to increase through a visual refinement procedure necessary for the progressive selection.

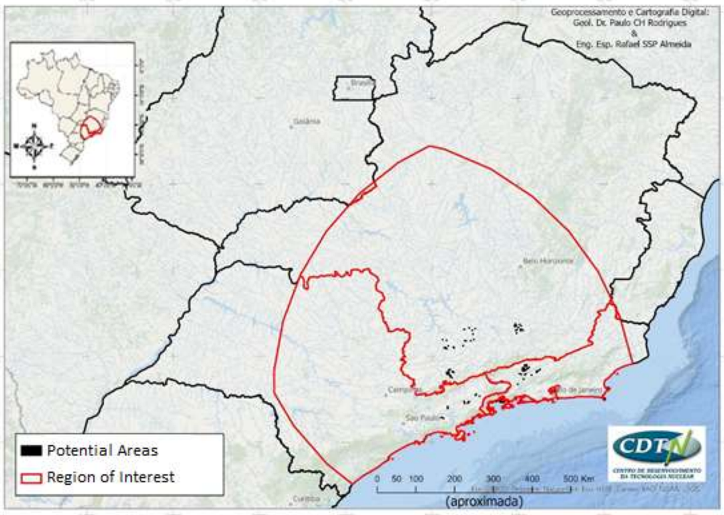

FIG. 3. Map of potential areas inside the region of interest.

2.4. Candidate Locations

To finish the geospatial analysis for the repository's site selection process, the Candidate Locations had to be selected. A limited number of places are needed that can be submitted first to government scrutiny and then to follow the public acceptance procedure.

Once again, the criteria determined in the CNEN NE 6.06 were not quite clear for the size of areas left in the previous stage so, for this analysis, the criteria considered were distance to water bodies of any size, covering the hydrographic criteria, distance of Permanent Protected Areas (areas protected by the Brazilian law, especially those areas in rivers borders), land uses (avoiding forests and agricultural areas), and minimal size of about 30 ha, which was considered to be suitable for the repository project. This analysis made use of the ArcGIS basemaps (Imagery) and of Google Earth Pro satellite images down to a visual survey, resulting a selection of 32 areas considered usable for the next step.

Block diagrams of these 32 areas were then generated using the Photoshop plugin "3D Map Generator – Terrain" to consider their geomorphological details, including the immediate surrounding areas (Fig. 4).

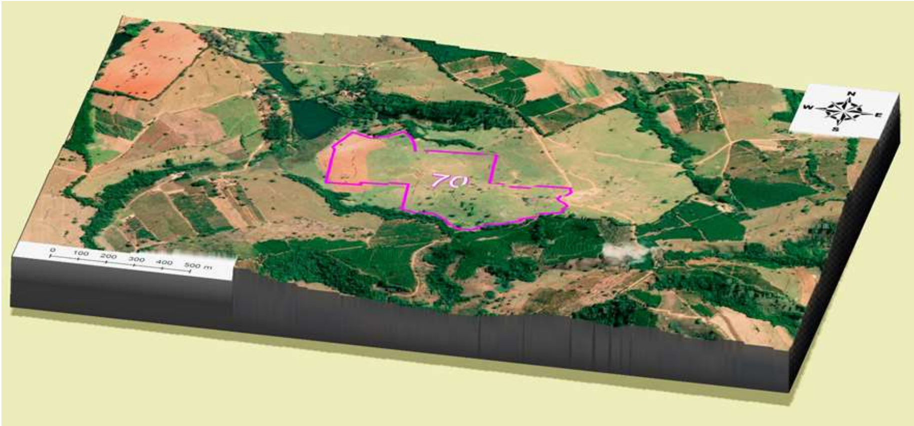

FIG. 4. Example of a block diagram used to study the candidate locations.

After all the analysis previously described, geodatabases with the 32 areas considered suitable to host the repository and their block diagrams were submitted to the project management evaluation, who made a checking process of the area's ownership and a finer visual ranking process to choose four final areas considered most suitable for the repository.

A Site Selection's Report was prepared to be sent to the Brazilian Nuclear Authority.

3. PUBLIC ACCEPTANCE FOR THE BRAZILIAN REPOSITORY

Nuclear activities can generate strong supporters but when it comes to hosting a repository of radioactive waste considerable and eloquent opponents can easily arise, as well. Even though Geospatial Analysis applies more sophisticated, precise, and convincing tools for the site selection procedures, they cannot underestimate nor substitute public acceptance, so highly sensitive dialogue with the local stakeholders has to be considered an independent and exclusive step.

In addition, the Brazilian environmental licensing can be greatly complex due to the mandatory Public Audiences, as it is an especially sensible and inevitable part of the legal path because of the potential adversities to this project by locals. Lack of an honest dialogue in the not-too-distant past concerning autocratic decisions by Brazilian authorities makes the public even more sceptical. And despite of a quite interesting flow of considerable support for the local municipality through financial compensations and likely signs of new jobs, public acceptance is considered a high risk issue. The team responsible for the site selection task and the project coordinators chose, therefore, to deal with the public acceptance as a separated and later step.

4. CONCLUSIONS

Despite the thematic complexity of the site selection task for the Brazilian medium and low activity repository and the inadequacies of the Brazilian regulations for this work when applied to the current scientific and technical conditions, the procedures based on Cartesian analysis using geospatial analysis proved to be highly robust and feasible. Very defensible and fully aligned results with Brazilian legislation were achieved. The availability of advances in computer science and of several official georeferenced databases were a great facilitator of the work. Among all the technical topics, the assessment of the hydrogeological data represented the most complex issue. And the appropriate choice of numerical parameters in association to the thematic criteria remained as the greatest methodological challenges. The use of visual analysis on a detailed scale in the last stage of the work made it possible to ensure a final selection without greater risk of the mentioned inadequacies.

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3.6. SESSION 6 – INTEGRATED WASTE MANAGEMENT

Early waste management programmes were largely based on the linear pattern of take-make-use-dispose and it is only relatively recently that the concept of sustainability and the principles of the associated circular economy have been incorporated into radioactive waste management programmes.

This new approach sees greater emphasis on reuse and recycling of materials with the recognition that even “waste” materials may have some value and that disposal should be avoided wherever possible. This is reflected in the waste hierarchy that is now widely adopted in many waste management programmes.

This new thinking on sustainability in waste management increasingly manifests itself as Integrated Waste Management (IWM). Waste management is not seen here as a straightforward process of retrieval and disposal but a series of life cycle steps: pursuing opportunities for waste minimization, re-use, and recycling, waste processing, packaging, storage, records management, and then final disposal where required. Not only does it incorporate the principles of the waste hierarchy but also encourages the operator to take a holistic view on all parts of the waste life cycle looking for opportunities to maximize the use of existing facilities and resource and extract maximum value for money.

Many Member States that have adopted the principles of Integrated Waste Management have found that this is driving a move away from interim storage and focussing attention on processing and disposal options. The broader view attained though the adoption of a holistic, unified approach, together with innovation brought about through application of the waste hierarchy, is leading to a better understanding of waste solutions.

This Session has provided an opportunity for proponents of the approach to showcase integrated waste management within their context, share learning from case studies and explain how adoption has benefited their programmes. Within the subject of integrated waste management, and as reflected in this Session, there are a broad and diverse range of topics to be covered; from describing what is integrated waste management, to setting holistic life cycle approaches, to proportionality in predisposal steps, to learning and planning as we progress through the life cycle as well as embedding experience and learning from across international communities and Member States.

Importantly, we are reminded that the key starting point for successful adoption of integrated waste management is to understand the waste; only then can we look for integrated, big-picture, holistic solutions.

Session Chairs: W. Neckel (Germany) and F. Galluccio (Italy)

Session 6 comprised eight papers from the United Kingdom, Russian Federation, Pakistan, Serbia, Canada, France, Japan, with an additional paper from one of the conference’s Young Professionals Showcase Leads (Australia).

- **Paper ID#303 by J. McKinney (United Kingdom)** presented the NDA’s Integrated Waste Management (IWM) Programme which has been established to assist in the successful delivery of the organization’s mission. The impact of IWM has been significant in various projects where waste minimization activities are constantly being explored and positive outcomes secured. The case study of the Low Level Waste Repository illustrated the benefits where significant waste diversion, away from the repository has been achieved through rigorous application of the waste hierarchy, recognising that even wastes may be a resource elsewhere in the supply chain. Key to the implementation of IWM is having a deep knowledge of the radioactive waste to be managed and the foresight to seek timely interventions that will improve the overall waste management systems.

- **Paper ID#301 by T. Rakitskaya (Russian Federation)** described radioactive waste management arrangements and how new legislation is driving change through a transparent, unified State approach, which is robust to future needs. With the creation of ROSATOM, the national waste management body, integrated waste management is increasingly being applied, so that the programme can better balance demands of the state, business and society. It has been found that IWM has become more complicated with time due to the changing role of technology (such as AI and digitalization), additional steps in the waste management process to get to disposal, as well as the intergenerational aspects of the programme. Multifunctional analysis of radioactive waste management systems and their interactions with stakeholder priorities have been used to drive transparency in predisposal preparedness and informed decision making. Whilst the views of future generations are not available today, predictive modelling and analytics across the life cycle and monitoring of changes in views and external factors such as 'green technologies' is being used to provide a dynamic balance of interests of current and future generations, ensuring challenges are addressed as they arise and not left for the future.
- **Paper ID#43 by S. Ali (Pakistan)** described the establishment of the Integrated Radioactive Waste Management Infrastructure (IRWMI) and how it is being applied within the field of radioactive waste management. IRWMI is a robust full life cycle management system bringing benefits through the development of proportional and integrated strategies which meet the current and future national programme needs. The life cycle is considered in two parts: predisposal (e.g., characterization, decontamination) and, disposal (e.g. site selection, waste emplacement) with transport as the interface between them. The radioactive waste life cycle is influenced directly and indirectly by technical and socioeconomic/political factors which need to be balanced and work mutually to deliver effective integrated waste management. Highlighted was the importance of educating and communicating with stakeholders to enhance public confidence, build trust and demonstrate credibility and transparency.
- **Paper ID#313 by Z. Drace (Serbia)** presented his analysis of the present status of integrated waste management processes and the further developments which should be incorporated to strengthen the certainty that desired outcomes can be delivered. Traditional strategy implementation is top-down, whereas an improved approach is top-down and bottom-up with continuous dialogue between all involved parties, it is iterative and involves all stakeholders. Furthermore, the outcome should be an implementable plan which leads to the concept of Integrated Planning. Integrated planning is key but first the problem has to be understood, i.e. what is the waste inventory? Accurate knowledge is essential to implement national policy and strategy, secure funding and then maximize opportunities for waste minimization, recycle, and reuse.
- **Paper ID#311 by F. Dermarkar (Canada)** presented the approach to integrated waste management that has been successfully employed across multiple sites, for multiple wastes and multiple waste missions. Looking at waste in an integrated holistic fashion and moving from waste storage to a disposal solution has facilitated waste management optimization, consolidation of facilities and increased certainty in inventory forecasting to determine future requirements. To deliver the integrated waste strategy and move projects forward, extensive engagement with stakeholders and Indigenous groups on waste management practices has been essential to build trust. This takes time and needs to be done in the right manner. Collaboration with stakeholders, other research institutes and industry partners is also essential to leverage capabilities and expertise.
- **Paper ID#178 by V. Wasselin (France)** described the French National Radioactive Materials and Waste Management Plan (PNGMDR) which sets out the management of all radioactive waste over a period of 5 years, identifying needs and setting improvement objectives to ensure the development of an enduring, long term, proportionate, waste-centred and life cycle approach. For each category of waste, a disposal route and design is identified.

This approach works well generally but there are some long-lived low level wastes, that do not fit the pattern. Such ‘in-between wastes’, unsuitable for surface disposal but not needing geological disposal are described in more detail as is the approach proposed to determine the management principles that will guide the future disposal concept.

- **Paper ID#193 by H. Asano (Japan)** presented an overview of a research study undertaken to examine the environmental impacts of geological disposal of HLW from operation of an advanced nuclear system. The study also investigated the sensitivity of the impacts to varying parameters such as burn-up and colling time. Future work will further explore how burn-up and implementation of minor actinide separation, changes the disposal impacts.
- **Paper ID#150 by H. Fei (Australia)** presented an update on siting studies undertaken in support of a proposed near surface disposal facility for low level waste. Site suitability assessment considered a range of technical criteria, generic concept designs, radiological safety, security, and environmental protection. The site is on farming land in a semi-arid environment with extreme temperatures and low rainfall. Site characteristics, such as flooding and groundwater depths/composition, have been modelled. Further site characterization will provide new data for modelling radiation dose to receptors in support of a future licensing application.

Paper ID#303

WHAT IS INTEGRATED WASTE MANAGEMENT AND WHY SHOULD WE USE IT? A VIEW FROM THE UNITED KINGDOM'S NUCLEAR DECOMMISSIONING AUTHORITY

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Abstract

Effective, optimized waste management is essential for the delivery of the Nuclear Decommissioning Authority (NDA) mission where radioactive waste needs to be appropriately managed until the point of disposal. The overarching NDA integrated waste management (IWM) Strategic Objective is "to ensure that wastes are managed in a manner that protects people and the environment, now and in the future, and in ways that comply with government policies and provide value for money."

For more than a decade the NDA has evolved its IWM strategic concept that advocates a holistic risk informed approach to radioactive waste management across the waste spectrum guided by seven Key Principles. The IWM strategic concept supports a process of close consideration of the radiological, physical, and chemical properties of the waste, the facility it currently resides in, the lifetime management and how waste management directly supports decommissioning or operations. This risk informed approach embraces a more effective application of the Waste Hierarchy, which underlines the importance of avoiding waste generation, minimization, re-use, recycling, and other environmentally sustainable options, as well as more optimal use of all waste infrastructure.

In 2019, the NDA published its Radioactive Waste Strategy that committed to the creation of an Integrated Waste Management Programme (IWMP). The IWMP has now been established and is actively exploring new management and technical solutions that will help to drive forward decommissioning in the UK, building on existing good practices. The vision is to develop a 'world-leading waste management programme' that delivers safe, sustainable, timely, and cost effective management of all radioactive waste in the UK. The paper will set out in more detail the aims and objectives of the NDA IWM Strategy, outline the programme for its implementation, and illustrate the benefits with case studies that explore a variety of waste types and their life cycle management.

1. INTRODUCTION

The NDA mission – to deliver safe, sustainable solutions to the challenge of nuclear cleanup and waste management – requires effective radioactive waste management arrangements to enable its delivery and to achieve the end state for its sites. The NDA is also committed to reducing environmental impacts, safely shortening timescales for nuclear decommissioning and site remediation programmes and delivering value for money to the UK taxpayer.

In the UK, radioactive wastes are classified in terms of the nature and quantity of radioactivity they contain and their heat generating capacity. While it is recognized that the classification system is predominantly risk based (ensuring the more concentrated and toxic radioactive waste is segregated so it can be disposed with increased protection from multiple barriers and long pathways to receptors), waste management practices in the industry have generally managed radioactive waste according to its discrete classification (low level waste (LLW), intermediate level waste (ILW)), irrespective of the relative risk posed by the waste. The management of these radioactive waste involves a series of key stages from initial preparation and planning, treatment, and packaging of generated wastes, storage as required, to ultimate disposal (see Fig. 1), which are subject to robust regulations over timescales that can cover many decades of operations.

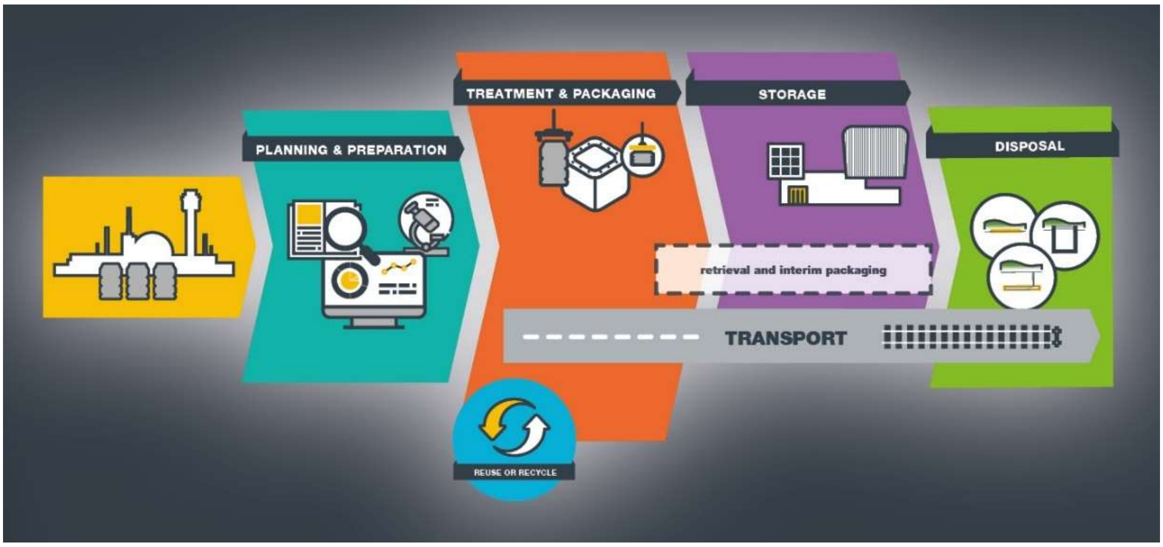

FIG. 1. The NDA's radioactive waste management life cycle.

In reality, UK ILW and LLW cover a very broad range of material types and levels of radioactivity, so the hazard they present lies along a continuum. Some ILW is less hazardous than LLW toward the LLW classification limit because it may contain radionuclides with less radiotoxicity, whereas, at the other end of the ILW spectrum, the ILW contains very high levels of radiotoxicity, similar to that of high level waste (HLW).

Decommissioning of the current UK civil nuclear infrastructure and the UK nuclear new build programme will lead to increasing volumes of wastes that need to be managed in a manner that is safe, environmentally sound, and cost effective. It has been recognized that the classification focused, binary nature of the current UK radioactive waste management approach means the radioactive waste management aspects of the decommissioning programmes are not as effective as they need to be and an integrated risk informed radioactive waste management model could provide an opportunity to support more effective delivery of the NDA mission.

2. BACKGROUND

Historical radioactive waste management practice in the UK was to package all radioactive waste in preparation for disposal to either the LLW Repository or a future geological disposal facility. In 2007, the UK Government published the UK policy for the long term management of solid LLW [1] and, in 2010, the nuclear industry LLW strategy was published [2], describing the strategic approach for implementing the policy, advocating that a more flexible, risk informed approach to managing LLW should be adopted, including the application of the Waste Hierarchy (see Fig. 2) to LLW. Since the publication of the policy and strategy the UK nuclear industry has delivered a significant change in LLW management culture and behaviours, with over 95% of LLW diverted from disposal to the LLW Repository to treatment and alternate disposal routes (including suitably permitted landfill sites for lower activity LLW).

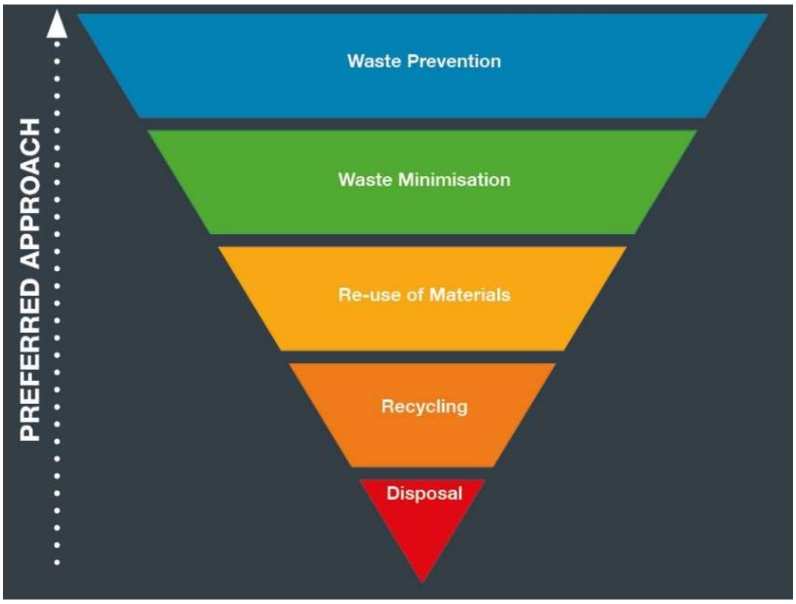

FIG. 2: The waste hierarchy.

The change in culture and behaviours within LLW management, and the benefits they have delivered, has led waste producers to begin to think differently about the ILW generated on their sites, recognizing there may be opportunities to manage some of the less hazardous ILW differently (adopting a risk informed approach). This has resulted in some wastes, identified as ILW in their inventories, through additional characterization or treatment being recategorized, allowing the waste to be managed as LLW. It has also led Sellafield to package some ILW from their decommissioning programme for unconditioned waste storage, enabling the decoupling of decommissioning activities from waste management treatment capabilities and routes helping to progress NDA's mission of site decommissioning and remediation.

Whilst there is clearly an appetite within the industry for exploring more effective approaches to the management of radioactive waste, much of the change embedded to date is within the LLW management area. Work in the ILW arena has focused on the immediate need to manage the ILW inventory in high hazard facilities and to develop bespoke solutions, although NDA has successfully investigated opportunities for sharing infrastructure such as storage capability and investments in technology development that should benefit the NDA waste producers. The opportunity going forward, as decommissioning ILW is generated in greater volumes, is to identify opportunities at a national programme, rather than local project, level for treatment and disposal of radioactive waste across the radiological classifications.

3. WHAT IS IWM AND WHY USE IT? THE NDA'S INTEGRATED WASTE MANAGEMENT STRATEGY

In support of the UK government's 2004 Energy Act, the NDA publishes its Strategy at least every five years. The NDA Strategy includes five strategic themes: Site Decommissioning and Remediation, Spent Fuel, Nuclear Materials, Integrated Waste Management and Critical Enablers. The term Integrated Waste Management was first used by NDA in 2009 in response to its first Strategy published in April 2006. For more than a decade the NDA has evolved its IWM strategic concept that first built on the success of the implementation of the 2007 UK Policy on Solid LLW management and the subsequent UK Nuclear Industry LLW Strategy. The NDA's Radioactive Waste Strategy was published in 2019, [3] a standalone document providing much of the underpinning for the current IWM Theme presented in NDA's latest Strategy, published in March 2021 [4].

In the UK, radioactive waste management is integrated within a wider decommissioning mission, where it is recognized a series of interventions can be pursued to minimize volumes, to change the ultimate waste destination or significantly reduce costs – waste management is not a standalone entity and is essential for a range of business needs. Effective waste management is key to delivering safe and timely decommissioning. In summary, IWM in the NDA group:

— Embraces a risk informed holistic approach where the properties of the waste (radiological, chemical, physical), the condition of the facility it resides in, and onward management are considered to help inform decision making;
— Reduces overall volumes of radioactive and non-radioactive wastes destined for disposal;
— Enables decommissioning and any continued nuclear operations;
— Makes best use of existing and future planned infrastructure throughout the waste management life cycle;
— Builds and maintains stakeholder confidence.

This IWM risk informed approach grasps the need to safely and securely manage high hazard waste while enabling more effective application of the Waste Hierarchy, as well as more optimal use of all waste infrastructure. These elements are the main reasons for using such a concept; and effective implementation will help to secure a sustainable future for radioactive waste management.

The UK's Radioactive Waste Inventory, most recently described through the publication in 2019 [5], details the volume and composition of Radioactive Waste and Materials currently existing ('in stock') and forecast to rise in future. Figure 3 illustrates the mass and composition of the inventory.

FIG. 3. High level components of the UK's radioactive waste inventory.

As there is such a broad range of radioactive wastes to be managed over extensive intergenerational timescales, IWM needs to be flexible and, at times, agile to support nearer term operational or decommissioning objectives. A flexible approach to waste management enables waste producers to consider a range of interventions, from better characterization to effective pre-treatment, such as decontamination, and successful volume reduction techniques across the waste life cycle (as shown in Fig. 1). Furthermore, the approach for high inventory wastes residing in an ageing facility will be very different from managing lightly contaminated building materials, where there could be real opportunities to reuse or recycle these types of wastes.

Throughout NDA's existence it has closely considered the best use of existing and future infrastructure and the ability to share treatment and storage capability whilst preserving precious disposal capability, by encouraging wider use of the supply chain (see case studies for further information). More specifically storage consolidation has been highlighted as an important part of the NDA IWM strategy which may result in a reduction in site footprint, hazard and security level reductions, optimal use of infrastructure and early site clearance [6].

The IWM strategic concept recognizes the radioactive continuum from the lowest threshold at the LLW and out of scope waste boundary, up to the LLW/ILW boundary and beyond. Effective boundary management is a key consideration whereupon the radiological, chemical, and physical properties are taken into close consideration whilst recognizing the importance of the life cycle journey from waste creation to final disposal.

To support IWM Strategy implementation, the NDA has developed seven key guiding principles [3] that provide an overarching framework. These are given as follows:

— Support key risk and hazard reduction initiatives by enabling a flexible approach to long term waste management. For some wastes it may be necessary to adopt a multistage process to achieve a final disposal product, which could include the separate management of bulk retrievals and residual material to support hazard reduction programmes.
— Consider the entire waste management life cycle, including how waste management is needed to support other NDA strategic or wider UK initiatives such as large scale decommissioning programmes.
— Apply the waste hierarchy (see Fig. 2), which is a permit requirement and should be used as a framework for waste management decision making. This enables an effective balance of priorities including value for money, affordability, technical maturity and the protection of health, safety, security, and the environment.
— Promote timely characterisation and segregation of waste, which delivers effective waste management.
— Provide leadership giving greater integration across the estate and the supply chain in particular by seeking appropriate opportunities to share treatment and interim storage assets, capabilities, and learning.
— Support and promote the use of robust decision making processes to identify the most advantageous options for waste management.
— Enable the availability of sustainable, robust infrastructure for continued operations, hazard reduction, and decommissioning.

4. IMPLEMENTING IWM

4.1. The NDA's Integrated Waste Management Programme

In 2019, NDA published its Radioactive Waste Strategy that committed to the creation of an Integrated Waste Management Programme (IWMP). The IWMP has now been established, guided by the high level IWM strategic principles, and is actively exploring new management and technical solutions that will help to drive forward decommissioning in the UK [7].

The Integrated Waste Management Programme vision is [7]:

"A world leading waste management organisation which delivers safe, rapid and cost effective management of all nuclear waste in the UK, enabling waste producers to optimise their arrangements and retire liabilities earlier, maintaining the highest safety and environmental standards."

The IWM Programme has the following clear objectives which are core to delivering the NDA's mission:

— Enabling the industry to manage its radioactive waste in an integrated way, according to the hazard posed by the waste;
— Ensuring the appropriate infrastructure and arrangements are in place when required;
— Avoiding unnecessary utilization of resources on packaging, conditioning, and storage where more appropriate alternative treatment, storage and disposal options could be made available;
— Supporting the acceleration of decommissioning programmes, earlier risk and hazard reduction;
— Exploring, researching, and exploiting all potential opportunities for additional efficiencies and improvements to waste management;

— Engendering and embedding a change in culture so waste producers think and act more flexibly about how they manage their waste;
— Enabling faster implementation of waste solutions;
— Facilitating a positive impact on UK Supply Chain providing global export opportunities.

4.2. Case studies

4.2.1. Case study 1 – building a waste services capability

The 2007 LLW Policy recognized that the UK was nearing a cliff edge in relation to LLW disposal capacity: the Low Level Waste Repository (LLWR) had only around one quarter of the total capacity needed for all of the LLW forecast to arise in the UK. The Policy recognized the opportunity to adopt a risk informed, flexible approach to the management of LLW, including the opportunity to use alternative waste routes (including the ability for some lower activity LLW to be disposed to permitted landfill sites); and required the application of the Waste Hierarchy to LLW.

The 2010 Nuclear Industry LLW Strategy, published by the NDA on behalf of Government, advocated a transformation in the culture and practice for LLW management through application of the Waste Hierarchy, making best use of existing waste management assets and the use of new flexible waste management routes. It included a series of ‘we will’ statements setting out how the Strategy would be implemented within the nuclear industry.

LLW Repository Ltd (LLWR Ltd) was responsible for leading the implementation of the 2010 LLW Strategy on behalf of the NDA and Government. There were two aspects to how this was delivered:

— The National Waste Programme (NWP) was set up, with the mission of achieving a sustainable culture for effective LLW management across the UK.
— The Waste Management Services (WMS) function was created to develop and manage a series of commercial frameworks to enable waste producers to access a range of treatment and alternate disposal routes in the supply chain, through a single contract with LLWR Ltd.

The WMS initially provided a narrow range of services, focussing on disposal to the LLWR (including packaging, compaction, and disposal) but, from 2010, grew the range of service offerings to the current scope. This now includes not only the original services, but also transport, characterization, metallic treatment, incineration, very low level waste (VLLW) disposal, and customer support and technical services (see Fig. 4). The benefits of this centralized service offering include:

— Commercial and technical independence;
— Management of the whole supply chain network, ensuring market risks and capacity issues are dealt with constructively and sustainably;
— Reducing set up costs and the overall cost of providing treatment services for customers by providing a standardized, supported approach to accessing the services;
— Opportunity for accelerated learning and knowledge gained by the central team delivering waste projects across the UK, allowing effective sharing of learning and knowledge with sites where there were similar problems;
— By acting as a central service provider, aggregating demand for treatment services to obtain best value from the supply chain by providing a consistent supply of material.

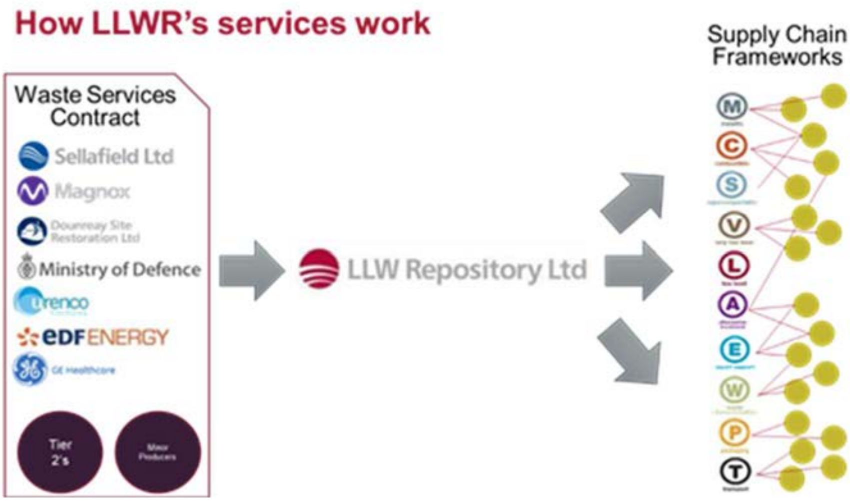

FIG. 4. LLWR Ltd waste services model (curtesy LLWR Ltd.).

Since 2010, over 140 000 m^3 has been diverted from disposal to the LLWR, including over 32 000 m^3 metallic waste sent for recycling and over 27 000 m^3 LLW sent for incineration (Fig. 5).

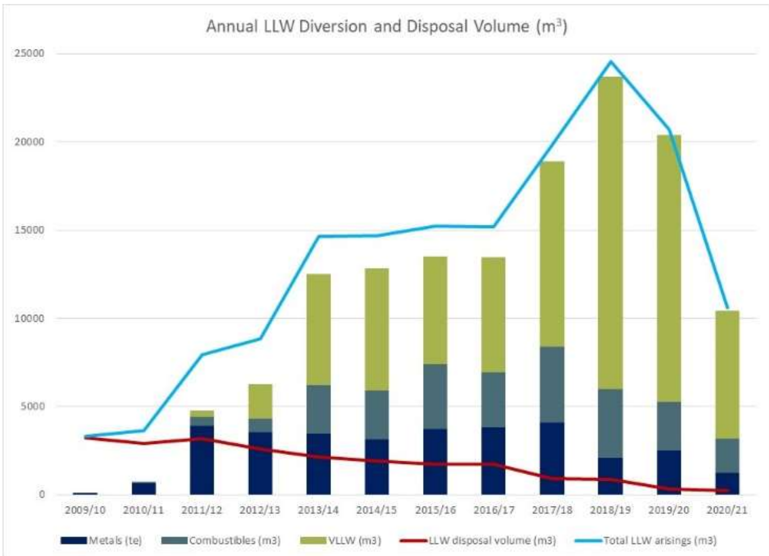

FIG. 5. LLW diversion and disposal volumes.

The successful change in the management of LLW in the UK has been achieved through the combined efforts of the NWP and WMS – the first driving the change in culture through its programme; and the second providing the services to allow waste producers to open routes to divert LLW from disposal to the LLWR, as required by the Strategy.

Also central to the success of the NWP and WMS in implementing the Strategy has been the visible line from policy through to implementation – the 'golden thread,' enabling LLWR Ltd and the industry to follow the direction of travel set out in the policy and strategy through the series of 'we will' statements set out in the strategy. It also meant that, when there was challenge to any of the implementation activities, the alignment to national policy and strategy could be demonstrated, providing a powerful incentive.

4.2.2. Case study 2 – enabling the management of boundary wastes

As the integrated approach to managing radioactive waste is moving to become business as usual within nuclear sites, waste producers have started exploring the opportunities for managing some of their ILW streams differently from the baseline assumptions for those wastes. This has included consideration of opportunities to reclassify the wastes from ILW to LLW, potentially enabling earlier management and final disposal.

There are several reasons why it may be possible to reclassify the wastes, including:

— They were incorrectly classified in the first place;
— They have undergone a period of decay;
— Using enhanced characterization / assay;
— Because the waste has been conditioned in some way, including segregation activities, pre-treatment or conditioning.

Once the opportunity has been identified, there are several challenges to enable the waste to be successfully reclassified to enable their management as LLW for disposal, including:

— Having sufficient information about the waste – its radiological, physical, and chemical properties;
— The available radiological and non-radiological capacity of the LLWR;
— The physical properties of waste and whether it meets the acceptance criteria for the LLWR;
— The proposed container and whether it is an acceptable package for disposal to the LLWR.

LLWR Ltd has developed a projectized approach that is used when working collaboratively with waste producers to progress these opportunities. Figure 6 shows simplified version of the model.

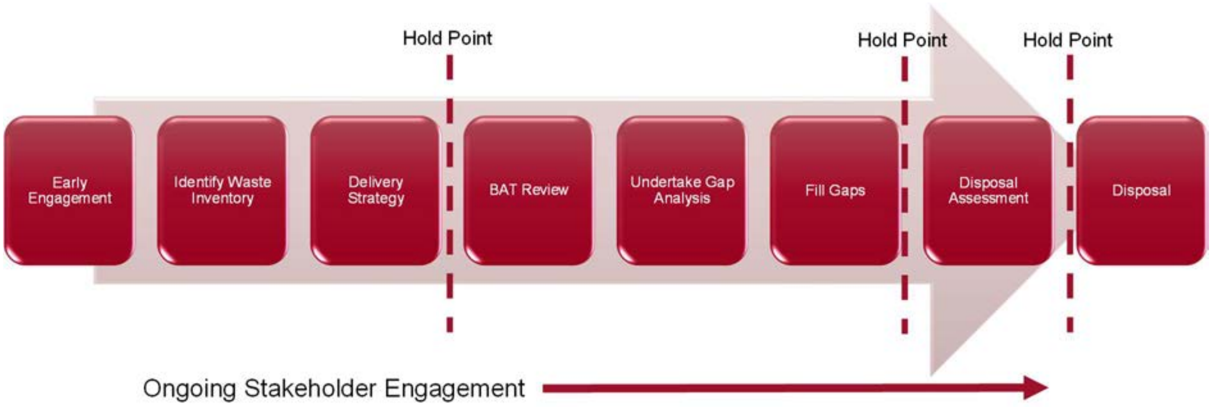

FIG. 6. Waste Management Services Projectized Approach to Boundary Waste Management

There has been significant learning from the application of the model that has been used to improve it:

— Early engagement between LLWR Ltd and the customer allows early exploration of the opportunity, the timescales, the need, the life cycle benefits from the project and the identification of key stakeholders.
— Inventory analysis allows high level screening to take place against the capacity of the LLWR to identify any initial issues, as well as identifying any key areas for consideration such as the use of a different type of package or any infrastructure requirements.
— The agreement of a delivery strategy with identified hold point allows the project team to increase certainty and reduce risk as they move through the process. This prevents abortive work, builds stakeholder buy-in and ensures the relevant permissions are obtained.
— The gap analysis ensures that information gaps occurring at any point in the waste management life cycle (including in waste information, packaging, infrastructure at the LLWR, etc.) are identified so they can be closed off in a timely manager. It also informs the scope of work needed to close the gaps, be it through

a desktop study, through further characterization and assay by the waste producer, or through an exploration of the infrastructure needed.

— The hold point prior to the disposal assessment ensures all relevant information is available and informs the complexity of assessment required, again reducing the likelihood of nugatory work. Because the output from the assessment goes through an internal governance process at LLWR Ltd, it can be escalated to the Environment Agency if receipt of the waste is seen as a change to the site's environmental safety case, ensuring regulatory confidence in the project.

The approach continues to be used and adapted to each new opportunity waste project, building expertise, and learning within the industry and allowing the sharing of good practice.

4.2.3. *Other case studies*

Further examples of IWM in action are presented in Appendix 2 of the NDA's Radioactive Waste Strategy and cover (i) ILW packaging, interim storage, and Fuel Element Debris at the Magnox sites and (ii) managing waste from Sellafield Legacy Ponds and Silos [7].

5. SUMMARY POSITION

The NDA has developed a risk informed IWM strategic concept to support its overarching site decommissioning and remediation mission. By embracing a holistic IWM approach, the NDA is seeking programme optimization throughout the waste management life cycle, which is guided by seven high level principles. It is recognized the destination of radioactive waste can be changed through effective interventions where precious disposal capacity can be preserved, as well as making best use of existing and future capability. The impact of IWM in the UK has been significant where waste minimization activities are constantly being explored and positive outcomes secured. Key to the implementation of IWM is having a deep knowledge of the radioactive waste to be managed and the foresight to seek timely interventions that will improve the overall waste management system.

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INTEGRATED WASTE MANAGEMENT IN THE RUSSIAN FEDERATION

From Waste Minimization/ through Cost Optimization/ to Poly-Systematization

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Abstract

In 2011, the Russian Federation adopted Federal Act No. 190-FZ "On the radioactive waste management…," which significantly changed the concept of radioactive waste management in the country. The paper provides a description of the Unified State System of radioactive waste management (USS RWM) in the Russian Federation, organized in accordance with the new Federal Act; the 10-year history of its formation; created management tools; new challenges and the working version of sustainable development that meets these challenges. The experience of the Russian Federation is distinguished by the complexity of the national waste management system in a country with a long history of the nuclear industry, accumulated problems and at the same time the implementation of a large scale programme for the construction of new facilities and the development of nuclear technologies.

1. INTRODUCTION

Evolution of human activity in general and in any specific field could be divided into three phases:

— Extensive development – when "conquering" nature is sooner or later checked by exhaustion of natural resources;
— Intensive development – based on attempts to rationalize utilization of limited natural energy sources and materials;
— Harmonious development – combines the cycles of social and technological advancement (human culture proper) with the cycles of nature.

This approach may conditionally be also applied to the Russian nuclear industry.

The first phase was driven by a very demanding objective directly linked to the survival of the nation - building nuclear weapons. Very short schedules, extremely difficult post-war circumstances, shortage of technical knowledge dictated that the objective has to be achieved at whatever cost. Issues associated with safety assurance of the public and the environment were relegated to secondary priorities and postponed until later dates. This is exactly what gave rise to problems such as discharges of radioactive waste, and appearance of trench-like repositories of the simplest designs possible.

The second phase involved the understanding of the enormous potential hazard posed by nuclear energy. As a consequence, many requirements and recommendations were introduced to regulate radiation safety, which are being continually improved ever since. New technical solutions are built into the designs of new industrial sites aiming to enhance safety of the technological processes, radwaste treatment technologies are being developed, waste processing complexes are being built, along with major facilities to ensure safety of long term waste storage.

And finally, the third phase has come along with the understanding that safety, including safety of radioactive waste management (RWM), is one of the key pre-requisites to further development of the competitive nuclear industry in global terms.

The task of creating a modern integrated waste management programme is problematic today, as:

- The notification of "integrated waste management" has become significantly more complicated over the past 20 years. There have been especially many changes in recent years, which is associated with the digital transformation of activities and the increasing role of artificial intelligence.
- We have started to manage installations and technologies, the life cycle of which significantly exceeds one generation of specialists. We need to learn how to create such technologies and installations that will be safe and effective in the long term and will be sustainable in the intergenerational perspective.

The paper highlights the Russian experience of consistent complication of approaches and tools in the field of radioactive waste management as a joint search for answers in problematic situations.

2. HISTORY

Federal Law No. 190-FZ has significantly changed the concept of waste management in the Russian Federation. As this law was adopted much later than other developed nuclear countries, it took into account the experience and best practices of legal regulation in the field of radioactive waste disposal. This fact allowed us to avoid many problems and implement the new concept quite quickly.

Federal Act No. 190-FZ has introduced some major changes to the concept of radwaste management activity (see Fig. 1):

- Imposed the requirement of obligatory radwaste disposal and financial responsibility of the organization whose operations led to the generation of that waste for all stages of RWM, including disposal;
- The radwaste disposal activity is a natural monopoly, so all radwaste has to be handed over for disposal to a national operator;
- Preparations for disposal and transport to the disposal location may be performed by specialized organizations;
- Radwaste currently stored on various sites has to be divided into two groups (waste generated before the effective date of the Act is defined as federally owned, and waste generated after that date utility owned);
- The State Atomic Energy Corporation (ROSATOM) is identified as the government administration authority responsible for management of radwaste.

Figure 1 illustrates innovations introduced by Federal Act No. 190-FZ. All new components are shown in red in the figure.

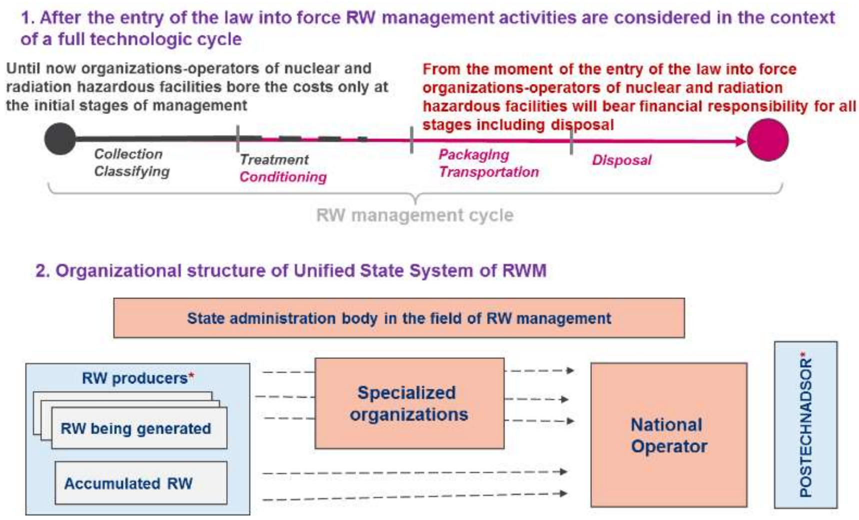

FIG. 1. Innovations introduced by Federal Act No. 190-FZ.

The Government of the Russian Federation has established the terms for the formation of the Unified State System of Radioactive Waste Management (USS RWM):

- In determining the funding mechanisms and the order of the transfer of radioactive waste to the national operator for disposal by the end of 2012;
- In terms of creating the institutional foundations of regulatory framework, conduct an initial registration of the accumulated radioactive waste by 2015;
- In terms of readiness for the disposal of low and intermediate level radioactive waste by 2020;
- In terms of readiness for the disposal of high-level radioactive waste by 2025;
- For legacy disposed waste and special waste, the procedure and terms are determined individually based on the initial registration of accumulated RW and their locations.

First, the task of ensuring safe and efficient waste management was solved.

Article 10 of Federal Act No.190-FZ identified six functioning principles of the USS RWM which are grouped in Table 1.

TABLE 1. FUNCTIONAL PRINCIPLES OF THE USS RWM

	Cost efficiency	Safety
RWM technologies	5. Principle: “Taking into account the interdependency between radwaste generation and radwaste management.”	6. Principle: “Ban on radwaste import into/export out of the country.”
RWM services	3. Principle: “Financial coverage of radwaste management activities at the expense of utility organization that generated the waste”	4. Principle: “Provision of members of the public and non-governmental organizations with access to information regarding safety assurance and accident prevention during radwaste management, as well as other information.”
RWM facilities and complexes	1. Principle: “Responsibility of Polluter for safety assurance during radwaste management.”	2. Principle: “Priority of human health and life protection, of both the current and future generations, and of the environment against the harmful effects of waste.”

Each of the six functional principles was supplemented with a management principle and a list of indicators was developed for these twelve principles, which allows multi-factor monitoring the RWM situation in the industry.

At the next stage of the USS RWM development, a second control circuit was formed (the multi-focus control circuit), which provided interaction with stakeholders considering the difference in their interests (Fig. 2).

After 2015, the stakeholder’s engagement in RWM bases on data of annually assessment of financial obligations in RWM, SNF management and Decommissioning, and on Public Reporting Process.

The ROSATOM has a broad circle of stakeholders in Russia and abroad due to the wide range and specific character of its activities (simultaneously solving state level and business related tasks). Selection of main stakeholders and goal-oriented interaction with them are determined, first, by the strategic objectives of the Corporation and by social responsibility.

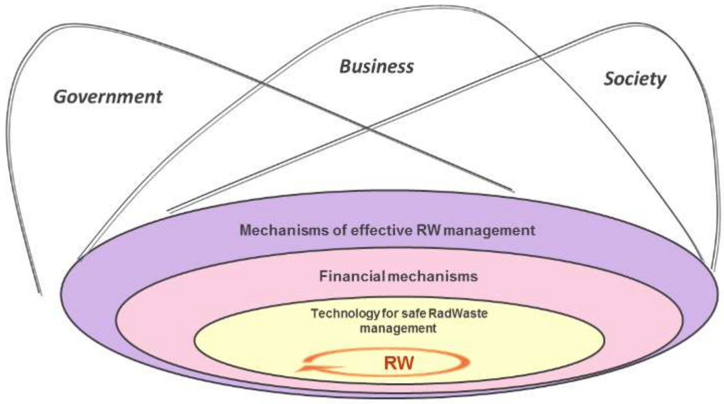

FIG. 2. Two management circuits (circuit of nested subsystems and circuit of autonomous subsystems).

The basic principles laying the ground for that interaction are:

— Respect and consideration for the legal interests of all participants;
— Open and productive cooperation;
— Informing the stakeholders of the corporation's activity in a timely and detailed manner;
— Aiming at concrete benefit for all participants;
— Fulfilling the norms of the international and Russian legislation and commitments assumed.

Public reporting process are based on Russian and international reporting requirements and standards.

3. NEW CHALLENGES

Today, the national Nuclear Energy Program (NEP) integrates life cycles of different nature and duration. The NEP would be sustainable (effectively coordinating and synchronizingла these cycles) if it would become a ‘two-way street” with counter-streams of values, knowledge, finances, and radioactive materials, including radioactive waste. At the same time, RWM is the core for a new assembly, since waste disposal is the longest technological cycle. As a result, it becomes possible to switch to Knowledge-Based Governance throughout the entire life cycle of the NEP.

Knowing how to build a new management system based on the principles of good governance ensures reliability and increases the level of safety of NEP. The use of digital models and artificial intelligence allows to more accurately consider the risks that future generations may inherit and find a balance of interests in the long term. As a result, new dimensions of sustainability are emerging, when we can consider the relationships between different systems within integrated digital ecosystems. Applied poly-systemic ontologies are needed to provide access to decision making for all interested parties, including future generations.

Working version of sustainability in the intergenerational perspective bases on the following:

— A focus on the dynamic balance of interests of current and future generations during NEP implementation. The scale of NEP is determined by the capabilities of existing infrastructures, namely: RWM infrastructure as having the longest life cycles of its facilities.
— Awareness of the interests and responsibilities of current generations in the field of RWM by multi-factor monitoring the RWM situation and multi-focus decision making in RWM.
— The interests of future generations are not available today, but predictive analytics can be developed.
— To ensure effective monitoring of the balance of interests of current and future generations (during NEP elaboration and implementation), it is necessary to develop applied (polysystem) ontologies, which will allow us not only to take into account different interests, including alternative energy sources, and make our analytics truly “predictive” but also successfully develop the nuclear and radiation technologies on the basis of integrated assistance.

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DEVELOPMENT OF NATIONAL INTEGRATED RADIOACTIVE WASTE MANAGEMENT INFRASTRUCTURE IN PAKISTAN

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Abstract

The Pakistan Atomic Energy Commission (PAEC) is a sole nuclear facilities operator in the country. The Pakistan Nuclear Regulatory Authority (PNRA) is an independent body to regulate all the nuclear facilities. Nuclear technology use is generating radioactive waste in various amounts and forms, from different facilities and activities. The major portion of this waste comes from nuclear power plants (NPPs) having total installed capacity of ~2400 MWe. To meet the energy demand, PAEC is planning to increase the existing installed capacity of nuclear power. Moreover, increase in use of other applications of nuclear technology is foreseen. This will increase generation of radioactive waste. This arises the importance to establish a well-integrated radioactive waste management infrastructure (IRWMI) to minimize the waste at source, maximize recycling–reusing of materials, adopt the modern technologies, and strong cooperation with other stakeholders. An effort to develop an IRWMI in Pakistan enhances the efficiency and sustainability of the national nuclear programme in a systematic manner. Devising this integration requires systemic analysis of all applicable necessities directly or indirectly involved in the development of infrastructure for radioactive waste management. The paper discusses various key factors, including policies and legal framework, safety case, international cooperation, and financial management influencing the core of an IRWMI, a radioactive waste management life cycle. It is a robust system to handle the unforeseen events and future developments efficiently and effectively regarding adding new nuclear facilities and activities, such as decommissioning. The implementation of an IRWMI has benefitted the national nuclear programme by standardizing the entire country's waste management practices while reducing the costs and efforts and build and maintain public confidence on safe solutions for managing all types of radioactive waste.

1. INTRODUCTION

Nuclear energy production is growing in Pakistan. Currently, there are five operating nuclear power plants (NPPs) with an installed capacity of ~2400 MWe. One NPP of 1100 MWe is in construction phase and will start operation in April 2022. One NPP has been permanently shut down this year. Moreover, under the national nuclear energy vision, it is planned to increase the installed nuclear capacity in near future. In addition, the use of nuclear technology is also increasing for medicine, agriculture, industry, and research. Eventually, these facilities will go through decommissioning activities too. Resultantly, generation of the radioactive waste will increase manifolds.

In Pakistan, management systems and practices for radioactive wastes were generally not developed as fully as the power generation systems and capabilities. With increasing quantity of radioactive waste likely to be generated and accumulated in the country, it is imperative that facilities and activities generating such waste have capacities and infrastructure to appropriately manage it. Thus, a need exists for developing an Integrated Radioactive Waste Management Infrastructure (IRWMI) to manage radioactive waste in an effective, efficient, systematic, and sustainable manner. The IRWMI will standardize practices and responses in normal and exceptional situations, to support the national nuclear programme. Specifically, the goal of the IRWMI would be to streamline waste management practices associated with handling, processing, transporting, storing, and disposing radioactive waste. The absence of an IRWMI was a major concern for workers safety, public health, environmental protection, and efficient utilization of resources.

In Pakistan, the IRWMI is a robust system capable of managing all types of radioactive waste, meeting present and future requirements to ensure the national nuclear energy programme continues to run safely and sustainably. The IRWMI complies with good international practices, national laws, and regulatory requirements and is broadly divided into two management efforts: (i) predisposal management and (ii) disposal management.

Predisposal management includes activities related to generation, segregation, pretreatment, treatment, conditioning, packaging, and storage. Transportation provides the interface for relocating waste packages from generator and storage facilities to disposal facilities. Disposal management focuses on suitable site selection and its characterization, development and operation of the facility, and its closure and post-closure activities. All these parts are well integrated and mutually dependent on each other such that the practices followed in one part are made in-line with the requirements of the other part.

The paper presents an overview of Pakistan's IRWMI as a systematic integration of all steps involved in the management of radioactive waste from its generation to final disposal. It describes the efforts to integrate the (i) policies and legal framework, (ii) strategies and planning, (iii) waste minimization and maximizing the reuse of materials (iv) development of facilities, (v) operation of facilities and activities, (vi) safety case, (vii) adopting the proven modern technologies, (viii) handling unforeseen events, (ix) research activities, (x) international cooperation and capacity building, (xi) financial management, and (xii) stakeholder's involvement. Implementation of the IRWMI is gradually proving beneficial in achieving set goals and helpful in further improving the trust of stakeholders through safe and secure operations of the facilities and activities.

2. RADIOACTIVE WASTE MANAGEMENET LIFE CYCLE

Managing radioactive waste in Pakistan through effective, economical, and long lasting solutions is central to the IRWMI. The management of all types of radioactive waste involves several steps from its generation to final disposal. These steps are part of radioactive waste management cycle and are shown in Fig. 1. From the management point of view, such steps are broadly divided in two main parts, predisposal and disposal. Transportation of radioactive waste is considered as an interface between predisposal and disposal, such that depending on the situation or case, it may be considered as part of predisposal management or disposal management. In Pakistan, transportation of radioactive waste is the responsibility of disposal. It is worth mentioning that steps involved in the predisposal management and disposal management are integrated and interdependent on each other. The management steps taken for predisposal guide the selection, development, and operation of the disposal facility. On the other hand, the requirements established by the disposal facility operator set limitations on the required predisposal management steps for waste to become appropriate for acceptance at the disposal facility.

The predisposal management of radioactive waste starts from its generation from any facility or an activity. Depending on the waste type, physical, and chemical characteristics, it is passed through different steps to become suitable for final disposal, if it is available, or for long term storage pending the development of the required disposal facility. Attention is given to integrating safety, health, environment, security, quality, and economic requirements while performing predisposal management activities. However, safety of the workers and public is the key factor in deriving a suitable route for a particular stream of radioactive waste. In Pakistan, radioactive waste is generated or is projected to be generated because of operation of nuclear facilities including, NPPs, medical centres, agriculture centres, research facilities, and decommissioning activities. The generated waste is classified as very short lived, very low level, low level, intermediate level, and high level [1]. The following sections briefly explain the main steps being practiced in Pakistan involving predisposal management, transportation, and disposal management.

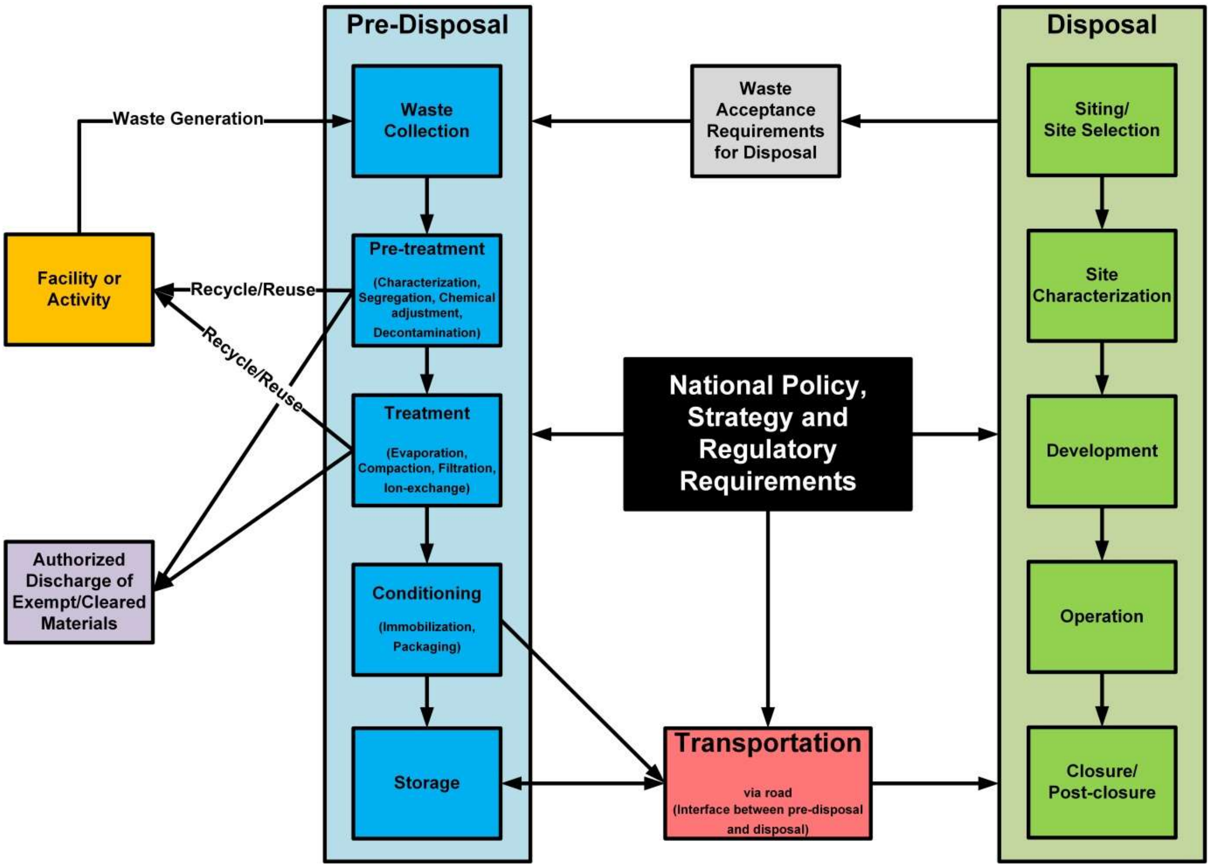

FIG. 1. Radioactive waste life cycle being practiced in Pakistan including pre-disposal, transportation, and disposal management.

2.1. Predisposal management

Predisposal management is the main part of the radioactive waste management life cycle, including management steps from radioactive waste generation to storage by ensuring an adequate level of protection and safety. Basically, this part is undertaken to prepare the radioactive waste for storage, transportation, and disposal. The following key steps are carried out for safe predisposal management of radioactive waste:

— Waste collection: This includes the removal of waste from temporary storage facilities, storage tanks, or direct generation from facility operation, decontamination, or decommissioning activities. After removal of the waste, it is sent for pretreatment, treatment, conditioning, and onsite regional storage.
— Pretreatment: It includes any or all practices such as waste characterization, segregation, size reduction, and chemical adjustment of radioactive waste. During segregation, waste is separated based on its chemical, physical, or radiological properties to facilitate waste handling and processing. Size reduction is performed to meet packaging requirements. Decontamination is performed to reduce the radioactive contamination to either reclassify the waste or to reduce the dose received during later operations. Careful considerations are given to the type of pretreatment, given the subsequent management steps.
— Treatment: It comprises physical, thermal, and chemical processes such as evaporation, compaction, filtration, and ion exchange. Resultantly, the waste characteristics are changed to support further management of the radioactive waste. Depending on the waste physical–chemical form, evaporation, compaction, filtration, and ion exchange processes are performed to concentrate the radioactivity for reducing the waste volume as far as practically achievable. It is also made sure that the treated waste is in a suitable physical and chemical form such that it can be conditioned or discharged appropriately.
— Conditioning: During this step, first the dispersible or liquid waste is immobilized, if needed. Afterward, the waste is packaged (i.e. loaded in a container) so the resulting product can be safely handled, transported, stored, and disposed of. Waste packages produced by conditioning have to satisfy the waste

acceptance criteria for storage and disposal. Moreover, it is ensured the waste and its container are compatible.

— Storage: Containing radioactive waste in a facility with the intention of its retrieval on availability of a disposal facility. There are two types of storage facilities in Pakistan, on-site storage, and regional storage facilities. For example, waste produced by the four operational NPP units at CNPGS is stored at its on-site storage facility. Whereas at PINSTECH and KANUPP there are regional storage facilities for disused sealed radioactive sources (DSRS). During storage, it is made sure that waste can be inspected, monitored, and retrieved for clearance, processing and disposal, or both. Moreover, adequacy of the storage capacity is periodically reviewed, while being mindful of the current and projected waste arising from normal operation and from unforeseen accidents, the expected lifetime of the storage facility, and of the availability of disposal facility.

2.2. Transportation

Transportation is considered as an interface between the predisposal and disposal management of radioactive waste. It consists of procedures and operations associated with the movement of radioactive waste packages. This includes the preparation, loading, shipment, and receipt of the waste package at a disposal facility. On-site transfer of conditioned waste from conditioning facilities to storage facilities is carried out by waste generators. However, off-site transportation of conditioned waste to regional storage facilities or the disposal facility is managed by both the predisposal management and disposal management. The transportation to disposal facilities is responsibility of disposal management, while transportation to regional storage facilities is managed under predisposal management. During the transportation, due consideration is given to safety and security and PNRA regulations regarding the waste transportation [2].

2.3. Disposal management

Disposal is the final step in radioactive waste management life cycle (Fig. 1). It involves placement of the waste in an appropriate facility with no intention of retrieval. Following necessary steps are carried out for safe disposal of radioactive waste:

— Siting–Site Selection: The disposal facility site is carefully chosen based on site exclusion criteria and site selection criteria. In this regard, investigations are made through siting process by considering geological formations, site location, hydrological features, ecological features, local demography, etc. Moreover, it is made sure that the selected site has enough space available to accumulate the current and projected radioactive waste inventory.

— Site Characterization: Site characterization is carried out to increase the knowledge about a site and its future evolution, including understanding its geology, hydrology, geochemistry, seismicity, meteorology, socioeconomic–political aspects, etc. This in combination with the waste characteristics and proposed disposal system engineering design presents a detailed scientific and technical description of the disposal system.

— Development: Development includes design and construction activities. The basic principle that dictates the design of the facility is that waste is contained and isolated from biosphere for the time it remains hazardous, without undue risk to human health and environment. For this, several safety assessments are performed which update the design accordingly. Once the design is finalized, construction is performed as per the design plans and approved safety case. Additionally, its construction is managed in accordance with the appropriate management system.

— Operation: Operation of the disposal facility is the process of emplacing the waste packages in the facility. Safety functions of natural and engineered barriers are preserved during operation which includes receipt of waste, waste emplacement, extension of repository (if required), backfilling (if required), surveillance, and environmental monitoring.

— Closure–Post Closure: Once the disposal facility is full and cannot accept more waste to be disposed of, the facility is closed with appropriate measures. During closure, activities such as sealing of the underground openings of the disposal facility, decommissioning of surface facilities, etc. is carried out and initial natural conditions of the disposal site are restored as far as practicable. After these activities are performed, the facility enters the post-closure phase, where monitoring, surveillance and, if necessary, corrective actions are taken to maintain the end state of disposal facility.

During the life cycle of radioactive waste, the safety of workers and the public and protection of environment is ensured by fulfilling the policy and regulatory conditions set forth by an independent regulatory body [3]. In addition, the regulatory body performs independent checks on waste management facilities operators by periodic evaluation and review of the procedures and documents in context of the licensing.

3. INTEGRATED RADIOACTIVE WASTE MANAGEMENT INFRASTRUCTURE

The IRWMI combines the radioactive waste management life cycle (collection, pretreatment, treatment, conditioning, transportation, and disposal) with the key factors influencing radioactive waste management. These factors include: (i) policies and legal framework; (ii) strategies and planning; (iii) minimizing waste and maximizing reuse; (iv) development of facilities; (v) operation of facilities and activities; (vi) safety case; (vii) handling unforeseen events; (viii) research activities; (ix) adopting the proven modern technologies; (x) capacity building and international cooperation; (xi) financial management; and (xii) stakeholder's involvement. Figure 2 shows how different factors for the radioactive waste management are integrated with each other, as well as with the radioactive waste management life cycle. The factors shown around the waste management life cycle in Fig. 1 are not independent of each other and are mutually integrated to enable objectives for effective, efficient, systematic, and sustainable management of radioactive waste to be achieved. These factors, discussed here, should be considered as early as possible to make comprehensive, integrated, and well-structured radioactive waste management programme.

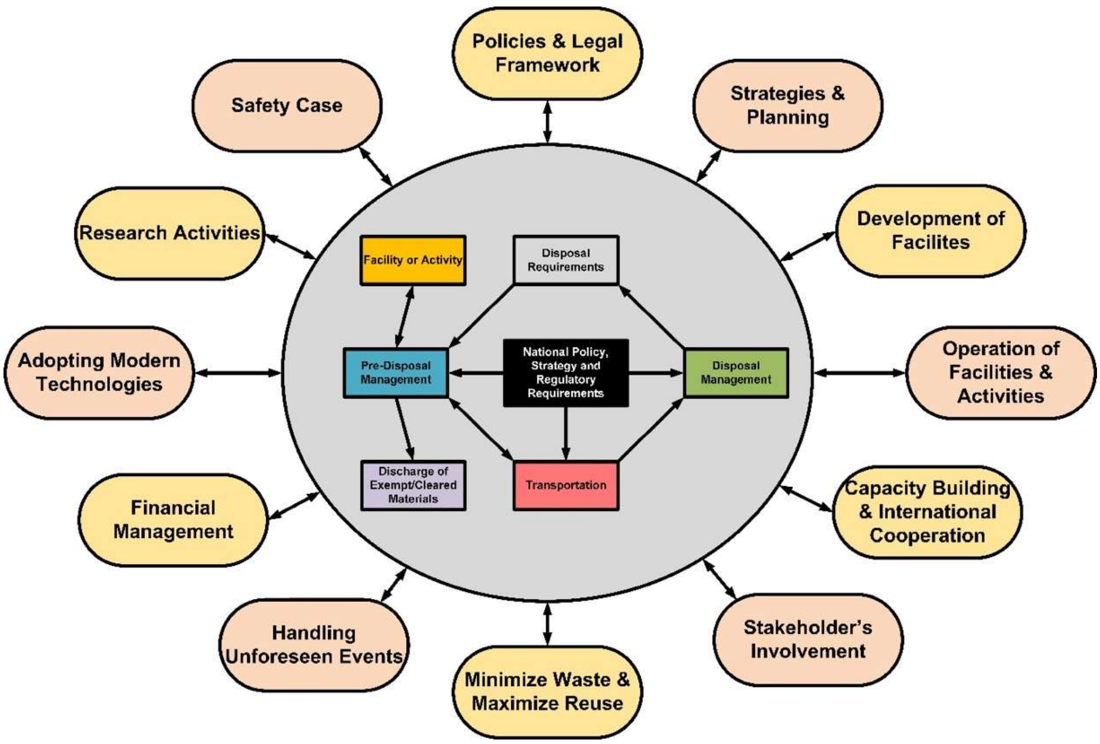

FIG. 2. Integrated radioactive waste management infrastructure (IRWMI) in Pakistan.

3.1. Policies and legal framework

The Pakistan Nuclear Regulatory Authority (PNRA) was established in 2001 by the Government of Pakistan's ordinance as an independent regulatory authority [3]. The Ordinance empowers PNRA for licensing of radioactive waste management facilities; developing and implementing regulations, guidelines, standards, and procedures; safety reviews; regulatory inspections; and enforcing PNRA regulations and licence conditions. Under this ordinance, PNRA had issued the National Policy on Control and Safe Management of Radioactive Waste in 2011 [4]. However, on recommendations and suggestions made by Integrated Regulatory Review Service (IRRS) of IAEA, the policy was revised and updated in 2018 as the National Policy on Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel in Islamic Republic of Pakistan [5]. This policy sets the course and principles for management of radioactive waste in the country. It highlights the commitment of government for safe management of radioactive waste such as to maximize the safety of human health and protection of environment from the risks associated with radioactive waste. Moreover, it also highlights the importance of socioeconomic factors such that the burden to safely manage radioactive waste is reduced for future societies. It supports the development of technical and legal infrastructure and designates the responsibilities. In addition to policy, PNRA has issued several regulations for safe management of radioactive waste [1] [6] [2].

3.2. Strategies and planning

Under the old national policy, a Strategy for Safe Management of Radioactive Waste in Pakistan was issued in 2011 [7]. However, with the revision of national policy in 2018, an updated National Strategy for Safe Management of Radioactive Waste including Disused Sealed Radioactive Sources is being formulated [8]. The strategy addresses the approach and planning for safe management of radioactive waste in Pakistan. This helps to realize the goals laid down in the national policy by benefitting from locally available technological options and resources and internationally recognized principles and approaches. As a result, ongoing radioactive waste management practices are optimized and standardized. Further, the strategy is flexible to accommodate all avenues for future development.

3.3. Minimizing waste and maximizing reuse

As per the national regulations [1] and national strategy [7] [8], the generation of radioactive waste is controlled, both in terms of radioactivity and volume. As such, measures are taken to prevent or minimize the waste generation as far as practicable. Moreover, measures to reuse the waste materials are also taken. For these various technologies, such as decontamination, evaporation, compaction, incineration, etc. are utilized. This not only helps to reduce the waste volume, but also sometimes reclassifies the waste to lower category or make it exempted from regulatory control, hence reducing the management efforts and related financial burden.

3.4. Development of facilities

During the design and construction phase of nuclear facilities, due consideration is given to possible minimum generation of radioactive waste [1]. The Preliminary Safety Analysis Report – submitted for acquisition of construction license and the Final Safety Analysis Report – submitted for permission to introduce nuclear material in the installation – both include chapters on radioactive waste management [6]. Moreover, the radioactive waste management programme (RWMP) is also submitted for permission to introduce nuclear material in the installation [6]. Design and procedures are ensured to accommodate the measures such that the radioactive waste is managed in a suitable manner and related hazards are minimized. Proper options and management routes are included in design of the facility to safely manage radioactive waste generation from normal or extraordinary situations.

3.5. Operation of facilities and activities

Procedures are made to manage the various types of radioactive waste During operation of the nuclear facilities or any activity, such as decommissioning. The facility or activity operator manages the radioactive waste according to the PNRA-approved RWMP [1]. Operation of the facility is performed in a manner to preserve the safety functions that are important for safety of the workers, general population, and protection of the environment. A systematic approach is used to optimize the activities and operation of the facilities while bearing in mind the risks and hazards associated with the radioactive waste. Moreover, the RWMP is also submitted for licensing of decommissioning [6].

3.6. Safety case

The safety case and supporting safety analysis and safety assessment and other documents are prepared for developing and operating a facility or activity [6]. This demonstrates the level of safety and protection provided by the waste management facility and gives confidence to all the stakeholders that the safety culture will be maintained throughout the facility life cycle. The facility licensee has to carry out periodic safety reviews and perform evaluations [6]. Several regulations issued by the PNRA are followed [1] [2] [9].

The safety case is sufficiently comprehensive and describes how siting, design, operation, shutdown, closure, decommissioning of the facility, and managerial controls will be performed. It includes the output of the safety assessment, supporting evidence and arguments on the robustness and reliability of the facility, its design, basis of the design, and the management system. Risks to workers, public, and the environment are assessed systematically to ensure the facility will fulfil all its safety functions to maintain the safety culture.

3.7. Handling unforeseen event

In Pakistan, the predisposal and disposal management facilities for radioactive waste establish and maintain plans to tackle with any unforeseen event, such as an incident or accident that could significantly impact the generation of waste and its quantities. At every step in radioactive waste management life cycle, adequate capabilities and resources, such as the availability of plans, infrastructure, responsibilities, coordination, staffing, equipment, training, and drills, among others are available to cope effectively with any emergency.

3.8. Research activities

Research plays an important role for management of radioactive waste. Finding the new and cost effective solutions to solve the radioactive waste processing, transportation and disposal issues is vital to the safe and sustainable management of radioactive waste. In this regard, all radioactive waste management facilities of Pakistan improve their understanding and knowledge based on in-house research activities or collaborative research activities with sister organizations and national universities. Examples of research works include wet-oxidation treatment of resins, vitrification of liquid intermediate level waste, plasma treatment of solid low level waste, among others. Moreover, laboratories are established and courses are taught at post-graduate level at the Pakistan Institute of Nuclear Science and Technology (PIEAS) – a public research university – to train students in the radioactive waste management field.

3.9. Adopting modern technologies

The safe management of radioactive waste is a colossal problem. To solve such a problem with an optimized strategy, it is inevitable to adopt proven modern technologies being used in other parts of the world. In this regard, Pakistan is adopting technologies that include advanced processes for waste treatment and conditioning, such as incineration and super-compaction, etc. Moreover, Pakistan is also considering developing underground research facilities to facilitate the disposal of high level waste for its national radioactive waste management strategy [8] with help from the IAEA and other international forums like the CANDU Owners Group (COG).

3.10. Capacity building and international cooperation

To cater the need of growing national nuclear infrastructure and for sustainable management of radioactive waste, facilities build and enhance their employee capacities through human resource development, education, and training; knowledge management; and by participating in relevant knowledge networks. In this respect, cooperation with international agencies and other interested relevant countries plays an important role. The role of the IAEA is especially important, as it provides an arena in which one learns from the experiences and ideas from other sister organizations. Examples of cooperation with the IAEA include several technical cooperation projects, participation in different professional networks activities, technical meetings, regional training courses, expert missions, workshops, fellowships, scientific visits, and equipment acquisition, among others.

3.11. Financial management

All radioactive waste management activities are financed from a central fund called the Radioactive Waste Management Fund (RWMF) [5], which is maintained by the PAEC. NPPs – through the sale of electricity – are major contributors to this fund. Other facilities like hospitals, research institutions, and industries contribute to this fund from their annual budgets. However, the Government of Pakistan is responsible to bear the expenditures in case funds are not available from the facility or an activity, and to manage ownerless radioactive waste [5].

3.12. Stakeholder's involvement

Engaging the public and other stakeholders in decision making processes enhances the public confidence and ensures public scrutiny of managing organizations and regulators. This is true even if they have an indirect or passive role in the decision making process [10]. Stakeholders are involved on the principles of accountability, credibility, transparency, and building trust by adopting various modes of educating the public, such as seminars, public hearings, and use of print, digital and social media. This supports in minimizing the economic, social, and political impacts arising from the management of radioactive waste.

4. BENEFITS OF IRWMI

As a result of the IRWMI, Pakistan is achieving robust radioactive waste management capabilities by incorporating safety objectives, environmental benefits, societal acceptability, and economic optimization. The following example of a radioactive waste super-compaction facility development is presented as an IRWMI case study. The first super-compactor facility of the country will be developed for compacting low level solid radioactive waste. The compactor with 2000 tonnes of force has volume reduction factor of 4 to 5 times, such that it can compact four 200 L drums into a single 400 L drum. The decision to develop this facility has taken in to account all important factors discussed in the previous section. The facility is being developed under the national policy and strategy to minimize the waste volume [5] [8]. This modern technology is being developed and is planned to be operated by giving due consideration to safety. Development finances are assured and stakeholders like regulators are fully involved. It also involves international cooperation; for example, the super-compactor is installed through the support of the People's Republic of China. The process parameters will be optimized using some research work. As shown from this example, all factors play a major role in facility development and the absence of one can significantly affect facility design, operation, and performance objectives. The installation of this facility will benefit in reduced waste disposal cost. Figure 3 shows the cost comparison with and without the super-compactor facility. After ~25 000 drums, the capital cost of super-compactor is recovered and disposal cost reduces as compared to the cost of not having a super-compactor facility.

The IRWMI has proven beneficial and improved the radioactive waste management system in following respects:

- Overall radioactive waste management costs have reduced by volume reduction of waste, reuse of materials, and use of modern technologies. This can generate better value to the taxpayers' money.
- The single radioactive waste management strategy reduces the duplication of efforts and delivers a robust strategy document to deal with all classes of radioactive waste. It is flexible enough to optimize the management of various classes of radioactive waste while considering worker and public safety, protection of environment, and cost–benefit analysis.

— The expected lifetime of low level waste disposal facilities can be increased, which will be able to accommodate more waste.
— Application of waste classification for optimizing the management route of radioactive waste. This results in increasing efficiency in the pre-treatment, treatment, conditioning, storage, transport, and disposal.
— Waste generators can understand better how their actions can influence health and environment.
— Regulators see the impact of regulations on the overall radioactive waste management infrastructure.
— Managers of radioactive waste can realize how the decision making can affect the society at-large.
— Enhancement in confidence of stakeholders, especially public about the accountability, credibility and transparency involved in the whole radioactive waste management infrastructure. They realize solutions to this problem exist and efforts are being made to minimize the health and environmental effects related to radioactive waste while economically managing costs.
— The IRWMI strengthens the national nuclear programme for handling any unforeseen or accidental situation by responding effectively, efficiently, timely, sustainably, and systematically.

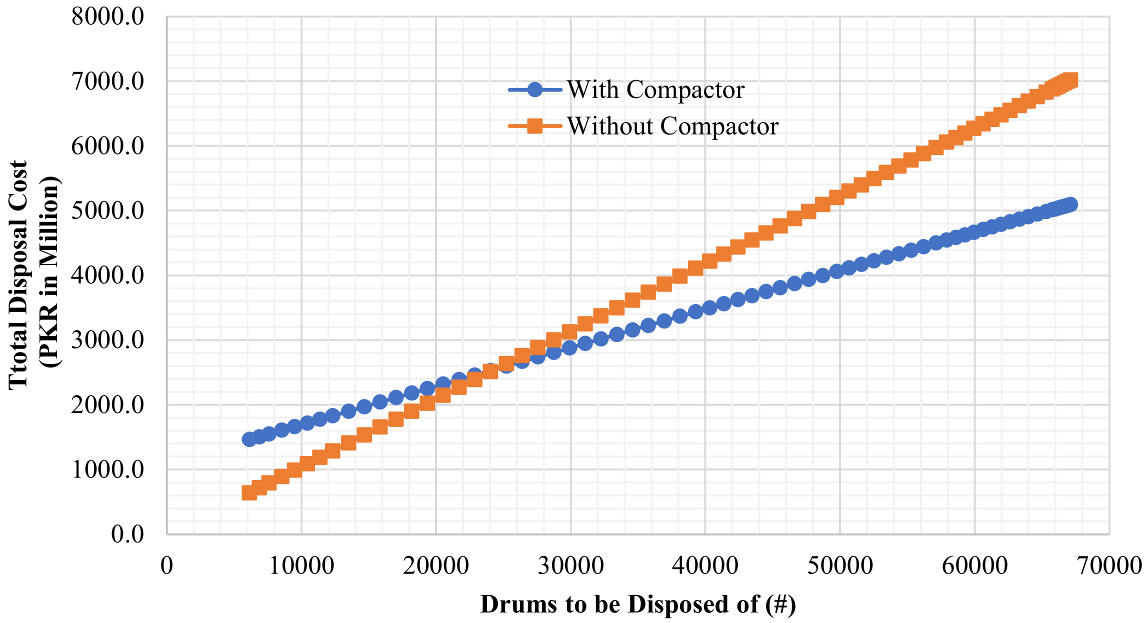

FIG. 3. Total disposal cost with and without compaction of waste drums

Finally, as the presence of international cooperation is a key factor, the integrated radioactive waste management infrastructure also results in a global benefit by promoting the best policy making, superior decision making, and the use of state-of-the-art technology to optimize waste management by minimizing radioactive waste generation and maximizing public safety and environmental protection.

5. CONCLUSION

Efforts are underway toward the developing an IRWMI in Pakistan to address several radioactive waste management steps and associated key influential factors. The IRWMI helps the country maintain and improve its national nuclear programme. At its core, the IRWMI manages radioactive waste through its life cycle, which broadly consists of predisposal and disposal management. These practices are influenced by key factors: (i) policies and legal framework; (ii) strategies and planning; (iii) minimizing waste and maximizing reuse; (iv) development of facilities; (v) operation of facilities and activities; (vi) safety case; (vii) handling unforeseen events; (viii) research activities; (ix) adopting the proven modern technologies; (x) capacity building and international cooperation; (xi) financial management; and (xii) stakeholder's involvement. These key factors together with the radioactive waste management life cycle establish an effective, well-aligned, optimized, sustainable, and efficient IRWMI. The IRWMI provides the benefit of integrated and proportionate tactics, which provide standardized practices and reduced costs over the entire national nuclear programme and radioactive waste management life cycle. The developed robust system has capability to adjust future national programme requirements, such as the addition of new nuclear facilities and activities like decommissioning and handling of unforeseen events in an efficient manner and with best utilization of the resources. Additionally, it will build and maintain public confidence on national nuclear energy programme and safe management of all types of radioactive waste.

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Paper ID#313

PROSPECTS OF INTEGRATED WASTE MANAGEMENT PLANNING

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Abstract

The objective of an integrated waste management (IWM) plan is to ensure the chosen Strategy for Waste Management that addresses safety boundaries, environmental concerns and stakeholders' interest can be implemented on the level of the country, but also on the level of individual waste generator, predisposal facility operator and disposal facility operator. The paper discusses major prerequisites for establishment of an IWM plan based on knowledge of inventory of waste streams in stock, forecast of waste streams that will be generated during established timeline for integrated planning, assessment of needs for different waste management facilities and selection of technologies to deal with waste from "cradle to grave" during the envisaged timeline, establishment of cost estimates and scenarios for different alternatives for waste management during planning period and approaches to funding for implementation. Iterative nature of planning process focusing of integration of "top-down" and "bottom-up" approaches will be discussed as well as advantages of waste minimization at the source during operation and by the design of facilities, as well as limitations, and restrictions to develop a flexible plan to address envisaged needs. Approaches to planning of nuclear fuel cycle (NFC) and nuclear power plant (NPP) waste generators and operators versus institutional waste generators and operator practices and the impact of these differences on the integrated plan will be pointed out and solutions proposed. The integrated plan needs to consider waste from decommissioning and remediation of nuclear facilities, legacy wastes and waste from accidents meaning that the IWM plan requires establishment of different planning scenarios as well as "holding points" to allow for adequate flexibility to address inevitable changes. In addition, an early assessment of waste management needs from development and use of advanced reactors and innovative nuclear fuel cycles is required to aid design and operation of such facilities as well as to understand their impact to overall waste management planning.

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INTEGRATION OF WASTE MANAGEMENT – GOING BEYOND TECHNICAL ASPECTS

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Abstract

Integrated waste management is the process of approaching all the aspects of the radioactive waste life cycle holistically, with the aim of optimizing outcomes, including minimizing negative impact on the environment and the broader business, and engaging with stakeholders. In addition to integration of the activities touching the various phases of the life cycle, integration can also be important across facilities, sites and missions. This is particularly relevant for multi-mission sites and organizations such as Atomic Energy of Canada Limited (AECL), where ongoing nuclear science and technology activities need to coexist with building decommissioning and site revitalization. AECL's approach has focused on leveraging international expertise and experience through its contractor, Canadian Nuclear Laboratories, under a Government-owned, Contractor-operated model. Significant work has been done over the last five years to develop an integrated waste strategy for all AECL sites and waste, taking account of the waste hierarchy. This presentation will provide an overview of the progress to develop and implement the integrated waste strategy for AECL-owned wastes, which result as a by-product from decades of research and development into nuclear technologies for the benefit of Canadians and the world. It will also look at stakeholder and Indigenous engagement aspects, and how those are taken into account in early waste management planning activities.

Note: This presentation is presented verbatim as deliviered by F. Dermarkar in Session 6 – Integrated Waste Management.

1. INTRODUCTION

Atomic Energy of Canada's role as a federal Crown corporation is to serve Canada and its people. We have been the leaders in Canada's nuclear science and technology since 1952. We take great pride in our nuclear legacy, which includes:

— The development of the CANDU reactor that has allowed the production of carbon-free electricity in Canada and around the world;
— The delivery of more than 1 billion doses of medical isotopes that have improved the lives of hundreds of millions of cancer patients worldwide;
— The advancement of nuclear science that has resulted in two Nobel laureates.

Today, AECL has two principal mandates:

— First: Our enduring mandate is to continue to enable nuclear science and technology going forward.
— Second: We also have obligations to clean up the legacy facilities, waste, and byproducts of research and development (R&D) that have accumulated over the past seven decades of operation, as well as other government of Canada responsibilities.

2. THE GO-CO MODEL

AECL delivers its mandate through a long term contract with Canadian Nuclear Laboratories (CNL), under a government-owned, contractor-operated, or GoCo model. This is akin to what you would find at the US DOE sites and has been in place since 2015. The GoCo model has enabled Canada to access world class knowledge and skills.

What makes the GoCo model particularly powerful is the ability of our contractor to reach back into its parent organizations to access targeted expertise to support the operation and management of CNL. The net result is that the pace of work completed under the GoCo has significantly increased, yielding tremendous value for Canada.

I will talk about some of this work in this presentation, particularly as it relates to waste management, with a focus on presenting an overview of the scope of our sites and cleanup activities. These span the breadth of Canada, and include decommissioning sites, as well as an active nuclear science and technology laboratory which, aside from having an ongoing science mission, is also seeing important decommissioning and remediation work related to some of the legacy facilities.

Our long term vision at AECL is to enable nuclear science and technology. As it has done in the past, a vibrant nuclear science and technology sector will continue to save lives, protect the environment, drive climate action, advance the development of highly qualified personnel and bolster the economy.

However, to move ahead, we need to continue to enhance stewardship practices. And we cannot do this alone. The land upon which we operate is unceded Indigenous land.

We are dedicated to working in partnership with Indigenous communities to recognize and incorporate Traditional Knowledge and ceremony, and Indigenous monitoring, cultural and stewardship practices in all aspects of our work. Working in partnership and collaboration is a key part of our environmental remediation mandate, including waste management.

Although this presentation is focused on integrated waste management, I would like to take a moment to talk about the enduring mission of the Chalk River site.

Canada's nuclear beginnings were at this site and the Chalk River Laboratories have been leading innovation in nuclear science and technology for almost 70 years, including medical isotopes and the CANDU reactor, whose design accounts for about 10% of all power reactors worldwide.

Some of our forward-looking work includes enabling the demonstration of small modular reactors, hydrogen as a fuel for renewable power generation, and the next generation of medical isotopes. We are enabling this through important investments in new infrastructure to transform the Chalk River Laboratories into a modern, world-class nuclear science and technology campus.

Close to 100 old structures have already been taken down and have been replaced with multiple new buildings, including new laboratory space. This illustrates the need for integrating the complex programmes of cutting-edge science, decommissioning and environmental restoration, and infrastructure renewal, which are all happening at the same time on the same site.

Our mandate encompasses a wide range of radioactive wastes – many the product of science and technology activities that have benefitted Canadians, for example, the production of medical isotopes and research supporting the development and deployment of carbon-free nuclear energy. These and others have been produced and stored over decades in various forms and locations across Canada.

These activities and past waste management practices have also contaminated several sites, buildings, and supporting structures. With our GoCo model, we have asked our contractor, Canadian Nuclear Laboratories, to accelerate decontamination, decommissioning, and waste management activities to protect the environment and reduce safety risks.

Because we manage legacy sites, we have a unique radioactive waste inventory. To put things into perspective:

- We have various types and forms of waste, including the largest volume of low level waste in Canada – more than all other Canadian producers combined.
- The specific role of R&D has resulted in a range of waste characteristics more complex than that produced by a nuclear power plant.
- Many of our buildings were used for a broad spectrum of activities. With this greater complexity, much more attention and investment is required for characterization, and the sorting and segregating of legacy waste in storage.

One of the many benefits of the GoCo model is the opportunity to set a range of priorities for our contractor Canadian Nuclear Laboratories. These include notably the identification of disposal solutions, which has enabled an important paradigm shift – from indefinite storage of radioactive waste to disposal now being actively pursued.

An important enabler to this has been the development of an integrated waste strategy. Specifically, we asked Canadian Nuclear Laboratories to look at what had been done internationally, notably in the United Kingdom.

3. INTEGRATED WASTE STRATEGY

The Integrated Waste Strategy considers current and planned future waste management requirements, including activities associated with operations, R&D, post-operational clean out, facilities decommissioning, environmental remediation, legacy and historic wastes, and waste received from small generators across Canada.

This requires a long term view with consideration of the full waste management life cycle to ensure there are long term waste management solutions for all categories of radioactive waste. In addition, it forms the vehicle to identify critical interfaces between the various missions, activities, and facilities.

What enabled us to do is to move away from site-specific ways of looking at waste and bring a strategic lens that considers the totality of our sites. And it also helped us identify where gaps existed, so that we could prioritize our work.

We have been safely storing waste in licensed waste management areas for over 70 years. Our approach to managing the waste before disposing of it consists of the following three key elements:

- First: characterization of existing structures, materials, and waste currently in storage. We are employing a range of techniques, both invasive and non-invasive.
- Second: Sorting and segregating waste.
- Third: Use of volume reduction technologies such as compaction, laser decontamination, and those offered by commercial vendors, such as metal melt.
- Fourth: Package the wastes for storage in “disposal ready” packages and store safely in licensed Waste Management Areas until the disposal facility is available.

On the low level waste front, we have three disposal facilities at various stages of development. Two engineered containment mounds have been built in the neighbouring communities of Clarington and Port Hope. Together, these facilities have safely received 2.4 million tonnes of waste and contaminated soils from existing facilities and other locations within these communities.

In the case of one facility, the remediation is complete, and the facility is being capped for long term monitoring. The other is being filled as remediation activities are taking place throughout the community. A third facility, also an engineered containment mound, is being planned to receive waste at our Chalk River Laboratories site.

There is a large inventory of radioactive waste being safely stored at the site, and our objective is to transition to long term management solutions. This facility is meant to receive legacy waste currently in interim storage, as well as waste generated from building decommissioning, land and soil remediation, and ongoing research at Chalk River Laboratories. It will also accommodate small amounts of waste from other Canadian producers such as hospitals and universities.

In the case of intermediate level waste, our waste volumes are relatively small compared to NPPs, and while the disposal route is not yet determined, activities are underway to improve storage and minimize future handling of waste packages.

One of the benefits of the advances in management of our low level waste, is improved clarity in the boundary between low level and intermediate level waste. This has enabled us to gain more certainty in our forecasted volume of intermediate level waste requiring disposal.

This coupled, with improvements and experience gained in characterizing, sorting, segregating, and reducing, has resulted in our forecast of intermediate level waste volumes reducing from more than 100 000 m3 to less than 10000 m3.

We are also learning from others. For example, we have recently piloted an approach to packaging the material into self-shielded containers that are disposal ready.

A process is currently underway in Canada to develop an integrated waste strategy for disposal of waste that does not have a solution; for us this involves intermediate level waste and we are actively participating in this process, which you would have heard my colleague Laurie Swami talk about.

Lastly, for high level waste, there are existing plans in Canada that involve the development of a DGR. This project is led by the Nuclear Waste Management Organization – again on this Laurie Swami provided more details at her talk.

As far as AECL is concerned, our considerations involve some of our research reactor fuel which, while slated for disposal in the DGR, will require complicated processing and packaging to meet the DGR waste acceptance criteria. We have about 100 tonnes of research reactor fuel which contains hundreds of fuel variations. This will be an important endeavour in the coming decades.

4. CONCLUDING REMARKS

I spoke at the beginning about working collaboratively with stakeholders and Indigenous groups. This is part and parcel of how we do things. There is significant engagement that happens on the waste projects, particularly those undergoing environmental assessments. But there is also longer term work that we do with Indigenous groups to build relationships, develop partnerships, and bring Indigenous viewpoints and knowledge to how we do things.

It is a work in progress. As I'm sure most people at this conference know well, building trust takes time. But we are committed to doing this in the right way. So what does this all mean?

We have a complex challenge in that we have multiple sites, multiple missions, and complex legacy waste and facilities. By looking at our waste in an integrated fashion and shifting from simply storing waste to actively developing disposal solutions, we have been able to make sense of the complicated radioactive waste management landscape at AECL sites.

It has also allowed us and Canadian Nuclear Laboratories to optimize plans in terms of what facilities are needed to execute our missions at the Chalk River Laboratories site. That means that decommissioning does not get in the way of science, and vice versa. And it means that decommissioning works hand in hand with the infrastructure group to make way for new buildings – and they work together to do this seamlessly.

As a result, continued execution of cutting-edge science, infrastructure renewal and environmental restoration can progress together in harmony.

The clarity that this process has yielded has been invaluable to both AECL and Canadian Nuclear Laboratories to fully participate in and support the review of Canada's national radioactive waste policy, and the development of an integrated radioactive waste disposal strategy for Canada. And doing this by engaging, communicating, and building relationships across the board is necessary to move projects forward.

Paper ID#178

THE SOLUTIONS STRATEGY: THE NEED FOR A GLOBAL, CONSISTENT, AND PROPORTIONATE APPROACH TO RADIOACTIVE WASTE MANAGEMENT

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Abstract

The objective of Andra's waste management strategy is to build an overall vision of existing and future management methods based on the development of a coherent and proportionate safety and environmental policy. There is a diversity in the types of waste or radioactive materials present in France. The development of a range of management solutions requires each solution to be adapted to the waste characteristics and hazard (radiological and non-radiological). This involves revisiting historical approaches and definitions, mainly based on the radiological classification of waste. For some categories, this classification is not well suited to define a disposal pathway. For example, studies and research to identify disposal solutions for low level long lived waste (LL-LLW) have highlighted the difficulty in defining LL-LLW. It can be like other waste categories due to the continuum of its activity level. It is clear that waste category alone is not sufficient to qualify waste hazardousness and, therefore, the choice of its disposal route. Thus, work is underway to identify waste management scenarios; particularly, the methodology to carry out these scenarios is being developed to justify the choices that will be made from a nuclear safety and environmental impact viewpoint. Methodological tools are developed to assess the environmental, health, and economic impacts of radioactive materials and waste management choices. This overall vision contributes to the search for technical and economic optimization of the distribution of the various categories of waste between the different disposal facilities, taking into account the timeframe of waste production and the best available technologies. This strategy provides a general framework for planning and coordinating Andra's actions according to the guidelines set out in the National Radioactive Materials and Waste Management Plan.

1. CHARACTERIZING RADIOACTIVE WASTE TO DEFINE ITS MANAGEMENT SOLUTION

The multiplicity of types of radioactive material and waste in France and, as a corollary, the development of a range of management solutions require proportioning each solution to the characteristics and the radiological and non-radiological waste hazards. For global consistency, this aim of proportionality leads to re-examining existing radioactive waste management approaches. Historically, this approach has mainly been based on radiological waste classification, which is structured by identifying the waste categories defined by the activity and the half-life of the radionuclides contained in the waste. For each category, a disposal design is identified, whether it is in use or planned. The French National Radioactive Waste Management Agency (Andra), which is in charge of the long term management of this waste, designs, builds, and operates disposal solutions. Very low level waste (VLLW) and low and intermediate level short lived waste (LILW-SL) are disposed of in dedicated surface disposal facilities, respectively Cires and the Aube Disposal Facility (CSA), both of which are located in eastern France. Regarding high level and intermediate level long lived waste (HLW and ILW-LL), a geological disposal project at a depth of 500 m in a clay formation is in the licence application phase: the Cigéo project. For low level long lived waste (LLW-LL), a disposal project at near surface depth is under study. For certain waste categories, the radiological classification has been found to be unsuitable for defining a management solution. The LLW-LL category is a good example.

The pairing "LLW-LL" includes radium-bearing waste and graphite waste, to which were progressively added bitumen-embedded materials, certain used sealed sources, uranium-bearing waste, and contaminated technological waste. Due to its origins, LLW-LL is intrinsically heterogeneous. In particular, depending on the type of waste, its activity changes over time in different ways, which raises questions about the confinement and the duration of isolation that a near surface disposal facility has to provide. The experience feedback from studies and research conducted to identify the management solutions for LLW-LL has highlighted the difficulties in characterizing the hazards of LLW-LL. This leads to the matter of what these waste types have in common, especially for establishing a single set of management principles (near surface disposal). Near surface disposal, as long as the depth is not fixed, theoretically offers possibilities for managing waste that is unacceptable for surface disposal. Alternatively, from an economic standpoint (compared to geological disposal), it also offers possibilities for certain types of ILW-LL.

The waste category alone is thus insufficient to qualify the hazardousness of radioactive waste and select the appropriate management solution.

2. ASSESSING THE IMPACT OF VARIOUS MANAGEMENT SOLUTIONS

The French National Radioactive Materials and Waste Management Plan (PNGMDR) describes the management strategy applicable to all radioactive materials and waste over a period of five years by identifying needs and setting objectives to improve this management. In its opinion on the environmental assessment of the PNGMDR covering 2016 to 2018, the Environmental Authority (AE) suggested building a global vision of radioactive waste management. Furthermore, the AE emphasised the need for this plan "to produce a comparative assessment of impacts, for the population and the environment (releases and waste), resulting from the various possible or planned alternatives; their consistency with the applicable management principles should also be demonstrated." Moreover, it recommended "applying a methodology suitable for each material or waste management solution, according to the main environmental issues concerning it." The AE thus calls for conducting a strategic environmental assessment of the various management solutions, tantamount to performing multicriteria analysis and requiring the identification of environmental impact categories. The management solution strategy aims to fit into this framework.

3. DEVELOPING A WORK METHOD SUITABLE FOR PUBLIC PARTICIPATION

This framework, described in the AE opinion, was strengthened by the conclusions of the public debate on the PNGMDR that were issued in November 2019. The special public debate committee emphasized the importance of ethics for the participants, specifically the questions of the legacy for future generations, governance, and citizen action. The public wishes "to participate in public decisions that impact the environment," and a need emerged for rethinking the connection between civil society and those institutions, economic players, associations, and experts that are involved in managing radioactive materials and waste. In response to the opinion of the special public debate committee, the French Ministry for Ecological and Inclusive Transition and the French Nuclear Safety Authority made public their decision on drafting the next PNGMDR. This decision specifies the assessment of environmental, health, and economic impacts of radioactive materials and waste management choices in the PNGMDR will be improved and a review of the cross-functional questions highlighted by the public debate (transport, environment, health, economy, waste harmfulness, regional impacts, etc.) will be drawn up in a participative manner.

Given these elements, the methodology for establishing the scenarios for managing various types of waste has to be completed to fully justify the proposed choices, both in terms of nuclear safety and environmental impacts. Furthermore, during the public debate on the PNGMDR, the public expressed its desire for governance of waste management that enabled its upstream involvement in waste management choices and the associated analysis grid.

The management solution strategy developed by Andra is thus part of this complex framework and aims to collectively build and share a global vision of management strategies, both those that already exist and those to be developed. This strategy needs to be based on creating a consistent and proportionate doctrine in the area of safety and the environment. This global vision needs to facilitate finding a technical and economic optimization of the breakdown of the various waste categories into the various disposal methods, taking account of the waste production timeframe and the best available technologies.

4. DEVELOPING THE MANAGEMENT SOLUTION STRATEGY

Developing the management solution strategy is based on:

— Setting up and maintaining the consistency of the principles applied to the long term management of all radioactive waste, and potentially radioactive materials if classified as waste, in France, based on proportionality with their respective hazards;
— Analysing the impact of changes in energy policy, waste management practices in producer facilities, and regulations on these principles;
— Identifying new solutions or solution elements that could be studied to optimize the global system;
— Optimizing the breakdown of the various waste categories between the various solutions given the waste production timeframe and that of setting up new solutions.

The work method adopted is the definition of waste management scenarios. The ultimate goal is to choose the most justified management methods for each waste type. It should be noted that “management scenario” refers to all waste management steps from production to elimination. A method with several steps is thus proposed:

— The first step involves inventorying all waste types in each category, whether they are being produced or will be later, with their volumes and main identified radiological and physical–chemical characteristics.
— The next step involves identifying, for each waste type, the various possible management options by widening the field of techniques, including (i) existing or planned disposal facilities, (ii) the possibilities of treatment upstream of disposal, and (iii) the use of new disposal solutions (sites and designs).
— Considering the options identified for each waste type, it then becomes possible to build management scenarios. Each scenario will consolidate a set of options to cover the full scope of the waste in the category, by having recourse to several disposal sites included in a consistent approach and by considering waste combinations based on similar issues. Furthermore, the disposal timeframe will also be considered.
— From the analysis of these scenarios, the opportunity to consider complementary disposal designs for certain waste types will be assessed, potentially leading to searching for sites suitable for these new designs.

These scenarios are notably under development for LLW-LL, for which a site for developing a near surface disposal project in a clay formation was selected, leading to geological investigations there. Working with scenarios needs to make it possible to identify and better characterize the inventory that will be disposed of at this site and the potential need to use complementary sites.

To perform these studies, the solution strategy requires developing methodological tools to qualify the waste hazardousness and compare management options, among other things. The first step of the solution strategy approach is to list the waste types and their characteristics. This list then makes it possible to define the management solutions proportionate to the radioactive waste hazards. For the large majority of waste types, waste management involves sending them to a disposal facility and isolating them as much as strictly necessary from humans and the environment. While this principle is commonly accepted, its concrete application in an exercise to define management options is far from self-evident, particularly because what is “strictly necessary” is linked to the harmfulness or hazardous nature of this waste and its changes over time, which are not directly and easily understandable concepts. Andra has thus initiated a discussion on “harmfulness” to create an indicator for orienting waste toward more proportionate management solutions. The indicator would help assess the waste’s intrinsic hazards, from a chemical and radiological viewpoint. This methodology proposes a single hazard indicator expressed in Disability Adjusted Life Years (DALY).

Regarding solution comparisons, Andra has already initiated an approach by developing a “strategic environmental assessment” aimed at comparing various management options for the same batch of waste using a set of environmental criteria. The methodological proposal that Andra is working on uses a tested method based on life cycle assessment (LCA) while including features specific to radioactive waste management.

Paper ID#193

STUDY ON ADVANCED NUCLEAR ENERGY SYSTEM BASED ON THE ENVIRONMENTAL IMPACT OF RADIOACTIVE WASTE DISPOSAL

An integrated cross-disciplinary approach to diversifying nuclear fuel cycle conditions

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Abstract

To present effective technical options for reducing the environmental load (amount of waste and radiological impact) in the disposal of radioactive waste, it is necessary to evaluate the relationship between the nuclear fuel cycle conditions and the waste characteristics quantitatively. In that case, exposure based on the nuclide migration, which is a long term safety evaluation for geological disposal, radiotoxicity of the waste, quantity balance of the full nuclear fuel cycle, effect of nuclide separation, and combustion characteristics of separated nuclides in fast reactors are involved. The paper presents an outline of and progress of cross-disciplinary nuclear systems research to support efforts to reduce the load of radioactive waste disposal.

1. INTRODUCTION

In order to realize reduced CO_2 emissions, which is an urgent global priority, the optimization of future nuclear systems that coexist and complement renewable energy is critical, and engineering of such systems should focus on the minimization of radioactive waste. Thus, it is necessary to present technical options for the nuclear fuel cycle that are technically feasible and can be commercialized.

Processes for implementing geological disposal of high level radioactive waste are being developed worldwide. However, the uncertainties associated with the long term safety assessments of radiation effects are also an issue in promoting disposal programmes. At the IAEA International Conference on Spent Fuel Management in 2019, it was highlighted that final disposal has to be realized urgently to promote the nuclear fuel cycle [1]. Although it is expected that nuclear energy will be used on a global scale, there are concerns that nuclear energy will be abandoned if the issue of radioactive waste management is not solved.

The geological disposal of high level radioactive waste evaluates and ensures long term radiation safety from nuclide migration based on isolation and containment [2]. In addition, methods are being developed to reduce the radioactive toxicity of radioactive waste by partitioning and transmutation [3] [4]. The fundamental characteristics of radioactive waste depend on the nuclear fuel burnup and are determined by the conditions of various nuclear fuel cycle processes. Therefore, to present effective and rational volume and toxicity reduction measures for radioactive waste, a cross-disciplinary study should be conducted to provide a perspective on processes upstream from waste disposal, which is the final stage in nuclear power use.

A research programme started in 2019 with the goal of presenting feasible nuclear system options by focusing on the relationship between the environmental load in radioactive waste disposal and the nuclear fuel cycle conditions [5] [6] [7]. Based on the outline and evaluation examples from this ongoing programme, this paper presents a methodology for cross-disciplinary study on reducing the environmental load of waste and optimizing the entire nuclear system.

2. RESEARCH CONCEPT

2.1. Research area

The areas examined in the study are shown in Fig.1. The environmental load of waste disposal, which is classified into the amount of waste and the effects of radiation on humans, is compared and examined in relation to the processes, conditions, and parameters that make up the entire nuclear system.

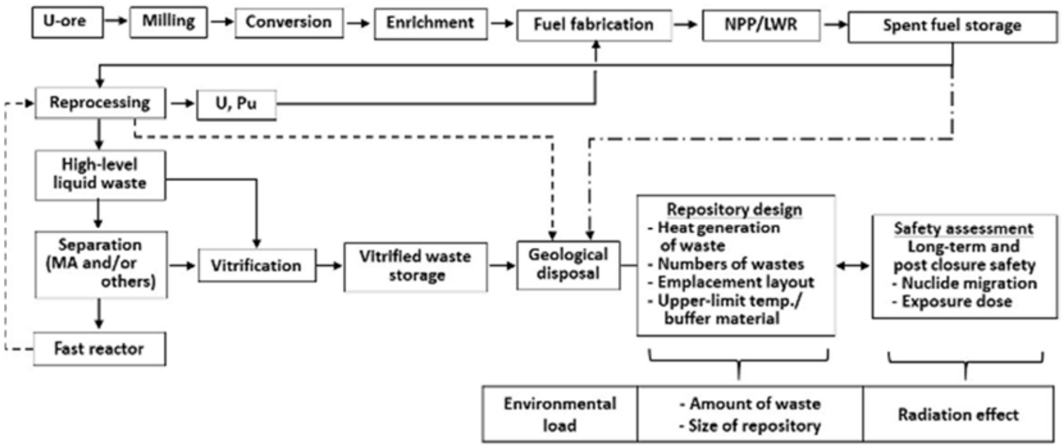


FIG. 1. Research that spans front- and back-end processes.

2.2. Research topics focused on reducing environmental load

Assuming the introduction of 70 to 90% minor actinide (MA) separation, called simplified MA separation, a combination of cycle conditions that contributes to reducing the environmental load will be presented as an option for nuclear power systems. The research topics are as follows.

(a) Study on the environmental impact of radioactive waste disposal.
   (i) Evaluation of environmental impact and introduction of environmental index for geological disposal.
   (ii) Evaluation of fuel cycle quantities for waste disposal load by using the Nuclear Fuel Cycle Simulation System (NFCSS) open simulation code.

(b) Engineering design study of simplified MA separation technology.
   (i) Validation of Am separation mechanism.
   (ii) Presentation of a feasible Am separation process.

(c) Development of an advanced fast reactor (FR) burnup calculation model.

2.3. Research schedule

The 4-year research schedule is shown in Table 1.

TABLE 1. FOUR-YEAR TIMETABLE FOR THE PRESENT STUDY

Items		FY 2019	FY 2020	FY 2021	FY 2022
(a)	(i)	Reference survey and investigation of input data	Investigation of environmental impact		Presentation of nuclear fuel cycle options and environmental impact index
	(ii)		Fuel cycle calculation/improvement of simulation method		
(b)	(i)		Verification/simplified separation mechanism		Options/flowsheet
	(ii)		Design study/simplified separation process		Options/basic specification
(c)			Improvement/FR burnup calculation model and waste property estimation		

2.4. Prerequisites for evaluation

A previous study [8,9,10] evaluated the effect of the fuel cycle conditions, including nuclide separation and vitrification conditions, on the waste-occupied area at a repository. The fuel cycle conditions for the inventory calculation of UO_2 fuel-derived waste are shown in Table 2. ORIGEN 2.2-UPJ [11] and JENDL-4.0 [12] were used for calculating conditions for 17 × 17 pressurized water reactor (PWR) fuel. The results [13] are shown in Table 3. The present research is being performed with reference to these previous results.

TABLE 2. FUEL CYCLE CONDITIONS FOR THE REFERENCE CASE

Reactor	Fuel	Burnup (GWd/tHM)	Spent fuel cooling period (years)	Reprocessing/ Purex process/ nuclide separation (%)		Vitrification/ waste loading (wt%)	Vitrified waste			Geological disposal/waste-occupied area (m^2)
							*	**	***	
LWR	UO_2	45	4	U/Pu	99.6/99.5	Approx. 20	2.3	50	0.35	44.4

* Heat generation rate, after vitrification (kW/glass unit); ** Storage period (years); *** Heat generation rate, after storage (kW/glass unit)

TABLE 3. PREVIOUS STUDY RESULTS [11]

Condition no.	Spent fuel cooling period (years)	Cs/Sr separation rate (%)	MA separation rate (%)	Mo/PGM* separation rate (%)	Waste loading (wt%)	Footprint ratio to reference case
Reference case	4	0	0	0	20.8	1.00
1	4	90	0	70	35	0.43
2	15	70	0	70	25	0.72
3	20	70	0	70	25	0.84
4	30	0	0	0	20.8	1.00
5	40	0	0	0	20.8	1.00
6	50	0	90	70	35	0.43
7	100	0	70	70	35	0.43

* Platinum group metals

3. RESEARCH PROGRESS

3.1. Evaluation of environmental load

Environmental impact is evaluated by the ratio of the environmental load to the contribution of nuclear power generation as shown in Table 4. The amount of waste contributing to the environmental load is related to the area of the repository via the heat generation capacity of the waste.

Radiation effects are classified as dynamic or static. The dynamic effects refer to the exposure in the biosphere due to the nuclide migration based on the basic scenario (groundwater scenario) in the geological disposal safety assessment. The static effects refer to the exposure from the radioactive substances in the waste buried in the repository. For the scenario leading to this exposure, the human intrusion scenario of borehole drilling penetrating the waste itself was selected based on previous studies [14,15,16,17], and exposure via direct observation of the core sample by a geologist was assumed.

The source of both exposures is the vitrified waste inventory. This inventory is determined by the vitrification and reprocessing conditions, and thus by the nuclear power plant operating conditions, such as the reactor, fuel type, and burnup conditions. The contribution of the power generation by the nuclear power plant was considered as a contribution.

TABLE 4. EVALUATION INDICES FOR ENVIRONMENTAL IMPACT

<table>
<tr><th colspan="3">Evaluation items</th><th>Phenomenon</th><th>Evaluation method</th><th>Unit</th></tr>
<tr><td rowspan="3">Environmental load</td><td colspan="2">Amount of waste</td><td>Heat generation</td><td>Waste-occupied area, or waste amount per repository area</td><td>m^2 or kg/m^2</td></tr>
<tr><td rowspan="2">Radiation effect</td><td>Dynamic</td><td>Nuclide migration</td><td>Exposure</td><td>Sv/y</td></tr>
<tr><td>Static</td><td>Presence of nuclides</td><td>Potential radiotoxicity</td><td>Sv or Sv/y</td></tr>
<tr><td>Contribution</td><td colspan="2">Power generation</td><td colspan="2">Power generation corresponding to the generation of vitrified waste</td><td>TWh</td></tr>
<tr><td colspan="3">Environmental impact</td><td colspan="3">Environmental load/contribution</td></tr>
</table>

The evaluation results of the radiation exposures based on Tables 3 and 4 are shown in Fig. 2. The maximum dose in the dynamic evaluation was caused by ^{135}Cs under all conditions (Fig. 2(a)). For conditions 1 to 3, 90% or 70% separation of caesium and strontium decreased the peak value of the dose. In contrast, the peak values of the remaining conditions, including conditions 6 and 7 in which 90% or 70% MA separation was performed, were the same as the peak values of the reference case. The static evaluation calculated the dose by ingestion due to human intrusion 300 years after the repository closure (Fig. 2(b)). Under all conditions, the main contribution to the dose was due to ^{241}Am. The dose under each of the conditions was higher than that of the reference conditions, but even if the spent fuel had a cooling period of 50 years and the waste content was 35 wt%, the dose under condition 6 with 90% MA separation was almost the same as the reference case. Thus, MA separation had no effect in the dynamic evaluation, whereas it did in the static evaluation [18].

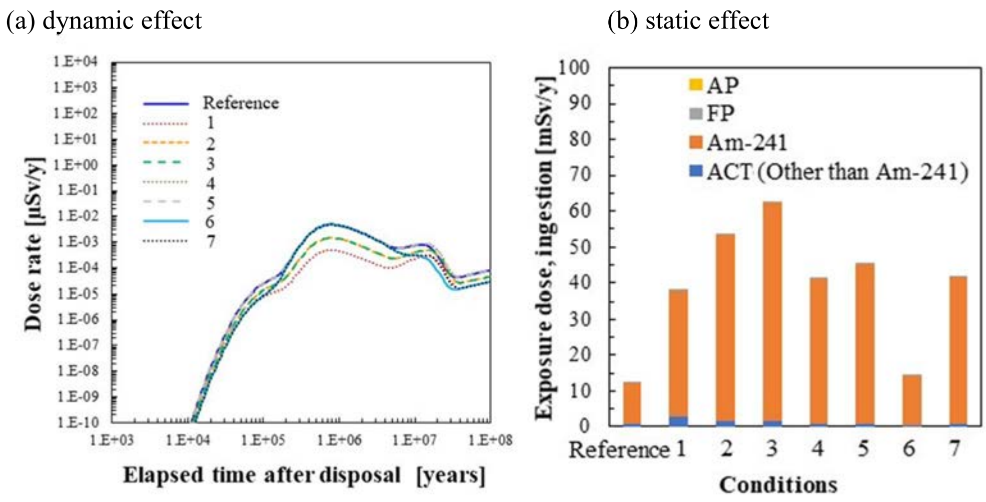


FIG. 2. Dynamic and static effects for environmental load under various fuel cycle conditions.

3.2. Quantities evaluation by NFCSS

Numerical analysis codes have been developed and used for evaluating various quantities in the nuclear fuel cycle [19,20]. The NFCSS, developed by the IAEA, is open-access code available on the IAEA website. Originally developed as VISTA, NFCSS provides estimates of material flows and various fuel cycle amounts, such as uranium resources and enrichment, volume of fuel fabrication and spent fuels, and accumulation of plutonium and MAs. In addition, the NFCSS can now calculate the decay heat and radiotoxicity of UO_2, MOX, and ThO_2 spent fuels [21]. However, additional functions are required to calculate the decay heat and radiotoxicity of MA and fission product nuclides for considering various process conditions, such as reprocessing, nuclide separation, and geological disposal. Therefore, the Excel file function is undergoing expansion for the calculations so that the back-end processes, such as the waste-occupied area and the layout of the disposal site, can be evaluated. (In this functional expansion, the publicly available NFCSS is used as an ad hoc basis for preparing the data required for calculation as a separate file. For this implementation, technical meetings were held with the Division of Nuclear Fuel Cycle and Waste Technology of the IAEA, which manages the NFCSS, and a practical arrangement was concluded between IAEA and RWMC in January 2021.

Decay heat and radiotoxicity were determined through the burnup calculation of PWR UO_2 spent fuel using the ORIGEN 2.2-UPJ code and JENDL-4.0 library under the same conditions as the NFCSS, and a benchmark with NFCSS data confirmed that the results matched with only a small discrepancy. Currently, the decay heat and radiotoxicity of high level radioactive waste are calculated considering the separation of uranium and plutonium, MA, and caesium and strontium, platinum group metals (PGM), and molybdenum in the reprocessing process. Figure 3 shows the current results comparing the effect of nuclide separation on the decay heat of high level radioactive waste with that of spent fuel.

3.3. Simplified MA separation

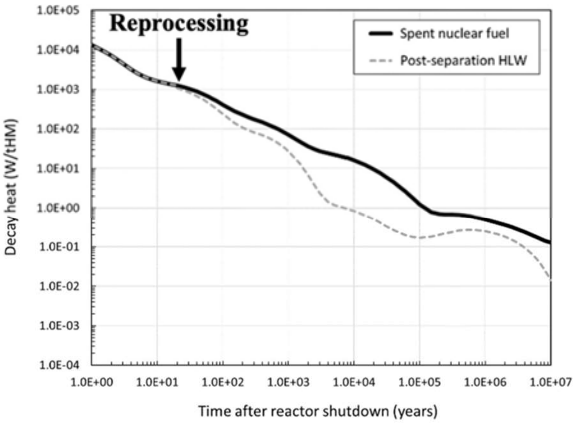
To present the engineering feasibility of the simplified 70 to 90% MA separation process, research on the mechanism and process aspects of the design is being conducted.

For the mechanism, the wet and dry processes were evaluated as flowsheets based on a literature survey, which identified the allowance of the accompanying rare earth elements (REs) and the low recovery rate and high purity of MA as important points in the selection and development of simplified MA separation.

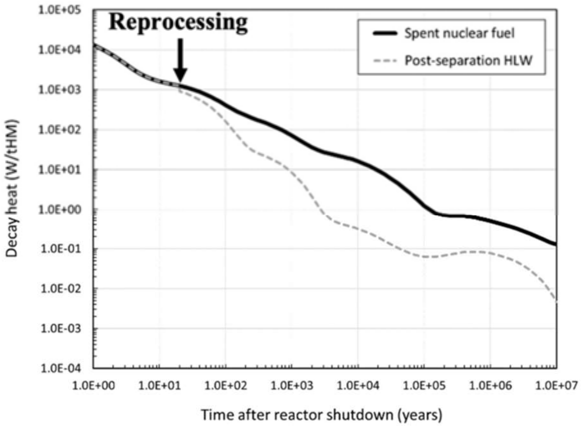
Progress focusing on product purity has been made in the wet process for transmutation technology for separated nuclides. However, mutual separation of MA/RE and the recovery of Am alone require multi steps in the separation processes and are major obstacles to realizing separation technology on an industrial scale [22]. Therefore, the simplified MA separation process was devised based on RE accompaniment focusing on the

Solvent Extraction from Liquid-waste using Extractants of CHON-type for Transmutation (SELECT) process that the Japan Atomic Energy Agency (JAEA) is developing for application to accelerator-driven and FR systems. A flowsheet of this process is shown in Fig. 4. The SELECT process, which aims for 99.9% or higher MA recovery and more than 90% MA purity for the transmutation system, requires 40 mixer–settler stages for the extraction and scrubbing in MA/RE mutual separation. The process has been confirmed by an extraction test using active high-level liquid waste and a calculation using PARC-MA process simulation code [23]. The results suggested a reduction in the number of separation stages in the solvent extraction process with MA recovery ratio , and possibility that adjusting the nitric acid concentration of the feed (product solution in the MA・RE recovery process) could reduce the amount of accompanying RE while maintaining the MA recovery ratio. At present, the calculation results show that the number of mixer-settler stages in the extraction and scrubbing can be reduced to 4–6 stages.

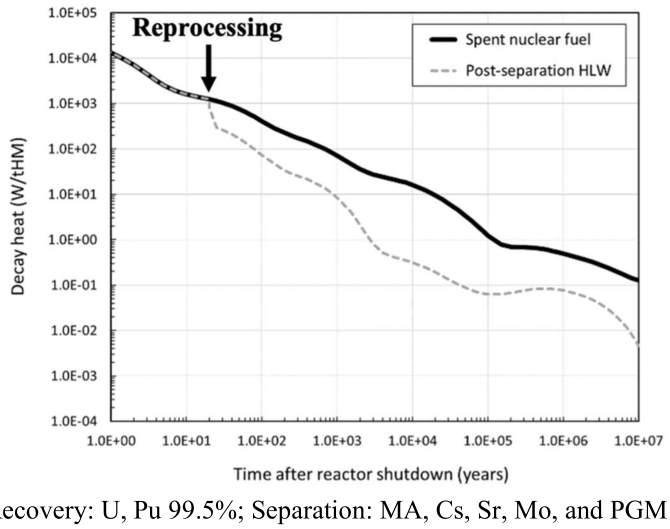
The dry process has been investigated, including the waste forms after processing on an engineering scale. However, it is currently difficult to evaluate the dry process in the same manner as the wet process because there are few evaluation cases related to back-end issues, such as long term safety assessment after waste disposal. Because the mutual separation of MA/RE is difficult in the dry process in principle, simplified MA separation to produce low decontamination fuel is suitable.



(a) Recovery: U, Pu 99.5%



(b) Recovery: U, Pu 99.5%; Separation: MA 70%



(c) Recovery: U, Pu 99.5%; Separation: MA, Cs, Sr, Mo, and PGM 70%

FIG. 3. Effect of nuclide separation on the decay heat of high level radioactive waste compared with that of spent fuel.

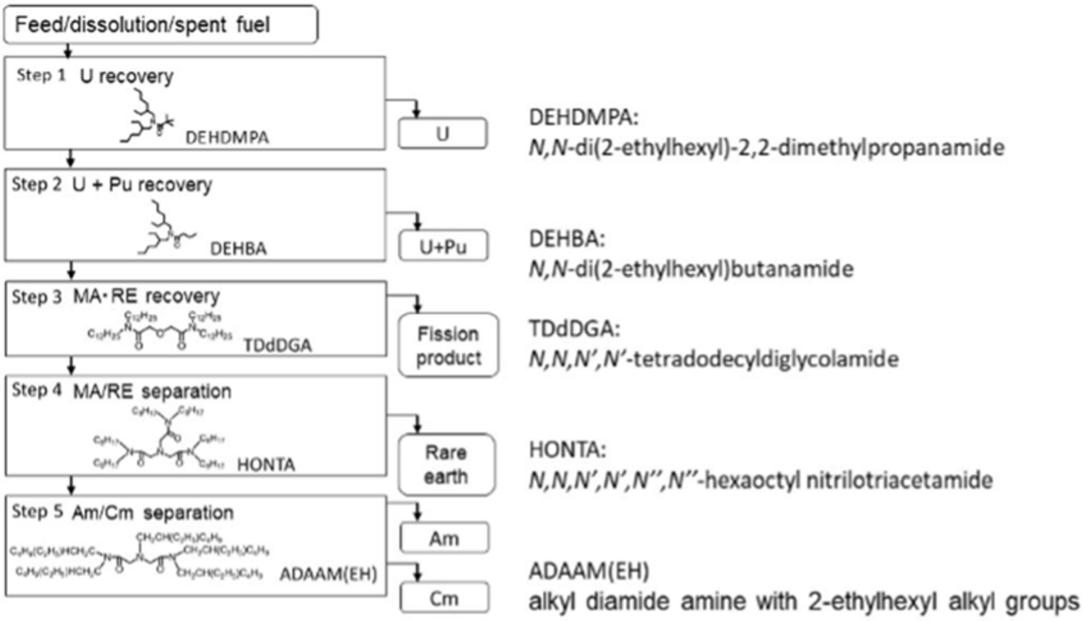


FIG. 4. Flowsheet of the SELECT process.

3.4. Development of FR burnup model

The calculation model for sodium-cooled fast reactor (FR) burnup is being upgraded to include uncertainties caused by various nuclear fuel cycle conditions. The goal is to prepare input data on fuel burnup, cooling and reprocessing of spent fuel, and other factors needed to establish the reactor core for recycling of MA nuclides based on simplified MA separation and to perform the burnup calculations. Because REs in FR fuel act as a neutron poison, RE accompaniment affects the core characteristics of FRs [24]. Therefore, FR burnup calculations considering the RE accompaniment from the simplified separation process are being conducted. The sodium-cooled FR to be evaluated is the large-scale MOX fuel high internal conversion type core (JSFR-1500) proposed in the “Feasibility study on commercialized FR cycle systems; Phase II” by the JAEA.

In the transition period from LWR to FR, transuranic waste (TRU; uranium, plutonium, MA) nuclides derived from LWR spent fuel will be used as FR fuel. However, the TRU composition depends strongly on the operating conditions of the LWR, including reactor type, fuel type, burnup, and void ratio in boiling water reactors, and the reprocessing conditions. A quantitative evaluation of the effect of uncertainty (diversity) on the prerequisites for this transitional LWR on the core characteristics and waste characteristics of FRs is being conducted [25].

4. DISCUSSION

The findings based on the results obtained at the end of the second year of the four-year plan are shown below.

4.1. Environmental load evaluation index and load reduction in waste disposal

The evaluation formulas for the three indicators in this study are as follows.

A. Amount of waste, waste-occupied area per waste package:

$$A_i / A_{reference}$$

where

A_i: waste-occupied area per waste package for individual fuel cycle conditions

$A_{\text{reference}}$: waste-occupied area per package for reference conditions

B. Radiation effect, dynamic effect, nuclide migration, dose:

$$B_i / B_{standard\ dose}$$

where

B_i: dose for base case scenario for individual fuel cycle conditions
$B_{\text{standard dose}}$: dose for base case scenario for reference conditions

C. Radiation effect, static effect, presence of nuclides, potential radiotoxicity:

$$C_i / C_{standard\ dose}$$

where

C_i: dose for human intrusion scenario for individual fuel cycle conditions
$C_{\text{standard dose}}$: dose for human intrusion scenario for reference conditions

In formulas A–C, the denominator is the waste occupied area under the reference conditions, the dose due to nuclide migration in the base case scenario, and the dose for direct exposure in the human intrusion scenario, respectively. The numerator is the value of each of these variables under the individual nuclear fuel cycle conditions, and the ratio represents the load reduction effect. This ratio also includes the effect of simplified MA separation. The dose value used for the denominators of the radiation effect (B and C) is the value under the reference conditions of the nuclear fuel cycle, the dose constraint, or the guideline dose under the safety regulations for evaluating the exposure. As shown in Fig. 2, the effect of MA separation does not appear in the dynamic evaluation, whereas the contribution of ^{241}Am dominates in the static evaluation. The evaluation method, such as comparing the calculation results of this formula individually or comparing the sum and multiplier, will be scrutinized in future work.

4.2. Consistency in quantitative evaluation of nuclear fuel cycle

In the environmental load evaluation of waste disposal, such as the waste amount and radiation effects, calculations are performed considering various fuel cycle conditions. Therefore, the consistency in selecting front-end and back-end processes and their condition settings, from the nuclear fuel use to waste disposal, needs to be considered. In this study, a functional expansion to prepare the data required for calculation as a separate file is being conducted by using NFCSS on an ad hoc basis. However, if these functions are incorporated into the NFCSS main unit, integrated evaluation, examination, and comparison will be possible with a single tool at the initial stage of examination for nuclear power use scenarios. In future, it will be necessary to construct a scenario for using nuclear power generation to reduce the load on waste management. NFCSS has the potential to evolve into an integrated scenario study tool that explores sustainable radioactive waste management and nuclear use.

4.3. Simplified MA separation

By relaxing the requirements for the separation process, which initially aimed for a high MA separation (recovery) rate and high purity americium products, in accordance with the requirements for reducing the environmental load of the disposal system, demonstrates the practical application of this technology. The separation ratio of MA needs to be considered with respect to repository design considering the heat generation of the waste and radiation effects after closure of the repository. There is an internationally recognized dynamic evaluation method for the radiation effects that has dose evaluation criteria, but for the static evaluation, the selection of scenarios and estimation conditions is a key issue. And it is not possible to set the simplified MA separation options without also considering the FR burnup, which is described in Section 4.4.

4.4. Interrelationships of processes in FR burnup calculation

For the fuel burnup characteristics of FR, which assume simplified MA separation, it is necessary to consider the effects of nuclides, especially for REs, in addition to MA (americium). The amount of RE accompaniment and americium purity depend on factors including the principle and configuration of the separation process, the type of extractant, and the acid concentration of the feed solution. In addition, the characteristics of spent fuel generated by FRs are related to the characteristics of the radioactive waste. Thus, examining the interrelationships of these processes is essential.

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Paper ID#150

SITE CHARACTERIZATION INPUTS TO SAFETY CASE DEVELOPMENT FOR AUSTRALIA'S NATIONAL RADIOACTIVE WASTE MANAGEMENT FACILITY

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Abstract

The Australian Radioactive Waste Agency (ARWA) is progressing plans to establish a National Radioactive Waste Management Facility (NRWMF). ARWA undertook comprehensive site characterization activities at three sites during a site assessment process. One of the sites has been identified as the preferred location for the NRWMF, based on technical suitability and broad community support. In the next phase of work, ARWA will conduct further site studies to provide critical inputs to the facility design and the safety case for the NRWMF to seek licences and approvals from regulators. This safety case will demonstrate the operational and long term safety of the facility, taking account of the existing environmental conditions at the site, the design of the facility, and the characteristics of the waste to be disposed or stored.

1. INTRODUCTION

The Australian Radioactive Waste Agency (ARWA) is progressing plans to establish a National Radioactive Waste Management Facility (NRWMF). This facility will be the first of its kind in Australia, designed to dispose of Australia's low level radioactive waste (LLW) and store Australia's intermediate level radioactive waste (ILW) until a permanent ILW disposal pathway is developed.

Three sites in South Australia at Lyndhurst, Napandee, and Wallerberdina were nominated by their landowners as candidates for hosting the NRWMF. Following a site assessment process considering technical suitability and community support, a site at Napandee, near the town of Kimba in South Australia, was identified as the preferred site for the NRWMF in 2020.

2. SITE SUITABILITY ASSESSMENT

The technical aspects of the site assessment process relied on a range of site characterisation data obtained at the three sites, in the following themes:

— Flora and fauna;
— Radiation;
— Climatic conditions and climate change;
— Bushfire risks;
— Hydrology and flood risks;
— Impacts of nearby human activities;
— Geology and hydrogeology;
— Landform stability;
— Seismic risks;
— Transport infrastructure;
— Utilities infrastructure.

These themes broadly align with and address the discretionary criteria described in IAEA Safety Standards Series No. SSG-35 [1]. Using categorised criteria and a generic concept design, the potential risks of each site were identified and assessed using a risk matrix of likelihood and consequence. The assessment also drew on other IAEA recommendations, such as in SSG-29 [2], as well as regulatory guidelines from the Australian Radiation Protection and Nuclear Safety Authority (ARPANSA) and the Australian Safeguards and Non-proliferation Office (ASNO).

The criteria derived from IAEA, ARPANSA, and ASNO documentation are focused on the radiological safety and security aspects of site suitability. A similar assessment was conducted for additional criteria that will be important for gaining approval under the Australian Government's main environmental regulation, the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999.

The risk assessments were to determine the extent to which it is likely that radioactive waste can be safely and securely managed at the NRWMF and which meets the necessary regulatory approvals and licences. The risk assessments focused on areas where a regulator would likely require more information than is currently known, or areas where current information suggests further design mitigations are required.

The risk assessments did not determine the technical risks of the site against reference events, such as earthquakes or floods. Instead, they estimated the probability that the regulator will have concern about a particular criterion (as the likelihood), and the level of potential concern based on currently available information (as the consequence). By taking this approach, the assessments do not pre-empt any outcome from the formal regulatory assessments. As a result, the risk ratings represent the level of 'regulatory risk,' rather than technical risk.

Figure 1 shows a summary of the regulatory risk ratings for each site, together with risks associated with facility establishment costs and other matters. In the figure, the height of each coloured rectangle represents the number of corresponding risk ratings for the site. In general, the regulatory risks were rated as low or very low for most criteria for all three sites. However, the risk of regulator concern for the earthquake and flooding criteria were rated as very high for the Wallerberdina site and high for the Lyndhurst site (for flooding only). No regulatory risks were rated high or very high for the Napandee site. All three sites were determined to be technically suitable for hosting the NRWMF if appropriate design mitigations were incorporated. Napandee was identified as the most suitable site.

More details on the site suitability assessment are described in the Australian Government's Site Assessment – National Radioactive Waste Management Facility report [3].

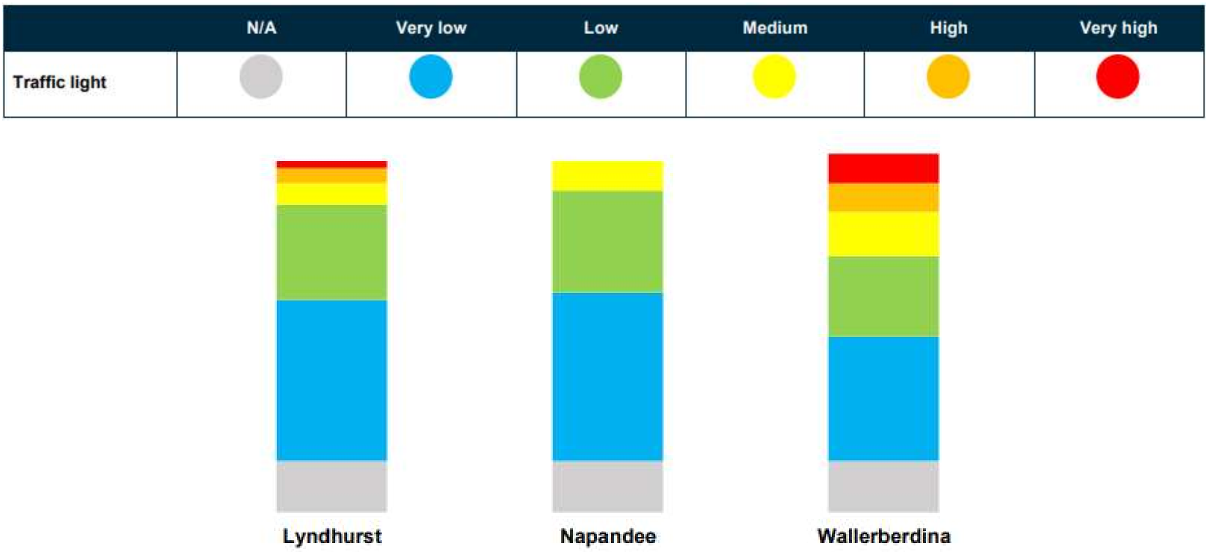

FIG. 1. Summary of regulatory risk ratings. [3]

3. SITE CHARACTERISTICS AT NAPANDEE

Throughout 2018 and 2019, ARWA, through its consultant AECOM, undertook comprehensive site characterisation activities to inform the site assessment process and demonstrate the sites' technical suitability.

Results from some key activities under the themes listed earlier are described and discussed below for the Napandee site. Further investigations will be undertaken on the site and surrounding area to obtain more detailed information that will be required for the facility safety case and regulatory applications.

The Napandee site has been used for agricultural farming and cropping for a significant period of time and native vegetation covers less than 5 per cent of the site. Figure 2 shows images of the site. As a result, only minimal vegetation clearance would be required to construct the facility. No threatened ecological communities listed under the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 were recorded on the site or in the surrounding area. A bird species listed as vulnerable may be present in the surrounding area, and this will require targeted field surveys to assess.

FIG. 2. Photos of the Napandee site.

There are no creek lines within 10 kilometres of the site but local drainage paths exist throughout the site. There is a large catchment in the region, but the site is located on higher ground than the catchment floodplain. Flood modelling shows that any flooding on the site is contained within the localised drainage paths, up to 1 metre depth in a probable maximum flood (PMF) event in current climate conditions (Fig. 3). The facility design will account for the risk of flooding on the site.

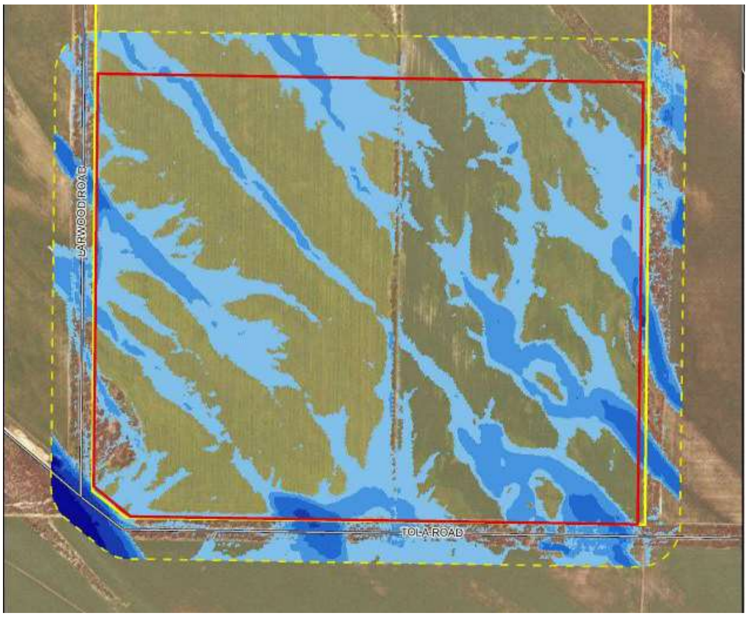

FIG. 3. Modelled PMF event. [4]

Groundwater was found to be present in an aquifer at depths more than 20 metres below the ground surface at the site. Samples of the groundwater showed that it is unlikely to be of beneficial use due to its high salinity and low yield, and no bores abstracting water for use were found in the local area. The waste disposal and storage structures at the facility will be designed to sit above ground, noting that some parts of the current ground surface will be removed to create flat surfaces, so the structural foundations will not intrude into the aquifer. This reduces the likelihood of creating a pathway for radionuclides (and other hazardous materials) in the waste to migrate into groundwater. The presence of kaolin clays above the water table may also limit radionuclide migration in the unlikely event of subsurface release.

The local area around the site receives low annual rainfall of approximately 347 millimetres, most of which occurs during winter and spring. The average daily maximum temperature is approximately 24°C and the average daily minimum is approximately 10°C. The area can experience extremely high temperatures, with the highest recorded temperature being 46°C in 2013. Climate projections indicate that the region will become hotter and drier in the long term, with less frequent but higher intensity rainfall events. Climate change considerations will be incorporated in the design of the facility.

A study of published data did not indicate any presence of elevated background radiation levels at the site. However, an area of elevated thorium levels was detected by an aerial radiometric survey, just to the east of the site. This is shown in Fig. 4. Further ground-truthing surveys will be conducted to establish the background radiation levels and determine the natural radioactivity of dust, soil and water samples collected on site.

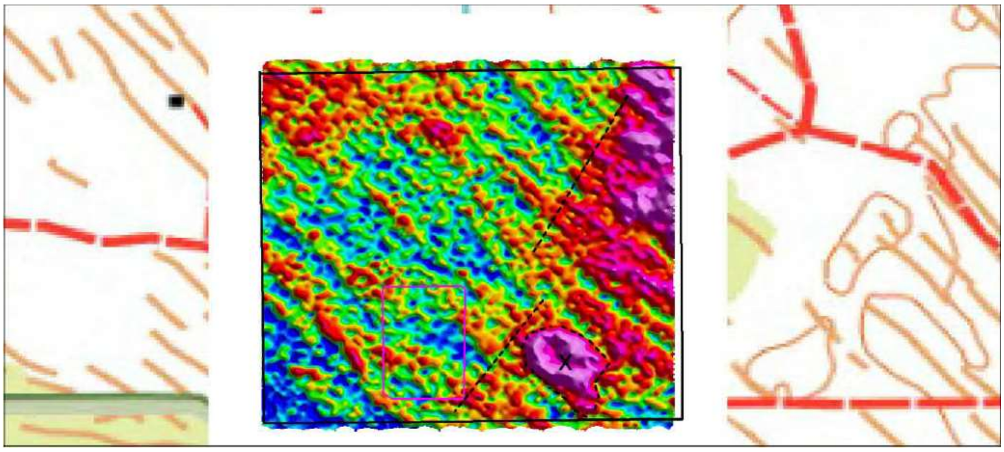

FIG. 4. Thorium anomaly. [5]

4. SAFETY CASE AND REGULATORY APPLICATIONS

The next phase of work will involve further detailed site investigations to determine the site characteristics and data required for development of a facility schematic design and a safety case. The safety case will demonstrate the operational and long term safety of the facility, taking account of the existing environmental conditions at the site, the design of the facility, and the characteristics of the waste to be disposed or stored. This will then enable the preparation of documents for regulatory applications.

In Australia, the relevant regulators are:

— ARPANSA, which is responsible for regulating the siting, construction, and operation of any radioactive waste management facility;
— ASNO, which is responsible for regulating nuclear material;
— The Australian Government Department of Agriculture, Water, and the Environment (DAWE), which is the federal regulator under the EPBC Act 1999 for projects that are of significant environmental interest.

To guide this process, the ARWA has drafted a safety strategy, which sets out a phased and iterative approach to developing the facility design and the operational and environmental safety cases throughout the facility lifespan. The safety strategy describes the current basis for operational safety taking account of the anticipated LLW and ILW operations, LLW and ILW facility concept designs, and dose optimization principles. A defence in depth approach is used for the LLW disposal concept, and safety functions, including potential isolation and containment features, are discussed. The development of scenarios using features and processes associated with the site characteristics will inform the long term safety assessment and dose modelling.

The basis for the LLW disposal safety concept and long term safety functions primarily comprises these passive features:

(a) The radiological aspects of LLW, including the radionuclide concentration and composition of the disposal inventory, will be limited and controlled using waste acceptance criteria (WAC). This will limit the overall radiotoxicity of the disposed waste and the longevity of the hazard it presents to the environment.
(b) The facility design concept for the near field and the near surface engineered disposal system, shown in Fig. 5, including:
    (i) The vault construction materials and the backfill around the waste packages;
    (ii) The facility capping design;
    (iii) The waste form, and particularly the chemical and physical compatibility of the waste form with the near field and the site characteristics.

    Each of these design features contribute to one or both safety functions of containment and isolation.
(c) The site geology and the geosphere will provide the safety function of limiting and delaying the migration of radionuclides to the biosphere through sorption and attenuation.

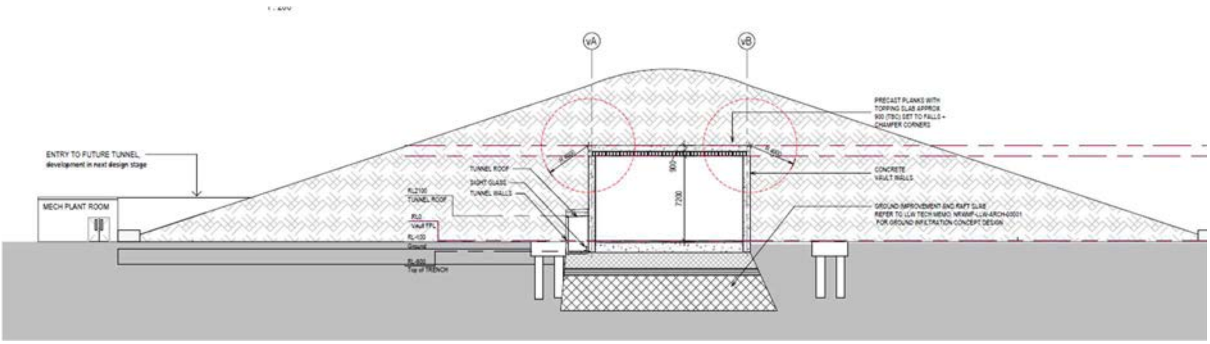

FIG. 5. Transverse section through completed, covered LLW disposal vault complex and earth mound. [6]

The containment function can be achieved through limiting contaminant releases from the waste forms, limiting water flow through the disposal system, and chemical attenuation of contaminant migration. The isolation function can be achieved through reducing the likelihood and consequences of inadvertent human (or biota) intrusion and ensuring stable physical conditions for the disposal system.

Overall, the safety concept will demonstrate that the disposed waste will be contained and isolated from the biosphere over the period where the waste remains hazardous, particularly for the period for decay of short lived radionuclides. Figure 6, taken from the safety case for the Dessel site in Belgium, illustrates how safety functions and other measures will operate during the operational and post-closure periods as the risk from the radionuclide source term declines. The aim is to ensure the risk to humans and the environment, resulting from the levels of radionuclides, which eventually reach the biosphere, are acceptably low.

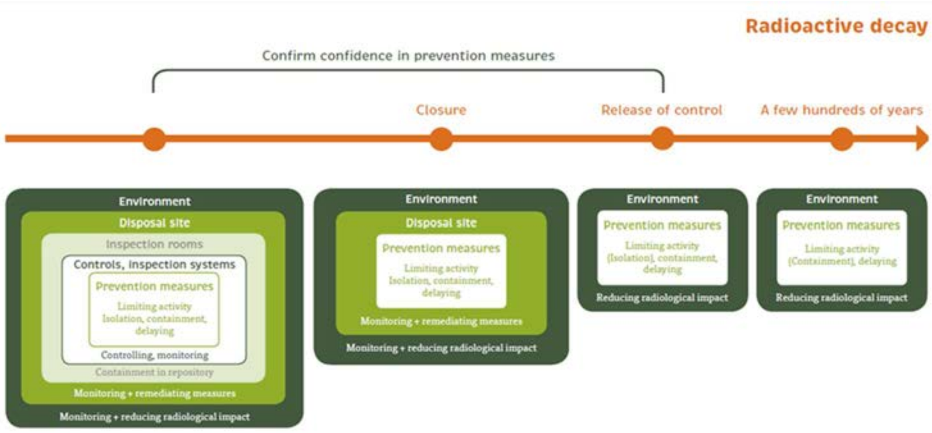

FIG. 6. Evolution of safety functions over time for LLW disposal. [7]

The site characteristics for the Napandee site, as described previously, will likely contribute to and support the safety functions. The site is located far inland in stable geology with deep saline groundwater overlain by a clay layer. Certain emergency scenarios, such as earthquakes and tsunamis are very unlikely, while the impact of other events like flooding or bushfire are limited by the landform and sparse vegetation. Initial work suggests the layered materials in the vadose zone have potential to provide a containment function through radionuclide sorption. This will be confirmed through further site studies, including soil analyses and solute transport modelling, and could be credited to the safety case arguments.

Suitable computer programs will be used for modelling radiation doses to receptors in the biosphere, including humans, plants, and animals (biota) living in or affected by the local environment at the site. The radionuclide fluxes in the near field and geosphere and the resulting long term risk from radiation dose for humans will be modelled. Separate modelling will be conducted for dose to biota. Current research into incorporating semi-arid environments in the modelling programs, which currently have default inputs assuming a temperate zone, will help to account for the environmental setting in regional Australia.

Further site studies will provide greater detail and certainty to the site characteristics, some of which will be essential data inputs to the radiation dose models described earlier. They will also establish important background measurements to provide a baseline for future environmental monitoring. These outputs will be used to assess the features, events, and processes associated with the site and their impacts on safety, through the development of normal and variant scenarios for the evolution of the disposal system and safety functions.

5. CONCLUSION

A site at Napandee was identified as the preferred location for the NRWMF after assessment of site characterization data from three sites in South Australia. The final selection of a site remains at the discretion of the Australian Government's Minister for Resources. The NRWMF will be Australia's first purpose-built facility for the consolidated management of radioactive waste.

The site characteristics at Napandee are likely to contribute to the safety functions of the waste disposal system. The ARWA will conduct further site studies to enable analyses of the features, events and processes involved in various evolution scenarios, as well as dose modelling and safety analyses of long term risk to humans and the environment. The ARWA will present these safety arguments to regulators in a safety case, as part of licensing applications, and will continue to update the safety case throughout the various licensing stages during the lifespan of the facility.

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3.7. SESSION 7 – MULTINATIONAL COOPERATION IN RADIOACTIVE WASTE MANAGEMENT

Multinational cooperation is of course the bedrock on which the IAEA is founded and several of the collaborative projects related to radioactive waste management have been discussed in previous Sessions. However, there are other international bodies that also promote multinational cooperation and this Session provides an opportunity for their work to be showcased.

In this Session there are presentations from the European Commission, World Nuclear Association (WNA) and OECD Nuclear Energy Agency (NEA) describing their work and collaborative programmes in the field of radioactive waste management.

Regulatory bodies have also formed international groupings which are designed to promote harmonization of regulations and promulgation of best practice. The Western European Nuclear Regulator's Association (WENRA) and Forum of Nuclear Regulatory Bodies in Africa (FNRBA) presented papers describing their work, initiatives to harmonise approaches through peer review and benchmarking and successes in improving the regulation of radioactive waste management.

The Chernobyl accident of 1986 has necessitated a major cleanup operation involving reactor decommissioning, environmental remediation, waste management activities and provision of new facilities on a major scale, in addition to the well-publicised New Safe Confinement structure installed in 2016. The scale of this undertaking is so large that it has necessitated an international cooperative effort to achieve involving both IAEA and the European Bank for Reconstruction and Development and a host of other international partners and contractors. This Session included a paper from Ukraine detailing the scale and challenge of the operation.

The clear message from these case studies is that all waste management programmes can learn from other's experience, public confidence is enhanced by inviting international benchmarking and peer review and working together on common problems and research offers opportunities to leverage additional resource both financial and intellectual. The Session also highlighted the importance of international standards and guidance and the benefits to be accrued from harmonization and improvement of regulatory frameworks around common safety standards.

Session Chairs: E. Verhoef (Netherlands) and H. Castro (Argentina)

Session 7 comprised seven papers from EC, WENRA, WNA, OECD NEA, Morocco and Ukraine, with an additional paper from one of the conference's Young Professionals Showcase Leads (United Kingdom).

- **Paper ID#314 by M. Krause (IAEA)** provided an overview of the IAEA's role in supporting multinational cooperation in radioactive waste management with a focus on the role of the IAEA Technical Cooperation Programme in fostering the safe and peaceful use of nuclear technologies. The IAEA helps Member States build their capacities in nuclear power, as well as nuclear applications in health, environment, and industry. In total, the IAEA currently assists 146 Member States over a wide range of topics, including the safe management of radioactive wastes generated by these applications through disposal.
- **Paper ID#96 by L. Théodon (EC)** described the European Joint Programme on Radioactive Waste Management (EURAD) which was launched in 2019 with the objectives to implement a robust and sustained research and technology programme, consolidate efforts on knowledge management, to investigate complex issues and identify emergent ones and to foster mutual understanding between participants as well as other stakeholders. The programme has 13 work packages in progress, is about to initiate a second wave of packages and has

implemented a knowledge management programme and strategy. It has also initiated a successful outreach programme to civil society.

- **Paper ID#230 by S. Morgan (WENRA)** described the work of the Western European Regulators Group (WENRA) which has been established with the aim to develop a common approach and to exchange experience and knowledge on nuclear safety. The grouping comprises the regulatory bodies of 18 European countries and 13 associated members and observers. The Waste and Decommissioning Working Group (WDWG) is charged with addressing the regulatory aspects relating to radioactive waste, spent fuel and decommissioning matters.
- **Paper ID#76 by K. Mrabit (FNRBA)** described the work of the Forum of Nuclear Regulatory Bodies in Africa (FNRBA) network which was established in 2009 and recognized as a Regional Intergovernmental Organisation in 2019. The grouping has established six working groups, of which the Radiation and Waste Safety group follows all matters in connection with radioactive waste, spent fuel and sealed sources. FNRBA plays an important role in promoting best practice, sharing of experience and advancing the safety of radioactive waste management in African countries.
- **Paper ID#296 by M. Pieraccini (WNA)** presented lessons learned on radioactive waste management from reactor decommissioning from the perspective of the World Nuclear Association (WNA). The lessons and subsequent recommendations are applicable and of relevance to all involved in the decommissioning industry. For waste management, he recommends there should be harmonization of national regulations so they align with agreed international directives. Of particular note is the suggestion that all should share the same definition of waste and waste categories.
- **Paper ID#306 by R. Tadesse (OECD NEA)** described the role of OECD NEA and in particular NEA activities related to radioactive waste management. NEA assists 34 member countries in the development of safe, sustainable and societally acceptable strategies for all types of radioactive waste. Its activities are governed by nine standing technical committee which bring together government officials, technical specialists and strategic partners to solve difficult problems, establish best practices and promote international collaboration. Two committees were highlighted: the Radioactive Waste Management Committee and the Committee on Decommissioning of Nuclear Installations and Legacy Management. Examples of their work and successes in the realm of safety case development, building public trust and publication of respected policy documents were highlighted.
- **Paper ID#299 by O. Miasnykov (Ukraine**) presented an overview of international cooperation within radioactive waste decommissioning and cleanup projects at Chernobyl. Both IAEA and the European Bank for Reconstruction and Development have played significant roles as have many other international partners. One of the significant issues on the site was the need to treat and manage water and liquid radioactive waste containing organics and trans-uranic materials. A treatment process and conditioning plant for these liquid wastes and likewise for solid wastes were successfully developed as part of an IAEA Technical Cooperation project. Other projects have addressed graphite, contaminated soils, waste characterization and training for personnel.
- **Paper ID#155 by C. Wighton (United Kingdom)** presented a project initiated by the NDA to develop and implement a strategy to support and deliver the next generation of young professionals to continue the work of remediating the UK's legacy nuclear sites. It is estimated that the workforce will need to grow by over 4,000 over the next six years to overcome the challenges associated with the ageing workforce. A number of initiatives are described.

Paper ID#314

MULTINATIONAL COOPERATION IN RADIOACTIVE WASTE MANAGEMENT

Keynote Address

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Abstract

There are 32 countries operating nuclear power plants in the world today, making up only about 20% of IAEA Member States. While the other 80% do not have a nuclear power programme, they still benefit from the use of nuclear technologies and techniques over a wide range of applications in health, environment, and industry, all of which generate radioactive waste. Having access to information and knowledge about different options for that waste is crucial for countries' own waste management solutions. The IAEA is very well suited to serve as a hub or a platform where such information and knowledge can be shared and to foster international cooperation, particularly through its technical cooperation programme. This presentation demonstrates the work of the IAEA to build Member States' capacities and capabilities in the peaceful use of nuclear technologies.

The paper is presented as a verbatim speech delivered by M. Krause as the keynote address for Session 7 – Multinational Cooperation in Radioactive Waste Management.

1. INTRODUCTION

Thirty-two countries operate nuclear power plants in the world today, which means that about 80% of IAEA Member States do not have a nuclear power programme. However, they still benefit from the use of nuclear technologies and techniques over a wide range of applications in health, environment, and industry. All these activities generate waste that has to be managed. As we all know, there is no single solution to managing different levels of waste, so it is not something that can simply be replicated from one national context to another. Having information and access to knowledge about different solutions is important because it helps countries to develop and implement their waste management solutions, within their own national context. But having information and access to knowledge is also important for innovation in this field, achieved through cooperation among international experts and governments. The IAEA is very well suited to serve as a hub or a platform where such information and knowledge can be shared and to foster international cooperation.

2. IAEA TECHNICAL COOPERATION PROGRAMME

One of the main mechanisms through which the IAEA transfers knowledge and technologies to Member States is the technical cooperation programme. Through this mechanism, the IAEA builds capacity in Member States for the safe and peaceful use of nuclear technology, and we do so at several levels. To enable experts to improve their skills, we run workshops, symposiums, meetings, we sponsor scientific visits and organize fellowships. We help institutions strengthen their ability to manage radioactive waste. This is done through working with the regulator, operator or for example a privately or publicly owned company where waste is generated. Finally, we support our Member States in assessing their national laws, agreements, and regulatory frameworks, while promoting strong sustainable global nuclear safety and security frameworks.

To do this as efficiently and effectively as possible, we listen to our Member States to understand their priorities and needs and work with them to achieve their goals. National governments play a crucial role in multinational cooperation. In the area of waste management, as in other areas, multinational cooperation can only happen with strong national support. That means establishing adequate policy framework, defining priorities, and funding and guiding the cooperation activities.

Through the technical cooperation programme, the IAEA provides support to 146 Member States on the order of 84.5 million euros per year. Another 12.3 million are provided through extra budgetary resources. We support our Member States in seven areas: water and environment, energy, health and nutrition, food and agriculture, radiation technology, knowledge management, and safety and security. Support in radioactive waste management is provided across all these areas.

Technical cooperation projects can be developed and implemented at the national, regional, and interregional level. About 60% of projects are implemented at the national level, with more focus on building infrastructure and addressing countries specific needs. The projects on the regional and interregional level directly support multinational cooperation, by providing networking and experience sharing on issues of common interest.

The nature of IAEA assistance in radioactive waste management is diverse. It includes bringing best practices and proven strategies to our Member States to help them build their own national radioactive waste management infrastructure. In addition to providing access to expert advice, training workshops, fellowships, and scientific visits, we also support Member States in obtaining needed equipment, materials, and services. We help countries to safely manage radioactive waste whether generated from the medical applications, from basic research, from the operation of existing or planned power reactors, or other activities. The assistance may include technical, regulatory, and safety oriented aspects in the management of different kinds of radioactive waste. It can range from the generation and classification of waste, waste treatment and conditioning, storage, and finally through disposal in properly designed and constructed safe disposal facilities. Support may also include the development of strategies for regulating discharges to the environment, decommissioning of facilities and environmental remediation of contaminated sites or the management of radioactive residues from legacy sites. Our support is always provided in accordance with IAEA safety standards and good practices.

Over the past two years, the IAEA support related to radioactive waste management accounted for about 20% of our biennial budget, or about 14 million euros. And there have been many successful projects. One of them is China’s selection of a site for their underground research laboratory, which will be used to confirm the suitability of the host rock for a high level waste repository. Another is the development of a new approach to the management of disused sealed radioactive sources, which is simpler and more cost effective. We have conducted more than 15 expert missions and 18 training courses on waste management through a series of interregional technical cooperation projects.

3. TRANSNATIONAL PARTNERSHIPS

Finally, we cannot talk about multinational cooperation without highlighting the role of transnational partnerships. Through partnerships, we implement joint research activities, develop norms and standards, and shape educational programmes. Partnerships enable us to be more effective in building capacity, in exchanging knowledge and information. We already have some great examples, and you will hear about them during this session. It is my hope that this session will also forge some new partnerships and I encourage you to talk to each other, ask questions, and learn about potential common initiatives. By working together, we can build and enhance the national and international knowledge and capacity base needed for the sustainable management of radioactive waste, now and in the future.

Paper ID#96

EURAD: A STEP CHANGE IN EUROPEAN JOINT COLLABORATION TOWARDS SAFE RADIOACTIVE WASTE MANAGEMENT

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Abstract

Within the domain of radioactive waste management (RWM) and deep geological disposal, the European Commission (EC) has funded research and development (R&D) for over 40 years, fostering what is today a strong cooperation between European waste management organizations (WMO), regulatory technical support organizations (TSO), and research entities (RE). The underpinning technical knowledgebase is now sufficient to allow Europe to be on the verge of operation of its first geological disposal facilities for spent fuel and/or high level and intermediate level long lived radioactive wastes. Despite this progress, continued R&D is necessary to develop, maintain, and consolidate knowledge throughout the stepwise development, increase safety margins and disposal robustness, support optimization, and integrate scientific and technological progress over long time of disposal facilities operation to the closure.

In a step change from a previous model of individual projects to a more enduring and integrated programme of cooperation activities between European Union (EU) Member State (MS) National Programmes, the European Commission has established the European Joint Programme (EJP) of collaborative research called EURAD.

Launched in 2019, EURAD is an initial 5-year EJP on RWM, built based on activities of shared importance between WMOs, TSOs, and nationally funded REs. Guided by a shared vision, roadmap, and strategic research agenda, EURAD supports MS at various stages of geological disposal implementation and focusses on scientific and technological R&D, aligned to implementation needs, scientific excellence and safety considerations and underpinned by an ambitious knowledge management programme.

EURAD's concept is to generate new and manage existing knowledge to support MS in implementing Directive 2011/70/EURATOM and, more specifically, to support and complement the national programmes in their development and delivery of safe, long term management solutions for different types of radioactive wastes, taking into account different programme sizes and stages of advancement.

1. A LEAP FORWARD

Over the last 40 years, Europe has acquired considerable scientific and technical knowledge concerning radioactive waste management (RWM), which has enabled countries to progress toward licensing geological disposal facilities (e.g. Finland, Sweden, and France) and contributed to the progress of numerous Member States' disposal programmes [1].

Recently, the European Commission (EC) has promoted a step-change in European research cooperation between European Union (EU) Member State national programmes by replacing EU competitive calls for projects with promoting inclusive joint research and development (R&D) programmes in Europe that attract and pool a critical mass of national resources on specific shared needs and challenges. The objective is to promote and co-fund an ambitious programme that brings together mandated entities from EU Member States and associated countries able to direct national funding and/or with national responsibilities to manage RWM R&D.

Based on the positive achievements of the European JOPRAD project to study the feasibility of creating such an EJP in the field of RWM, a first five-year European Joint Programme on Radioactive Waste Management (EURAD) was launched in 2019.

1.1. The vision

EURAD pushes for a step change in European collaboration toward safe RWM, including disposal, through the development of a robust and sustained science, technology, and knowledge management programme that supports timely implementation of RWM activities and serves to foster mutual understanding and trust between Joint Programme participants [2].

The aim is to implement a research programme and knowledge management activities of common interest at the European level, bringing together and complementing EU Member State programmes to ensure cutting-edge knowledge creation and preservation in view of delivering safe, sustainable, and publicly acceptable solutions for the management of radioactive waste across Europe now and in the future.

Research, Development and Demonstration (RD&D) efforts in RWM, including disposal, are necessary to:

- Develop, maintain, and consolidate scientific and technical knowledge throughout the progressive development, operation, and closure of disposal facilities, which will be spread over many decades and make this knowledge available to all end users;
- Ensure the optimization of waste management routes and of disposal solutions;
- Address evolving regulatory concerns;
- Reduce the risk of shortages of the skilled, multidisciplinary human resources needed to develop, assess, license, and operate facilities for RWM;
- Reinforce knowledge transfer and collaboration between advanced and less advanced programmes of European Member States;
- Contribute to gaining and maintaining public confidence.

EURAD supports implementing the Waste Directive in EU Member States, considering the broad spectrum of stages of advancement of national programmes, particularly with respect to their plans and national policy towards implementing geological disposal. Programmes differ significantly depending on the national waste inventory, with some member states only responsible for relatively small volumes of medical and research reactor wastes, compared to others that have comparatively large and /or complex waste inventories from large nuclear power (and fuel reprocessing) and defence programmes [3]. Programmes also differ significantly in the way in which they are managed, regulated, and funded, particularly with respect to the national policy and sociopolitical landscape in relation to longer-term storage and geological disposal.

EURAD, therefore, gathers Members States:

- With no nuclear power programme operating, but with research, training, or demonstration reactors, and/or other sources of radioactive waste;
- With a nuclear programme;
- At different stages of advancement in the implementation of their national RWM programme;
- With plans for geological disposal for spent fuel, high level waste, and long-lived intermediate level waste, with different host rocks and different disposal concepts and at different stages of implementation [3].

1.2. A community

In EURAD, participation as a Beneficiary is limited to organizations that have received a mandate by their national programme owner(s) (ministry, national–regional authority, or private organization in charge of establishing and managing a national programme) and that are willing to adopt and share in the EURAD Vision/Strategic Research Agenda and Roadmap for European collaborative R&D.

115 organizations, from 23 European countries (20 Member States and 3 associated countries) are working in EURAD: 51 are mandated organizations and 61 are Linked Third Parties to the mandated actors and 3 are international partners. All participating organizations are part of one of the three EURAD colleges:

— Waste Management Organizations (WMOs) having the ultimate responsibility for the implementation of geological disposal (which includes the management of a supporting research, design, and development (RD&D) programme [4]), and for some other topics of RWM (e.g. waste characterization, treatment and packaging, interim storage, etc.). WMOs from across Europe form a core part of the Joint Programme and provide a driving force for what is needed for successful, safe, and practical implementation from an industrial perspective. WMOs conduct RTD their own programmes and have established a network and coordination framework for RD&D needs of the implementers of geological disposal at the European level via the Implementing Geological Disposal Technology Platform (IGD-TP) [4].
— Technical Support Organizations (TSOs) carrying out activities aimed at providing the technical and scientific basis for supporting the work and decisions made by a national regulatory body [4]. This includes the safety cases for waste processing, storage, and disposal development, as well as the safety case reviews and independent scrutiny responsibility by regulatory organizations in the framework of the decision making process. In contrast, regulators supervising EURAD members are not part of the EURAD. Several TSOs, together with other organizations fulfilling a regulatory expertise function and Civil Society Organizations have established the SITEX network to support independent technical expertise in geological radioactive waste disposal safety [4].
— Research Entities (REs) working to different degrees on the scientific challenges of RWM, including disposal (and sometime in direct support to implementers or WMOs or TSOs), under the responsibility of Member States [4]. This includes national research centres, as well as research organizations and universities. RE's ensure scientific excellence and leading-edge research related to managing radioactive waste and, therefore, represent an important proportion of the contributions to the Joint Programme. The RE's have established the EURADSCIENCE network, an inclusive network to ensure scientific excellence and credibility to RWM.

A group of representatives of the European Civil Society Organizations who are involved in RWM activities at EU or national level are also participants of EURAD through participation of a Civil Society expert group that follows technical work packages leading to an improved understanding of RD&D performed in the perspective of safety. A process has been defined to select the members of this group to allow an equilibrium between representatives of all EU countries and a quite well balanced gender representability.

1.3. The governance

EURAD cooperation is structured via a specific governance composed of a general assembly, a bureau, a programme management office, and a coordinator.

The General Assembly (GA) is the ultimate decision making body, which is composed of a member of each Mandated Actor and responsible for agreeing the strategy in line with the content of the founding documents and Euratom Work Programme.

The Bureau is an accompanying body to the GA and is composed of three representatives from each College and assists the GA in defining the second wave of R&D and strategic studies, the work plan for knowledge management, and updating the EURAD Strategic Research Agenda and Roadmap. The Bureau acts in close interactions with the Programme Management Office.

The Programme Management Office (PMO) oversees scientific and technical coordination of the implementation of the programme, as well as day-to-day management and communication activities. It is responsible to the GA for the overall top-level work plan planning, coordination, and implementation.

The Coordinator is the legal entity acting as the intermediary between the Beneficiaries and the EC [5].

Sixteen work package leaders, with support from task leaders and sub-task leaders, supervise work programme execution.

The EURAD governance is completed by an appointed Chief Scientific Officer whose role is to enforce the scientific leadership on aspects of science, technology, and knowledge management and to act as a high level spokesman able to contextualize EURAD's progress.

In addition to the initially planned EURAD governance mechanisms, after a year of operation, an independent External Advisory Board (EAB) was created to operate at a more strategic level. Composed of four distinguished members, the EAB focus is to ensure:

— The EURAD consortium is well informed and acts upon the expectations of "the outside world";
— The EURAD programme is visible to the outside world.

The members act to provide expertise, a balanced perspective, and strategic advice to support EURAD as it establishes and delivers a step change in European collaboration toward safe RWM.

2. DEPLOYMENT PLAN

The cooperative research over the coming decades will be guided by a common vision as described but also by a Roadmap, shared Strategic Research Agenda and an Implementation Plan. This strategic approach will foster scientific capability and enhance the knowledge needed to implement safe management solutions, including disposal, of radioactive waste, promoting European research and delivering beneficial societal and economic impact for EU citizens [4].

2.1. Roadmap

The EURAD Roadmap is a roadmap for implementing RWM, leading to geological disposal. It is a representation of a generic RWM programme that has to enable users and national programmes to 'click-in,' and access existing knowledge and active work or plans in EURAD and elsewhere [6].

The content is focused on what knowledge and competencies (including infrastructure) are considered most critical for implementing RWM, aligned to the EURAD vision.

For each phase of the disposal programme from programme initiation over site identification and site selection and characterization over facility construction, operation and closure, the roadmap describes typical programme goals, activities, and capabilities needed against the 7 Themes: (1) project management, (2) predisposal, (3) engineered barrier system, (4) geoscience, (5) design and optimization, (6) siting and licensing, and (7) safety case.

These themes are each further broken down into Subthemes and Domain Insights, in what is called the Goals Breakdown Structure [7]. The Roadmap allows one to identify gaps in knowledge and competencies needed individually by each of the member states to take action accordingly.

The Roadmap provides a common set of rules for contextualising knowledge, a common structure or schema for categorising knowledge, and common language and glossary – aligning where possible with glossaries and schema from IAEA, NEA and advanced (RWM) programmes. Experts have also evaluated a high level view on the current status of knowledge across each of the seven themes, identifying in a rough sense where resources exist and where efforts should be focussed as a programme evolves through successive phases of a waste management programme.

2.2. Strategic research agenda

The EURAD Strategic Research Agenda (SRA) provides a description of scientific and technical (S–T) themes and sub-themes of common interest between the colleges. It should not be considered as an exhaustive list of all R&D initiatives or active work within Europe and includes only those that were considered relevant for cooperative work between EURAD colleges. The SRA is structured by the previously mentioned seven scientific themes, as illustrated in Fig. 1, and should allow to capture all relevant areas for implementing waste management solutions. Although all technical in nature, theme 1 is overarching; themes 2 to 5 are predominantly focussed on fundamental science, engineering, and technology; and themes 6 and 7 include aspects focussing more on applied science and integration [8].

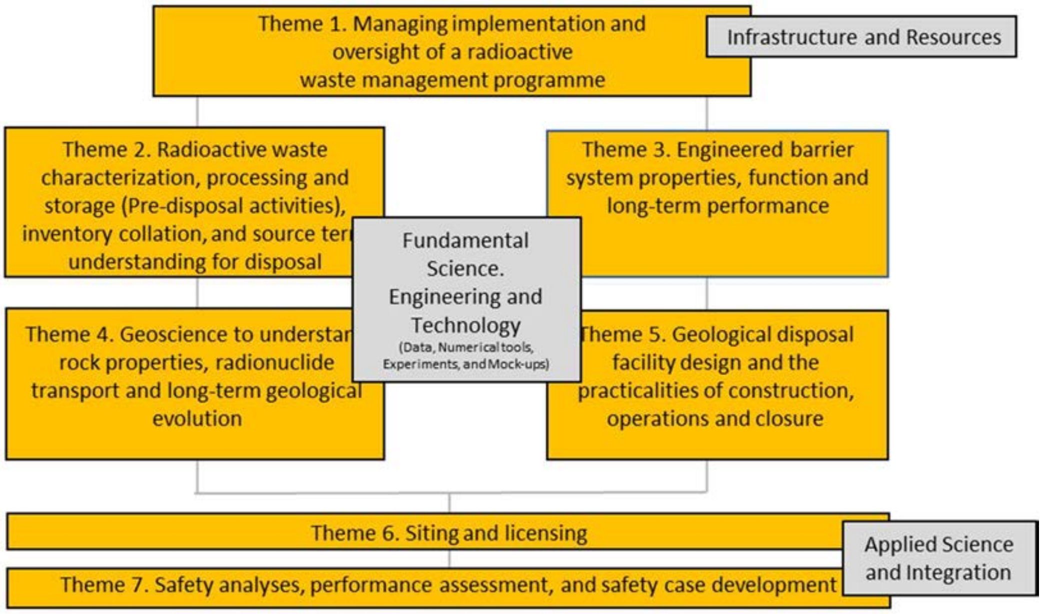

FIG. 1. EURAD strategic research agenda themes [8].

The S–T scope in the SRA covers cutting-edge S–T activities on RWM from cradle to grave, including predisposal, interim storage, and disposal solutions – mainly geological disposal of spent fuel, high level waste (HLW), and intermediate level waste (ILW). The EURAD SRA has been set up as a dynamic and living document that has to be updated periodically to integrate outcomes of RD&D activities as well as any emerging collaboration needs identified by the RWM community during the implementation phases of EURAD [8].

2.3. Deployment

To deliver against EURAD objectives, different types of activities have been adopted and are each briefly described here.

RD&D activities – The main activities of EURAD consists of RD&D activities aiming at developing and consolidating scientific and technical knowledge for themes as identified in the EURAD Strategic Research Agenda and Roadmap. There has to be a balance between operational RD&D in direct link with implementation of repository concepts, as well as concerns to safety requirements and prospective RD&D such as short and long term experiments and/or modelling work to demonstrate the robustness of the waste management concepts, to increase understanding and predictability of the impact of fundamental processes and their couplings together with their associated uncertainties, and to maintain scientific excellence and competencies throughout the stepwise long term management and disposal of radioactive waste [4].

Strategic Studies – Complementary to RD&D activities and in support of the implementation of the Member States' national programmes, Strategic Studies need to give the opportunity to participants and expert contributors to network on methodological and strategic challenging issues that are common to various national programmes, often in close link with scientific and technical issues.

Knowledge management – Beyond RD&D and Strategic Studies, a large effort of EURAD is to consolidate efforts across Member States on Knowledge Management – this includes providing access to existing Knowledge (State-of-Knowledge), guiding the planning and implementation of a RD&D plan of national RWM programme, and developing–delivering training and mobility opportunities in line with identified core competencies.

Civil Society engagement – Specific interactions with Civil Society are organized as cross-cutting tasks providing access to knowledge–results and corresponding feedback that can be directly embedded in specific technical and strategic work packages.

The coordinator of EURAD is supported for the day-to-day work by the PMO, which is responsible for the proper coordination and implementation of the overall EURAD work plan as approved by the GA.

2.4. Flexibility mechanisms

Some flexibility had to be maintained in defining the programme to enable EURAD's ambition to be as needs-driven as possible and inclusive (allowing the integration of new organizations) (Fig. 2). At the start of the programme, this flexibility was implemented for R&D and strategic studies with only 70% of the budget being allocated. A year after the launch, the remaining 30% has been allocated through a second wave.

EUROPEAN JOINT PROGRAMME ON RADIOACTIVE WASTE MANAGEMENT (EURAD)							
EURAD 1 Work Packages (2019-2024)		Indicative Budget	EURAD Strategic Research Objectives	EURAD Beneficiaries			
		Total Cost (EC + Beneficiary Contributions)	How the Work Package will address objectives, priorities and activities of high common interest in the EURAD Strategic Research Agenda	WMOs	TSOs	REs	Coordinator
				◆ = Beneficiary Organisation; ◇ = Coordinating Beneficiary Organisation			
	Programme Management Office	**7%**					
WP1	Administration, Scientific Coordination, Communication and Dissemination	€3.5 M		◆◆	◆	◆◆	**ANDRA (France)**
	Collaborative RD&D	**75%**					
WP2	Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED)	€5.1 M	Multiscale approach and process integration to improve long-term modelling and assessments .	◆◆◆◆◆	◆◆◆◆◆	◇◆◆◆◆◆◆◆	**SCK-CEN (Belgium)**
WP3	Cement-Organics-Radionuclide-Interactions (CORI)	€4.7 M	Improved understanding of the role of organics (either naturally occurring or as introduced in the wastes) and their influence on radionuclide migration in cement based environments.	◆◆	◆◆◆	◇◆◆◆◆◆◆◆◆◆	**KIT (Germany)**
WP4	Development and Improvement of Numerical Methods and Tools for Modelling Coupled Processes (DONUT)	€3.7 M	Improved understanding of the upscaling of THMC modelling for coupled hydro-mechanical-chemical processes in time and space.	◇◆◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆◆	**ANDRA - BRGM (France)**
WP5	Fundamental Understanding of Radionuclide Retention (FUTURE)	€4.6 M	Quantification of long-term entrapment of key radionuclides in solid phases to inform reactive transport models and the influence of redox.	◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆◆	**FZJ (Germany)**
WP6	Mechanistic Understanding of Gas Transport in Clay Materials (GAS)	€5.6 M	To increase understanding and predictability of gas migration in different host rocks.	◇◆◆◆◆◆◆	◆◆◆	◆◆◆◆◆◆◆◆◆	**ONDRAF/NIRAS (Belgium)**
WP7	Influence of Temperature on Clay-based Material Behaviour (HITEC)	€5.3 M	Improved THM description of clay based materials at elevated temperatures.	◆◆◆◆◆◆◆◆◆◆	◆◆	◇◆◆◆◆◆	**VTT (Finland)**
WP8	Spent Fuel Characterisation and Evolution Until Disposal (SFC)	€5.8 M	Reduce uncertainties in spent fuel properties in predisposal phase.	◇◆◆◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆◆◆◆	**SKB-UU (Sweden)**
WP15	CONtainer CORrosion under Disposal conditions (ConCorD)	€4.8 M	Evaluate cooperatively the long-term behaviour of container materials to such an extent as to be able to ensure confidence in the performance of engineered barriers	◇◆◆◆	◆◆	◆◆◆◆	**Nagra (Switzerland)**
WP16	Chemo Mechanical AGIng of Cementitious materials (MAGIC)	€4.2 M	Increase the confidence in Chemo-Mechanical simulations by reducing uncertainties in input data and understanding of key coupled	◆◆◆◆	◇◆◆	◆◆◆◆◆◆◆	**IRSN (France)**
WP17	Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure (MODATS) *	€4.7 M	Evaluate, develop and describe methods and technologies and to provide the means to measure, treat, analyse and manage data in a consistent manner	◇◆◆◆◆	◆◆◆	◆◆◆◆	**ANDRA (France)**
	Strategic Studies to Address Complex Issues and Expert Networking	**10%**					
WP9	Waste management routes in Europe from cradle to grave (ROUTES) *	€1.9 M	Waste Management Routes across Europe considering different waste types and their specified endpoints.	◆◆◆◆◆◆◆◆◆◆◆◆	◇◆◆◆◆◆◆◆◆◆◆◆◆	◆◆◆◆◆◆◆◆◆◆◆	**IRSN (France)**
WP10	Uncertainty Management multi-Actor Network (UMAN) *	€2 M	Further refinement of methods to make sensitivity and uncertainty analyses and the development of a multi-actor network for uncertainty management.	◆◆◆◆◆◆◆◆	◇◆◆◆◆◆◆◆◆◆◆	◆◆◆◆◆◆◆◆◆	**BelV (Belgium)**
	Knowledge Management	**8%**					
WP11	KM State-of-Knowledge (SoK)	€1 M	To maintain information, knowledge and records over the long lead- and implementation-timelines of geological disposal programmes, from pre-licensing through to the post-operational phase.	◇◆	◆◆	◆◆	**BGE (Germany)**
WP12	Guidance	€0.7 M	To identify RD&D and knowledge transfer needs in support of defining pre-licensing activities that can support success in the siting and licensing phase/process.	◇◆	◆◆◆		**SURAO (Czech Republic)**
WP13	Training & Mobility	€1.2 M	Training and competence maintenance of skills and expertise to support safe radioactive waste management including disposal.	◆◆	◆◆◆	◇◆	**SCK-CEN (Belgium)**

* Interactions with Civil Society

FIG. 2. EURAD Overview of Work Packages (1st and 2nd wave).

This second wave consisted of proposals of new work packages that were of common interest to the three colleges. The EURAD Bureau developed a specific selection process, open to new partners, with different steps, such as a long list of eligible proposals, a consolidated list, a short list, and a time for development of the selected work packages before their submission to the GA and EC. For the knowledge management, the principle of flexibility is ensured by a yearly allocation of the budget. This has allowed at the end of the second year to redefine and plan new knowledge management activities and to allocate budget to finance those activities.

3. AMBITION

As stated above, the main goals of EURAD are to:

- Support Member States in developing and implementing their national RD&D programmes for the safe long term management of all radioactive waste types through participation in the RWM Joint Programme;
- Develop and consolidate existing knowledge for the safe start of operation of the first geological disposal facilities for spent fuel, high level waste, and other long lived radioactive waste, and supporting optimization linked with the stepwise implementation of geological disposal;
- Enhance scientific and technological knowledge management and transfer between organizations, Member States, and generations in a framework of implementation (design and safety) as contextualized area.

3.1. Complement the national programmes

EURAD complements national efforts and enables the effective use of resources and experts by sharing RD&D efforts and by making existing knowledge more easily available to end-users across national boundaries. Overall, the following impacts can be expected:

- Support compliance with European regulations – by supporting Member States in implementing RD&D, developing skills and providing for transparency in order to develop solutions for their radioactive waste [9]
- Support safety of RWM solutions – by contributing to the responsible and safe management of radioactive waste in Europe, including the safe start of operation of the first geological disposal facilities for high level and long lived radioactive waste–spent nuclear fuel, as well as improvement, innovation, and development of science and technology for the management and disposal of other radioactive waste categories
- Help to gain or maintain public confidence and awareness in RWM by fostering transparency, inclusiveness, credibility, and scientific excellence [2]
- Support RWM innovation and optimization by aiding the development of solutions for different waste streams and types and continuously improving and optimizing waste management routes and disposal solutions, including identifying needs specific to small inventory programmes with their distinct challenges with respect to access to critical mass of expertise and developing appropriate disposal options [1]
- Contribute to addressing scientific and technical challenges and evolving regulatory concerns by prioritizing activities of high common interest, and creating conditions for cross fertilization, interaction, and mutual understanding between different Joint Programme contributors and participants
- Foster efficient use of the RD&D resources at the EU level by sharing and advancing existing knowledge, facilities, and infrastructure rather than repeating and duplicating efforts
- Bring together Civil Society partners from different Member States to transpose EURAD RD&D outcomes to the public.

3.2. Ensure the sustainability of the knowledge

The capitalization and transfer of scientific and technical knowledge generated in EURAD is essential. EURAD aims to establish a sustainable, inclusive, transparent, leading-edge scientific, and goal-oriented approach on European collaboration toward safe RWM. The robust and sustained scientific and technological programme will guide cooperative research and investments in the RWM field over the coming decades in Europe. It is developing an approach to ensure preservation and accessibility of publicly financed knowledge generated over the past, ongoing, and future RD&D activities, in close link with needs for implementation (design and safety). This is essential to ensure Member States can take advantage of this knowledge and expertise. Ensuring sustainability in view of the long lead-times and operational time spans for RWM also means to provide support to ensure the necessary expertise and skills are maintained through generations of experts for ongoing and future projects. EURAD provides an opportunity for programmes to collect, share knowledge and experiences, and organize (in a common way) a preservation and transfer between organizations–programmes and for future generations.

This requires acknowledgement of existing knowledge structures and networks, as well as of tacit knowledge, as over 40 years of developed RWM knowledge is codified and accessible in the various documents, procedures and processes, organizations, and people of the RWM community.

The knowledge management role in EURAD is, therefore, to make better use of this existing knowledge and integrate newly created knowledge, giving weight to:

- Importance: Improved orientation of knowledge – how knowledge contributes to specific implementation goals and safety constraints in RWM
- Proficiency: Improved definition of needed competences – what level of proficiency is needed and available to support national programmes
- Codification: Improving accessibility to knowledge by signposting to people, communities of practice and documents, use of a common structure, digitalization, or other codification activities – how knowledge is documented, stored, and easily reused
- Diffusion: Improving socialization, training, and networking, as well as production of guidance documents – how knowledge is transferred and spread
- Reflection and feedback: a number of functions, e.g. chat forum and webinars, are utilised to obtain swift response on produced deliverables–output–activities for continuous improvement.

3.3. Act as a platform

For the first time, EURAD collects a large part of European expertise covering WMO, TSO, and RE aspects, in one collective RD&D, Strategic Studies and Knowledge Managment and Networking programme, thus creating a platform for discussion, networking, and communication.

Uniting organizations in Europe with a key responsibility for directing RD&D on RWM irrespective of the stages of development of their national programmes, EURAD fosters mutual understanding and trust between participants and other stakeholders, including from the civil society.

To avoid duplication of effort and resources and to benefit from participation, exchange, and cooperation with international organizations and expert networks, the PMO have regular exchanges with international organizations, such as the International Atomic Energy Association (IAEA) and the Organization for Economic Co-operation and Development – Nuclear Energy Agency (OECD-NEA), other EU projects, especially the PREDIS project (Predisposal management of radioactive waste) and has now three international partners collaborating in the framework of the work package CONCORD (CONtainer CORrosion under Disposal conditions).

4. CONCLUSIONS

In line with the European waste directive 2011/70/EURATOM, EURAD, the European joint programming in RWM intends to initiate a step change in European collaboration between advanced and early stage programmes on RWM and disposal, as well as between waste management organizations driving for a timely establishment of geological disposal solutions, technical support organizations ensuring safety always remains the priority, and research organizations ensuring scientific excellence through the many decades of any disposal programme.

Two years after its launch, EURAD has achieved most of its objectives and milestones planned for its midterm.

The EURAD colleges have each found their voice, through their Bureau representatives and formal position papers, providing important governance and oversight used to drive EURAD strategy [10].

Most work packages have now reached their third year of implementation and are delivering encouraging results and the launch of the second has been timely implemented and will be further developed by considering lessons learned from the first years of the programme.

It is clear that the ambitious goals of EURAD require a long term perspective over another 10 or more years. The building of confidence, trust, and common understanding among the various categories of actors is a cornerstone of future success.

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WENRA'S SAFETY REFERENCE LEVELS CONTRIBUTE TO CONTINUOUS IMPROVEMENTS AND HARMONISATION OF REGULATORY APPROACHES FOR RADIOACTIVE WASTE MANAGEMENT IN MANY EUROPEAN COUNTRIES

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Abstract

The paper describes the positive impact of Western European Nuclear Regulators Association's (WENRA) Safety Reference Levels (SRLs) in helping to harmonise and improve regulatory approaches for radioactive waste management (RWM) in many European countries. WENRA is a group comprising the heads of the regulatory bodies of 18 European countries, together with 13 associated members and observers from Europe and the rest of the world. WENRA's aim is to develop a common approach to nuclear safety, and to allow chief nuclear safety regulators in Europe to exchange experience and discuss significant safety issues. WENRA has established three thematic working groups, including the Working Group on Waste & Decommissioning (WGWD) which addresses the regulatory aspects relating to radioactive waste (RAW), spent fuel and decommissioning matters, and typically comprises the national regulator's head of department for RWM for each WENRA country. WENRA has developed six sets of Safety Reference Levels (SRLs), which reflect expected practices agreed by the regulatory authorities to be implemented in the WENRA countries. The SRLs are expectations against which each WENRA member is assessed, and each WENRA member has committed to implement actions to ensure the SRLs are met within its national regulatory framework. SRLs build on and complement IAEA Safety Standards. The paper focuses on three sets of WGWD SRLs (comprising 240 different SRLs) relating to RAW processing, storage and disposal. The SRLs are administered by WGWD, which rates each member's performance against each SRL. Each country undertakes a national self-assessment against each SRL, which is then benchmarked or moderated by WGWD members, with a rating of A (fully conforming with SRL), B (not applicable, or SRL addressed satisfactorily in another way) or C (improvements needed). Members with identified areas for improvement then develop a National Action Plan (NAP) to respond to the findings, usually within 2 to 3 years and are again benchmarked. The paper presents the harmonisation approach developed within WGWD and includes case studies on how diverse countries, such as the Czech Republic, Spain, France, Ukraine, Slovakia, and the UK, implement WENRA SRLs. Finally, the paper assesses the significant progress made by WENRA members in harmonising and improving their regulatory approaches for RWM.

1. INTRODUCTION

The Western European Nuclear Regulators Association (WENRA) is an international body made up of the heads of nuclear regulatory authorities of European countries with nuclear power plants. WENRA was established in 1999 and comprises 18 European countries, together with 13 associated members and observers from Europe and the rest of the world. The main objectives of WENRA are to develop a common approach to nuclear safety, to provide an independent capability to examine nuclear safety and to serve as a network of chief nuclear safety regulators in Europe exchanging experience and discussing significant safety issues.

WENRA has established three thematic working groups: the Reactor Harmonization Working Group (RHWG); the Working Group on Waste & Decommissioning (WGWD); and a newly formed Working Group on Research Reactors. WGWD was established in 2002 and addresses the regulatory aspects relating to radioactive waste (RAW), spent fuel and decommissioning matters. Unlike the regulatory situation with respect to nuclear reactor operations, RWM usually involves several licence holders, locations and facilities at different steps of the waste management process.

WENRA has developed six sets of Safety Reference Levels (SRLs), which reflect expected practices agreed by the regulatory authorities to be implemented in the WENRA countries. In December 2005, WENRA members agreed on a policy statement in Stockholm committing them to improve and harmonise their nuclear regulatory systems, using the SRLs as a minimum. Four sets of SRLs have been developed by WGWD and are structured to address thematic activities applicable to a wide range of facilities, regardless of the main purpose of the facility in question. Some of them address specific facilities, like the disposal report; others are primarily activity-oriented, like the processing report.

The four thematic areas developed by WGWD are: RAW and spent fuel storage, decommissioning of nuclear installations, RAW disposal facilities and processing of RAW (including treatment and conditioning). There are 302 separate SRLs across all four WGWD thematic areas for which 240 relate to RAW processing, storage and disposal (the focus of the paper) and 62 relate to decommissioning.

The paper describes the methodology used by WENRA members to achieve compliance with the SRLs (and therefore harmonisation) and their progress against the existing WGWD SRLs and describes the experiences of achieving compliance using a series of case studies. The paper concludes with a discussion of the benefits of harmonisation and areas of future work for WGWD.

2. METHODOLOGY

The process of each WENRA member in assessing compliance with the SRLs follows a two-step benchmarking methodology. In the first step, participating countries perform a self-assessment of their national regulatory system against the SRLs. Across all WENRA working groups, three scores are used uniformly in the benchmarking of SRLs: A, B and C. An ‘A’ rating means the requirement is covered explicitly by the national regulatory system and no action is required. A ‘B’ rating means a difference exists but can be justified from a safety point of view and no action is required. A ‘C’ rating means a difference exists and should be addressed in the National Action Plan (NAP) for harmonisation purposes.

For the self-assessment, each country justifies the proposed rating by quoting the relevant text sections from the corresponding national regulation in an evaluation table. In the second step of the benchmarking, the self-assessment is reviewed by other countries and the results are ratified by the plenary of all WGWD members. In this open and transparent process, WGWD scrutinises rigorously the evidence presented. Where necessary members then develop NAPs to harmonise their national regulations with WENRA SRLs.

3. RESULTS

WGWD members are progressing toward full compliance against the SRLs in each thematic area (Fig. 1). To track progress, a ‘snapshot’ is taken periodically by WGWD to update the thematic reports. Between these updates, progress is discussed more informally through bi-annual WGWD meetings.

Greatest progress has been made in the areas of storage and decommissioning; in both areas all members are either fully compliant or implementing a NAP. With different national programmes for disposal of radioactive wastes and different facility requirements for low activity wastes and higher activity wastes, the pace of progress against the disposal SRLs is more varied and more dependent on the country’s national programme. Processing of RAW, including treatment and conditioning, is the latest and most recent thematic area for which WGWD has developed SRLs and therefore progress by members towards self-assessment and benchmarking is currently less mature.

To understand where progress is being made in harmonising safety to a common base level, it is necessary to analyse common areas where WENRA members do and do not achieve compliance with SRLs. Figure 2 shows the number of countries achieving compliance with the SRLs for RAW storage during the benchmarking exercise and after implementing a NAP intended to address all shortfalls in compliance. As can be seen in Fig. 2, compliance with SRLs increases markedly with implementation of the NAP.

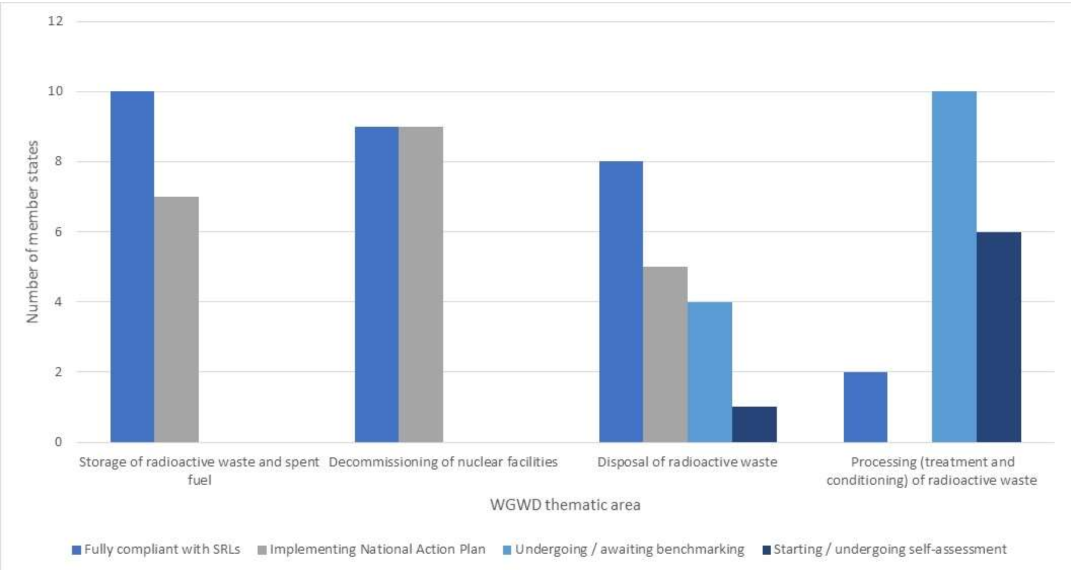

FIG. 1. Chart showing progress towards full compliance with the SRLs for each of the thematic areas.

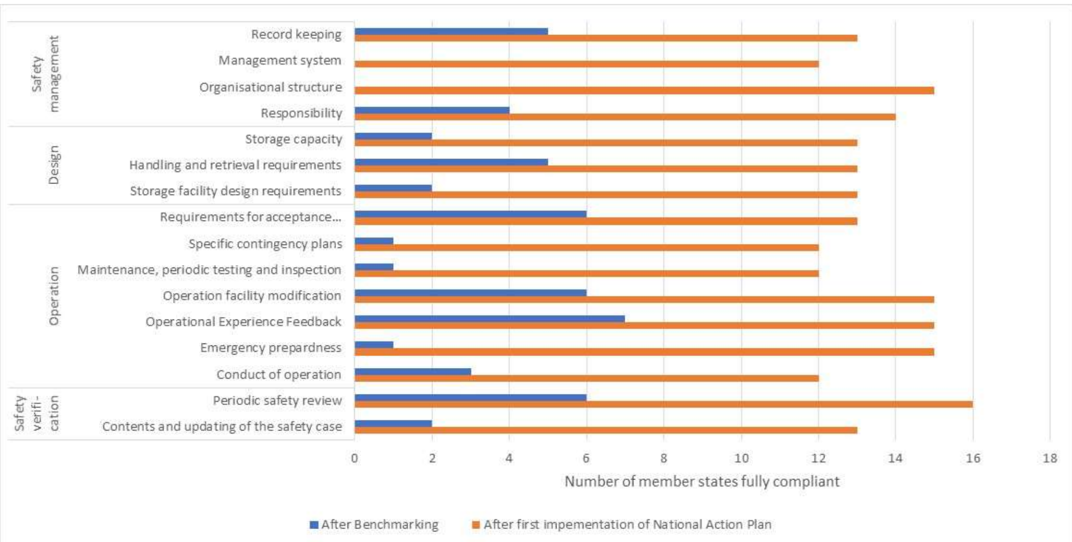

FIG. 2. Chart showing progress towards SRL compliance for radioactive waste storage.

4. CASE STUDIES

The results presented in the paper show broadly the level of harmonisation attained across the members for each WGWD thematic area. Seven national case studies are presented in this section illustrating insights how the SRLs have contributed, or are contributing, to continuous improvements and the challenges occasionally faced in harmonising regulatory approaches.

4.1. Ukraine

The State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) is a central executive body whose activities are directly coordinated by the Cabinet of Ministers of Ukraine, which is responsible for forming and implementing state policy in the field of nuclear energy safety. In 2015, SNRIU became a member of WENRA and WGWD.

The Ukrainian legal and regulatory framework in the field of nuclear energy use, including RAW management, is now largely comprehensive. The first nuclear regulations were developed in the mid-1950s in the former Soviet Union, part of which was Ukraine. Ukraine gained independence in 1991 and has since continued to improve and develop legislation in nuclear energy use.

The Ukrainian legislative framework governs the use of nuclear energy and nuclear and radiation safety, including RAW management. The fundamental document in this sphere is the Law of Ukraine "On Nuclear Energy Use and Radiation Safety" [1] which came into force in 1995, with changes and amendments introduced later. Certain aspects of the use of nuclear energy and nuclear and radiation safety are regulated in special laws, in particular, "On Radioactive Waste Management" (1995) [2], "On Human Protection against Ionizing Radiation" (1998) [3], "On Ratification of Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management" (2000) [4] and "On Permitting Activities in the Field of Nuclear Energy" (2000) [5]. The nuclear legislation system also includes regulations of the Cabinet of Ministers of Ukraine standards and rules on nuclear and radiation safety.

SNRIU harmonises its regulations with the requirements of the European Union (EU), IAEA recommendations and WENRA SRLs. Membership in WENRA and participation in WGWD encourages SNRIU to develop new regulations and revise existing regulatory acts. The WGWD benchmarking procedure and SRL-compliance reporting are viewed as good mechanisms to improve national regulations.

SNRIU annually approves plans for the development of new and improvement of existing regulatory requirements (including RAW management and decommissioning) that have to comply with WENRA SRLs. As a WENRA member, SNRIU has quickly developed documents on RAW processing facilities, and general safety provisions on decommissioning and RAW disposal in accordance with WENRA SRLs.

The benchmarking results demonstrate the new Ukrainian regulatory requirements comply sufficiently with WENRA SRLs. Regarding RAW disposal, the regulatory requirements now comply fully with SRLs. SNRIU is committed to improving RAW storage and processing regulatory requirements in terms of determining RAW ownership, the use of mobile installations and the provision of passive protection measures in facility design.

Once the regulatory documents came into force, licensees have to update their RAW management activities and facilities in accordance with the new requirements, as applicable. Licensees have to develop appropriate plans to be approved by SNRIU, and then implement necessary corrective measures. New facilities for RAW storage, disposal and processing have to fully comply with the new safety requirements.

4.2. Netherlands

The Central Organisation for Radioactive Waste (COVRA) – a central facility for interim storage of all radioactive waste and spent fuel – is the only company in the Netherlands tasked with collecting, processing, and storing radioactive waste. All businesses in the Netherlands which have a permit to work with radioactive substances (pursuant to the Dutch Nuclear Energy Act) are obliged to tender their radioactive waste to COVRA and transfer it as soon as reasonably possible.

As such, the WENRA SRLs are implemented not only in national legislation but also directly in the COVRA licence to ensure practical implementation of the WENRA SRLs in dealing with radioactive waste in the Netherlands.

For the Netherlands, having a centralized storage facility is a security measure that facilitates the implementation of the principles of isolation and control of radioactive waste. It also facilitates the regulatory supervision of the waste facility.

WENRA has introduced SRLs aiming to harmonise reference levels for nuclear safety, the safe management of spent fuel and radioactive waste and for decommissioning. Within the scope of the paper, the WENRA SRLs for storage of radioactive waste and spent fuel and for decommissioning are especially relevant; these have to be implemented in the Dutch regulatory framework. For example, an important part of the regulation on decommissioning and financial provisions for the costs of decommissioning in the Governmental Decree Bkse was based on WENRA SRLs.

The Dutch Authority for Nuclear Safety and Radiation Protection (ANVS) participates as the competent authority in the WENRA WGWD. In developing and designing Dutch policy on radioactive waste, regulations and supervision, the ANVS and the ministries involved closely follow European and other international frameworks. Furthermore, links are sought with internationally accepted principles, recommendations, practices and agreements as established under the IAEA, Heads of the European Radiological Protection Competent Authorities (HERCA) and WENRA. To guarantee nuclear safety and radiation protection remain current in relation to RAW management, the competent authority and COVRA participate in international peer review mechanisms. Dutch policy on the management of radioactive waste and spent fuel is also periodically assessed by other countries, in the framework of the Joint Convention treaty and the EU directive 2011/70 Euratom.

4.3. United Kingdom

The nuclear regulatory framework in the United Kingdom (UK) is different from that in most European countries. The Office for Nuclear Regulation (ONR) is the UK regulator for nuclear safety, security and safeguards, for radioactive materials transport by road and rail, and for non-nuclear safety on nuclear sites. Environmental protection on nuclear sites and with respect to radioactive material more widely is regulated by the environment agencies established within each separate country of the UK: the Environment Agency (in England), Natural Resources Wales, the Scottish Environment Protection Agency and the Northern Ireland Environment Agency.

ONR enforces a wide range of legislation including the Nuclear Installations Act 1965 [6], the Health and Safety at Work etc. Act 1974 [7], and associated regulations. The environment agencies also enforce a range of legislation including the Environmental Permitting (England and Wales) Regulations 2016 [8] and the Environmental Authorisations (Scotland) Regulations 2018 [9].

The nuclear industry in the UK is diverse, and includes operating reactors, fuel enrichment and fabrication facilities, research and sites in varying states of decommissioning, some of which have been operated since the 1940s. With such a diverse industry and with well-established legislative and regulatory regimes, the UK decided to join WENRA and WGWD early in their inception. Through the self-assessment and benchmarking process described in Section 2, the UK has been shown to be fully compliant with the SRLs for waste and spent fuel storage, as well as for decommissioning. Compliance with the SRLs for RAW treatment and conditioning, and those for disposal, is ongoing and the UK has been shown to be largely compliant. The SRLs for which further evidence is required to demonstrate compliance with, in terms of RAW conditioning and treatment, relate largely to demonstration and assurance of product quality, including acceptance of unconditioned waste against the operating treatment envelope, ensuring the conditioned product complies with its specifications and provisions for products that do not meet those specifications.

ONR regulatory guidance considers WENRA SRLs to constitute ‘relevant good practice’ in the UK, and is part of the regulatory basis for considering whether the licensee has met its legal duty to ensure health and safety “so far as is reasonably practicable”. Under the Legislative and Regulatory Reform Act 2006 [10], regulators are required to carry out regulatory activities in a way which is transparent, accountable, proportionate and consistent, and are targeted only at cases in which action is needed. The requirements of the relevant licence conditions and environmental permit conditions are sufficiently goal setting, rather than prescriptive, such that compliance with the SRLs is achieved through the regulatory regime without requiring legislative change.

4.4. France

The French Nuclear Safety Authority (ASN), created by the 13 June 2006 Nuclear Security and Transparency Act [11], is an independent administrative authority responsible for regulating civil nuclear activities in France. On behalf of the French State, ASN ensures the oversight of nuclear safety and radiation protection to protect people and the environment.

Basic Nuclear Installations (BNI) are facilities which, by their nature or by reason of the quantity or activity of radioactive substances they contain, are subject to special provisions to protect people and the environment. The general technical regulations, provided by article L. 593-4 of the environment code, include all the texts of general scope establishing technical rules on matters of nuclear safety, whether they are ministerial orders or ASN regulatory decisions. They are supplemented by circulars, fundamental safety rules (RFS) and ASN guides, which are non-binding. The objective is to have general technical regulations for BNI that are adapted and proportionate to the issues of safety and radiation protection and reflect the best safety standards.

ASN was a founding member of WENRA in 1999 and has participated in WGWD since the beginning of 2002. The most recent benchmarks for France have been performed for ‘Decommissioning’ SRLs in February 2013, ‘Storage’ SRLs in April 2014, ‘Disposal’ SRLs in September 2015, and ‘Waste Treatment and Conditioning’ SRLs in September 2018 and March 2019. The French case study focuses on RAW treatment and conditioning and disposal SRLs.

In January 2019, 89% of WGWD SRLs were implemented in French regulations mainly through the Order of 7 February 2012 setting general rules for BNI, and in ASN’s decisions. The remaining SRLs were B-rated or addressed in an NAP for benchmarking.

Before 2017, in the French legal and regulatory framework, provisions on waste packages and acceptance criteria were limited to a provision in the environmental code which requires that the waste management organization (WMO) has to provide acceptance criteria for its disposal facilities and has to also give its opinion on the specification of waste conditioning to the competent authority. In chapter VI of the Order of 7 February 2012 [12], articles 6.7 and 6.8 require0 RAW packages to be compatible with the subsequent management steps, and the conditioning of RAW packages intended for RAW disposal facility (which is not yet operational) is submitted for ASN approval.

From 2010 to 2017, ASN developed a decision relating to the RAW conditioning and the conditions for accepting RAW packages in disposal BNIs. At the same time, the ASN participated in developing reports on Disposal SRLs (2014) and Treatment and Conditioning SRLs (2018). Discussions within WGWD assisted in its decision making. Thus, the ASN decision contains provisions related to:

- RAW package acceptance criteria for disposal facilities (chapter 2.3 of the Disposal SRL report);
- The process of authorization of waste package processing operations whether the package is intended for an existing disposal facility (authorized by a WMO) or a facility still under development (authorized by ASN);
- The conditioning baseline requirements needed to be submitted for authorization;
- Clarification of responsibilities between owner and processing facility operator.

The decision was published on 23 March 2017 [13] and came into force in July 2018. Since its publication, ASN has strengthened its inspections in this field.

4.5. Czech Republic

The Czech Republic decided to join WGWD in 2004 to harmonise its regulatory framework with SRLs, and ever since has taken a leading role in WENRA and WGWD. At that time three near surface and underground

RAW disposal facilities and two spent fuel storage facilities were operated in the country and two additional spent fuel stores were under construction or design (both are now in operation).

The first self-assessments for decommissioning and RAW/spent fuel storage showed, despite implementation of almost all SRLs, there remained a need to harmonise legal documents. National Action Plans were developed and implemented in detail from 2009, when the Czech nuclear safety regulator, SÚJB, started to review and replace the national legal framework with a new atomic act and an extensive suite of SÚJB decrees.

The impact of WGWD RAW/spent fuel storage SRLs on the requirements of the new legal documents, which have been in effect since 2017, is as follows: 1) For general requirements not specific to RAW management and related mainly to management systems, operational experience feedback (OEF) and periodic safety review, SRLs have directly influenced the text of the Act No. 263/2016 Coll., Atomic Act and related decrees on management system (Decree No. 408/2016 Coll.) and safety assessment (Decree No.162/2017 Coll.); 2) For specific RAW management requirements for facility design, contingency plans and the acceptance of waste and spent fuel packages and unpackaged spent fuel elements, compliance with SRLs was provided particularly in articles of Decree No. 377/2016 Coll., on the requirements for the safe management of radioactive waste and on the decommissioning of nuclear installations or category III or IV workplaces and Decree No. 329/2017 Coll., on nuclear installation’s design requirements.

The implementation of RAW management SRLs introduced to the legal framework the following new specific legal requirements in the following areas:

— Consistency of the licensee’s strategy for RAW management with national RAW and spent fuel management strategy;
— Ageing management programmes for RAW management facilities;
— An OEF programme;
— Licensee procedures for the receipt of RAW failing to meet waste acceptance criteria;
— Periodic safety review;
— The use of mobile RAW processing equipment;
— A characterisation programme for RAW disposal facility sites;
— Disposal facility decommissioning and closure programmes.

Benchmarking of the Czech self-assessment by WGWD members showed the new legal framework of the Czech Republic complies with the majority of SRLs for RAW management facilities under operation and development. The only ‘B’ ratings related to the concept of RAW ownership. In the Czech Republic, RAW is always owned by the licensee who operates the RAW management facility. The ultimate ‘owner’ of RAW is the Czech Republic, as the disposal of RAW is performed by the Czech Radioactive Waste Repository Authority (SÚRAO).

As a supplement to the legal documents, SÚJB regularly issues safety guides summarising and in detail developing valid legal requirements. These safety guides are not mandatory but should support the licensee e.g. by the development of licensing documentation. The Safety Guide BN-JB-OD-1.1 [14] on Licensing of RAW Management Activities uses WGWD SRLs not only as a reference, but as a basis for parts of the guidance; an overview of benchmarking results is provided at the end of the safety guide.

4.6. Slovak Republic

The Slovak Republic joined the EU and WGWD on 1 May 2004 to harmonise its regulatory framework with WGWD SRLs for decommissioning and RAW/spent fuel management at the following RAW management facilities already in operation: the near surface disposal facility for low level RAW in Mochovce, two centralized RAW processing facilities and a wet spent fuel storage facility. Decommissioning of NPP A-1 was ongoing and NPP V-1 was preparing to transition from operation to decommissioning. Enlargement of the disposal facility for very low level waste and of the existing spent fuel storage capacity for dry storage were both under consideration at that time, as well as a new integral storage facility for RAW that does not comply with the waste acceptance criteria for the Mochovce disposal facility.

The legal and regulatory framework had been already well established in 2004. The Atomic Act and respective decrees were developed in the late 1970s in connection with the development and operation of the first NPPs with VVER reactors in the former Czechoslovakia. The original regulatory body, Czechoslovak Atomic Energy Commission (ČSKAE), was replaced by the Nuclear Regulatory Authority of the Slovak Republic (ÚJD SR) in 1994.

The first self-assessments for decommissioning and RAW or spent fuel storage provided a very good level of compliance. However, an area for further harmonisation of legal documents was identified and two NAPs containing details of the harmonisation process were proposed. In 2021, an additional NAP was developed for RAW disposal. Benchmarking against the processing SRLs is currently under preparation.

National Action Plans for storage of RAW or spent fuel and decommissioning were fully implemented by an update of the Atomic Act in 2006 and an extensive set of ÚJD SR decrees in force since 2012. Since then, there have been further amendments which also reflect WENRA's RHWG harmonisation efforts.

The impact of RAW/spent fuel storage SRLs on the requirements of the new legal documents, which took effect in 2006 and were further amended later, are very similar to those of the Czech Republic given the similarities of the two legal frameworks.

Benchmarking of the disposal self-assessment, performed by WGWD members in 2021, showed that the new legal framework of the Slovak Republic complies with the SRLs for RAW management. The three 'C' ratings, which have been proposed by ÚJD SR and agreed by WENRA WGWD, relate to measures necessary for the purpose of accounting for, and the control of, nuclear materials. These will not unacceptably affect the operational and post-closure safety of a deep geological repository (DGR) (Di-31) and the need to develop a programme of safeguards before starting the decommissioning and closure of a DGR (Di-69).

Decree No. 30/2012 Coll. [15] on RAW and spent fuel management needs to be further amended to refine the assumptions of the safety case for a DGR. The licensee has to gather information during the construction phase of the DGR to improve the knowledge of the intrinsic properties of the host environment and the response of the host environment to the presence of the disposal facility (Di-52).

It can be concluded that the Slovak legal framework fully complies with all relevant RAW management SRLs for storage and decommissioning and is implemented at all operating RAW management facilities.

The NAP for disposal was agreed in 2021 and changes to legislation are being prepared to fully comply with requirements of Di- 31, Di-52 and Di-69. Processing benchmarking is scheduled to be carried out virtually in 2021.

4.7. Spain

Spanish regulatory requirements for waste disposal facilities are basically the same as for other nuclear facilities. They are subject to the regulatory framework of the Spanish national safety policy and strategy, which is integrated into several legal instruments, the most important of which are: Nuclear Energy Law 25/1964 [16], establishing the general concepts and principles governing peaceful use of nuclear energy; Royal Decree 1836/1999 [17], approving the Regulation on Nuclear and Radioactive Facilities (RINR); Royal Decree 783/2001 [18], approving the Regulation on Sanitary Protection against Ionizing Radiations (RPSRI).

Royal Decree 102/2014 [19] for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, transposing the 2011/70/Euratom European directive, establishes more specific regulatory requirements regarding waste disposal facilities. Additionally, the CSN Creation Law (15/1980) [20] empowers the Nuclear Safety Council (CSN) as the sole competent body on nuclear safety and radiation protection. CSN issues mandatory and binding reports concerning all issues related to nuclear safety or radiological protection before the granting of the licence by the Ministry.

The regulatory framework is supplemented by CSN instructions and guides, which are technical standards on nuclear safety and radiological protection issues. Instructions are issued by CSN, published in the Official State

Gazette, and informed to Parliament and European Commission, and are legally binding for every licensee. Guides provide guidance to meet the regulatory requirements but are just recommendations.

CSN can also issue conditions and Complementary Technical Instructions (ITC) to licence holders, whose implementation is mandatory, but only for the licensee receiving them.

The CSN self-assessment showed that a significant quantity of the Disposal SRLs were already incorporated as mandatory in the operation of the 'El Cabril' facility either as conditions included in its licence or as specific ITCs addressed to Empresa Nacional de Residuos Radiactivos S.A. (ENRESA). However, most of the SRLs are not yet integrated into general Spanish legislation, especially those requirements related to the final parts of the repository lifetime: the closure and post-closure phases.

In accordance with the objectives of WGWD, the NAPs require SRLs, which are not yet implemented in Spanish regulations, to include the issue of specific thematic instructions from CSN. So far, there are two instructions already issued and in force (relating to spent fuel storage casks and high activity waste storage facilities) and three more are in draft relating to decommissioning and RAW disposal).

The draft safety objectives for a RAW disposal facility refer exclusively to the incorporation of SRL criteria concerning the disposal of RAW. Once this instruction is approved, the Spanish regulations will fully comply with WGWD safety reference levels for RAW disposal facilities.

The CSN instructions will also be compatible with the incorporation of some SRLs in the main nuclear regulations (RINR) when these are revised. Currently, the RINR is undergoing a major review to transpose some European Directives.

5. DISCUSSION

The Ukraine case study is an example where the established or evolving legal framework is informed directly by and aligned to international standards and principles including WENRA SRLs. These may be added verbatim which makes demonstrating compliance more straightforward but may be subject to revision in line with changes to the SRLs themselves. The regulatory authority then approves measures for existing facilities (licensees) to ensure implementation of the legal requirements and to ensure regulatory decisions are consistent.

Conversely, the UK is an example of an enabling legal framework that is goal setting, i.e. focused on required outcomes for nuclear and environmental safety. UK legislation enables regulators to issue a nuclear licence/environmental permit and to attach conditions to each that are legally binding and enforceable. Harmonisation of regulation through SRLs is potentially harder to demonstrate but easier to implement from the national plan. So, while adopting SRLs into legislation directly makes demonstrating compliance easier, the goal-setting legal framework in the UK is suitably flexible to accommodate changes in relevant good practice without requiring continual amendment.

The Czech Republic case study highlights some of the areas that have challenged many members. The self-assessment process identified requirements to harmonise legal documents, leading to a revised legal framework with additional enforcement powers for the regulator. The broad, encompassing nature of SRLs provides a basis for standardising safety across a similarly broad range of waste management areas, including management systems, periodic review, waste acceptance criteria, use of mobile processing equipment and management of ageing facilities/equipment. Many of these areas are already regulated and taken into account by operators/licensees but the process of harmonisation ensures the requirement to comply has a basis in legislation, as is highlighted in the Spanish case study for RAW disposal.

The French case study for disposal facilities (especially on waste acceptance criteria) and treatment and conditioning RAW activity, emphasises the need to develop regulation in this area to give a clearer locus within which the authority can perform control. Indeed, this is not specific to France and many of the case studies have similarities, where the opportunity to discuss them within the wider international community of WGWD has proven to be valuable.

An example of good practice arose in Finland where the Finnish Nuclear and Safety Authority (STUK) uses commercially available database software for requirement management and development. The database was first used when STUK made the latest major update to its regulatory guides. It contains all nuclear safety-related legislation, regulations and regulatory guides and is used to manage all requirements set by STUK. All requirements in the database are given attributes based on their related licensing steps, life cycle phases and other relevant attributes. The SRLs from RHWG have been added into the database and they have been linked to corresponding national requirements; work to implement the WGWD SRLs to the database is pending. When any requirement is viewed in the database, if it is linked to WENRA SRLs, the relevant SRLs can be seen. If non-conformances have been identified in the SRL benchmarking process, notes about any needs for development can be added and considered later when the requirements are updated. Using a database approach allows all those involved in regulatory development to be aware of SRLs and allows SRLs to be considered when making changes to national requirements to ensure that no changes are made that would result in non-conformance with the SRLs.

As can be seen through the case studies in particular, WENRA has achieved a high degree of harmonisation by keeping the focus of its activities on this target through regular benchmarking exercises to a consistent methodology and requiring members to adopt and implement NAPs to address compliance shortfalls. The fact that WENRA is an informal organization, meeting as regulators and experts and not as national governments, is also pivotal in achieving harmonisation: this approach relies on members not defending their own national performances to the detriment of progress, but rather in being flexible and championing change where it is beneficial to safety to do so.

There are many clear benefits to harmonising safety and setting common minimum standards across all WENRA members through the SRLs. However, the evolution of SRL thematic areas over the previous two decades means that WENRA has had to take steps to maintain a common set of up-to-date SRLs covering all relevant topics and to benchmark their implementation on a regular basis. WGWD is looking currently at opportunities both to rationalise safety areas common to all thematic areas (e.g. management systems) and to make the links from the SRLs to the underpinning safety references more transparent. Rationalisation will allow safety areas repeated in different thematic areas but worded and arranged slightly differently to be presented once in a goal-setting way, such that compliance applies to all safety activities and does not need to be demonstrated more than once. Linking SRLs to their underpinning references ensures their currency can be demonstrated dynamically using electronic tools (such as databases for instance) and allows changes to references (updates, withdrawals, etc.) to be noted early for evaluation by WGWD.

6. CONCLUSIONS

Since 2002, when WENRA WGWD was established, clear benefits of the harmonisation process have become obvious for all members. WGWD has identified and approved minimum common standards of safety based on SRLs derived from the IAEA Safety Standards as a baseline, and from the experiences and practices of WGWD countries regulating RAW management activities. In this way WGWD has promoted changes and improvements in members' regulations against the backdrop of national priorities and existing legal frameworks.

As part of WGWD self-assessment and benchmarking activities, the regulatory bodies of member countries have identified overlaps, inconsistencies and complementarities in their national legal frameworks. The harmonisation process is not finished yet, but many members have already reached a very good degree of harmonisation with the SRLs for RAW management.

WENRA provides an excellent opportunity for regulators to learn informally from the experience of other members, whether they have similar or different legal frameworks.

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THE OBLIGATION OF MULTINATIONAL COOPERATION TO PROMOTE AND ADVANCE THE SAFETY OF SPENT FUEL AND RADIOACTIVE WASTE MANAGEMENT

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Abstract

Safe, secure, and sustainable management of spent fuel is an international obligation for countries operating nuclear research reactors or nuclear power plants, as well as for potential newcomers. For countries either using nuclear power for electricity generation or using radioactive materials for medical, research, or industrial purposes, the main concern relies in long lived radioactive waste requiring distinctive measures to ensure the decay of radioactivity to levels not presenting a significant hazard to the people and the biosphere.

The Kingdom of Morocco, as a Member State of the IAEA since 1957 and the first African country that ratified the Joint Convention in 1999, is fully aware cooperation between countries is very crucial in radioactive waste and spent fuel management. As such, the Moroccan Agency for Nuclear and Radiological Safety & Security (AMSSNuR) has committed itself to contribute to global nuclear safety regime , while fulfilling its international commitment under the IAEA auspices and sharing its experience regionally with African countries within the framework of African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA), and Forum of Nuclear Regulatory Bodies in Africa (FNRBA) network, Formally recognized as a regional intergovernmental organization in September 2019 [1].

In this regard, the AMSSNuR has developed a national policy and strategy on radioactive waste and spent fuel management, intended to address radioactive waste management in a coordinated and cooperative manner with all the concerned parties, in line with the international instruments signed and ratified by the Kingdom of Morocco, particularly the joint convention on safety of spent fuel management and safety of radioactive waste management.

To ensure the fulfillment of its regional and international commitment, the AMSSNuR is actively involved in several international knowledge networks, notably the FNRBA chaired by the Director General of AMSSNuR.

This forum is a key instrument aiming to enhance, strengthen and harmonize, regulatory framework and practices associated to spent fuel, radioactive waste management radiation and waste safety. To ensure the safe and secure management of radiation, FNRBA has dedicated one of its six thematic working groups to radiation and waste safety.

The paper will address AMSSNuR contributions to FNRBA activities in the field of radioactive waste and spent fuel management among the African Member States and discuss the multinational cooperation as a tool to promote and advance the safety of spent fuel and radioactive waste management.

1. INTRODUCTION

The safety and security radioactive materials and disused sealed radioactive sources require a sound regulatory and technical infrastructure, as well as an appropriate legal, governmental, and regulatory framework to be in place in accordance with international safety standards and international obligations.

Over the past decades, several countries have made considerable progress in the development of radioactive waste and spent fuel management strategies. The Kingdom of Morocco, as an IAEA Member State since 1957, was among the first African countries to sign and ratify the Joint Convention on the Safety of Spent Fuel Management and the Joint Convention on the Safety of Radioactive Waste Management [2]. In this regard, the Moroccan Agency for Nuclear and Radiological Safety and Security (AMSSNuR), the Moroccan regulatory body created in 2016, has committed itself to global and regional nuclear safety regime, while fulfilling its international commitment under IAEA auspices and sharing its experience with African countries within the framework of the

Forum of Nuclear Regulatory Bodies in Africa and the framework of African Regional Cooperative Agreement for Research, Development, and Training related to Nuclear Science and Technology (AFRA).

2. RADIATION AND WASTE SAFETY IN THE FORUM OF NUCLEAR REGULATORY BODIES IN AFRICA

The Forum of Nuclear Regulatory Bodies in Africa (FNRBA), currently chaired by the Director General of AMSSNuR, was launched in 2009 to enhance, strengthen, and standardize radiation protection, nuclear safety, and security regulatory infrastructure and framework among its members. The regional knowledge network functions as a platform facilitating sustainable regional cooperation focused on capacity building and infrastructure development. While regulation remains a national responsibility, the FNRBA plays a key role in sharing and maintaining the knowledge in radiation protection, nuclear safety and security [3].

Through its six Thematic Working Groups, the FNRBA serves as a forum for dialogue to discuss and share common interest with the intention to develop innovative approaches.

Aware of the importance of the management of spent fuel, the FNRBA has established the Thematic Working Group on Radiation and Waste Safety (TWG), in accordance with Article 8 of its charter. This group aims to ensure the establishment and implementation of radiation protection and waste safety infrastructure. It has been established with membership drawn from radiation protection and radioactive waste management experts to identify areas of improvement of the Members States.

2.1. Objectives of the radiation and waste safety thematic working group

The objective of the TWG is to foster cooperation amongst the FNRBA members to help to enhance radiation protection and waste safety infrastructure in the different Member States. This group aims to:

- Promote the development and implementation of radiation protection and waste safety infrastructure in National Legislations and Regulations amongst FNRBA members;
- Promote the alignment of radiation protection and waste safety requirements in National Legislation and Regulations with the IAEA Safety Standards [4];
- Promote the development and implementation of radiation protection and waste safety guides;
- Promote sharing of experiences, lessons learned and best practices in the implementation of radiation protection and waste safety measures amongst FNRBA Member States;
- Promote cooperation amongst FNRBA members to help provide mutual support on the establishment of Radiation Protection and Waste Safety in National Legislations and Regulations.

2.2. Work programme and approach

The TWG focuses on the need of members states to ensure radiation protection and waste safety infrastructure are addressed in national legislations and regulation. It also encourages closed collaboration with the IAEA for a goal of ultimately aligning national legislations to ensure National Legislations and Regulations are well aligned with IAEA standards.

The TWG includes the following African IAEA Member States, all committed to improve radiation protection and waste safety situation in African Member States through bilateral and multilateral cooperation: Burkina Faso, Egypt, Ethiopia, Ghana, Ivory Coast, Kenya, Nigeria, Mauritius, Morocco, and Zimbabwe.

2.3. International and multinational cooperation

The TWG cooperates with other regional initiatives to leverage resources, knowledge, and benchmark approaches and engages with international partners as potential sources of training and capacity building and sharing information.

Aware of the increasing need for regional, international, and multinational cooperation, the FNRBA assigns high priority to this aspect by establishing an MoU with the African Commission on Nuclear Energy (AFCONE) to address the challenges faced by the African IAEA Member States.

3. CONCLUSION

The AMSSNuR is committed to share its experience in all its areas of expertise with other African Member States of the IAEA. It also strives benefit them from the assistance it receives from its international partners whose nuclear infrastructure is solid and developed, through different modalities, and uses multinational cooperation as a tool to promote and advance the safety of spent fuel and radioactive waste management.

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MATERIAL AND WASTE MANAGEMENT CONSIDERATIONS FOR DECOMMISSIONING STRATEGIES

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Abstract

According to the IAEA's 2020 Key World Energy Statistic edition, 4.9% of the global energy supply in 2019 was from nuclear power, a drastic decrease from 10% as late as 2017. With a focus on Organisation for Economic Co-operation and Development (OECD) countries, 9.7% of their electricity is delivered by nuclear power plants (NPPs). This illustrates fossil energies (oil 31,6%, coal 26.9%, natural gas 22.8%) remain a significant means of global power supply despite their negative impact on climate change. This emphasizes the necessity for all nuclear power producers to adjust their strategies to strengthen their place in the low carbon energy production mix. To reach such a global aim, it is necessary to increase nuclear industry credibility, therefore, embedding public acceptance. Among some key factors (economy, efficiency, high technology, low environmental impact, among others) this will result in demonstrating continuous improvements of waste management and decommissioning fields, which commonly appear as the main public concerns regarding the nuclear industry. For World Nuclear Association (WNA) members and operators (such as EDF Group, which operates 75 reactors in three countries, as well as decommissioning 10 units in France), it is well known that a proper and cost-efficient management of back-end activities, i.e. Waste Management & Decommissioning (WM&D), is key for sustainable nuclear power operation and construction (new build).

Globally, 187 civilian nuclear power reactors had ceased operation in 2019. Besides these NPPs, various other types of nuclear facilities such as experimental reactors, fuel cycle, waste treatment and laboratories are already shut down, awaiting, or in active decommissioning or dismantling.

Hence, this worldwide rise of nuclear dismantling sites, emphasized the demonstration of a technically and financially mastered decommissioning programme is key to increase any nuclear operator's credibility.

Furthermore, considering environmental and sustainable development, this demonstrated that effective WM&D facilitates the legal, social, and public acceptance, assuming the operator's responsibility in compliance with the future use of the site, whether it is unrestricted or not. To ensure this aim, decommissioning is to be prepared as early as in the design phase.

Consequently, preparing decommissioning of nuclear installationsrequires setting several strategies consistent with existing waste routes. Optimization, involving efficiently available resources, managing materials, reducing waste, improving techniques and perspectives, is vital for sustainable, safe, and cost-efficient decommissioning to avoid an undue burden on future generations.

1. INTRODUCTION

Gathering the global feedback related to the preparation and definition of existing nuclear decommissioning programmes worldwide, it appears that such tasks involve a wide range of various activities requiring long planning and implementation time. Therefore, whatever are local considerations, the almost 30 years of Opex in decommissioning showed that the earlier is defined the strategy of a nuclear decommissioning program, the better it is.

In addition, it needs to be emphasized that all the main decommissioning steps have to consider material and waste management aspects.

To gain the public confidence and stakeholders involvement, it is crucial that all involved nuclear parties (operators, regulators, …) highlight and demonstrate that the real amount of real hazardous nuclear waste being generated is quite negligeable (i.e., less than 1%).

Lessons learned from decommissioning projects the total amount of material and waste from a NPP decommissioning programme consists of a few hundred thousand tonnes of which typically 80% can be classified as conventional material and waste.

The major portion of the remaining 20% of materials and waste arising from decommissioning can be, either directly or after certain treatment, released from control after having undergone a clearance process.

As mentioned, only a few percent (1–3%) of the total materials and waste from a decommissioning project has properties which require that it is to be disposed of. However, the regulatory framework for clearance of materials differs from country to country. Nevertheless, the alignment of national regulations coupled with the availability of waste management infrastructures and disposal options, are key determinants of a waste management system for very low and low radioactive materials and waste. In addition, the change in the last 10 years of some nuclear national policies made radioactive waste disposal capacities decrease faster than projected. Moreover, adding new landfill capacity is becoming more difficult due to low societal support and increasing pressure on land resources.

Hence, a suitable decommissioning strategy needs to be determined soon, considering not only the future use of the site but also the essential necessity to reduce the amount of waste. The experience gathered from ongoing decommissioning programmes emphasize that storage capacities have to be considered as limited resources to be preserved as much as possible. Therefore, defining appropriate decommissioning strategies before shutdown (i.e. since the design phase) is fundamental to choose, select, and accurately sort materials to dispose only radioactive waste.

Many materials generated and traditionally considered as waste can be subject to clearance. Then, upon completion of the clearance process, the waste can be safely released and recycled allowing further use of the material. One key area in decommissioning waste management is the handling of metals.

To enhance the implementation of material and waste management strategies, some WNA members, for instance, major worldwide nuclear operators such as EDF Group, have developed or invested in waste treatment facilities. In the case of EDF Group, these industrial capacities are located at three different sites distributed over Europe (France, UK, and Sweden). Consequently, the facilities serve external customers and internal EDF Group needs. Therefore, this paper will discuss important strategic aspects in terms of materials and waste management in a life cycle perspective with special focus on how the materials and waste strategy can have an impact on the decommissioning cost, the financial and technical risks and the environmental aspects.

The paper aims to explain how a decommissioning strategy should enable counterparts to examine how to manage (very) low level radioactive waste arising from decommissioning, throughout all steps of the process, from its generation during dismantling up to its destination (clearance, landfill, repository, recycling, …).

Based on several international approaches, the present paper explores strategies drivers leading to optimization. The main factors (end state definition, radiological assessment, environmental and industrial safety), measurements (characterization and categorization), means and resources (technical operational and organizational aspects, waste routes identification) as well as the various interrelations among drivers and the related mechanisms (stakeholders' involvement and financial and economic factors) are described. It also identifies constraints in the practical implementation of optimization and then necessary public acceptance.

As a finding deduced from lessons learned, decommissioning / waste management become a topic being addressed worldwide.

Indeed, as a matter of fact, all concerned countries realize one after the other, that mMost nuclear facilities now under operation or already shutdown haven't been originally designed to be fully decommissioned. It is therefore useful to share international experiences, to gain efficiency, to increase safety and credibility by inducing a common methodology.

Currently, dismantling, and waste management operations are implemented since the early phases of design and conception. The demonstration of a sound defined decommissioning programme 60 years before it occurs is also, in many countries an essential criterion to obtain the operation licensing of a new nuclear facility. This has been emphasized with the numerous unexpected situations during NPP decommissioning. They encourage the sharing of experience and solutions based on real cases to improve safety, reduce the environmental impact and ensure an economic optimization.

Despite some specificities between national regulation policies, optimizing decommissioning and waste management led, over the years, to a sound, solid and matured — but still evolving — dismantling process based on some shared common principles.

In addition, tThe lessons learned from the past, provide some current pragmatic incentives to improve the existing nuclear technologies and, at least, some associated designs commonly spread worldwide: light water reactors (LWR), fast breeder reactors, and others. These potential improvements of current nuclear facilities, tackled in the paper, could significantly modify the current perception of decommissioning and waste management by mitigating the risks as well as the environmental impacts.

2. DECOMMISSIONING STRATEGIES AND KEY PARAMETERS

The principles reminded hereafter constitute what is commonly called the decommissioning strategies. According to international standards, three options are offered to define the operations sequence to achieve a decommissioning project:

— Immediate Strategy: Although this option is often preferred by stakeholders, it first leads to higher activity levels of the generated RAW due to the missing decay time. Nevertheless, the advantage is that this strategy will shorten the overall duration of the decommissioning project by reducing the number of operations (for example, fewer surveys, less site maintenance, no need to update inventory frequently) and therefore lower overall costs are expected.
— Deferred Strategy: This option may allow to reduce the activity level of the generated radioactive waste thanks to natural decay which, potentially, enables more manual operations instead of remote handling. This is supposed to lead to decreased disposal expenses, but potentially higher overall decommissioning costs due to longer post-operational duration.
— Entombment: Although this option can still be found in some isolated sites over the world, it can't be considered as a real strategy, as it doesn’t really solve the issue. It can only be justified to return specific accident cases to a safe situation as quickly as possible. In addition, it can’t be reliably envisaged in homelands with limited available areas or with nearby high density population, and only postpones the resolution of the problem to the next generations.

Furthermore, it appears as though the most expensive means can only provide a temporary solution. A site survey will have to be ensured eternally and consolidation or renewal of the so-called “tomb materials” will have to be periodically envisaged.

As a matter of consequence, only the two first options, Immediate and Deferred, can be considered as valid potential strategies to be chosen in between.

Independently from any national policies orientation, the choice will be made according to the following international common principles:

— Definition, at the earliest stage, of the end state and future (unrestricted or restricted) use of the site.
— A regular, periodic, assessment of physical and radiochemical inventories during the operation phase until shutdown. As an axiom, the amount of waste being generated needs to be accurately assessed prior to decommissioning to enable the choice of suitable treatment processes leading to selection of the best available option.
— Availability of funds to perform the decommissioning programme following the chosen strategy.
— Availability of existing waste treatment facilities associated to available confirmed routes.
— Enhancing the efficiency of existing techniques as well as training operators continuously.
— Sorting, segregating materials to recycle what can be reused in a profitable and sustainable way while reducing, as much as possible, the quantity of real radioactive waste devoted to disposal.
— Managing, preserving storage capacities as rare resources with the same concern of relevance performed for non-renewable material and environmental impact.
— Performing a technical survey to continuously improve methods, strengthen skills as well as public acceptance and stakeholders’ confidence as a fundamental asset.

This robust process enables worldwide nuclear operators to assume their responsibilities, improving safety, efficiency, and sustainability.

Nevertheless, over the last three decades, this awareness of all nuclear stakeholders, coupled with a growing interest of public consideration for the nuclear field, led to the need to demonstrate that the nuclear community is continuously working towards improvement in compliance with careful considerations of social and environmental impacts.

As a matter of fact, decommissioning and radioactive waste management have become a worldwide challenge with the increasing number of nuclear facilities reaching the end of their lifetime or due to national policies evolutions regarding nuclear power production.

Therefore, to keep the confidence of all stakeholders, and to increase public acceptance, nuclear operators have not only to demonstrate the robustness of their capability but also their technical, financial, environmental, and social capability to perform a safe decommissioning phase.

Beyond being successful in this challenge, it is necessary to remind all counterparts that decommissioning and waste management is one of the three founding phases of the life cycle (Construction – Operation – Decommissioning and Waste Management) of all nuclear facilities.

Demonstrating that the mastery of WM&D is not only a financial challenge proving technical and sustainability capacities, but also, that nuclear power generation is a fundamental means which takes place in a low carbon worldwide energy policy.

As a consequence, identifying ways of optimizing existing processes is a permanent concern for the entire nuclear community coupled with some pragmatic R&D. The aim shared worldwide is to profitably and sustainably improve efficiency, including environmental impacts.

2.1. Waste management and decommissioning guidelines within major nuclear operators like the EDF Group

The EDF Group created a devoted WM&D directorate called DP2D. Within this entity, gathering all engineering skills and industrial WM capacities, EDF has developed some guidelines to perform the decommissioning programme of its nine French nuclear reactors of the first generation. The experience acquired over the last decade enabled the Group to strengthen these guidelines to prepare the decommissioning of the 2nd generation PWR fleet, starting with the first of them: Fessenheim NPP.

Following an immediate strategy option as required by the national policy, these guiding principles are reminded hereafter:

- Remediation of all loops and circuits to mitigate the radioactivity (chemical operations, decontamination, specific treatment, …).
- Adjustment of the onsite operational waste zoning in compliance with new decommissioning purposes and needs.
- Preparation and settlement of all necessary means for decommissioning operations before the launching of decommissioning (temporary waste storage areas, handling means, ventilation systems, among others).
- Limitation of the construction of new buildings as necessary, particularly in case of those of no foreseen further use. Adaptation of existing ones is encouraged, particularly for those devoted to sorting operations and preparation of waste shipments. An inventory of existing systems (ventilation, power, fluids treatment, among others) allows to keep only the suitable ones with the scheduled decommissioning operations.
- Dismantling work is scheduled step by step to free space progressively without preventing from working in parallel as soon as areas are clearly distinct in compliance with safety considerations.
- The choice of decommissioning scenario is mainly driven by a continuous concern to mitigate the radioactive inventory by addressing and evacuating in priority the most activated and irradiated equipment.
- The fire risk is constantly mitigated by integrating the extraction of high heat load components in the priority of decommissioning scenarios.

- Most irradiated or activated equipment are dismantled using remote handling tools or underwater scenarios. Areas to set or maintain robots, recovery procedures in case of failure, decontamination operations, operators training are foreseen in areas scheduled and available before the start of decommissioning,
- Decommissioning scenarios obey to French national guidelines criteria (PNGMDR) to never generate waste without outlet and to optimize their volume reduction as much as possible:
  - Sorting of waste particularly between conventional and low level waste. The implementation of waste zoning onsite warranties the management of waste in appropriate relevant channels as well as the reduction of waste areas.
  - Waste management optimization is considered from cradle to grave, including minimization of: workers' dose, environmental impacts (releases), safety risks, and costs. Off-the-shelf solutions are preferred to specific solutions. Innovative improvements are envisaged following some prior feasibility studies assessment ensuring pragmatism and confidence in short term outcomes.
  - Considering disposal as a rare resource to be preserved and shared between all waste producers. Ultimate waste volume reduction is systematically sought thanks to continuous optimization of waste zoning application, packing density, incineration, melting, metal recycling, and reuse.
  - Decontamination is envisaged as much as possible as far as it allows to ship ultimate waste to near surface rather than geological disposals, considering the complexity and expensive characteristics of these latest ones.
  - Never produce a waste since the availability of its outlet hasn't been clearly identified and confirmed (Program law n° 2006-739 June 28th 2006).
  - Control and packing of waste as soon as they are produced in compliance with disposal and waste treatment facilities Waste Acceptance Criteria. This enables minimizing temporary storage areas, as well as increasing delays, workers' exposure, and associated cost due to necessary repacking operations. Synchronization of waste production, storage, shipment, and evacuation to disposal or treatment facilities.

The already available waste routes are key to define the decommissioning scenarios. Innovation and new specific means are more considered as potential alternatives.

- Handling and shipping operations are scheduled and planned to be as shortest as possible to avoid delays, as well as workers' exposure to dose rate.
- Concrete rubble generated by conventional buildings dismantling is mainly used as backfill on site to mitigate transportation and carbon footprint.
- Site remediation is performed gradually as the worksite is progressing, zone after zone. A global site re-organization is scheduled at the end of the decommissioning project.
- Pragmatic R&D and innovations are envisaged following some prior feasibility studies assessment ensuring compliance between needs, costs, and short term expected outcomes.

2.2. New incentivization built on experience

In 2019, the WNA published "A methodological guide to manage materials and waste from decommissioning." This latter gathers international experiences nuclear stakeholders (operators, regulators, economists, suppliers, …) from 7 different countries. It relates the feedback from ongoing successful decommissioning worksites, among which can be found some of the above EDF guidelines regularly applied to define decommissioning scenarios.

These pragmatic rules are more and more commonly shared worldwide thanks to the exchanges of experiences between nuclear operators or in the frame of WNA activities and devoted working groups. As a result, the definition of strategies for a suitable nuclear decommissioning and waste management appears as a global process with several key parameters all interconnected.

National specificities, contextual characteristics, economical consideration, availability, on time, of resources and technical means have to be managed commonly to find the smoothest combination. Nevertheless, while gathering experiences from several countries, lessons learnt could lead to new incentivization to improve even more strategies in decommissioning:

After more than 60 years of experience in Light Water Reactor (LWR) operations, most of the technological issues have been solved. All unexpected situations, identified misconceptions, and adjustments made necessary over the last six decades due to regulatory evolutions, technical improvements, or environmental considerations have been undertaken, assessed, optimized, and applied. New risk are unlikely to be discovered regarding LWRs, as this mastered nuclear technology is being worldwide tested and trusted.

Consequently, LWR technology appears as an already efficient low carbon energy provider means commonly experienced and approved all over the world.

Therefore, relying on and improving this technology's sustainability by optimizing the associated decommissioning strategy is one of the most rational and pragmatic sign of progress.

Reducing the duration of decommissioning and enabling the quick reuse of the site could gather an increase of acceptance, as well as inducing a huge time reduction conducting to economic, social, and environmental profits. Hence, improving the LWR decommissioning strategy seems to be the most pragmatic way of nuclear incentivization when considered during the construction design phase.

The improvement of the design and conception of new NPPs based on the LWR principle could be pragmatically promoted by considering all components as spare parts of a global structure. Therefore, it will enable to change all kind of components, including the vessel as it is already done for other major parts, including steam generators or internals.

Such consideration at the design phase of a nevertheless well-known and an at least 40-year tested nuclear technology would significantly reduce the decommissioning process duration. It will also increase the feasibility of a complete replacement of all necessary components in less than 10 years allowing:

- Different perspectives of the reuse of the site;
- Ability to secure skills, human resources, training, and education;
- Ability to increase workers safety and environmental considerations;
- Minimization of social and environmental impacts;
- Incfreased public acceptance while reinforcing the perception of decommissioning as a normal step of a usual NPP life cycle.

It will certainly embed dismantling as part of the operation phase, strengthening operators' motivation, securing skills, and knowledge management as nearby population's confidence and perspectives.

Currently, segmenting a shutdown LWR plant vessel and extracting its parts are methods that have been used enough worldwide to be mastered even though they still require specific skills and training.

After remediation and decontamination operations, a major improvement could be to adapt the new LWR design to enable the implementation of a new vessel to replace the previous one.

Replacing the vessel, as it is currently done for major other components (steam generators, pressurizer, exchangers, loops), will move decommissioning from a costly, long and risky operation into a maintenance phase lasting not more than 5 to 10 years by adopting a conservative approach toward safety verification. Buildings will be kept as such, because their construction (and consequently the concrete with which they are made of) was conceived to last more than 300 years, resisting to earthquakes, to missiles or airplane crashes and even more.

Simply keeping the buildings as such will immediately lead to avoiding the generation of more than 90% of the conventional waste usually produced during the deconstruction. Consequently, it would erase the associated environmental impacts.

Furthermore, enabling the "regeneration" of the LWR NPP over 5 years with renewed major components will provide benefit to social and environmental impacts, including preservation of landfills and disposal capacities, maintenance of social and industrial networks around the plant, major economy of usually devoted WM&D funds, enabling investments in education, modernization, environment protection, and sustainability, among others.

This extended stabilization of the nuclear site for a longer period than the previous six decades will positively impact the confidence in nuclear industry, providing not only low carbon, safe, and cheap energy, but also employment and social and economic perspectives in a safe and preserved environment.

As a finding, the usual life cycle of a nuclear facility consists of 20 years to build a LWR NPP, then 40 to 60 years of operations, followed by 30 to 40 years of decommissioning.

During this last phase all the social and industrial networks need to move or to be adjusted for other perspectives, inducing, in between, loss of skills and knowledge as well as social and economic issues in addition to environmental impacts.

Moving the decommissioning to a 5-year maintenance phase instead of 40 to 60 years (withreuse of the site after nearly half a century), will promote a different perception of the role of nuclear industry. It will emphasize it as an asset demonstrating its undoubtable advantage in a circular economy perspective coupled with a sustainable low carbon energy generation.

Regarding the 300 years longevity of the concrete that composes the buildings, it could be therefore envisaged to reproduce this process at least three times safely and the plant would be operated for 180 years, being renewed every 40 or 60 years. Such an incentive based on three successive life cycles of the NPP leads to 200 years of operation (including the maintenance phase in between) which conservatively remains safely below the 300 years of natural lifetime of the concrete.

Such approach of decommissioning simply based on a slight modification of the reactor building allowing the entry of a new vessel every 40 or 60 years, could certainly change the global perception of the nuclear industry, while remaining based on a worldwide already safely tested and experienced LWR technology.

If the technical feasibility of such improvement has already been assessed and largely accepted, one more aspect that needs to be adressed is the regulatory framework harmonization. National policies are characterized by their specific considerations, and are derived from international safety directives, commonly approved by most of the Member States. A potential approach to a harmonized regulatory framework could be to foster a retrospective alignment of national regulations to their original international statements and standards.

International official organizations, such as the IAEA or the International Commission on Radiological Protection (ICRP) are continuously updating these international standards, by addressing some of the topics that are discussed below.

The variety of clearance levels between countries is one of the outcomes of this lack of harmonization, thereby impacting the principles of the circular economy as well as recycling and reuse. The lack of alignment of regulations leads to confusion and impacts public understanding, with potential consequences on the nuclear industry's credibility.

In addition, discrepancies between regulations prevent stakeholders from clearly benchmarking the efficiency of methods and waste treatment between countries to enable a real choice of best available techniques (BAT) while seeking for optimization or innovative improvements. With globalization of decommissioning and waste management issues, individual/national initiatives may not seem sufficient to avoid generating confusion in public consideration towards the nuclear domain.

Waste Management & Decommissioning (WM&D) optimization could be achieved through a global approach, by involving the countries which are implementing WM&D projects, and which could enable identifying and listing the respective needs, skills, capacities (space, geological characteristics, waste treatment capacity), and to distribute them while considering the various assets involved and the concerns that could be solved.

A similar approach is currently being developed with the idea of a Multinational Repository project on behalf of several international organizations. For instance, such a project could answer the need of countries that can afford such a deep geological disposal but can't realize it due to national technical constraints (seismic, population density). On the other hand, it could become an opportunity for other countries that don't have to deal with these specificities but can't justify the associated investment of a stand-alone national deep disposal due to the small amount of waste they have to address.

Waiting for a real international commitment, promoting horizontal nuclear companies' structure (from cradle to grave) is also one of the pragmatic ways of strategy optimization being envisaged. A nuclear operator being involved at each step of the nuclear process, like a kind of horizontal trust, might avoid any conflict of interest in waste management between operators and waste treatment facilities or depositories. A company involved in all aspects (mining, operation, maintenance, characterization, treatment, disposal) could, therefore, easily assume its responsibility and manage its needed skills for many years.

In a long term process such as dismantling, this "span over" industrial attitude might increase nuclear industry credibility allowing a real share of techniques or means between countries. It would enable optimization especially if the sharing is coupled with (or induced by) a kind of harmonization of the national regulations.

Harmonization could align the national regulations and associated practices to international directives, agreements and accepted guidance. Such alignment would be an incentive to improve benchmarking of techniques, efficiency, and developments.

3. CONCLUSIONS

The worldwide experience and lessons learned from the last two decades of decommissioning worksites lead to the following conclusions:

- the decommissioning strategies would be benefited by the alignment of regulations
- If this objective is achieved, it could enhance the nuclear industry's credibility.
- It could significantly improve foreseen strategies, easing future decommissioning but also minimizing operations costs.
- It would enhance knowledge management, education, securing skills, keeping stakeholders' motivation and confidence as well as preserving environmental impacts, social life, local economy, national energy independence, and profitable industrial organizations.

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THE NUCLEAR ENERGY AGENCY ACTIVITIES IN THE AREA OF RADIOACTIVE WASTE MANAGEMENT, DECOMMISSIONING NUCLEAR INSTALLATIONS, AND LEGACY MANAGEMENT

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Abstract

At the back end of the nuclear fuel cycle, there is a need to ensure the safety of radioactive waste at all stages including its final disposal. The NEA assists member countries in the development of safe, sustainable and societally acceptable strategies for the management of all types of radioactive waste. In addition, the NEA assists its member countries in their needs for developing, reviewing and updating effective safety cases supported by a robust scientific-technical basis. The work of the Agency in this area is coordinated through the radioactive Waste Committee in its subsidiary bodies. As many radioactive waste disposal programmes rely on volunteer or consent-based siting, safety case communication is another important aspect that is common to all types of disposal facilities. The scientific and technical basis for disposal facilities should be accessible to all stakeholders to enable them to participate in the decision making process. In this respect, it is key to build trust and confidence in the licensing process, tailor communication, explanation or concertation towards different audiences, and be concerned about stakeholder needs. As many nuclear power plants will reach the end of their operating lives over the next 20 years, decommissioning is an increasingly important topic for governments, regulators, industries and the public, among other stakeholders. Decommissioning activities have to be carried out at the end of life of the nuclear facilities and sites. Some countries are further challenged with the decommissioning of legacy (i.e. complex) sites. The NEA created the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) was created in 2018 following the request from Nuclear Energy Agency (NEA) member countries to enhance the NEA's visibility in nuclear decommissioning and legacy management. The committee also aims to achieve a collaborative advance of the state of the art of technical, environmental, policy, financial and societal aspects in its areas of work. The work of these two Standing Technical Committees apply a holistic as well as a sustainable approach to dealing with radioactive waste management as well as in the area of decommissioning and legacy management. In this way, the committees systematically identify its activities by focusing on three aspects 1) regulatory and legal; 2) economic; and 3) societal. These aspects, according to the holistic approach accepted by the CDLM and RWMC, are considered in the context of three frameworks: legislative, organizational and regulatory.

Note: This presentation is presented verbatim as deliviered by R. Tadesse in Session 6 – Multinational Cooperation in Radioactive Waste Management.

1. INTRODUCTION

As you know, the NEA is an intergovernmental agency that facilitates cooperation among countries with advanced nuclear technology infrastructures to seek excellence in nuclear safety, technology, science, environment, and law. The 34 member countries produce 80% of the nuclear capacity in the world. The NEA operates under the guidance of the Steering Committee for Nuclear Energy, through eight specialised standing technical committees. These specialised standing technical committees and 80 subsidiary bodies represent the major areas of the Agency's programme, each of which overseeing various specialised working groups and task groups. Our committees are comprised of policy makers, regulators, and implementers to address the technical issues that are found in nuclear energy programmes. The 8 technical standing committees cover Nuclear Science, Nuclear Technology and Economics, Nuclear Regulatory Safety, Nuclear Law, Radiation Protection, Nuclear Decommissioning, and Nuclear Waste Management. Due to the growing demand for decommissioning, the NEA created the Committee for Decommissioning of Nuclear Installation and Legacy Management in 2018.

2. NUCLEAR ENERGY AGENCY - RADIOACTIVE WASTE MANAGEMENT AND DECOMMISSIONING ACTIVITIES

Within the Radioactive Waste Management Committee (RWMC), we have several groups that work on different aspects of waste management: we have the working parties on Knowledge, Data and Information Management, and Integrated Group for safety cases. Within each working parties for those committees there are subgroups that deal with different geological formations, how you address operational safety, DGRs and low level waste, and the working party on knowledge management. This looks at how you do preservations, make archiving, and make sure that safety cases are documented such that they would be available throughout the process of the DGR. In addition, we have expert groups on robotic and remote systems and as well as on Regulator and Implanter dialogue. That gives you an overview of the activities the RWMC is addressing. In addition to the RWMC, we have two groups that support the work of the RWMC and the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM), the Regulatory Forum, and the Forum for Stakeholders. The regulatory forum brings regulators together to address the regulatory technical issues regarding radioactive waste management and decommissioning. Other areas that the Regulatory Forum works on are competency management of the regulator. The forum was set up 20 years ago to serve as a platform for understanding stakeholder dialogue and discussing methods to develop shared confidence, informed consent, and approval of radioactive waste (RW) management solutions. As I indicated earlier, the CDLM was created in 2018, because many nuclear power plants will reach the end of their operating lives over the next 20 years. Consequently, decommissioning has become increasingly important topic for governments, regulators, industries, and the public, among other stakeholders. Some countries are further challenged with the decommissioning of legacy (i.e. complex) sites. These sites are comprised of different levels of uncertainty, such as a lack of clear governance (e.g. policy, regulation), limited funding, or unclear disposal routes for the contained waste. The sites and facilities in question serve a wide range of uses, resulting in varied radiological characteristics and levels of complexity regarding decommissioning.

The CDLM has divided its work activity in the following areas: organizational aspects of decommissioning and legacy management, technical, environmental and safety aspects, and societal aspects. In addition, we are looking at decision making processes, making sure decisions consider all potential hazards of each approach. A holistic decommissioning decision making process considers the environmental, the economic, and societal impact. In addition, Information Management during operation plays a critical role in decommissioning.

Now I will focus my presentation on strategies for developing Integrated Safety Cases. There are several questions that need to be addressed: what do we know about the facility or the geological formation, how do we make sure we can demonstrate what we know, how do we make sure that it is demonstrated in terms of the practical aspect of it, and how do we communicate the results? What the Integration Group for the Safety Case (IGSC) tries to address from the scientific basis are assessing the performance of the barriers, observing rock formation behaviours, identifying things we don't know and need to answer, and demonstrating that the safety cases evaluated, the role of features, events, and processes play in the development of the safety cases, as well as create a database for features, events, and processes (FEPs). We look at the scenario development for the DGRs, both deterministic and probabilistic, for demonstration. Once we have demonstrated the safety case developed meets the regulatory acceptance, we also need to look at operational safety, such as facility design and the performance of engineering barriers. Since the DGR development process is long, it is essential that we maintain the information and data used to develop the safety case. Therefore, we are working to develop strategies and processes for digitalization of the safety case and develop supporting documents that will be able to be used in the future. The last part is to communicate the information developed in the safety case to the stakeholders. The forum for stakeholders plays a significant role in supporting the IGSC by developing communication tools and having a workshop.

What is the value of the IGSC to member countries? We provide peer review on site for specific, as well as generic safety cases for DGR siting. The IGSC provides an opportunity for like-minded people to come together to address the technical issues that they are facing, develop tools and databases to address generic technical issues, and develop methodologies for communicating uncertainties to stakeholders, so member countries could utilize the information IGSC developed in the development of their safety case.

3. NUCLEAR ENERGY AGENCY SUPPORT ACTIVITIES IN THE FIELD OF RADIOACTIVE WASTE MANAGMENT

The Forum on Stakeholder Confidence (FSC) plays an integral role in bringing together national stakeholders and FSC members to provide a neutral ground for discussion, dialogue, and advancement of knowledge on long term radioactive waste management. FSC also develops tools for communicating uncertainties, building trust, and communicating the added value for the community that is hosting this facility. FSC publishes a lot of practical guidance to facilitate stakeholder engagement throughout the DGR development process.

Other activities that we are involved in to support member countries in addressing sustainability of nuclear energy include the high level international roundtable discussion that the NEA, the United States Department of Energy (DOE), and the Ministry of Economy, Trade and Industry of Japan jointly organized on the final disposal of high level radioactive waste and spent fuel, with the participation of 15 countries and the IAEA. At these meetings, policymakers from 15 countries gathered with the IAEA and shared knowledge about public understanding and technological development related to final disposal, as well as identified areas where international cooperation in sharing experience and knowledge, as well as research facilities could be strengthened.

The report [1] summarizes the discussions held and experiences shared at these roundtable sessions held during 2019 and 2020. The report also collects key findings and policy messages from these discussions about the role of governments and how to strengthen international cooperation for stakeholder and public engagement, and technological collaboration. It compiles the country-specific best practices and strategies identified by participating countries that could advance radioactive waste disposal solutions.

Another document [2] that we published pertained to management of the disposal of highly radioactive waste. This report is a policy-level compendium of the current status of knowledge, technological developments, safety standards, and rules and requirements applicable to evaluating the feasibility of DGRs. It summarises how the international scientific community has intensively collaborated to bring sound arguments and evidence into the debate that spent nuclear fuel/high level waste (SNF/HLW) will not cause harm to either humans or the environment. It also documents how deep geological repositories are moving forward in several countries after the case, for their feasibility was accepted by scientific and regulatory authorities and other stakeholders – including through public consultations. There is now confidence, based on science, about the ability to safely manage and dispose of SNF/HLW and what it can contribute to the overall sustainability of nuclear energy

In addition to supporting the report, we held a webinar discussion with experts looking at how the manage the back end of the fuel cycle as it is crucial for the sustainability of nuclear energy. To facilitate the discussion, we invited experts that could provide the historical perspective on the development of DGR, the role of the stakeholder in siting and licensing a DGR, the DGR itself, as well as new advanced technologies. Additionally, we invited a newcomer to the nuclear industry to speak on how past experiences have been incorporated in the development of their radioactive waste management strategies. This webinar provided a high-level overview on how waste management needs to be considered in the entire life cycle of nuclear energy. The webinar video is available on our website.

One of the outcomes of the international roundtable discussion was to create a joint project for utilisation in underground research laboratories in member countries for research and development as well, in addition to the goal of training a young generation of scientists. To identify interest in the topic we held a virtual workshop this past September to discuss the needs of member countries for underground research laboratories (URLs), as well as identify areas for technical cooperation. The objective is to understand what the technical issues are that need to be addressed and how we address those issues in a shared underground research laboratory. Since developing URLs are very costly, it is beneficial to understand the type of experiments that could be shared, as well as provide the opportunity to be trained at existing facility.

In the predisposal area, we held a workshop that brought together the different NEA standing technical committees together to address optimization of predisposal management. The objective of the workshop was to address waste management from cradle to grave; from nuclear science, legal, radiation protection, regulatory, and decommissioning perspectives in addition to how best to optimize the waste production and management and identify key barriers to optimization to explore how they can be resolved in the future by addressing it in our programme of work.

In the area of advanced technology, our expert group on Application of Robotics and Remote Systems is in the process of publishing a report that looks at what lessons the nuclear industry could learn from other industries that have successfully used robotic systems, identifies the challenges the nuclear industry faces, as well as the regulatory changes for using robotic and remote systems and recommendations on how to address those issues.

Regarding upcoming events, we are organizing a workshop to better understand how the IGSC's experience on the topic of deep geological disposal and other disposal options can be shared in the development, use and communication of a safety case. This workshop objective is to identify similarities, differences, and how we can leverage the lessons learned in the DGR and other type of disposal.

The Sixth International Conference on Geological Repositories (ICGR) will take place in Helsinki, Finland from 4-8 April 2022. The conference itself will take place on 4-7 April, and a site visit to a low and intermediate level waste repository with an exhibition on the underground rock characterization facility (ONKALO) at Olkiluoto, Finland will take place on 8 April. The conference will bring together senior level decision makers from countries advancing programmes for deep geological repositories. This conference will showcase the development of DGRs from design to operation, demonstrate the technical accomplishments that have been made and some of the challenges that needs to be addressed, explore how to engage the young generation, as well as how to build and maintain trust throughout the process.

Last but not least, we are planning to have a workshop looking into how Radioactive Waste Management and Decommissioning needs to be addressed during the development of new advanced reactors or technology. The workshop with be co-hosted with National Resources Canada that looks at bringing designers, regulators, implementers, and operators together to address what the technical issues are that need to be addressed for the new fuel, from a design perspective for decommissioning, and the lessons learned from existing facilities. This will be a week-long workshop to look at the regulatory and legal framework and to make sure when people are building new reactors with new fuel and new designs that they are looking at the back end and considering the issues that might be coming across from these areas.

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INTERNATIONAL COOPERATION WITHIN RADIOACTIVE WASTE MANAGEMENT PROJECTS AT CHORNOBYL NUCLEAR POWER PLANTS

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Abstract

Currently, several projects have been implemented to different degrees at the Chornobyl nuclear power plant (NPP) site with international support of organizations, such as the International Atomic Energy Agency (IAEA), the European Bank for Reconstruction and Development (EBRD), and the European Commission (EC). Construction of the following facilities is at different stages of commissioning or pre-commissioning with a gradual increasing of production capacity: Liquid Radioactive Waste Processing Plant, Industrial Complex for Solid Radioactive Waste (RAW) Management, Industrial Complex for Containers and Drums manufacturing (packaging kits for RAW), Facilities for Radioactively Contaminated Water and Liquid Radioactive Waste Purification from Organic Compounds and Transuranium Elements, and New Safe Confinement. IAEA technical cooperation projects have significantly contributed to developing approaches for "problem" radioactive waste streams management. Joint strategic directions have been developed for managing radioactively contaminated waters containing organic compounds, radioactively contaminated graphite, and significant quantities of radioactive soil. Additionally, the level of radionuclide composition characterization in radioactive waste has been significantly increased. The paper provides more detailed information relevant to the radioactive waste management projects at Chornobyl NPP and the exchange of experience among the organizations involved in these projects.

1. INTRODUCTION

The 1986 Chornobyl Unit 4 accident released a significant number of radionuclides into the environment and, to a significant extent, into the area around the plant. Initially, the remains of the power unit were covered with a sarcophagus to establish a safe condition. As the structure (now known as the "Shelter" object) was not durable, the New Safe Confinement (completed in 2019) will ensure dismantling of shelter object unstable structures and retrieval of fuel-containing masses.

The Chornobyl NPP (ChNPP) had no infrastructure for safely processing radioactive waste (RAW). Elimination of the Chornobyl accident consequences accumulated significant amounts of liquid and solid RAW in temporary storage facilities at the Chornobyl site. As such, there was a need to create the facilities for their processing and to develop technologies for safe management of accidental radioactive waste contaminated with transuranium elements.

During decommissioning of the remaining Chornobyl NPP units and auxiliary facilities, which have been contaminated since 1986, there is also a need to establish facilities to manage radioactively contaminated equipment and materials (metal, concrete, graphite), to release radioactive materials from regulatory control.

The Chornobyl NPP with international technical assistance and support of international organizations, such as the International Atomic Energy Agency (IAEA), the European Bank for Reconstruction and Development (EBRD), and the European Commission (EC), has successfully implemented construction projects for such facilities as Liquid Radioactive Waste Treatment Plant, Industrial Complex for Solid Radioactive Waste Management, Complex for the containers and drums (packaging kits for RAW) manufacturing, New Safe Confinement for the Shelter object, Facility for Radioactive Materials Release from Regulatory Control, among others.

2. LIQUID RADIOACTIVE WASTE TREATMENT PLANT

The Liquid Radioactive Waste Treatment Plant (LRTP) is intended for processing liquid radioactive waste accumulated during ChNPP operation (including elimination of the Unit 4 accident consequences) and those generated during ChNPP decommissioning, as well as operational waste of the Shelter object.

Taking into account the lack of experience in RAW processing in Ukraine, within the framework of input data preparation for the design of the LRTP at the ChNPP has studied the world experience with the support of experts from Westinghouse and AMEC NNC, and LRAW treatment technology based on the cementation method was selected.

The LRTP was constructed under the international technical assistance project of Nuclear Safety Account Grant #006, administered by the European Bank for Reconstruction and Development.

The LRTP is a complex facility providing LRAW retrieval from storage tanks, acceptance, preparation, volume reduction, solidification, packaging and temporary storage of conditioned LRW. The LRTP is located within the ChNPP industrial site, close to LRAW storage tanks and is connected with them by a process pipelines system.

Implementation of the LRTP project started in 1999 under the Contract between ChNPP and a consortium consisting of: BELGATOM \ SGN \ FMECANNICA Sp D'AZI A ANSALDO NUCLEARE.

The contract was terminated in 2006 upon agreement of the parties due to repeated deadline delays and impossibility to increase the cost. Following the funding resumption in 2008, construction work resumed with involvement of new Contractors, and in 2018 LRTP has started the industrial operation phase of one of three types of LRAW – evaporated bottom.

The second type of LRAW, spent ion exchange resins, contains significant transuranium element contamination, which required additional analysis in terms of its safe disposal. It is planned to start this LRAW type treatment after regulatory approval of the results of comprehensive active tests of LRTP in 2022.

The third type of LRAW, filter perlite and sludge, is an abrasive product causing the failure of the existing LRAW separator. Therefore, a decision was made to postpone the filter perlite treatment after the ion exchange resin. At the moment European Commission's International Technical Assistance Project No. U4.01/14A "Specification of waste forms to allow safe treatment, storage and disposal of problematic radioactive wastes held at Ukrainian Nuclear Energy Facilities" is being implemented; the adjustment of technology for this "problematic" LRAW stream management is under development.

3. INDUSTRIAL COMPLEX FOR SOLID RADIOACTIVE WASTE MANAGEMENT

The Industrial Complex for Solid Radioactive Waste Management (ICSRM) is intended for processing of solid and combustible liquid radioactive waste accumulated during Chornobyl NPP operation (including consequences of the accident elimination at Unit 4) and those formed in the process of NPP decommissioning, as well as operational waste from the Shelter object.

The ICSRM was constructed in the framework of an international technical assistance project funded by the European Commission under the TACIS Action Plan for 1996.

The ICSRM is an integrated facility, providing storage, sorting, processing and immobilization of all SRAW categories and incineration of combustible Low-Level SRAW.

The ICSRM consists of four separate SRAW management facilities, which are interconnected into a single technological cycle (Lots):

Lot 0 - Temporary Storage Facility for High Level Waste (HLW) and Low and Intermedium Level Long-Lived Waste (TS HLW and LIL-LLW), designed for temporary (up to 30 years) storage with subsequent transfer of TS HLW and LIL-LLW to geological disposal facilities to be constructed.

Lot 1 - Facility for retrieval of all categories solid radioactive waste from the Solid Waste Storage Facility (SWSF) located at ChNPPP site. Location: directly above the SRAW storage facility building. The facility allows removal of SRAW from SWSF compartments, primary sorting, fragmentation of large and long fragments, and preparation for waste batches transportation to the Solid Radioactive Waste Processing Plant (SRWPP) (Lot 2).

Lot 2 - The SRWPP is located within the ChNPP industrial site near the existing SRAW storage facility and is connected to the SRW Retrieval Facility by a process gallery. The SRWPP provides the following functions: sorting of all SRAW categories (HLW, LIL-LLW and LIL-SLW); conditioning of HLW and LIL-LLW for temporary storage in Lot 0; sorting of LIL-SLW into combustible, compactable and non- compactable; SRAW compaction; combustible SRW and LRW incineration with further ash compaction; immobilization of processed SRAW by cementation in reinforced concrete containers KZ-3.

Lot 3 is Engineered Near-Surface Disposal Facility for Solid Low and Intermedium Level Short-Lived Waste. The location is the Vector complex site in the Exclusion Zone. The disposal facility is intended for disposal of radioactive waste processed at Lot-2 (in KZ-3 containers) and LRTP (in 200-l metal drums).

Implementation of ICSRM project was carried out under Contract between ChNPP and NUKEM Technologies GmbH.

Within the framework of this contract implementation, Lots 0 and 3 of ICSRM were commissioned in 2014 and 2008 respectively. Lots 1 and 2 passed two stages of hot tests, after which a deficiency was identified in terms of radionuclide composition characterization - the radiation process control system of SRPP is not able to measure neutron fluxes with the necessary accuracy. Based on the results of additional investigation of the identified deficiency, a number of IAEA expert missions were carried out to review the approaches to characterization of SRAW radionuclide composition, and at the moment ChNPP has implemented a modification to introduce the radionuclide vector method, involving the preliminary characterization of SRAW with subsequent measurement of only main reference nuclides at SRWPP and calculation of the entire radionuclide composition based on SRAW characterization data.

The final stage of the ICSRM hot test is planned for the second half of 2021, after that Lots 1 and 2 will be commissioned.

4. COMPLEX FOR MANUFACTURING STEEL DRUMS AND REINFORCED CONCRETE CONTAINERS (RAW PACKAGES)

The Complex for Manufacturing of Metal Drums and Reinforced Concrete Transport Containers for radioactive waste storage (CMMD&RCC) is intended to produce packaging kits to support Radioactive Waste Management processes at the Chornobyl NPP.

The CMMD&RCC project has been implemented under the International Technical Assistance Project No. U4.01/04W funded by the European Commission under the TACIS Programme. The facility was commissioned in 2012.

The CMMD&RCC for radioactive waste storage belongs to the infrastructure necessary for Chornobyl NPP decommissioning. It was necessitated by the ICSRM) and the LRTP construction and commissioning at Chornobyl NPP.

The complex as an integral part of the radioactive waste management programme ensures safety of technological processes of RAW management during radioactive waste collection, transportation, storage, processing and disposal.

5. PURIFICATION FACILITY FOR RADIOACTIVELY CONTAMINATED WATERS AND LIQUID RADIOACTIVE WASTE FROM TUE AND ORGANICS

One of the most problematic issues of radioactive waste management at Chornobyl is the presence of organic compounds in the radioactively contaminated water, used in response to the 1986 accident and currently continues to be used for dust suppression inside the Shelter. The mentioned dust suppressing compounds (DSC) are water soluble, which causes contamination of the Shelter facility drainage water, and their further presence in the evaporated bottoms. A feature of DSC is the possibility of their polymerization under condition of increased concentration and temperature inherent to the evaporation processes. This property leads to evaporators failure during their deep evaporation to a higher salt content.

To address this problem, a process to remove organic compounds and transuranium elements from the Shelter waters and from the stored evaporated bottom was successfully developed as part of a technical cooperation project with IAEA, with involvement of the experts from the Institute of Chemistry, Far East Branch of the Russian Academy of Sciences. The process has been successfully tested on a small scale in a pilot plant.

Based on the results of the pilot studies, the European Commission (EC) has scheduled, in the framework of the Instrument for Nuclear Safety Cooperation Program (INSC), funding for 2011 and 2012 for the implementation of Project №U4.01/11C on creation of the Industrial Facility for the Shelter water and evaporated bottom purification from organic compounds and TUE (IFLRWP) at ChNPP site.

The project provides for creation of the facility, performing the function of preliminary treatment of Shelter waters and LRAW from TUE and DSC for further treatment of the purified product in the Special Water Treatment Facility and LRTP. The purification technology of the industrial facility is based on the application of methods: coagulation with subsequent filtration - for the Shelter waters and hydrothermal treatment - for the evaporated bottom.

In 2014, a contract was signed with NUKEM Technologies GmbH to implement this project, but due to limited funding, the project has only been partially implemented - the design stage has been completed. Implementation of the next stage is pending.

6. FACILITY FOR FREE RELEASE OF MATERIALS FROM REGULATORY CONTROL

The project for the Facility for Free Release of Radioactive Materials from Regulatory Control is funded by the European Commission under the Instrument for Nuclear Safety Cooperation Programme (INSC) for 2011.

The overall objective of the project is to improve the safety and cost effectiveness of all types radioactive material management and to take all possible measures to reduce the waste volume.

As part of this project, taking into account the experience of other countries, the methods for radioactive materials free release from regulatory control have been analysed, a methodology and techniques for release from regulatory control have been developed for ChNPP, and pilot operation of the facility is underway. The first batches of decontaminated metal are expected to be released in the 4th quarter of 2021.

7. NEW SAFE CONFINEMENT

The Shelter has been constructed under very tight terms to allow the destroyed reactor to be preserved as quickly as possible. At the same time, taking into account the radiation situation and the need to protect personnel, the work was carried out without compliance with traditional norms of nuclear facilities designing, construction and commissioning. The building structures of the Shelter are a combination of the “old” structures of the destroyed Unit 4 and the "new" structures built after the accident. They do not meet the requirements of the normative and technical safety documents in terms of structural integrity and reliability. This makes it impossible to determine its service life, and subsequent surveys have shown that a significant reduction of the shelter hazard is possible only as a result of the construction of a new containment structure over the facility - the New Safe Confinement (NSC).

The NSC project has become one of the most significant projects at the Chornobyl site. The NSC is 257 m wide, 108 m high and 162 m long.

The NSC project is part of one of the stages of the “Shelter Implementation Plan” into an environmentally safe system. This Plan involves sequential implementation of the stages: Stabilization (stabilization of the current Shelter object), Preparation for Transformation (creation of additional protective barriers, dismantling of unstable structures, preparation of infrastructure for RAW management and fuel-containing mass retrieval), and Transformation itself (fuel-containing mass and radioactive waste retrieval and disposal).

During 2004–2008 the stabilization phase was implemented, which allowed the safe operation of the Shelter facility to be extended until 2023.

Stabilization stage was implemented during 2004–2008, that allowed the safe operation of the Shelter object to be extended until 2023.

In 2019, 45 donor countries joined efforts with Ukraine to construct NSC and more than €1.5 billion of funding for the project was collected. A total of 10,000 workers from 40 countries were involved in the project.

As a result, NSC erection had a positive impact on the radiological conditions around ChNPP and on the environment in general. According to gamma radiation measurements the levels in the former Arch construction zone, radiation levels decreased by an average of 10 times. The Arch also protect the Shelter facility from atmospheric precipitation. In comparison, the amount of radioactively contaminated water pumped from the Shelter during the first half of 2017 decreased on average by more than 4 times compared to the same periods of previous years. In addition, the release of radioactive aerosols through cracks in the Shelter has also decreased. The NSC prevented the direct influence of sunlight and wind on the Shelter, which created air flows inside the Shelter and carried radioactive aerosols outside. The total volume of releases was reduced by an average of 5 times.

8. IAEA TECHNICAL COOPERATION PROJECTS

8.1. Radioactively contaminated waters management

From 2009 to 2012, pilot tests on the treatment of radioactively contaminated water from the Shelter object and evaporated bottom containing TUE and organic compounds were carried out at the ChNPP site under IAEA project UKR3003. These tests were implemented jointly with IAEA technical experts, in the process of these tests the technology of RCW treatment from TUE and organic compounds using the precipitation method was identified, and the technology of sludge treatment using the hydrothermal method was tested. The testing of these technologies became the basis for the design of the Industrial Facility for treatment of the Shelter water and LRAW from TUEs and organic compounds at ChNPP. Within the subsequent period in 2016–2018 the works were performed to determine the acceptability of the secondary waste form from the Industrial Facility for treatment and disposal. Based on the results of these activities, the methods of LRAW treatment were specified and the volumes of expected RAW were significantly reduced.

Also, taking into account the technical changes at the ChNPP site that occurred since the last power Unit shutdown in 2000, it has become necessary to review the whole Radioactive Water Management System at SSE ChNPP, since the volumes of RCW generation were no longer consistent with the capacity of existing evaporation units, and energy costs have increased significantly. During the IAEA expert mission in 2016, a simplified RCW treatment scheme was developed based on filtration and distillation methods. In 2021, ChNPP started to implement the adjustment of RCW treatment system with use of vacuum evaporators.

8.2. Radioactively contaminated graphite management

To date, in the world there is no single solution relevant to Radioactive Graphite Management, despite the fact that there are quite intensive scientific developments in field of the graphite management, aimed at finding technically and economically justified methods of the Radioactive Graphite management. At the same time, the following are being investigated:

- Methods of engineering barriers creation for long term storage of graphite in the form of solid RAW;
- Methods of chemical transformation of the graphite in order to separate dose-forming isotopes and reduce volumes for further storage.

The major part of Radioactive Graphite from ChNPP in the form of reactor cladding, in accordance with the Decommissioning Strategy, will be enclosed in a “preservation zone” for long term safe enclosure, but the remaining part in the form of channel graphite is to be retrieved and processed in preparation for preservation.

Approaches to channel graphite management and characterization at the Chornobyl NPP were addressed during the workshops organized by IAEA in 2017–2019. Based on the results of these workshops, recommendations for graphite characterization and temporary storage (up to 30 years) at the Chornobyl site have been developed.

8.3. Radioactively contaminated soils management

During the NSC construction more than 125 000 m3 of radioactively contaminated soil was formed, which, taking into account the contamination levels at large areas around the ChNPP site, was placed for temporary storage 5 km from the ChNPP at the so-called Technological Materials Temporary Storage Site (TMTSS). Part of this soil was used for backfilling during excavations.

After NSC construction about 20 000 m3 of the most contaminated material was disposed in special surface storage at the Exclusion Zone territory and 100 000 m3 of technological materials remain in temporary storage at TMTSS. The necessary storage facility to dispose the rest of the technological materials is not available.

In 2019, during the IAEA expert mission regarding the decisions on further management of the technological materials, the decision of the ChNPP to extend the storage of these materials at TMTSS was addressed and a number of recommendations on the Radiation Safety Measures improvement for such storage were developed. Currently, the ChNPP has developed a decision with the Action Plan for further safe storage of the accumulated materials and approval from the regulatory authorities of Ukraine is awaited.

8.4. RAW characterization

After the accident at Unit 4, many scientific institutes and specialized companies were involved in the emergency response to the accident; they used their developments to localize the consequences of the accident. Chemical agent and reagents as well as unknown materials, which are present now in RWDS, have been used. Characterization of this type of accidental waste requires a special approach and joint study. Therefore, ChNPP actively cooperates with IAEA in this area and organized a number of workshops and staff training involving specialists, specialized enterprises and companies.

In September 2019 the workshop within IAEA project UKR 9/038 was organized at ChNPP to gain experience in RAW management and to obtain information on modern methods related to the liquid, solid and accidental RAW characterization.

This workshop elaborated the close links between Waste Acceptance Criteria and the waste characterization and predisposal stages. The main focus was on the identification of Long Lived Difficult to Measure radionuclides and, in particular, on justification for a differentiated approach and links to international experience.

Practical examples of the post-accident situation at the ChNPP were presented and the need for extensive use of process knowledge as a very important tool, or characterization of the waste arising from the accident, was pointed out.

8.5. Supply of equipment

Cooperation between ChNPP and IAEA is also implemented in the framework of international assistance for procurement of equipment and materials to implement the projects and the programmes related to RAW management. Particularly, in the framework of the testing of sedimentation purification scheme for Shelter object water and ChNPP evaporated bottom purification from dust suppression emulsion and transuranium elements, in 2010 and 2011 equipment was purchased under the IAEA Project UKR3003 for pilot facility installation. This equipment is currently being actively used to test methods for the RCW and LRAW management.

In 2015, the Raddec PYROLYSER-2 Trio System laboratory unit was purchased for ChNPP as part of international assistance from IAEA to solve problems in the field of RAW management. The main purpose of this equipment is to prepare radioactive samples and identify Difficult to measure radionuclides (^{14}C, ^{3}H, ^{36}Cl). At the present time, the adapted documentation on the safe operation of this unit at Chornobyl NPP was developed and the activity was implemented to extract ^{14}C, ^{3}H and ^{36}Cl from metal samples. Work with irradiated graphite samples is planned in the nearest future.

In 2019, a Stereozoom S9i digital stereo microscope was purchased as part of the IAEA international assistance project UKR9038. The basis for procurement of this equipment was laboratory research in field of radioactive waste management in order to visually study physical and chemical processes and samples with the possibility of video and photo recording of material for further study and analysis together with representatives of scientific institutes. Due to this equipment, ChNPP has determined the processes taking place during the hydrothermal treatment of the evaporated bottom containing dust suppression compound. Sediments on the heat and mechanical equipment and the presence of sludge in the spent ion exchange resins and filter-perlite pulp were analysed.

Implementation of IAEA project UKR9040 is ongoing. At the moment under this project delivery of a set of equipment, consumables and manuals is awaited for the radiochemical separation of difficult to measure radionuclides and their specific activity measurement using radiometric equipment. The approach to measurement of alpha nuclides specific activity in RAW at ChNPP is presently limited by mass spectrometer with inductively coupled plasma using developed and approved methods. Unfortunately, this approach can be considered only for identification of radionuclides with high activity and error. Identification of radionuclides with low activity, which the ChNPP encountered in the accidental SRAW characterization, this method is not suitable. Delivery of a set of equipment for alpha radionuclides chemical separation will allow the ChNPP to determine an individual approach to each group of alpha nuclides and obtain initial data on the content of difficult to measure radionuclides for each RAW stream.

8.6. Training courses

With IAEA assistance, organized activities at ChNPP and Ignalina NPP provided an avenue for experience exchange and training for ChNPP personnel in current methods of detecting difficult to measure radionuclides in RAW samples.

From 2018 to 2019, the IAEA engaged LOKMIS (Lithuania) to provide training to ChNPP personnel in operation and maintenance of Agilent 7500CS inductively coupled plasma (ICP MS) mass spectrometer, as well as an Agilent 1200 Series high performance liquid chromatograph (HPLC). The training included a short course on the theoretical basics in mass spectrometry and practical use of the equipment in LRAW characterization, including analysing the obtained results and equipment maintenance.

In 2019, as part of IAEA project UKR 9038, specialists from ChNPP visited the Ignalina NPP for training in RAW characterization. During the fellowship, RAW sampling activities were studied and analysed in practice. Additional knowledge was obtained in sample preparation and radiochemical analysis of standard and emergency RAW samples. On-the-job training was realized in radionuclide activity measurement using spectrometric equipment and in equipment maintenance.

The fellowship enabled ChNPP to exchange experience, obtain information regarding Ignalina NPP approaches and best international practice in RAW characterization, to analyse the obtained information, and to initiate optimal implementation of this approach in the complex of RAW management measures at ChNPP.

9. CONCLUSION

In summary, considering the Ukrainian organizations lack of necessary experience, international cooperation played a key role in developing the Chornobyl NPP radioactive waste management system. When implementing the discussed projects and choosing the technologies for radioactive waste management the exchange of experience between organizations possessing the experience in similar radioactive waste streams management and scientific developments in this area was an undoubted factor in the successful implementation.

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ADOPTION AND IMPLEMENTATION OF AN INTEGRATED WASTE MANAGEMENT STRATEGY TO SUPPORT AND DELIVER THE NEXT GENERATION OF YOUNG PROFESSIONALS IN THE REMEDIATION OF THE UK'S NUCLEAR LEGACY

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Abstract

The Nuclear Decommissioning Authority (NDA) is a non-departmental public body of the Department for Business, Energy, and Industrial Strategy, formed by the Energy Act 2004. The NDA is responsible for cleaning up the UK's earliest nuclear sites safely, securely, and cost effectively, with consideration and care for people and the environment [1]. In 2019 the NDA published the Integrated Waste Management (IWM) Strategy, aiming to promote cross-category waste management optimization across the whole waste management life cycle, within the NDA estate. This supports a risk-informed approach while protecting people and the environment to deliver the NDA mission [2]. The adoption and implementation of an IWM strategy will require people, with the appropriate range of skills and knowledge, to provide capability throughout all the relevant disciplines involved across the waste management life cycle. The IWM strategy should offer opportunities for young professionals to drive the delivery of the NDA mission and create a culture in which they can thrive. The NDA nuclear graduates programme, Nuclear Skills Strategy Group (NSSG), early career networks, mentoring and shadow Boards are essential to support the next generation of young professionals in the remediation of the UK's nuclear legacy.

1. INTRODUCTION

The Energy Act 2004 created the Nuclear Decommissioning Authority (NDA), a non-departmental public body to take responsibility for decommissioning 17 legacy NDA sites across England, Wales, and Scotland. Some of these sites present unique and difficult nuclear decommissioning challenges [1]. The NDA are also responsible for implementing geological disposal and the UK's nuclear industry's solid low level radioactive waste (LLW) strategy. The NDA mission will take an estimated 100 years or greater to complete at a cost of over £120 billion to deliver.

In 2019, the Integrated Waste Management (IWM) Radioactive Waste Strategy was published, whereby the NDA made a commitment to: 'ensure that wastes are managed in a manner that protects people and the environment, now and in the future, and in ways that comply with government policies and provide value for money' [2]. The IWM Strategy replaces the Higher Activity Waste Strategy published in 2016 with a greater focus on promoting cross-category waste management optimization across the entire waste management life cycle within the NDA estate. This ranges from planning and preparation to treatment and packaging, storage, and final disposal, as well as materials that may be declared as waste in the future, as highlighted in Fig. 1. The strategy also supports a risk informed approach with greater emphasis placed on the radiological, physical, and chemical properties of the waste, and the safety case rather than classification (i.e. high level waste (HLW), intermediate level waste (ILW), low level waste (LLW) and very low level waste (VLLW)), aiding identification of the most appropriate management route [2].

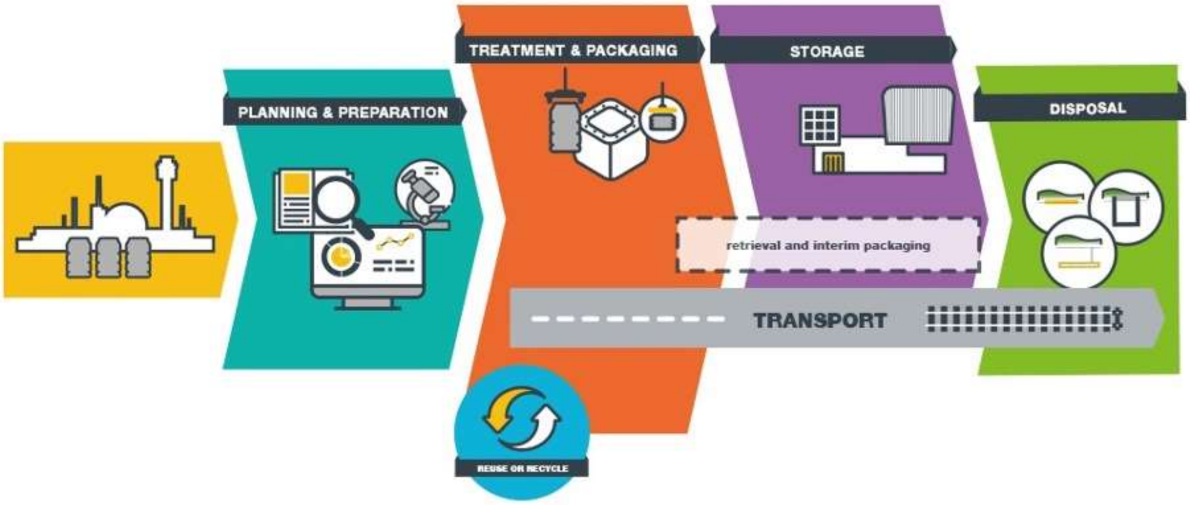

FIG. 1. The NDA waste life cycle [2].

The successful adoption and implementation of this strategy will require people with the appropriate range of skills and knowledge to provide capability across all the relevant disciplines involved in the waste management life cycle [2]. By its very nature, radioactive waste management is an intergenerational issue due to the very long timescales associated with the waste life cycle. The existing workforce needs to grow by an estimated 4700 people a year over the next six years to overcome the challenges associated with the ageing workforce and attraction and retention rates [3]. In addition, over the same period, 3900 people are expected to leave the sector, mostly due to retirement meaning the sector will need to recruit approximately 8600 people each year to sustain the UK's nuclear skills base [3]. Therefore, it is essential plans to address this are put in place now. including addressing issues such as skill gaps, management of data and information, and succession planning. The exact timing and availability of the required skill sets is vital to the success of this strategy.

The paper presents an overview of the adoption and implementation of the IWM strategy and how it can support and deliver the next generation of young professionals in the remediation of the UK's nuclear legacy. The paper also provides some case studies which highlight examples of how IWM can support and deliver the next generation of young professionals.

It should be noted that other areas within the wider NDA mission that require support, such as Site Decommissioning and Remediation and Spent Fuels and Nuclear Materials, are beyond the scope of the paper.

2. AN INTEGRATED RADIOACTIVE MANAGMENT STRATEGY

A risk-informed approach will provide the NDA with greater flexibility in seeking solutions for treatment, packaging, storage and disposal of both radioactive, non-radioactive wastes and materials yet to be classified as wastes. For example, for some wastes, it may be necessary to adopt a multi-stage process to achieve a final disposable product. This could include the separate management of bulk retrievals and residual material to support hazard reduction programmes. The strategy will ensure there is sustainable waste management infrastructure to facilitate timely decommissioning and remediation of facilities and sites, making best use of existing waste management assets and developing new fit-for-purpose waste management routes as required [2].

The risk-informed approach also enables the more effective application of the waste hierarchy (Fig. 2), where it is practicable and appropriate to do so, recognizing that hazard and risk reduction and nuclear safety priorities may limit its application in certain circumstances. The waste hierarchy highlights the importance of waste minimization, re-use, recycling, and other environmentally sustainable options, as well as a more optimal use of all waste infrastructure to minimize overall volumes and drive waste prevention [2]. This also includes driving and facilitating changes in waste management behaviours and cultures. For example, using alternative waste management and treatment routes and consolidation, where appropriate, to improve the overall management of higher activity waste (HAW)[1] has negated the need for building ILW storage facilities at Dungeness A, Sizewell A, Oldbury and Wylfa. Use of the waste hierarchy ensures that radioactive waste is disposed of efficiently [2].

The NDA estate need to apply and consider all stages of the waste hierarchy, to extract as much value as practicable from their waste and to manage their environmental impacts appropriately.

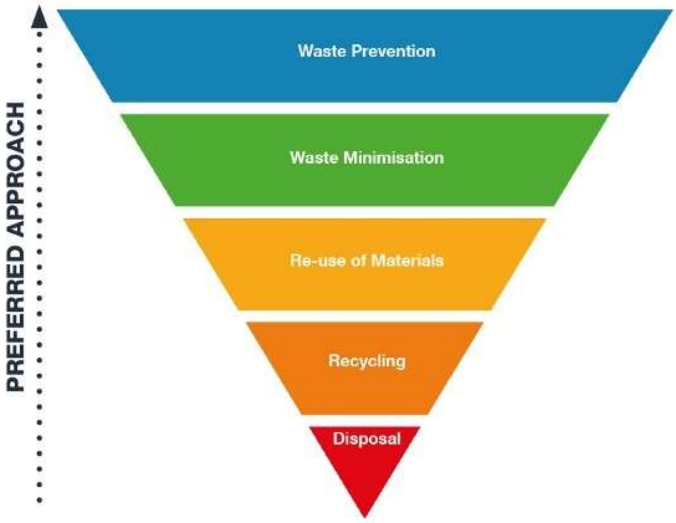

FIG. 2. Applying the waste hierarchy [2].

To deliver the strategy, the NDA are developing a programme of work (an Integrated Waste Management Programme (IWMP) [3]) that will drive forward activities to enable NDA businesses to manage its radioactive waste from waste generation through to disposal more sustainably, efficiently, and unified.

2.1. Benefits of the IWM Strategy

The IWM strategy, presenting the NDA's strategic requirements for radioactive wastes in a single document, will provide greater opportunities to optimize the management of wastes, resulting in reduced costs and schedules. This will contribute towards helping to achieve the commitments set out in the Nuclear Sector Deal (NSD), such as savings of 20% in the costs of waste management and decommissioning by 2030 [4].

It will also provide the mechanism for an IWMP as mentioned in Section 2. The strategy seeks to improve coordination across the industry and waste management life cycle, and to assist waste producers and site operators overcome a range of possible challenges in relation to risk and hazard reduction [5]. This can be achieved through promoting and supporting robust decision making processes and identifying the most advantageous options for managing legacy waste facilities at Sellafield Limited (Ltd.), for example.

Integrated Project Teams (IPTs) led by Sellafield Ltd., Radioactive Waste Management Ltd. (RWM), and Low-Level Waste Repository Ltd. (LLWR) have also been developed to address cross industry issues, develop thermal treatment technologies, and improve the management of problematic wastes.

3. SUPPORTING AND DELIVERING THE NEXT GENERATION OF YOUNG PROFESSIONALS

To attract, retain, and develop high performing, highly skilled, talented, and motivated young professionals in the remediation of the UK's nuclear legacy, opportunities need to be offered for young professionals. This is stated in strategy 4 as an objective under one of the key critical enablers; people and is essential in driving the delivery of the NDA mission and creating a culture in which they can thrive [1].

[1] Higher Activity Waste refers to all radioactive material that has no further use that falls into the following categories: high level waste (HLW), intermediate level waste (ILW) and the relatively small volume of low level waste (LLW) that is not deemed suitable for disposal at the Low Level Waste Repository or the LLW facility at Dounreay.

Methods of support and delivering the next generation of young professionals are discussed in Section 3.2. The application of these methods will ensure understanding of radioactive waste will remain resilient (due to the rapidly changing technological landscape), be clearly recognized (due to social and organizational change), and taken seriously, whilst supporting professional and personal development.

The IWMP is committed to working closely with Site Licensing Companies (SLC) and the supply chain across the nuclear industry to identify the key skills and knowledge requirements, to develop plans to maintain capability, and manage skill gaps.

3.1. The NDA's 'Our People' Strategy

The NDA recognize that people are a critical enabler to deliver the NDA's mission. The People Strategy presented within strategy 4 considers the complexity of skills requirements, unique geographies of some NDA sites, diverse range of stakeholders who have a legitimate interest in the progress of the NDA's mission; relationship with regulators, UK government, and devolved administrations and the necessity to deliver value from the taxpayers' perspective [1].

Since the beginning of the Covid-19 pandemic, employee expectations continue to change markedly around flexible working, agile and digital working, environmental challenges, sustainability, and mental health. Diversity and inclusivity are also driving internal workplace culture and wider societal considerations that enable employees to feel accepted and valued. Inclusivity also attracts a broader range of perspectives and a broader pool of talent across the nuclear sector. In addition, the NDA has to be more responsive to the changing implications for the workforces, present and future, of new technologies and increasing digitalization; aiming ultimately to reduce exposure to risk and improve safety performance [1]. The NDA needs to harness the most effective communication methods available and, if necessary, provide new platforms for the more focused dialogue to engage with a broader range of stakeholders.

The benefit of nurturing a positive workplace culture, whereby all employees within the NDA Group, regardless of their position or who they are, should be able to work in an environment where they feel they are respected, included, and valued.

3.2. The Right Role for the Suitably Qualified Personnel

It is essential for the delivery of the NDA's mission that relevant roles are fulfilled by Suitably Qualified and Experienced (SQEP) personnel at the right time. This includes, and not limited to: identifying recruitment and development programmes for specific skills to support functional strategies and priorities (such as stakeholder relations, procurement and the supply chain); ensuring specific niche and nuclear skills are maintained and invested through the NDA Group and supply chain (including cyber security, environmental science, and radiation protection); supporting and actively championing the sharing of resources to develop careers; and deploying skills effectively on a NDA Group-wide basis.

Other areas of significant importance are being clear about what great leadership looks like within the NDA Group and ensuring 'One NDA' leadership standard is clearly understood and embedded within the next generation of young professionals. The standard sets clear expectations for all NDA Group business leaders across four lenses including creating the future, safely delivering results, inspiring people, and collaborating to unlock potential. 'One NDA,' created in 2017, aims to transform how the NDA manages its businesses (listed below) – through working together to find more effective and efficient approaches to nuclear cleanup and decommissioning on behalf of the UK taxpayer.

- Radioactive Waste Management Ltd;
- Nuclear Transport Solutions (NTS);
- NDA Archives Ltd;
- NDA Properties Ltd;
- Sellafield Ltd;
- Dounreay Site Restoration Ltd;

— LLW Repository Ltd;
— Rutherford Indemnity Ltd;
— Magnox Ltd;
— Energus.

Developing a talent acquisition approach for the short, medium, and long term, recognising the challenges in attracting skilled individuals including groups generally regarded as hard-to-reach groups (including those geographically and digitally isolated [1]) and addressing the public perception of the industry, will also be of equal importance in ensuring the successful delivery of the NDA's mission. This includes supporting and encouraging the uptake of key study areas to meet the NDA's demand for wide-ranging future skill requirements.

It is essential to embed the NDA's ongoing commitment to apprentices and graduates in line with government targets and priorities (i.e. the Nuclear Sector Deal) and develop school engagement strategies, as well as develop NDA Group-wide attraction. Initiatives are already in place to excite the next generation and their influencers on the career opportunities within the nuclear industry and are discussed in detail in Section 4.

3.3. Create a culture in which our people can thrive

The NDA strives to create a positive workplace environment across all aspects of the employee life cycle such as attraction, recruitment into the NDA Group, onboarding, professional and personal development with effective leadership, retention, and separation. Therefore, promotion opportunities and secondments should be made available across the NDA Group to attract and retain the younger generation.

A strong mental health and wellbeing culture should also be encouraged. This will ultimately create a supportive working environment, where the young generation feel they are able to openly discuss mental health in the workplace and access support, if they need it.

A culture of equality, diversity and inclusion is also necessary to ensure every voice is felt welcomed, heard and respected, and is fundamental to the sustainability, growth, and improvement of organizations. High levels of employee engagement and satisfaction are not only ethically correct but also drive significant business value and support an effective nuclear and environmental safety and security culture.

4. INITIATIVES FOR SUPPORTING AND DELIVERING THE NEXT GENERATION OF YOUNG PROFESSIONALS

Several initiatives have been established to support and deliver the next generation of young professionals in the remediation of the UK's nuclear legacy and address the intergenerational issues as previously discussed. The Nucleargraduates programme [7] is a comprehensive scheme to train and develop the next generation of young professionals. Graduates and those with experience can influence people through their attitude and actions to help effect change and drive efficiencies across the nuclear industry without compromising its excellent safety record. The Nuclear Strategy Skills Group (NSSG) [4] is another initiative to address the key risks to skills and resources facing the industry, as well as the NDA Young Generation Network (YGN) Industry Partnership [10] that is committed to creating closer working relationships between the NDA and the YGN.

Further details of the initiatives as well as a personal perspective on the adoption and implementation of the IWM strategy, to support and deliver the next generation of young professionals, in the remediation of the UK's nuclear legacy are provided below.

4.1. Case Study 1 – Nucleargraduates

The NDA Nucleargraduates programme, founded in 2008, demonstrates NDA's commitment to attracting, retaining, and developing a highly skilled, talented, and motivated workforce and creating a positive workplace culture [1]. The Nucleargraduates programme is a two-year graduate development programme managed by Energus and sponsored by a range of organizations, including the NDA, Sellafield Ltd, Magnox Ltd., Nuclear Transport Solutions (NTS), Rolls-Royce, Office of Nuclear Regulation (ONR) and the Environment Agency (EA)

[6]. To date, the programme has recruited over 400 graduates, has gained an outstanding reputation having been awarded the Princess Royal Training Award in 2020 for outstanding training and skills development, and plays a key role in attracting diverse critical skills and talent into the nuclear sector [1].

Nucleargraduates recruits in a broad range of specialisms, such as engineering, science, human resources, commercial, project management, communications, strategy, and risk [1]. The programme has developed excellent relationships with universities across England, Scotland, Wales, and Northern Ireland and continues to attract high calibre graduates from across a diverse range of backgrounds and specialisms. The programme includes three industry placements to expand their knowledge and develop their professional networks. Placements also deliver great business benefit to the sponsoring organizations by enhancing industry exposure and enabling graduates to bring a wider perspective back to their sponsors [6].

All graduates are Science, Technology, Engineering and Maths (STEM) ambassadors and participate in various STEM activities over the two years, helping to influence the next generation of young people through various events and activities, and encouraging them to consider a career in the nuclear industry [1]. The programme is aligned to the priorities of the UK government's NSD and contributes to the 40% of females employed by the sector by 2030 [1]. In 2019, 46% of the nucleargraduate intake was female, and nucleargraduates continue to strive to achieve greater levels of diversity and inclusion.

4.2. Case Study 2 - Nuclear Skills Strategy Group (NSSG)

The NSSG aims to bring together major employers, Government, regulators, and trade unions to address the nuclear sector skills challenge [6]. The group is accountable for developing a Nuclear Skills Strategic Plan that is aligned with the NSD themes, addressing the key risks to skills and resources facing the civil and Defence nuclear sectors. Themes include enhanced skills leadership, sector transferability, pathways, and apprenticeships, staying at the cutting edge and exciting the next generation about the nuclear sector [8].

Through the planning and implementation of the aforementioned themes, the group intends to launch the Next Generation schools outreach programme to attract young people into the nuclear sector, increase visibility of nuclear careers (2019), establish a sectoral transfer pipeline to improve the mobility of skilled people (2021), and achieve a highly skilled and diverse workforce (target of 40% women in nuclear) by 2030 [8].

4.2.1. Shadow boards

Sellafield Ltd is responsible for the safe and secure operation and cleanup of the Sellafield nuclear site located on the coast of Cumbria, England. From cleaning-up the country's highest nuclear risks and hazards to safeguarding nuclear fuel, materials, and waste, its mission is nationally important. Sellafield employs over 11 000 nuclear experts through direct employment and the supply chain [9].

Sellafield Ltd has recently formed a Next Generation Executive Committee, which acts as a shadow to the formal Executive team and aims to bring diversity of thought and the voice of those earlier in their career. The Group aims to bring the thoughts, opinions, and perceptions of a new generation to the business of running Sellafield. The Group is set to challenge norms and ask questions to bring about positive change and aims to address issues regarding social impact, the environment and equality, diversity, and inclusion [9].

Shadow boards provide opportunities to succession plan and attract, identify, and develop people with the potential for good leadership.

4.3. Case Study 3 – The NDA Young Generation Network (YGN) Industry Partnership

The NDA has partnered with the Nuclear Institute's YGN as its industry partner for a 12-month term, with the aim of creating a closer working relationship between the NDA Group and the YGN [10].

The YGN is the young members section of the Nuclear Institute (the professional body and learned society for the nuclear industry) for those under the age of 37. A committee of young generation representatives, from each of the NDA group companies, has been created to help the NDA Group maximize the benefits from the partnership for the young professionals within their organizations [10]. This has included organizing webinar series and virtual tours of NDA sites, producing articles for Nuclear Institutes national Nuclear Future Journal and the UK Government website, and increasing apprentice engagement across the NDA estate.

The representatives are united by their passion for improving the working relationships between NDA Group subsidiaries and bringing together the young generation. This platform can aid and support the adoption and implementation of an IWM strategy to deliver the next generation of young professionals. Through increasing exposure of YGN events and opportunities across the NDA Group, increasing representation of the NDA Group across YGN events, and influencing YGN contributions to support the NDA mission.

4.4. Case Study 4 - Personal Perspective

Personally, as a young professional with two-years' experience in the nuclear industry, I believe strengthening collaborative working relationships, learning from experience across the NDA Group and the wider nuclear industry, will enable the benefits of the IWM Strategy to be maximized, leading to a sustainable future. I also believe sharing approaches to skills gaps and training, and where appropriate, co-creating and procuring solutions to the challenges and opportunities ahead will also benefit the nuclear sector.

Throughout my time at Radioactive Waste Management Ltd (RWM), I have volunteered and engaged with STEM activities at primary schools and participated in outreach events. I also volunteer for early career networks including becoming an RWM Company Representative for the NDA Industry Partner Steering Committee, Young Generation Network (YGN), and the Young Nuclear Professionals Forum (YNPF). The YNPF provides an alternative perspective on the challenges facing the nuclear industry today, supporting the Safety Directors Forum (SDF) and the Nuclear Engineering Directors Forum (NEDF).

Mentoring has also been a beneficial development tool for myself since I joined RWM, whereby I have received practical advice, encouragement, and support, as well as learning from the experience of my mentor. Fortunately, an exciting opportunity arose to become a 'buddy' for a nucleargraduate who had recently joined RWM. Buddying meant that I was responsible for providing guidance and advice and supporting them with their transition into the organization. I found this incredibly rewarding to know I am making a difference to someone else. The mentoring and buddying schemes ultimately aim to support people with their personal and career development, creating both an inclusive and supporting culture that will attract and retain young professionals.

The platforms have collectively allowed me to network, engage, and collaborate with individuals across the NDA Group and the wider nuclear industry, supporting my professional and personal development.

5. CONCLUSION

The successful adoption and implementation of the IWM Strategy to support and deliver the next generation of young professionals in the remediation of the UK's nuclear legacy will require people with the appropriate range of skills and knowledge to provide capability across all relevant disciplines involved in the waste management life cycle. Suitably qualified and experienced people will continue to be needed who have a thorough understanding of chemical and waste processing hazards to support the safe and secure management of radioactive waste.

The NDA needs to work closely with SLCs and the nuclear industry to identify key skills and knowledge requirements, develop plans to maintain capability and to manage gaps, as well as drive and facilitate changes in waste management behaviours and cultures. Mechanisms for doing so, have been discussed throughout the paper, including the Nucleargraduates programme, young generation networks, and the NSSG. It is also vital that NDA Group businesses engage with primary and secondary schools through STEM related activities, as well as organizing and attending outreach events at Universities and Colleges offering apprenticeships and degree programmes. This will ultimately support and deliver the next generation of young professionals in the remediation of the UK's nuclear legacy.

ACKNOWLEDGEMENTS

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4. SUMMARIES OF THE SIDE EVENTS

4.1. PAKISTAN – IAEA COOPERATION IN SAFE MANAGEMENT OF RADIOACTIVE WASTE

Moderator Muhammed Tayyeb Mizra, Pakistan Atomic Energy Commission

Panel Muhammed Naeem, Pakistan Atomic Energy Commission
Safdar Ali, Pakistan Atomic Energy Commission
Musharraf Hussain Rizvi, Pakistan Atomic Energy Commission
Abdulghani Shakhashiro, Pakistan Atomic Energy Commission

Introduced by Mr Andrey Guskov, this Side Event was designed to highlight the progress made by Pakistan in radioactive waste management within the Technical Cooperation programme first instituted with IAEA in 2007.

An Inaugural Address was first presented by Mr Aftab Ahmad Khokher, Pakistan's Ambassador to Austria. Thanking the IAEA for the support given to Pakistan under the Technical Cooperation programme, he introduced Mr Muhammed Naeem, Chairman of PAEC.

Mr Naeem opened proceedings and introduced the speakers who would provide an overview and update on the interactions between Pakistan and IAEA under the remit of the Technical Cooperation (TC) programme that commenced in 2007. He was very pleased to have the opportunity to highlight the benefits of such a relationship.

Mr Ali gave an overview of the Pakistan and IAEA cooperation timeline, starting with the first TC agreement in 2007, and then subsequently in 2009, 2012, and 2015. A further programme commenced in 2018 and is still active. These programmes have cumulatively strengthened Pakistan's radioactive waste management expertise and infrastructure and have led to more than 400 additional trained individuals. Mr Ali noted that due to the TC programmes Pakistan is now in the position that it has the expertise to contribute to the development of other Member States.

Mr Rizvi talked in more detail about radioactive waste management in Pakistan. Pakistan has modern facilities for the treatment and storage of wastes arising from research and power plant operation and with IAEA assistance has undertaken site selection for two near surface disposal facilities, one for north and one for south of the country. Pakistan has yet to decide whether fuel from its nuclear power plants will be reprocessed or sent for direct disposal: in either case, Pakistan will need a geological disposal facility and development of such a facility is part of future planning. A disposal fund has already been established to provide the financial security needed for such a long term programme.

Mr Shakhashiro talked in more detail about the IAEA Technical Cooperation programme and the management arrangements that were used to bring the various stages to successful completion. He noted that a nuclear power plant needs to be managed in a safe and efficient manner throughout its life, whereas the radioactive waste management is important for a much longer timescale. Pakistan has recognized this and has used the IAEA TC programmes to strengthen its radioactive waste management infrastructure, practices, and expertise in several areas including waste characterization, facility design, safety case development, site selection, human resources, and regulatory functions. Mr Shakhashiro concluded these achievements were only possible because of the exemplary partnership working and assistance provided by IAEA and that Pakistan looked forward to continuing this relationship within the framework of TC 2022-25 which is currently under approval.

Questions were asked about Pakistan's plans to increase nuclear generating capacity and implications for radioactive waste management. Planning for near surface disposal is well advanced with sites selected and designs in progress. Desk top studies for geological disposal are in hand and site selection criteria being developed: this one of the topics that Pakistan wants to work with IAEA on. Spent fuel is currently considered a resource and is safely managed at the nuclear power plant site. Pakistan's strategy is for initial cask storage pending decisions on whether to adopt an open or closed cycle.

4.2. INNOVATION IN RADIOACTIVE WASTE MANAGEMENT FOR A SUSTAINABLE FUTURE

Speakers Christina Van Drunen, Canadian Nuclear Laboratories, Canada
Rob Whittleston, National Nuclear Laboratory, United Kingdom
Meggan Vickerd, Canadian Nuclear Laboratories, Canada
Cherry Tweed, Radioactive Waste Management, United Kingdom
Frank Allison, FIS360, United Kingdom

Introduced by Mr Bennett, this Side Event was a collaboration between UK and Canada bringing together a panel to discuss their experience of innovation in radioactive waste management, how this can be embraced, what the barriers might be, and how these can be overcome.

Ms Van Drunen opened the session noting we have heard today that nuclear technologies need to be part of the solution to the zero-carbon objective: many of these solutions will be familiar to the waste management community but what about new solutions we haven't yet thought about?

Ms Vickerd used the example of the Waste Hierarchy – prevent, reduce, reuse, recycle, dispose – to explore how innovation can be brought about when you realize that even waste at the end of that chain can have a value and maybe rather than dispose, have you overlooked some other reuse options. The reuse of sources in alternative and novel medical treatments as an example. She also cited examples from Canadian Nuclear Laboratories (CNL) where innovative approaches had led to reduction in nuclear liabilities in terms of cost and ease of deployment. The journey from 'science to deployment' needs all parties to be aligned and working to a common purpose; as ever, good communication and engagement is key.

Mr Whittleston introduced Mr Allison who has worked extensively with National Nuclear Laboratory (NNL) and Sellafield using a structured process to help researchers and developers identify new approaches and technologies and to provide initial funding to develop innovation through to feasibility and proof of concept stage. This "Game Changer" approach opens a challenge to a diversity of workers and therefore to a diversity of thought and gives confidence to regulators and stakeholders. The challenge owner is involved throughout and because of the investment in the proof of concept gets confidence that the solution is implementable. Mr Allison invited attendees to think about the innovation required to develop alternative waste encapsulants for the net-zero world which could replace the traditional cementitious wasteforms.

Ms Tweed spoke about some of the barriers to innovation. The waste management community tends to be risk averse, in fact many of our stakeholders see this as a strength – we use existing proven technologies and avoid the uncertainty that comes with innovative approaches. Cost is often a significant factor, and benefits have to be sufficiently strong to make us stop and change track. Ms Vickerd noted we often reward the supply chain for using existing technologies, whereas experience shows new thinking and for example, cross-pollination from other industries, can be very beneficial.

In summary:

Innovation is a necessary component part of the scientific and engineering process underpinning radioactive waste management and needs to be embraced if we are to successfully support nuclear in the net-zero world.

The waste management community tends to be risk averse and there are barriers to innovation that have to be overcome. Working in a staged way, engaging with management at all levels and getting buy-in throughout the journey are steps that will reduce the risk-averse culture.

Working across industries introducing new approaches (cross-pollination) should be considered.

We should recognize that different regulatory regimes may impose different or additional requirements and we may need to spend time establishing relationships with new suppliers. Do not expect new technologies to be adopted wholesale, be prepared for the need to adapt them to suit your purposes or regulatory environment.

International organizations, such as IAEA and OECD NEA, have an important role in helping innovation. Events such as the Waste Management Conference play an essential role in sharing experience, expertise, and best practice approaches. Networking opportunities are great for sparking ideas for exploration on return to base.

International organizations can also help through provision of peer review and feedback.

Question why do we do it this way; why not do something else? Understand the perspective and background. With understanding we can enhance public understanding and confidence. Work as a team, share results, and broaden public engagement.

4.3. SAFEGUARDS: THE OFTEN-OVERLOOKED REQUIREMENT IN WASTE MANAGEMENT

Speakers Jeremy Whitlock, Division of Concepts and Planning, IAEA
Nick Smith, Division of Nuclear Fuel Cycle and Waste Technology, IAEA

This Side Event was co-organized by the Departments of Nuclear Energy and Safeguards, as an opportunity to improve knowledge of international nuclear safeguards and how safeguards requirements may impact radioactive waste management. There have been many examples of where safeguards requirements have been identified late in the day, much to the detriment of the project, perhaps requiring retroactive design changes or plant modifications.

Mr Smith (NEFW) introduced the topic noting that safeguards obviously apply to nuclear fuel, to uranium and U_3O_8 (yellowcake) but what about the depleted uranium shielding used to protect an iridium source, or a common laboratory product such as uranyl nitrate or thorium contaminated soil?

Mr Smith explained the various stages that an operator needs to go through to determine whether there are safeguards implications for the materials being handled, and if so, the various options for subsequent management. Spent nuclear fuel will obviously need to be handled in a safeguarded facility, and by implication, a geological disposal facility would also need to be safeguarded. For other wastes the option exists to terminate safeguards, but this is dependent upon the extent to which the fissile material can be shown to be “practicably irrecoverable”, as agreed to in the safeguards agreements of all Non-Nuclear Weapons States under the NPR. Depending upon the difficulty of recovery from a waste form, so the concentration allowable for safeguards termination can be increased. The benefits of agreeing to the safeguards approach early in the design stage should be obvious.

Mr Whitlock (SGCP) expanded upon this approach, discussing "Safeguards by Design" whereby the developer/operator can initiate an early dialogue with the safeguards authorities (national, regional, or IAEA) so all parties can be clear about obligations and requirements. At the earliest stages of design this is a purely voluntary process but has been shown to offer significant benefits to all parties – not just in obvious cases involving novel processes or waste forms, but across the board since safeguards requirements, unbeknownst to many operators and even some regulators, can be more stringent than safety requirements.

4.4. MEMBER STATE UPDATES AND PROGRESS IN THE MANAGEMENT OF DISUSED SEALED RADIOACTIVE SOURCES AND THE GLOBAL PATH FORWARD

Speakers
Ahmad Al-Sabbagh, Jordan Atomic Energy Commission, Jordan
Ioannis Kaissas, Aristotle University of Thessaloniki, Greece
Lina Al Attar, Atomic Energy Commission of Syria, Syria
Charles Streeper, Los Alamos National Laboratory, United States of America
Marcelo Mendoza Contreras, Chilean Nuclear Energy Commission, Chile
Mohammed Zaidi Ibrahim, Malaysian Nuclear Agency, Malaysia

Mr Xerri (IAEA) introduced this Side Event noting that sealed radioactive sources are widely used across the globe for industrial and medical purposes and their safety and security is a particular problem especially when they come to the end of their useful lives. As a result, IAEA has taken a particular interest in the management of Disused Sealed Radioactive Sources (DSRS) and has issued Guidance on their management and has established a multi-regional project to help, in particular, Member States without an established nuclear infrastructure. The Side Event presents an opportunity for information sharing on some of the different approaches and progress being made in six different Member States.

Mr. Alsabbagh gave a brief introduction to recent activities that have been implemented in Jordan, to recover and repackage several legacy sources that were stored in an inappropriate location and condition. The initial step was to prepare a work implementation plan taking into consideration security, safety, and radiation protection. The plan was approved by the regulatory body before dismantling work took place. The mission to dismantle and recover the sources took two weeks: 33 drums were emptied, and 166 sources recovered. The sources were shipped back to a centralized storage facility and successfully repacked and conditioned in new waste packages.

Mr Kaissas described the status of DSRS management in Greece. There is no capability to recycle redundant sources in Greece so, back in 2001-06, some 3,000 orphan sources of 120 TBq were recovered and exported to Germany where they could be recycled. A further consignment is now being planned and assistance is being received from IAEA and International Source Suppliers and Producers Association (ISSPA). Prior to making firm arrangements, the Greek Atomic Energy Commission has sought to build a database of cost and other information which will inform consideration of the different options available. The assessment has tried to identify the factors which are significant cost drivers (e.g. radionuclide, form of source, activity), the availability of necessary hardware (e.g. transport containers), and identification of contractors with the appropriate expertise.

Ms Al Attar described a project in Syria whereby DSRS have been successfully recycled and, in some cases, reused. This exercise was undertaken within a dedicated DSRS dismantling facility: the recycled sources were returned to storage in a newly constructed tube store. The exercise also allowed a Co-60 level gauge and a Cs-137 brachytherapy source to be re-used as sources in a calibration laboratory. Ms

Al Attar recommended the IAEA network, the DSRSNET, as a useful and effective tool for sharing information and facilitating discussion between Member States on the topic.

Mr Streeter described the work of the Offsite Source Recovery Program which has been established to recover orphan sources of US origin. Since its initiation, the Program has repatriated some 45,000 sources from 28 different countries, which otherwise could pose a safety or security risk. The Program has worked in cooperation with IAEA and can assist with capacity building, such as provision of training in DSRS safety.

Mr Zaiad Ibrahim described progress with an IAEA Technical Cooperation programme to implement borehole disposal of DSRS in Malaysia. The TC programme commenced in 2011 with a planning phase and has been followed by predisposal preparations phase (2015) and a disposal phase starting in 2018, which continues. A suitable disposal site has been identified and a licence for construction was awarded in 2019. The inventory for disposal comprises some 12,928 individual sources which are planned to be accommodated within a single borehole. The disposal zone is proposed at depth between 105 m and 165 m, this being chosen to avoid an unsuitable breccia zone at 97 m. After emplacement, disposal containers and borehole will be backfilled with a cementitious grout manufactured from Portland cement and local sands. Grouting trials to determine the optimum formulation of the mixture of cement/local sand/admixture were performed in Croatia. This project continues.

The last presentation was by Mr Contreras, who described a project to remove Cat I and Cat II sources from Chile. Before deciding on a preferred course of action the advantages and disadvantages of two options were considered: to return to the supplier (overseas) or to retain in storage but after dismantling. The assessment concluded it would be preferable to export the DSRS from Chile as this option would increase Chile's storage availability by 18 m^3 and would extend the store capacity by some 30 years.

4.5. BUILDING STAKEHOLDER CONFIDENCE FOR SUSTAINABLE RADIOACTIVE WASTE MANAGEMENT

Chairs	Alexandre De Ruvo, World Nuclear Association (WNA) Soufiane Mekki, OECD NEA
Speakers	Rebecca Tadesse, OECD NEA Nuria Prieto Serrano, Enresa, Spain Yves Lheureux, National Federation of Local Information Commissions (ANCLI), France Julie Brown, Canadian Nuclear Safety Commission (CNSC) Cécile Evans, Orano, France (on behalf of WNA's Sustainable Used Fuel Management Working Group and Waste Management and Decommissioning Working Group)

Radioactive waste management back end issues are embedded in broader societal issues including the environment, risk management, energy, health policy and sustainability and, as such, often generate considerable interest and concern. The objective of this side event was to bring together a panel with experience from industry, regulators, international coordination and civil society, to discuss the issues around stakeholder confidence with a view to identifying examples of best practice and ongoing challenges.

Ms Prieto Serrano introduced the work of the NEA Forum on Stakeholder Confidence (FSC) which was established in 2000 following recognition that, until that time, engagement with communities affected by radioactive waste management activities, especially site selection for disposal facilities, had largely a technical focus and hadn't been particularly successful. The FSC aim is to foster learning about stakeholder dialogue and ways to develop shared confidence of RWM solutions. The FSC has documented a wealth of experience through topical sessions and studies, and particularly through national workshops and community visits. The FSC Report on Dialogue in the Long-Term Management of Radioactive Waste was published in 2021 and presents a catalogue of the various approaches FSC members have used to establish effective and robust dialogue with their local, regional, and national stakeholders. The FSC have identified these lessons:

- Transparency and openness as key principles;
- Be ready to change your approach, admit mistakes, and co-design with stakeholders;
- Credibility and trust need to be earned and kept – it is very easy to lose;
- Be proactive – create networks, take care of them, and feed them;
- Listen to stakeholders, be humble, be empathetic;
- Train technical staff so they can better communicate with a non-technical audience;
- Recognize that social science has a key role in disposal facility site selection.

Mr Lheureux from the National Federation of Local Information Commissions spoke from his experience of dialogue between communities, industry, regulators, and technical support organizations. He concluded successful programmes are those that provide space for dialogue with civil society and stakeholders. Such space is necessary to share information, for understanding of technical topics, for listening, for exchange of points of view and opinions. Consultation, participation, and dialogue are tools to enable citizens to exercise their rights, not to rebuild lost trust.

Ms Brown of the Canadian Nuclear Safety Commission provided a regulator's perspective on building stakeholder confidence in radioactive waste management. In addition to the traditional role of developing safety standards and guidance and evaluating safety reports, today increased attention is being given to transparency through the provision of information to public and stakeholders and through the facilitation of public understanding of the regulatory process and associated decision making.

Outreach and engagement activities are now considered to be key functions, as important as the traditional technical activities. The Canadian experience is that communities appreciate the regulator as a trusted and independent source of scientific information, CNSC have concluded that it is important and beneficial to build relationships with communities and indigenous groups, to communicate throughout a project's life cycle and to convey technical information in accessible language.

Ms Evans spoke about the importance of dialogue as a means of increasing stakeholder confidence from the perspective of a nuclear site operator. She illustrated her presentation with examples from France, the UK, and the Netherlands. In France, common with many Member States, waste management sites such as Orano La Hague strive to adopt good communication practices with provision of annual environmental reports, supporting local information committees, public tours and meetings, and provision of open information fostering relations with various audiences. An example of an innovative visual means of communication was presented from the Dutch HABOG facility, which is repainted every 20 years, but in paler colours illustrating the decay of activity of the waste inside.

The WNA highlighted three areas which would serve to improve stakeholder confidence in waste management activities and strategies:

International alignment of waste definitions and associated regulations for waste types and boundaries. Despite efforts of IAEA and others, there remain different definitions and approaches which can cause difficulty in presenting a consistent and simple international picture.

Application of the waste hierarchy (clearance, diversion, recycle and re-use of materials) has been shown to achieve some impressive results where the volume of waste for disposal is much reduced and leads to a greater degree of sustainability. Wider adoption of these 'best practice' approaches with their resultant smaller volumes of waste for disposal, would increase public support.

Misconceptions of the impact of low doses of radiation creates a disproportionate fear of radiation from radioactive waste. This could be remedied through active engagement with stakeholders, providing the opportunity for open debate and focus on scientific facts.

4.6. FINAL DISPOSAL OF SPENT NUCLEAR FUEL IN FINLAND

Speakers Mika Pohjonen, Posiva Solutions Oy, Finland
Pauliina Aalto, Posiva Oy, Finland
Pasi Rantamäki, Posiva Oy, Finland
Barbara Pastina, Posiva Oy, Finland
Tuomas Pere, Posiva Oy, Finland

Mr Pohjonen welcomed Conference attendees to the Side Event on the Spent Fuel (SF) disposal project in Finland. It is intended that the event will provide an opportunity for attendees to learn about Posiva's experience in developing the safety case for encapsulation and final disposal of SF at the Olkiluoto site in South-West Finland. The project started in the 1980s and Posiva Oy expects first emplacement of encapsulated SF in 2025. As of 2021 the Encapsulation building civil works are almost complete and fitting out will commence shortly. Underground works are well advanced and on schedule despite changes to working practices on account of the Covid pandemic.

Ms Aalto described the site selection studies that led to the selection of the Olkiluoto site for the location of the final repository. Screening to find areas of potentially suitable geology covering the whole of Finland were carried out between 1978 and 1986, with preliminary site investigations at five sites between 1987 and 1992, and finally detailed investigations at four sites between 1993 and 2000. The Olkiluoto site was selected as the preferred site and furthermore detailed investigations were undertaken to verify the decision, and to identify and characterize a suitable rock volume for SF disposal. Investigations commenced with surface-based shallow and deep boreholes and were followed by the construction of the ONKALO Underground Research Laboratory, permitting researchers to get underground and undertake in situ studies in support of the safety case and repository construction. The characterization programme has led to the publication of four stages of site descriptive models, with the 2011 version forming the basis of the construction licence application.

Prior full industrial scale operation, Posiva will demonstrate that they can manage the entire disposal operation, by undertaking a full-scale Trial Run project as part of the final commissioning tests. The Trial Run will involve the production, transport and emplacement of dummy SF assemblies in four disposal canisters testing, as well the operating organization and procedures. The project will also demonstrate the plant's ability to retrieve a damaged canister. Mr Rantamäki said Posiva would welcome international collaboration on the Trial Run project, as this would enable other programmes obtain valuable knowledge and experience to help in their own endeavours. A Trial Run project organization will be the operating organization of Posiva and it has already been established.

The development and current status of the safety case was described by Ms Pastina. The safety case is essentially where the developer presents all the arguments as to why they believe the facility will be safe, both now and in the long term. The safety case has been developed in an iterative fashion taking account of new information and understanding as the site descriptive models have evolved. The safety case will continue to be subject to periodic update when the facility is operating as it is recognized that over a prolonged period (about 100 years) there will be learning, things and perhaps technology will change, and these need to be reflected in the safety case. The safety case has been developed and structured following IAEA and NEA standards and guidelines.

Mr Pere described the monitoring arrangements that have been conducted and will continue into operations. Monitoring is undertaken in these five broad areas: rock mechanics, hydrogeochemistry, hydrology and hydrogeology, the surface environment, and the engineered barrier system (EBS). This is important as it provides information to support the construction programme, environmental impact studies and the safety case to confirm that the EBS and host rock are performing as planned and expected. Monitoring results relevant to safety are compared against the action limits and requirements to confirm that the disposal system is operating within the safety envelope.

4.7. BEISHAN UNDERGROUND RESEARCH LABORATORY IN CHINA

Speakers Ju Wang, Beijing Research Institute of Uranium Geology, People's Republic of China
Liang Chen, Beijing Research Institute of Uranium Geology, People's Republic of China

Mr Nieder-Westermann introduced Mr J. Wang and Mr L. Chen from Beijing Research Institute of Uranium Geology (BRIUG), who would be leading the Side Event providing an update on the underground research laboratory being constructed at Beishan in the Gobi Desert in northwest China.

The Xinchang site in Beishan was selected as the site for an underground research laboratory (URL) in 2018 following a site selection process for HLW disposal that started in the 1980s. Mr Wang explained the URL will be located at a depth of 560 m in granite with construction approval given in June 2021. The initial construction phase will have a seven-year duration and will see construction of a seven m diameter ramp using TBM, and three shafts. The research programme is envisaged as five stages with a duration of more than 15 years, gathering data to support performance studies of the multi-barrier system, develop construction and operation technologies, to supply parameters for safety assessment and environmental impact and culminating with prototype testing of technologies for HLW disposal.

The Beishan URL project has been set up with the ambition of welcoming international collaboration. Mr Chen described the purpose-built International Cooperation Centre established this year and the potential advantages to other programmes that may be planned for granite or crystalline environments. Potential collaborative research topics could include investigation of improved site characterization technologies and development of repository construction methods and techniques for monitoring rock-mass response. Mr Chen reported that nine research projects have already been approved for the URL construction phase. Mr Chen concluded by showing an animation called "A-Fu's Journey to Find a Home" which was developed to explain the concept of HLW disposal for a younger audience.

4.8. COLLABORATIVE RESEARCH AND INNOVATION IN RADIOACTIVE WASTE MANAGEMENT IN THE EURATOM COMMUNITY

Speakers Seif Ben Hadj Hassine, European Commission
Robert Winkler, Commissariat á l'énergie atomique, France
Massimo Morichi, Costruzioni Apparecchiature Elettroniche Nucleari SpA, Italy
Erika Holt, VTT Technical Research Centre of Finland Ltd, Finland
Louise Théodon, Agence Nationale pour la Gestion des Déchets Radioactifs, France
Anthony Banford, National Nuclear Laboratory, United Kingdom

Felicia Dragolici welcomed Mr Hassine from the European Commission who introduced the Euratom Research and Training Programme and in particular the Horizon 2020 framework, from which four on-going research projects related to the safe management of radioactive waste, are funded and which will be described in further detail. These being the SHARE, MICADO, and PREDIS projects and the EURAD programme.

Mr Winkler described the SHARE project initiated within the Horizon 2020 innovation action programme to increase coordination between stakeholders involved in research activities related to decommissioning and who have an interest in ensuring decommissioning and waste management can be implemented in a safe, effective, and sustainable manner. The project is a collaboration between 11 partner organizations and aims to deliver a roadmap for future research needs, identified through collaboration with a wide range of stakeholders in the field of decommissioning and radioactive waste management. After seeking stakeholder inputs the project will provide a prioritized roadmap based on analysis of responses and inputs, development of a strategic research agenda and gap analysis. The project is due to report in March 2022.

Mr Morichi described the MICADO project designed to develop a cost effective solution for non-destructive characterization of waste, implementing a digitization process that could become a referenced standard, harmonising methods used throughout waste management. The project is funded by the Horizon Framework and involves eight European partner organizations. Currently, non-destructive characterization tends to require use of several un-automatized instruments and operator interventions to record results in a database. The RCMS DigiWaste platform is intended to produce a modular hardware and software system to unify and standardize procedures and methods for non-destructive characterization and monitoring of radioactive waste ultimately to become an international reference for all operators and research laboratories facilitating the exchange of fundamental and critical information.

The PREDIS project has been established to develop and improve treatment and conditioning methods for radioactive wastes for which no adequate or industrially mature solutions are available. Ms Holt, project co-coordinator, introduced the four-year duration project which started in 2020 and has 47 partners from 17 countries. The project is focussed on problematic waste such as metallics, liquid and solid organics, and cemented wastes and is investigating characterization techniques, new treatments and conditioning methods, and performance evaluation of proposed solutions. The project has an on-going outreach programme enabling stakeholders to contribute and shape the forward work plan.

Ms Théodon introduced EURAD, the European Joint Programme on Radioactive Waste Management, a five-year project which started in 2019. The project aims to implement a joint strategic programme of research and knowledge management at the European level, bringing together and complementing EU Member State programmes to ensure cutting-edge knowledge creation and preservation to deliver safe, sustainable, and publicly acceptable solutions for the management of radioactive waste. There are currently 17 work packages underway including three work packages (from the second wave) that started in June. The participants include 51 mandated organizations, 61 linked third parties and three international partners (NWMO, CSIRO, NUMO).

5. SUMMARIES OF THE YOUNG PROFESSIONAL EVENTS

5.1. CAREER PATHS FOR A SUSTAINABLE FUTURE

Chair Christina Van Drunen, Canadian Nuclear Laboratories, Canada

Panel Karen Wheeler, Radioactive Waste Management, United Kingdom
Laurie Swami, Nuclear Waste Management Organization, Canada
Tony Wickham, Consultant, United Kingdom
Hans-Juergen Steinmetz, Aachen University of Applied Sciences, Germany
Musharref Hussain Rizvi, Pakistan Atomic Energy Commission, Pakistan
Meggan Vickerd, Canadian Nuclear Laboratories, Canada

This was the first of two events organized specifically to provide a forum for young professionals starting out on a career in waste management, to explore potential career paths and to connect with and learn from, engineers, scientists, and waste management professionals. This, the first session, was held on the day before the Conference opening and provided an opportunity for the young professionals to meet their peers and to interact with several of the waste management leaders who would be attending the Conference.

The Chair introduced the six Speakers, drawn from across the waste management sector, representing academia, research, consultancy, waste management and final disposal. Each Speaker gave a short resume of their background and careers, with particular emphasis on the steps and decisions taken at key junctions of the career path. The Chair asked Speakers to highlight learning that had been important to them and would like to pass on to the young professionals.

The Speakers described their academic background, their interests and first career steps. They described the way their careers had evolved, and how they came to the roles that they now hold, often involving significant decisions along the way. Following the Chair's invitation, Speakers considered what had been important to them, what they had learnt and what they would like to pass on to the young professionals.

The Chair thanked the Speakers on behalf of the young professionals for sharing their experiences and learning. The Chair summarized the learning points and advice as follows:

— Learn how to 'make things happen'. This is a key skill that is truly transferable and can be applied in all organizations and projects.
— Recognize the importance of people in your work. These may be colleagues, co-workers, or stakeholders. Remember, every organization or communication is ultimately about people.
— Follow your heart. Whatever career path you follow, do something you want to do, do it well, and get results: that's how you'll get noticed.
— Work very hard to expand your experiences and learning. Take time and effort to invest in yourself.
— Believe your dream will happen! The outcome might not turn out like you anticipated but it will nevertheless take you to a better place.
— Don't be afraid to 'stick to your guns' and make the case for what you want or believe in.
— Don't become too entrenched in a single specialism. You'll always be happier if you have one or two other interests.
— Don't take the easy option. Take the route that's not normally taken, that'll be the most rewarding.

The Chair concluded the session noting that a follow up is planned for Friday afternoon which would provide an opportunity for the young professionals to reflect on the week's proceedings and shape the recommendations and messages in the final report from the Conference.

5.2. YOUNG PROFESSIONALS FEEDBACK EVENT – LOOKING TO A SUSTAINABLE FUTURE

Panel
Christina Van Drunen, Canadian Nuclear Laboratories, Canada
Karen Wheeler, Radioactive Waste Management, United Kingdom
Lisa Frizzell, Nuclear Waste Management Organization, Canada
Muhammed Naeem, Pakistan Atomic Energy Commission, Pakistan

This was the second event designed for the young professionals and was intended to provide an opportunity for the young professionals to provide feedback on the Conference which would help the Organizing Committee in planning for the next event.

Ms Van Drunen welcomed attendees and said the format of the session would be in the form of Q and A, with unusually the Panel asking the questions of the attendees.

Q. What from this week's Conference worked well for the young professionals?

Answers:

— University courses tend to be exclusively technical, and we don't learn how to deal with people. The Conference has been an excellent opportunity to network, to meet new people and to hear about career options we might not have heard about otherwise.
— I've really enjoyed and benefitted from, hearing about what's happening overseas in other countries. At university, we concentrate on specific subjects but here at the Conference I've learnt so much and across a broad spectrum of topics.
— I've come away with lots of new ideas. I've learnt about new technologies and how they can be applied to radioactive waste management.
— I feel like it's an honour to have been able to take part in the Conference, I have to thank the IAEA for giving me the opportunity. What I think worked particularly well was the ability to meet others, to build my network and of course the sharing of information.

Q. What were the key insights? Or put another way, what were the top three things you will take away?

Answers:

— I've been inspired by hearing about the career journeys in the first session and this week I've heard about the importance of social and communication aspects, and that might be something I want to be involved in; I've got to meet lots of great people; I've also had the opportunity to act as co-chair of a session.
— I've learnt that we're not alone – at the Conference you find that others are facing the same problems and are working on solutions, we can learn from their experience.
— We've been impressed by the enthusiasm of the attendees.
— I've realized that we have to solve waste management challenges not just for our generation but also for future generations.

Q. Having seen how the week evolved what would you advise is done differently or more of, next time?

Answers:

- The fact that you made special provision for young professionals, not just to attend but to have a central role, has been a great feature of the Conference, one that should be continued and built upon.
- When you first set out learning about nuclear science and waste management it's overwhelming to think that you can start a career and be part of the community, but after hearing the Panel's stories I've started to see how that progression can happen.

Ms Wheeler noted all Member States struggle to find enough workers with the right skills, and this is where organizations like IAEA can help, not just with Conferences but with Technical Cooperation programmes. She referred to the assistance the Agency had afforded Pakistan and, as a result, they now had an additional 400 skilled scientists and engineers working in the field of waste management. Mr Naeem added that PAEC has established two training centres as there is a continual need for qualified engineers, health physicists and chemists.

The point was made that it's often unclear to university students what jobs will be like in practice and more information to bridge this gap would be helpful. Christophe Xerri noted everyone can play a part by taking the opportunity to engage with young professionals and speak about career paths, jobs, and the working life. He also suggested that since everyone agreed social science had a central role in much of waste management, then next time the door should be opened to young professionals with a social science background too.

Back to the question above…

- Next time perhaps encourage papers on waste management from nuclear site operators about application of the waste hierarchy in practice, with case studies on examples of waste avoidance or minimization.
- And in a similar vein, discussion on design taking account of waste management would be interesting.

There followed a presentation to Professor Steinmetz by his students from Aachen University of Applied Sciences. Professor Steinmetz thanked the students, noting he was very impressed by the group and thought they and all the young professionals had risen to the challenge and made a great contribution to the Conference. He thanked IAEA for including the young professionals as an important theme of the Conference.

Mr Naeem responded his conviction was that nuclear energy would continue to grow in importance in many Member States and, hence, radioactive waste management would grow in tandem. He said the future in waste management would be full of opportunities, and he wished the young professionals well in their careers.

Ms Frizzell said she had taken much from the presence of the young professionals and was heartened to hear many had expressed an interest in communication and communicating. She advised them to seek out the communication professionals in their home organizations, offer assistance, and get involved.

Ms Wheeler said she had enjoyed meeting the young professionals and hearing their presentations. She thanked the IAEA for making time and space in the Conference and for recognizing the importance of the young professionals in the future sustainable waste management industry. She concluded by telling the audience not to hesitate to make contact, to invest in yourself, arrange visits to sites/organizations of interest and organize mentoring or work experience to help with future career advancement.

Ms Van Drunen thanked everyone for their feedback and inputs. The key feedback to IAEA was the young professionals' provision in the Conference was good, was to be applauded but could be improved. There is a gap between university courses and work that needs to be bridged. Young professionals have realized this week that radioactive waste management is a broad subject requiring many specialisms and a wide spectrum of expertise: this needs to be better explained with more accessible information and opportunities to gain experience. Remember, she said, you are not alone and use the networks established throughout the week.

Mr Nieder-Westermann concluded with his parting advice that to be successful in radioactive waste management maybe you have to be interested, maybe you have to be enthusiastic; certainly you don't have to be born a genius, but you will have to be willing to work hard, diligently, and together as a team.

6. CLOSING SESSION

Mr Nieder-Westermann opened the closing session of the conference, expressing the thanks of the Conference Team to all participants, attending in-person and virtually, as well as IAEA's Conference Services and the supporting staff. As a keynote address for the closing session, he welcomed Mr. Patrick Landais, High Commissioner for Atomic Energy, CEA, France, to discuss the achievements and solutions highlighted during the week at the conference and next-step opportunities for the radioactive waste management community to further increase efficiencies and enhance these available solutions towards a sustainable future.

6.1. OPPORTUNITIES FOR SCIENCE AND TECHNOLOGY ACHIEVEMENTS IN RADIOACTIVE WASTE MANAGEMENT

Patrick Landais
High Commissioner for Atomic Energy, French Atomic Energy Commission (CEA), France

Mr Landais opened by recalling the Director General of the IAEA's statement to CoP26 that nuclear power has an important role to play in the mix of technologies providing carbon-free energy. But what of the view that waste management is still regarded as the Achilles Heel of nuclear power? In France nuclear power is an important source of electricity and thoughts are also turning to a new generation of reactors, reactors that are smaller, safer, and more responsive and connected to a more flexible grid system of nuclear and renewable energy sources. We heard this week he said that the Finnish success at Olkiluoto is a game changer, but still the debate over radioactive waste management continues. A recent opinion poll in France saw significant support from the public for nuclear power, but contrarily didn't agree that the waste could be safely managed. When asked what the main challenges are facing mankind, they had nuclear waste just behind climate change and preservation of natural resources and ahead of treatment of plastics and protection of biodiversity.

It does seem that waste management, despite the views of the industry, does remain an issue with the public. What then is to be done he asked. We have integrated waste management plans including holistic life cycle approaches and countries develop proportionate and consistent management of all radioactive waste. We know that geological disposal can be achieved to provide a safe and effective solution to the waste management issue. Its not easy: its a long and winding road but it is feasible if we take a step-wise approach that allows the development of specific concepts such as reversibility to be fully developed and understood and build trust with our citizens as we go. We also need to learn from others and build on their successes: learn together from the vast amounts of data already available to go further. We should also be clear and transparent up front about the factors for success and at all stages along the road take our stakeholders with us. Is this enough, what more do we need to do?

Mr Landais identified two options that could be combined: to continue the journey with stakeholders following the present road or innovate and explore new avenues reflecting the expectations of the younger generation and the technological world that they inhabit. Generation Z is the first to have grown up with access to the internet and portable digital devices. They know how and where to get data, are numerate and familiar with research and analysis tools. This is the generation we should be talking to because, he said, they'll be the ones developing waste management solutions in 20 or 30 years' time. In addition, we need to start by embracing the digital age and turn around our way of thinking so that it's in line with their expectations.

He gave several examples where such innovation could take us, including wider use of digital tools to integrate datasets and facilitate sharing with our stakeholders. This could include such things as smart sensors used for repository monitoring and surveillance, digital simulation to describe and model processes at all scales and 'digital twins' say to improve the representation of disposal facility evolution.

Another area of innovation might be to identify new materials and manufacturing processes for waste containers. Imagine if a new material, for example ceramic or carbon composite, was available and which avoided the containers' corrosion issues and the generation of hydrogen. How much easier would be the communication of the disposal narrative?

Moreover, innovation is not strictly technological, it includes societal expectations and should not remain an addition of innovative technologies, but a more global approach dedicated to support transformation.

Not only should we rethink our approach to research and innovation in the digital-age, but we should extend this to encompass future needs in knowledge and data-management, and societal trends where we can expect to see more participatory science and a stronger public input to scientific governance.

In conclusion, he noted that over the long timescales for which radioactive waste management will have to be considered, knowledge and knowhow will change. There will be competition between our industry and others for resources particularly expertise in AI and digital processes. We need to recognize the future challenges, start exploring the new digital avenues and start preparing the younger generation to be the architects of our waste management projects.

6.2. CLOSING SESSION - REPORT OF THE SESSION CHAIRS

Mr Nieder-Westermann invited the Session Chairs to provide a summary report of the key points to arise during the presentations and discussions in their sessions. He reported that Mr Utkin had had to return to Moscow and that Mr Barlow had kindly agreed to report in his place. The session chairs were as follows:

- Session 1. Radioactive Waste Management – National Programmatic Perspectives: Steve Barlow, presenting on behalf of Sergey Utkin
- Session 2. Implementation of Waste Management Strategies: Cherry Tweed
- Session 3. Solutions for Specific Wastes: Maria Lindberg
- Session 4. Role of the Safety Case Development in Supporting Radioactive Waste Management: Christina Van Drunen
- Session 5. Socioeconomic Aspects of Radioactive Waste Management: Safdar Ali
- Session 6. Integrated Waste Management: Wolfgang Neckel
- Session 7. Multinational Cooperation in Radioactive Waste Management: Ewoud Verhoef

Session 1, Radioactive Waste Management – National Programmatic Perspectives

Mr Barlow thanked Mr Utkin for his chairmanship of Session 1 and said that he would attempt to summarize the key points on his behalf. First, he highlighted some common themes, namely the importance and benefits of international collaboration: sharing of ideas, experiences, and best practice has been shown to be a major factor in improving and accelerating Member State's national programmes. A second theme that various presenters had mentioned was the need for step-by-step or iterative development. They may have been discussing technical topics such as site characterisation, safety case or design development or something softer such as stakeholder engagement or communications. In each case it's clear that working in an iterative way lets us take account of feedback received, redirect, or shape our direction of travel and embrace continual improvement.

Mr Barlow recalled that we heard that radioactive waste isn't necessarily the problem that some think it is and that there are implementable solutions. However, we should remember that we shouldn't rest on our laurels as this isn't a 'one size fits all solution' but one that needs to be tailored to take account of national circumstances. The good news is there are standards and best practices that we can work to and benefit from.

Social acceptance has been recognized as the remaining major challenge in radioactive waste management and successful waste management organizations are those that are taking it much more seriously than hitherto was the case. Allied to that and put another way as it was in the session, the focus of many developers now is on social acceptability as we know the technical issues can be dealt with.

In the session we heard from Member States that were at the early stages of implementing radioactive waste management structures and of the benefits that their programmes had accrued from working with international partners who were willing to share lessons learned and best practices. And, of course, the IAEA were mentioned many times in connection with the helpful interventions whether through peer-review or Technical Cooperation programmes.

We also heard from organizations that are further down this journey and have more mature and well-established organizational structures. Even here we heard about organizations taking timeout to ask the question, are our structures allowing us to work in the most efficient way? Where are the bottlenecks; what aren't we doing so well; how can we improve communication; and how can we better engage with our stakeholders? And we heard examples of how this process of continual improvement is being implemented in practice.

And lastly Mr Barlow concluded, we heard of examples from Member States that despite the problems caused by Covid, they adapted to remote working, adapted to safe working practices on site, and managed to continue with their plans be it site selection, facility design, construction or engagement with their local communities and stakeholders.

Session 2, Implementation of Waste Management Strategies

Ms Tweed said that the key points from Session 2 can be captured under the following headings: Progress, Time, Learning and Problem solving, Teamwork and finally Planning.

Progress – The standout news from the session was of course the progress being made in Finland with the construction of the Olkiluoto geological disposal facility for spent fuel. This facility hailed as a 'game changer' by Mr Grossi in his opening statement is on course to start the trial run phase of commissioning in 2023. Whilst this may be the highest profile project discussed, there were numerous other examples of progress being made by a range of organizations and for a range of waste types, all contributing to our shared objective of a sustainable future.

Time – We saw various timelines and one can imagine the initial reaction of stakeholders, "why does it take so long?". We know, and we heard, that these are complex projects involving multiple strands of interconnected science, engineering and social science leading to highly engineered facilities and not the 'dumps' that the press would have us believe.

Learning and Problem solving – We saw examples where waste management organizations had to face problems, acknowledging past mistakes, and coming forward with revised strategies and action-plans. Each facility and society in which it sits is unique, and these strategies and action-plans have to be informed by the learning and tailored to be suitable for the environment, the wastes, and the society.

Teamwork – Successful waste management strategies are those that recognize that waste management is a team enterprise, involving experts from many disciplines, all working towards a common solution.

Planning – Radioactive waste management might be a back-end activity, but it needs planning from the outset of the project and not left as a back-end afterthought as in many cases it has been. The planning will have to cover the technical aspects of the project and also be wide ranging and recognize that the long timescales involved will require the baton to be passed on to future generations. Planning therefore has to also address the training and skills needed by the younger generation to equip them to take on their future roles in strategy development and implementation.

Session 3, Solutions for Specific Wastes

Session 3 said Ms Lindberg, had provided several case studies describing waste management challenges posed by specific wastes and the solutions that had been developed and successfully implemented. An example from Italy highlighted the steps taken to solidify and package a small volume of liquid waste and from Iran an example of both technology and infrastructure development to improve the management and safety of radioactive wastes from the oil and gas industry. Thermal treatment methods are also being effectively used both for metals as illustrated in Sweden and also for cellulose, plastic and rubber as in India.

From small arisings in Italy to the huge volumes and wide range of waste types arising because of cleanup operations at Fukusima Daiichi and its surroundings. And lastly case studies illustrating innovation to develop geopolymers as encapsulants for otherwise problematic wastes.

Ms Lindberg concluded that the session amply illustrated that we have most of the technologies we need for conditioning and treatment of wastes; we just have to identify which technique to use. This requires knowledge of the waste and its characteristics, applicable waste acceptance criteria, and understanding of the governing regulatory requirements. Armed with this knowledge, the most appropriate processing technique can be selected and fine-tuned as required.

Session 4, Role of the Safety Case Development in Supporting Radioactive Waste Management

Ms Van Drunen reported that safety cases have an essential role in all stages of waste management whether in waste processing, handling, storage, or disposal and for all types of waste. The safety case is the key vehicle where safety arguments demonstrating the operator’s understanding of the performance of waste packages and the disposal system are presented. The session heard about progress in safety cases from low level surface waste facilities, through to geological disposal facilities for high level waste and spent fuel.

We heard how the safety case is developed in a step by step manner, with successive iterations capturing new information and learning. For a disposal facility the safety case is a living document and may span many decades as the facility is planned, developed, operated, and eventually closed. The safety case needs to be accessible to all and be based on international safety standards and best practice so that host communities can understand present and potential future impacts and public confidence strengthened.

The session also discussed the development of waste acceptance criteria, research and development and innovation and the interaction between them and how the safety case is subject to periodic updates to allow learning to be incorporated. In turn the safety case also informs and shapes the research agenda, ensuring its focus on resolving uncertainties and strengthening safety arguments.

Ms Van Drunen concluded that safety case development is a highly collaborative, multi-disciplinary effort requiring careful management of interfaces and robust configuration management, such that the safety case evolves in step with the facility. Whilst it might start off based on expectations of performance, it then progresses to reflect the as-built condition and successive design modifications and behaviours found in practice: the physical facility, design basis and safety case should always be consistent.

Session 5, Socioeconomic Aspects of Radioactive Waste Management

Ms Ali provided a summary of the key points to arise from session 5 in which speakers described experience of communication, stakeholder engagement and other socioeconomic aspects of radioactive waste management from a range of countries.

A key message from several radioactive waste management programmes is that societal and political acceptance can be a deciding factor for implementation of the programme. The focus of many developers is now on social acceptability as the priority, as they realize technical issues usually have a more straightforward solution. Successful programmes today are those that can draw upon expertise from social and political scientists, and which start thinking about their stakeholders from the very start.

The session also heard about experience from the Netherlands where Covra, the national radioactive waste management organization espoused the benefits accrued from openness and transparency. This doesn't, we were advised, mean that you'll be welcomed into a community, but you will get exposure and visibility. And visibility is important as your attempts at engagement will fail if you become invisible. With their striking buildings that are both practical and works of art, Mr Ali noted this organization clearly demonstrates their unique approach to maintaining visibility.

Alongside the key principles of openness and transparency Mr Ali recalled advice to listen to stakeholders, to be humble and empathetic, to be proactive in creating networks, to take care of them and feed them. Don't assume that information exchanged will be retained since stakeholders like our own organizations will change and evolve over time so be prepared to repeat your messages and, if necessary, repeat again. Successful programmes are those that have built credibility and trust with stakeholders, but he concluded, be warned trust is hard to earn and easy to be lost.

Session 6, Integrated Waste Management

Session 6 said Mr Neckel had introduced us to the concept of Integrated Waste Management which is being successfully implemented in many advanced programmes. The key to successful Integrated Waste Management is having a deep knowledge of the inventory (the waste) and the foresight to seek timely interventions that will improve overall waste management, seeking to maximize opportunities for waste minimization, recycle and reuse. A recurring theme from all presenters was the waste hierarchy, a powerful tool to make us stop and think, how do I extract value from this waste material or am I just looking for the nearest dustbin?

Integrated waste management requires us to take a broader view of the national 'big picture', balancing social, economic and environmental considerations, not just for this generation however, it also needs to balance todays needs without foreclosing future options or leaving new legacies to be dealt with. To be successful, early and continuous stakeholder engagement is essential as this way builds public trust and support.

Integrated waste management requires the owner to identify and deal with the central issues not just the obvious symptoms. As is often the case, understanding the problem is key to the solution. However, a key message from the session was that solutions are not universally applicable and need to be considered on a case by case basis, and tuned to reflect the limits and constraints, the politics and stakeholder environment.

Lastly, we were reminded of the need to think about waste management before the waste is generated, ideally designing the process and operation so waste is avoided or if not possible, minimized. Mr Drace's presentation summed it up thus: "The greatest lesson we can learn from the past 60 years of the peaceful use of nuclear technology is to think about waste management before the waste is generated and then integrate its management at the country level to provide trust to stakeholders which mostly perceive nuclear waste as a problematic issue".

Session 7, Multinational Cooperation in Radioactive Waste Management

Session 7 Mr Verhoef reported, we heard examples of the challenges and in particular opportunities addressed by multinational cooperation or team work as it was better described. These examples had shown how international collaboration has helped to provide sustainable solutions for waste management in different countries, which is a key element in making the case for the safe application of nuclear technology, which as we know, is a topically issue being discussed at CoP 26 this week.

We learned how international bodies such as the IAEA, OECD NEA, EC, and others can facilitate international collaboration, by sharing knowledge, experiences and lessons learned, by peer reviews and issue of guides and standards. International organizations can also provide direct assistance as for example was the case in development of different waste facilities at the Chornobyl NPP.

We also heard about collaboration between regulatory bodies and of efforts to apply lessons learned in design, operation, and safety approaches and how harmonisation of legislation has led to cost and timescale benefits in decommissioning.

Mr Verhoef cautioned that international cooperation does bring with it challenges; parties have to work together and may have very different social and economic backgrounds, legal frameworks and differing objectives. If you are prepared to make it work, then surely the benefits will outweigh any difficulties. Or as the proverb says: alone you may go faster, but together you get further. And that is important because the road to develop sustainable radioactive waste solutions often is long. It is better and easier not to walk it alone.

6.3. SUMMARY OF THE CONFERENCE CHAIR MS KAREN WHEELER AND CO-CHAIR MR MUHAMMAD NAEEM

Ms Wheeler and Mr Naeem used this session to recall the highlights of the week and to share some perspectives on the papers presented. Ms Wheeler noted that the major takeaway from her perspective was to recognize that that although we accept that there are waste management solutions that can be implemented safely, we also understand that this in itself is not enough. There is now widespread acceptance that we need to involve our communities, our politicians and the public so that they can understand the challenges and that we can together settle on mutually acceptable solutions.

She noted that the Session Chairs had earlier provided a summary of the key points to arise from each session and that she and Mr Naeem did not want to repeat or cover the same ground, instead they would present a personal perspective of learning from each of the sessions.

In the opening session Mr Grossi repeated the message that he had delivered to the CoP26 in Glasgow, that nuclear technologies are an important contributor to the safe implementation of sustainable energy solutions but what he asked, about the waste? This he said will be a recurring theme throughout the Conference, which indeed it was with many contributors addressing this and providing examples and case studies of sustainable waste management practices.

The opening session also included a panel discussion on multilateral collaboration which emphasized the efforts being undertaken to foster information exchange and the positive outcomes from international collaboration. Ms Wheeler cited this Conference as a very good example of the international community working together and she took the opportunity to thank the IAEA and the partner organizations for making this event happen.

The last presentation of the Opening session was on waste management in Austria, the Conference host and example of a small-inventory country. The presentation was a helpful reminder that radioactive waste management is an important consideration for all countries since even those without large-scale nuclear power plants most will have arisings from industry, research and medicinal uses.

The first of the Side Events followed and featured presentations on the IAEA Technical Cooperation programmes that have benefited Pakistan and facilitated a strengthening of its radioactive waste management infrastructure, practices and expertise in several important areas. Pakistan is now able to pass on its expertise to other Member states.

In Session 1, national programmatic perspectives were discussed, and Ms Wheeler recalled the case studies and presentations describing steps taken to establish legal and regulatory frameworks and the waste management organizations and facilities that can safely manage waste and inspire confidence in their communities. The importance of listening to stakeholders and continuous improvement were key messages.

The opening day concluded with the Side Event discussing innovation in radioactive waste management and its contribution to sustainability. The speakers spoke of their experience of promoting innovative thinking and technologies and identified how these can be harnessed to overcome waste management challenges.

Day 2 commenced with Session 2 on the topic of implementation of waste management strategies. This was said Ms Wheeler, an interesting session as it was able to showcase the successful Finnish programme as well as others that had not gone according to plan and had needed to regroup and retrieve a difficult situation. There were good lessons and learning for all in this session.

Session 2 was followed by the Safeguards Side Event and Mr Naeem reminded attendees that safeguards need to be applied to all nuclear materials and facility designers and operators need to be aware of safeguards obligations and requirements from an early stage. ‘Safeguards by design’ is often found to be helpful and is a service offered by IAEA Safeguards to designers to help them navigate the requirements at an early stage thereby avoiding potentially costly late design changes.

In Session 3 Mr Naeem recalled, we heard about a wide range of solutions already implemented for large and small inventories of waste. A key message from the session was to understand your waste, then you may be able to tailor one of the existing solutions to your needs. Regulators and international partners can complement your in-house expertise.

Day 2 concluded with the Side Event discussing experience in the management of disused sealed radioactive sources (DSRS). Mr Naeem noted that DSRS exist in almost every Member State and that they present unique and challenging problems. Thankfully best practice management solutions are being promulgated by IAEA and in the related event we heard about the successes in securing such sources and their onward management though reuse, recycling, or disposal.

Session 4 discussed the role of the safety case which Mr Naeem described as the central unifying component of many successful waste management programmes. By its nature it is a multidisciplinary and a multi-interface process. It is also iterative, requiring update throughout the lifetime of a management facility taking account of experience, learning and more recent research. The safety case is used to manage design changes and to guide supporting research and development.

Session 4 was followed by a Side Event on the important topic of building stakeholder confidence. Ms Wheeler noted that many waste management programmes are now moving forward because developers and operators have realized that the involvement of civil society in their programmes is a necessary and essential component. Waste management solutions take time to mature but so does the relationship with a community and hence so does the building of trust and stakeholder confidence. All successful programmes are now devoting time and effort to build and importantly to maintain stakeholder confidence.

Session 5 was devoted to socioeconomic aspects of waste management, a topic said Ms Wheeler, that is increasingly recognized by waste management organizations as being an essential consideration in the relationship with host, and potential host, communities. Communities engaging in radioactive waste management need to be supported and listened to. Transparency and openness to help them understand the challenges and contribute to solutions will help build trust but give time as trust will not be built quickly, it has to be earned through actions.

The last event of Day 3 was the Side Event devoted to final disposal of spent fuel in Finland, the programme described by Mr Grossi in his opening address as a ‘game changer’. Ms Wheeler recalled the successes of the Finnish programme and the heartfelt welcome of the news that the construction licence had been granted. She said she looked forward to further updates regarding the proposed trial run before the commencement of active operations.

Day 4 started with Session 6 on the topic of integrated waste management. Mr Naeem noted that this is a relatively new discipline that has a growing, and important role in delivering safe and sustainable waste management solutions through strengthening a holistic view on all parts of the waste life cycle – from ‘cradle to grave.’ In the words of Mr Drace “The greatest lesson we can learn from the past 60 years of the peaceful use of nuclear technology is to think about waste management before the waste is generated and then integrate its management at the country level to provide trust to stakeholders which mostly perceive nuclear waste as a problematic issue.”

Session 6 was followed by a Side Event dedicated to the Beishan underground research laboratory being developed in China. Mr Naeem recalled the progress made to date and plans for the future, including the offer that international cooperation would be welcomed.

Session 7 was on the topic of multinational cooperation in radioactive waste management. In this session we heard from IAEA and international organizations included OECD NEA, WNA, and EC, who spoke about the collaborative programmes that they are working on for our mutual benefit.

The closing event on Day 4 was a Side Event on the topic of collaborative research and innovation in the Euratom Community. Mr Naeem recalled the different programmes and was pleased to report that non-European organizations were also able to participate.

Having completed the run through of the preceding four days' events Mr Naeem handed over to Ms Wheeler again. She started by thanking the authors of the e-posters which had been available for viewing and inspection during breaks and lunch sessions and which had been of high quality.

She then paid tribute to the Young Professionals who had made such an important contribution to the Conference with their excellent papers and support in the various sessions by acting as Co-chairs. She said it was great to meet them and hear from them at the Young Professionals event that was held on Sunday evening and looked forward to further interaction at the remaining feedback session.

Ms Wheeler also thanked the exhibitors for providing interesting and informative exhibits and for funding coffee breaks which made the breaks so pleasant to gather and enjoy some refreshment.

Ms Wheeler concluded by thanking IAEA, speakers, Session Chairs and Co-chairs, and all contributors and participants.

Mr Naeem added his thanks to the Scientific Secretaries and backroom supporting staff for their hard work and making it all happen.

6.4. WASTE MANAGEMENT. AN ATTRACTIVE PROPOSITION FOR A SMART WORKFORCE

(As prepared for delivery)

Christophe Xerri
Director Division of Nuclear Fuel Cycle and Waste Technology, IAEA

Good morning to all of you. I have been asked to say some words more specific to the young generation.

So this morning … I have something like 200 neckties, and I was wondering which one to take. I thought I'd choose one with an attractive orange autumn colour which would be a good fit, but then I decided to take this one. Green. Green because this is now the Autumn of the nuclear life cycle and waste is the Spring of it, because without proper waste management there is no way to ensure sustainable use of nuclear applications and nuclear power. So waste is really from the beginning, the Spring of nuclear applications.

So going to waste management, I consider that is an 'attractive proposition for a smart workforce.' And let me explain to you my thinking on that.

First its Back to the Future and innovation and when I say Back to the Future it has several meanings. If you go back 50 or 60 years, those people, your father or grandfather, mother, or grandmother, were pioneers of nuclear energy and nuclear applications. Today, many of you working in waste management are the pioneers of waste management. Not that there's nothing been done so far, but there are still a lot of new things to be done in waste management and one of them is the proper final waste management of those wastes created by the pioneers. So its really from pioneers to pioneers.

Innovation also because we all think that nuclear applications, for cancer and for food and so on and also nuclear energy, are the future and a long future. And when we go to for instance nuclear energy, we see a lot of development of the Generation IV reactors, SMRs and so on. And for these innovative concepts there will be wastes to be managed and that has to be taken account of from the beginning. So that's another part of innovation, to support the fleets of next reactors and with so many new technologies coming on like digitisation, 3-D printing and so on.

Its also Action. Not only research and innovation, its Action. And here for most of you, doing operations its about managing the waste safely and to avoid waste arising, and that's important in terms of the circular economy and waste avoidance. So from waste avoidance to waste minimization, to waste management and waste disposal, its Action. And you are the 'Waste Busters'!

And with all that in mind you are protecting the planet, protecting the environment, protecting the people in line with the Sustainable Development Goals.

All this means that there are many things to be done in the field of waste management, many things that are exciting, which are pioneering, which are innovation and which are action for the benefit of the planet and which relate to the Sustainable Development Goals. We've got here (on the slide) Number 13 – Climate Action and here Number 12 – Responsible Consumption and Production. So being part of the waste management community you do good for the planet and good for your career. You'll have a stimulating career path in front of you and you can in addition benefit from all the experienced people around you and in this room

So I wish all of you a very successful career in radioactive waste management.

We are counting on you to be ambassadors and promote the interests of radioactive waste management among your peers and fellow university students.

Thank you very much.

6.5. PRESENTATION TO YOUNG PROFESSIONALS

(As prepared for delivery)

Mikhail Chudakov

Deputy Director General, Head of the Department of Nuclear Energy, IAEA

Mr Chudakov presented awards to seven young professionals who in the opinion of the Organizing Committee had made an exceptional contribution to the Conference. Awards were presented to:

Havard Kristiansen, Norway – for his paper Development of a comprehensive nuclear waste management programme in a small-inventory state

Alexey Kuznetsov, Russian Federation – for his paper Complete recycling of boric acid from the primary circuit coolant obtaining commercial borate products

Hasna Hamdane, Morocco – for her paper Solidification of radioactive resins with geopolymer package: a circular economy concept of handling nuclear waste with mine tailings

Matthew Herod, Canada – for his paper Canadian regulatory review of waste acceptance criteria for a low-level near surface disposal facility

Rafael Soares Souza Pimenta de Almeida, Brazil – for his paper Site selection methodology for the Brazilian repository for low and intermediate level radioactive waste through geospatial analysis

Haoxiang Fei, Australia – for his paper Site characterisation inputs to safety case development for Australia's national radioactive waste management facility

Celia Wighton, United Kingdom – for her paper Adoption and implementation of an integrated waste management strategy to support and deliver the next generation of young professionals in the remediation of the UK's nuclear legacy

Mr Chudakov congratulated the award winners and wished them good luck in their future careers.

6.6. INTERNATIONAL ATOMIC ENERGY AGENCY ACTING DEPUTY DIRECTOR GENERAL DEPARTMENT OF NUCLEAR SAFETY AND SECURITY CLOSING REMARKS

(As prepared for delivery)

Peter Johnston

Acting Deputy Director General of the Department of Nuclear Safety and Security, IAEA

Ladies and gentlemen, dear colleagues,

As Acting Deputy Director General of the Department of Nuclear Safety and Security at the IAEA, I want to thank you for your participation in this International Conference. Let me congratulate you on the high quality of the presentations, posters, discussions held on Radioactive Waste Management Solutions.

This week we have seen many examples of safe solutions for the predisposal management and disposal of all classes of radioactive waste. And although the conference was held in a hybrid mode, fruitful discussions took place including on innovations, on how to further improve safety in radioactive waste management, as well as on the importance of working in partnership with stakeholders towards our common goal of a sustainable future.

The conference has re-emphasized the importance of the Safety Case as the central concept for guiding the development of safe waste management and disposal facilities. For disposal facilities in particular, an ever-growing number of highly developed safety cases has been developed, and these are supported by over 40 years of research and development.

The conference was also an opportunity, through side events, to address specific topics such as the benefit of international cooperation, the management of disused sealed radioactive sources, and safeguards approaches in the management of radioactive waste. Once again, we saw that radioactive waste management, including disposal, involves highly regulated activities. And for all these reasons, presented and discussed during this successful conference, we gained even further confidence that the solutions to 'the waste question' exist and can be safely implemented.

The conference also confirmed that international cooperation is a highly important part of achieving this common goal, and that integration and harmonisation of safety in the management of radioactive waste remains an essential goal.

The International Conference on Waste and Environmental Safety: Integrated Approach to Strengthening Sustainable Development which will be held in Vienna from 6 to 10 November 2023, will contribute to reaching this aim. This next conference will have a broader scope and will provide a forum for all interested parties to discuss, exchange and share experience on ensuring waste and environmental safety. It will address at the same time the safety of waste management, decommissioning, remediation, and environmental releases.

Before giving the floor to the Deputy Director General, Head of the Department of Nuclear Energy, Mr Chudakov, for the official final closure of the conference, let me thank you once again for your support and participation. I wish you all safe travels and look forward to seeing you again soon.

Thank you.

6.7. INTERNATIONAL ATOMIC ENERGY AGENCY DEPUTY DIRECTOR GENERAL DEPARTMENT OF NUCLEAR ENERGY CLOSING REMARKS

(As prepared for delivery)

Mikhail Chudakov

Deputy Director General, Head of the Department of Nuclear Energy, IAEA

Dear Chairwoman Karen Wheeler, Chairman Muhammad Naeem, Ladies and Gentlemen,

Good morning and thank you for giving me the opportunity to close this International Conference on Radioactive Waste Management.

The theme of this event is very timely. Sound radioactive waste management is crucial for the development of nuclear energy and nuclear technology applications. So before highlighting the important global progress and lessons learned in this field, demonstrated through all the contributions to this conference, let me digress and briefly remind us why sound radioactive waste management is so important!

Not a day goes by, it seems that scientists don’t warn us about climate change and the drastic impact it will have on our world. At the same time, the world needs more energy to fuel its economic development. Nuclear power, as a low carbon energy source, can help to ensure reliable energy supply while at the same time curbing greenhouse gas emissions. Some of our Member States still have limited access to essential cancer therapy, resulting in thousands of unnecessary deaths. Medical uses, research, as well as agricultural applications, critical to our food supply chain, give rise to a small and well understood amount of radioactive waste.

It is subject to clear regulations supported by internationally agreed safety standards. We understand and know how to choose effective technical solutions for all types of waste streams and for all steps in their management – as shown, once again, by the contributions and discussion at this conference. More importantly, this conference has demonstrated that indeed, national waste inventories are being effectively managed.

And yet, radioactive waste continues to be one of the main concerns associated with the use of nuclear power and the wider use of nuclear technologies. This is something I often hear when talking to people about our work here at the Agency.

In these situations, I tell them:

- Disposal facilities for low level and intermediate radioactive waste are operational worldwide,
- Around 80% of the solid radioactive waste that has been generated in the last 60 years has been disposed,
- Innovative solutions are being developed to allow small inventory Member States to dispose of their DSRS inventories – safely and cost effectively,
- Great progress has been made on projects to develop facilities for the deep geological disposal of high-level radioactive waste and spent fuel declared as waste.

And I assume you do the same, backed with all of your extensive experience and expertise in radioactive waste management!

We are pleased to hear that the world's first, deep geological repository, in Finland, is expected to start receiving spent fuel in 2023. Sweden and France are close, and Canada and Switzerland are nearing the formal recommendation for a disposal site.

Ladies and Gentlemen, there is one thing I am sure of – the continued success in all areas of radioactive waste management will have a profound impact on the political and public acceptance of nuclear power… including our capacity to share needed applications of nuclear technologies in health care, agriculture, and research.

Ladies and Gentlemen, there are a number of pervasive myths regarding radioactive waste … some lead to regulation and actions which are totally counterproductive to human health, safety, and even our environment! The world needs to be clear that trusted, proven technologies exist for the management of radioactive waste. This conference has demonstrated to the world that radioactive waste is managed effectively and safely every day all around the world.

This is our job! We need to get the message out there!

The key point here is that solutions already exist and can be implemented right away. But as in all other industrial sectors, optimization and innovation are a continuous process: waste management is no exception.

I would like to thank you all for your contributions. I especially thank our Chairwoman and Chairman and all the experts who have actively supported the organization of this important conference.

Thank you and I now declare this Conference closed.

ANNEX I. STATISTICAL REPORT

International Conference on Radioactive Waste Management: Solutions for a Sustainable Future

1 – 5 November 2021

STATISTICAL REPORT

Location	Vienna Headquarters and virtual
Scientific Secretaries	G. Nieder-Westermann (NEFW) F. Dragolici (NEFW) A. Guskov (NSRW) D. Bennett (NSRW)
Scientific Support	C. Bal (NEFW) B. Altenhofer (NEFW)
Administrative Support	M. Tolstenkova (NEFW) E. Goek (NEFW)
Conference Coordinator	J. Zellinger (MTCD)
Exhibition Coordinator	E. Paniagua-Miranda (MTCD)
Conference Technical support	S. Padmanabhan (MTCD)

REGISTRATION/ATTENDANCE

Total no. of participants and observers	886
Total no. of official participants	538 including invited speakers
From Member States	527 from 92 Member States
From Organizations	11 from 4 organizations
In person attendance	229
Virtual attendance	309
Total no. of observers	348
From Member States	310 from 71 Member States
From non-Member States	-
From Entities	-
From Organizations	38
Total no. of invited persons	42

ATTENDANCE STATISTICS

	Through the IAEA virtual platform			
	Total	via Desktop	via Mobile	via Tablet
Monday, 1 November	2,972	2,817	125	30
Tuesday, 2 November	2,276	2,160	95	21
Wednesday, 3 November	2,026	1,890	121	15
Thursday, 4 November	1,445	1,317	110	18
Friday, 5 November	510	461	38	11

PROGRAMMATIC INFORMATION

Structure	1 opening session with 6 opening remarks, 1 panel discussion and 1 oral presentation, 7 technical sessions and 1 closing session
No. of oral presentations	Total of 55 oral presentations: • 48 speakers à 20 minutes • 7 young professionals à 5 minutes 7 panel discussions with live Q & As
Side Events	• Pakistan – IAEA Cooperation in Safe Management of Radioactive Waste • Innovation in Radioactive Waste Management for a Sustainable Future • Safeguards: The Often-Overlooked Requirement in Waste Management • Member State Updates and Progress in the Management of Disused Sealed Radioactive Sources (DSRS) and the Global Path Forward • Building Stakeholder Confidence for Sustainable Radioactive Waste Management • Final Disposal of Spent Nuclear Fuel in Finland • Beishan Underground Research Laboratory in China • Collaborative Research and Innovation in RWM in the Euratom Community
Young Professional Events	Being Part of the Solution – Career Paths for a Sustainable Future Looking to a Sustainable Future (Young Professionals Feedback)
No. of e-posters	169 in total • Session 1: 36 • Session 2: 24 • Session 3: 52 • Session 4: 19 • Session 5: 11 • Session 6: 12 • Session 7: 15

COOPERATING ORGANIZATIONS

- Organisation for Economic Co-Operation and Development / Nuclear Energy Agency (OECD/NEA)
- World Nuclear Association (WNA)
- European Commission (EC)

DETAILED REGISTRATION INFORMATION

1) Total no. of official participants: 538

- 527 from 92 Member States:

Argentina	7	Lithuania	6
Australia	13	Madagascar	1
Austria	7	Malaysia	5
Azerbaijan	1	Mauritania	3
Bangladesh	2	Mexico	1
Belarus	4	Montenegro	1
Belgium	5	Morocco	8
Benin	2	Myanmar	2
Bosnia & Herzegovina	1	Netherlands	11
Brazil	4	Nigeria	8
Bulgaria	6	Norway	5
Chad	1	Oman	2
Cameroon	2	Pakistan	8
Canada	11	Philippines	2
Central African Republic	1	Poland	3
Chile	2	Portugal	2
China, People's Republic of	12	Qatar	2
Comoros	4	Republic of Moldova	3
Congo	1	Romania	6
Croatia	1	Russian Federation	35
Cuba	5	Rwanda	1
Czech Republic	6	Saudi Arabia	6
Denmark	1	Serbia	5
Dominican Republic	1	Sierra Leone	1

Egypt	2	Singapore	9
Estonia	2	Slovakia	16
Ethiopia	2	Slovenia	1
Finland	9	South Africa	2
France	19	Spain	6
Georgia	2	Sudan	1
Germany	53	Sweden	6
Ghana	4	Switzerland	5
Greece	6	Syrian Arab Republic	1
Hungary	2	Thailand	9
India	4	Türkiye	3
Indonesia	9	Uganda	2
Iran, Islamic Republic of	4	Ukraine	5
Israel	7	United Arab Emirates	7
Italy	13	United Kingdom	35
Jamaica	1	United Republic of Tanzania	3
Japan	7	United States of America	20
Jordan	3	Uzbekistan	1
Kazakhstan	3	Viet Nam	1
Kenya	3	Yemen	3
Korea, Republic of	5	Zimbabwe	1
Kyrgyzstan	2		
Libya	1		

- 11 from 4 international organizations:

European Commission	3	World Nuclear Association	3
OECD/NEA	4	Western European Nuclear Regulators' Association	1

2) **Total no. of observers: 348**

- 348 from 71 Member States:

Algeria	1	Libya	1
Argentina	7	Lithuania	1
Armenia	2	Luxembourg	1
Australia	4	Malaysia	4
Austria	11	Mexico	4
Bahrain	1	Netherlands	4
Bangladesh	3	Nigeria	4
Belgium	3	North Macedonia	1
Bolivia	1	Norway	1
Brazil	14	Oman	1
Bulgaria	3	Pakistan	2
Canada	13	Peru	1
Central African Republic	1	Philippines	6
Chad	1	Poland	1
Chile	1	Portugal	2
China, People's Republic of	19	Romania	4
Colombia	2	Russian Federation	5
Congo	1	Saudi Arabia	14
Croatia	6	Singapore	7
Czech Republic	5	Slovakia	2
Denmark	1	Slovenia	1
Estonia	1	South Africa	10
Ethiopia	2	Spain	5
Finland	4	Sweden	2
France	7	Switzerland	4
Germany	24	Taiwan	2
Ghana	1	Thailand	1
Hungary	2	Türkiye	8
India	3	Uganda	1
Indonesia	7	Ukraine	2
Italy	5	United Arab Emirates	1

Japan	9	United Kingdom	16
Jordan	1	United States of America	17
Kazakhstan	1		
Korea, Republic of	5		
Lesotho	1		

- 19 from 2 organizations:

IAEA	18
OECD/NEA	1

ANNEX II. CONTENTS OF THE SUPPLEMENTARY ELECTRONIC FILES

The supplementary files for this publication can be found on the publiucation's individual web page at www.iaea.org/publications. Note that only the original papers presenting the work summarized in associated posters for each of the poster sessions are provided; the posters themselves are not provided.

TITLES AND AUTHORS OF PRESENTED PAPERS FOR THE POSTER SESSIONS INCLUDED IN THE SUPPLEMENTARY FILES AS THEY APPEAR IN THE CONFERENCE PROGRAMME

NATIONAL PROGRAMMATIC PERSPECTIVES (Poster Session 1)

ID#11 National strategy and planning for the safe and sustainable management of radioactive waste and spent nuclear fuel
S. Esseyin, E. Joseph

ID#16 Challenges of newcomers in development of radioactive waste management
S. Gezer

ID#22 On expedience and safety of high-level radioactive waste borehole disposal
B.T. Kochkin, V.I. Malkovsky, M. I. Ojovan, V. Petrov, S.V. Yudintsev

ID#33 Regulatory framework for radioactive waste management in Myanmar
M. M. Win

ID#41 Radioactive waste management approaches in Pakistan – Legal framework, policies and strategies
S. Ali, M. Abbas, M. H. Rizvi, A. Amjid

ID#52 Development of spent fuel and radioactive waste management strategy for the proposed nuclear energy programme in the Philippines
R. Piquero, A. A. Asuncion-Astronomo

ID#55 Creation of the final system for the isolation of radioactive waste in the Russian Federation
V. Igin

ID#58 Spent fuel and radioactive waste management in the HTGR fuel cycle - Polish Perspective
K. Kiegiel, I. Herdzik-Koniecko, L. Fuks, A. Miskiewicz, G. Zakrzewska-Kołtuniewicz

ID#60 Solid radioactive waste management of Atomic Energy Centre Dhaka, Bangladesh and its implication to worker & public safety
M. S. Rahman, M. Siraz, S. Banik, S. Pervin, S. Yeasmin

ID#70 Moroccan experience on radioactive waste management
K. Mrabit, J. El Mabtoul, M. Mohammed, D. Ben Abdelhadi

ID#71 Radioactive waste management and regulation under the new Nuclear Energy for Peace Act, Thailand
C. Ussawaphuchai, P. Suntrapri

ID#75 Role of regulatory body in controlling radioactive discharges from multi-unit nuclear power plants site in Pakistan
S. Fayyaz, J. Iqbal, M. Amir

ID#78 Study on the radioactive burnable waste management of nuclear medicine facilities in Indonesia: Case of Sardjito Hospital's Waste
H. Nursetya Putra, D. Insani Al Haq, D. Yuwono, R. Khalis, S. Andrew Y. M., A. Radya Priadi, J. I. Santosa

ID#82 Assessment of the Current State of disused sealed radioactive sources management options from different applications in Ethiopia
E. Wondimagegn

ID#83 Analysis of indonesian regulatory infrastructure for radioactive waste management and its implementation
V. Zahrawati

ID#88 Radiological cleaning of rubble contaminated with Ra-226 - Important milestone in the Dominican Republic
J. Gomez Nunez

ID#91 U.S. Nuclear Regulatory Commission Approach to very low-level radioactive waste
M. Heath, S. Dembek, M. Wong

ID#119 Multicriterial site assesment of potential deep geological repository sites in Czech Republic: Integration of safety, technical feasibility and environmental approach
L. Vondrovic, J. Augusta, A. Vokal

ID#126 Radioactive waste management education in Thailand
S. Chanyotha, P. Pengvanich, R. Kritsananuwat

ID#130 Management of the concrete and cast iron waste resulted from the decommissioning of the VVR-S Nuclear Research Reactor Block from IFIN-HH
L. Done, E. Ionescu, D. Gurau, C. Alexandru, M. Mincu

ID#156 The search for a geological repository site in Germany – Its unique features and the safety case
T. Faß, M. Pekala, F. Emanuel, J. Mibus , S. Schöbel, M. Riede, C. Borkel

ID#169 The joint effort journey to finding a deep geological repository for German high level waste (International experiences and regulatory framework concerning the science-based site selection process in Germany)
F. Emanuel

ID#174 Research in terms of the German site selection procedure – The regulator's commitment to interdisciplinary
J. Ahlswede, C. Borkel, M. Jendras, W. Wartenberg

ID#185 Dutch legacy waste project, an overview from the regulator
G. Menard, M. J. van Bourgondiën, L. P. van Dam-Snell

ID#195 Radioactive waste management facility regulation in Thailand: History and challenge
C. Soontrapa

ID#197 Challenges of implementing Thailand's policy and strategy for management of radioactive waste
N. Prasertchiewchan, K. Yubonmhat, W. Katekaew

ID#205 Study on the fast reactor system characteristics in the transition period from LWR to FR
H. Kato, G. Chiba, H. Asano

ID#222 Magnox TRS Drums: A first of a kind non-routine disposal at the UK's low-level waste repository
A. S. Jackson

ID#238 Radioactive waste management in Nigeria – Programmatic perspectives
E. C. Akueche, T.C. Akpa

ID#240 Improvement of regulatory framework in the field of radioactive waste and spent nuclear fuel management in the republic of Serbia
I. Avramovic, M. Vujovic, B. Brajic, J. Milovanovic, S. Velinov

ID#241 Establishing a radioactive waste repository in Estonia
M. Leier, I. Tatrik

ID#261 Implementation of national strategies for radioactive waste management in an increasingly international context – Opportunities and challenges from a regulatory perspective
B. Hedberg,

ID#272 Establishing a national waste management strategy: Challenges and experience of a new regulatory body
C. Nattie

ID#279 National perspectives of radioactive waste management in Madagascar
T. Randriamora, M.A.L. Ralaivelo, H.A. Razafindramiandra

ID#282 The DEMAIN Project: An academic research center on nuclear dismantling and decommissioning
L. Mathieu, C. Sergeant, B. Thomas, D. Horlait, M. Aïche, C. Cerna, F. Piquemal, H. Guégan

ID#285 Moroccan experience on managing radioactive waste
R. Touhami, B. Abderrahim

IMPLEMENTATION OF WASTE MANAGEMENT STRATEGIES (Poster Session 2)

ID#29 Dismantling and removal of Cs-137 Blood Irradiator from Jordanian hospitals
A. H. Alsabbagh, R. M. Mustafa

ID#37 An introduction to the new near surface disposal repository in China
D. Wu, P. Zhu, X. Zhang

ID#51 Assessment of completeness and sufficiency of ongoing research activities in underground research laboratory of the Nizhnekansky Massif
A. Ponizov, D. Murlis, A. Mishagina, P. Vereshchagin, I. Lobodenko,
O. Ushanova, M. Felitsyn, K. Lebedkin

ID#54 Development of a quality management system for the accreditation of the radioactive waste management service in the Philippines
R.E. Piquero, A.A. Panlaqui, K.M.D. Romallosa

ID#63 Management of disused sealed radioactive sources in Syria
L. Al Attar, B. Safia, B. Abdul Ghani, S. Al Khattab, A. Al Ali, F. Heso

ID#73 Regulation of sealed radioactive sources in Pakistan
J. Iqbal, H. Shoukat

ID#74 Licensing of PINSTECH pre-disposal radioactive waste management facility - PNRA Experience
J. Iqbal, A. Aslam

ID#104 Development of national infrastructure for radioactive waste management (Georgian case)
G. Nabakhtiani, V. Gedevanishvili, I. Giorgadze

ID#105 The borehole disposal system - A safe disposal option for management of disused sealed radioactive sources
E. T. Glover, P. Essel, E. Akortia, G. Gbeddy, Y. Adjei-Kyereme, M. Nyarku, E.O. Sarfo, E.A. Aberikae, E.M. Ameho

ID#108 Conceptual design of disposal facility for very low-level, low-level and short-lived intermediate-level radioactive waste of the Belarusian NPP
M.L. Zhemzhurov, A.V. Kuzmin, N.D. Kuzmina

ID#128 Evolution of the environmental monitoring programme in 40 years of operation of the low and intermediate radioactive waste repository Baita Bihor / Romania
B.T. Obreja, L. Done, E. Neacsu, L.R. Zicman, M. Nicu

ID#173 Regulatory and infrastructural framework for radioactive waste management in Cameroon
J.F. Beyala Ateba, A. Simo

ID#183 Dismantling of a radiopharmaceutical production plant: Waste management strategy and achievements
M. Gaelens, H. Van Humbeeck

ID#190 Modular and transportable conditioning systems for LLW/ILW – Sogin Experience
M. Nasta

ID#198 Pre-decommissioning of Bangkok radioactive waste incineration plant
P. Nuanjan, K. Yubonmhat, W. Katekaew, N. Prasertchiewchan

ID#207 Development of a non-destructive gamma spectrometry technique for validation of neutron activation calculations
A. Markopoulos, D. Mavrikis, E. Ntalla , A. Ioannidou, A. Savidou

ID#208 Development of a non-destructive gamma spectrometry technique for optimization of metallic waste characterization
D. Mavrikis, A. Markopoulos, E. Dalla, A. Ioannidou, A. Savidou

ID#233 The development of Beishan Underground Research Laboratory for geological disposal of HLW in China
J. Wang, L. Chen, X.G. Zhao, R. Su

ID#245 Optimised waste management for nuclear site decommissioning on side disposal technical learning to inform regulatory advice and assessment
C. Emery-Scheib, R. J. Clarke, T. Montgomery, J. Long, A. Fairhurst, P. Fahey, T. Howard, C. Glaister, P. Robinson, J. Heavingham, J. Foy, A. Hill, G. Beaven

ID#265 Regulatory experiences in policies and strategy implementation for radioactive waste and disused sources management
O.M. Fornet Rodríguez, F. Pérez González

ID#274 End-of-life considerations during the transition to alternative technologies
S. Norris, S. Cotton, M. Keskula

ID#276 Demonstration of an end-to-end process for decommissioning ILW waste
M. Guy

ID#291 Integrated waste strategy for Canadian Nuclear Laboratories
M. Vickerd

SOLUTIONS FOR SPECIFIC WASTES (Poster Session 3)

ID#5 Waste solidification using CRT glass for retardation of hazardous elements in spent resin
N. F. H. Jamaludin, S. Mohd Fadzil, R. Ba'an

ID#12 Uranium recovery from liquid waste composed of uranyl nitrate solution
E. L. C. Campelo, F. V. D. Fonseca, R. D. A. Medronho, W. Pereira, R. D. D. Santos

ID#13 Safety and security of radioactive sources: the role of the radioactive waste management centre of Ghana
A. M. A. Dawood

ID#19 Progress on the management of DSRS at China Institute for Radiation Protection
C. Gao, X. Hong, J. Liu

ID#26 Control and management of nuclear waste water with a novel nano technology method
M. Haghi, S. Rashidi Dafeh

ID#32 Management of disused radioactive sources from the Irradiation Facility Product I in Cuba
M.M. Salgado, N. González, J.M. Hernández, R. Castillo, G. Turruella, J. Mendoza, L. Horváth

ID#39 Investigating the feasibility to characterise nuclear waste from the Asse II Mine using cosmic-ray muon tomography
R.B. Kaiser, C. Vieh, K. Föhl, M. Dauke, G. Yang, S. Gardner

ID#56 Waste management in a uranium enrichment plant
F. S. Pereira

ID#62 Chemical durability and structure analysis of simulated radioactive waste glasses
O. Farid, Y. Abdelaziz, S. Waly

ID#65 Segregation and disposal of legacy mixed organic liquid waste in Malaysia
A.K. Zahari, N. Zakaria, R. Salihuddin, N. Harun

ID#67 Sorption on inorganic sorbents supported by ultrafiltration - Hybrid method for treatment of radioactive liquid waste
L. Fuks, A. Miskiewicz, G. Zakrzewska-Koltuniewicz, L. Maskalchuk

ID#68 Sorption of selected radionuclides from liquid radioactive wastes by sorbents of the biological origin
L. Fuks, I. Herdzik-Koniecko

ID#69 Characterization and preliminary study for solidification of organic alpha-contaminated liquid waste
M. I. Cozzella, G. A Marzo, F Pancotti, P. Negrini, F. Troiani

ID#87 Development of mid- and long term strategies for TRR Spent Fuels Dry Storage
E. Abedi, Z. Gholamzadeh, A. J. Vaziri

ID#93 Treatment of liquid radioactive waste containing organic substances
A. Miskiewicz, K. Kiegiel, I. Herdzik-Koniecko, L. Fuks, G. Zakrzewska-Kołtuniewicz

ID#95 Decommissioning of radon type radioactive waste storage facility in Lithuania
A. Šimonis, G. Poškas, P. Poškas, G. Klevinskas

ID#97 Effects of thermal load on behavior of cherkasy bentonite as a buffer material
B.P. Zlobenko, Yu.G. Fedorenko, S.P. Buhera, A.N. Rozko

ID#112 Liquid radioactive waste treatment – Volume reduction in solution that containing uranyl nitrate
M. Mendoza, V. Pereira

ID#114 Non-destructive material characterization of radioactive waste packages with QUANTOM
L. Coquard, A. Havenith, T. Koeble

ID#115 Characterisation of radioactive boundary wastes - A Bayesian solution
P. Hiller, C. Pyke, K. Yoshikazu, O. Keiichi

ID#118 Conditioning and immobilization of inactive ion exchange resins in thermoplastic polymers
M. Spinosa, L. J. Dos Santos, M. C. Lorenzo, P. Eisenberg

ID#122 The impact of radiation loads on the structure and properties of the cement compound as a promising matrix for the immobilization of high-level waste
A.P. Varlakov, A.V. Germanov, A.A. Zherebtsov

ID#123 Processing design for a pyrochemical-distillative recovery alternative in nuclear waste management
D. Boehm, J-C. Lewitz, K. Czerski

ID#133 Improvement of accuracy in waste characterisation by applying innovative techniques (ASGS)
M. Fritsche, M. Dürr

ID#136 One step low temperature thermochemical process in air at atmospheric pressure to denitrate a simulated HLLW without or with addition of an aluminoborosilicate glass powder
A. Fernandez Zuvich, S.G. Pérez Fornells, A.M. Bevilacqua

ID#137 Pyrolysis and high-performance plasma treatment applied for the treatment of spent ion exchange resins
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