THE CALCULATION OF HARM AND NO-HARM DISTANCES FOR THE STORAGE AND USE OF TOXIC GASES IN TRANSPORTABLE CONTAINERS

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Prepared by WG-4 Special Gases

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Amendments from 189/14/E Corrigendum

Section	Change
	Editorial to align to EIGA Style Manual
1	Addition of a paragraph to highlight that the document is intended to be used by skilled personnel able to assess real situations

Note: Technical changes from the previous edition are underlined

1 Introduction

EIGA members are filling toxic gases, including their mixtures, in different types of gas containers (cylinders, cylinder bundles, pressure drums, MEGC, portable tank) and they deliver these containers down their supply chains for many kinds of applications.

The EIGA Doc 75 *Determination of safety distances* [1][1] defines the general principles in order to determine safety distances for the different risks associated with the hazardous properties of the gases: inhalation of toxic gases, thermal radiations and overpressure. However, EIGA Doc 75 does not give a detailed description of how to calculate the distances for harm and no harm effects.

This publication provides a methodology to determine the harm and no harm distances related to the risk of inhalation of toxic gases due to the storage and use of transportable containers containing toxic gases using gas dispersion modelling software.

The assessment of the risks associated with the storage and use of toxic gases and the methodology to determine the harm and no-harm distances are both complex subjects. They require technical knowledge and judgment as well as skills in the use of the dedicated dispersion models. It is the intention that this document be used by qualified personnel. Qualified personnel are those who have sufficient training and experience in hazard identification and risk assessment on one side and/or in the use of dispersion models on the other side. The collaboration of several experts in different skills could be necessary.

2 Purpose and Scope

2.1 Purpose

This publication is intended to help EIGA members and their customers in their dealings with authorities in order to obtain permits for the safe storage and use of toxic gas in transportable containers, in particular in countries where harm and no harm effect distances are not defined in standards or regulations.

The recommendations in this publication apply to toxic gases and toxic gas mixtures in transportable containers. Toxic gases are defined in Section 3.

2.2 Scope

This publication defines scenarios for potential leaks from transportable gas containers according to the experience of EIGA members who have shared accident reports and analysis for more than 30 years. Because of their very low frequency of occurrence, catastrophic failures such as rupture of the container are not considered as potential scenarios.

This publication provides the distances for harm and no harm effects for transportable gas containers in storage and use without taking into account the probability of the occurrence of leaks. It also contains examples of mitigation measures which lead to a reduction of distances.

The publication covers most common toxic gases and most common containers and their typical uses by EIGA members and their customers. It should enable the reader to determine harm and no harm distances for other cases.

The description of the safety measures to be taken during the transport of these containers is outside the scope of this publication.

For liquefied gases the scope is limited to containers under the vapour pressure of the gas at ambient temperature (with no heating or external pressurisation of the container).

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[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

Safety distances for the fixed storage of toxic gases are outside the scope of this publication.

3 Terminology and definitions

Acronyms used in this publication are given in Section 10.

3.1 Terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Toxic gases

Gases that are classified according to the *Classification, Labelling and Packaging* Regulation, (CLP) [2] as Acute Toxic, category 1, 2, or 3.

This corresponds to the gases having a $LC50_{\text{rat1h}} < 5\,000$ ppm or a $LC50_{\text{rat4h}} < 2\,500$ ppm.

The toxic gases and mixtures most commonly handled by EIGA members are listed in 10.1 with their main physical and toxicological properties.

More data are listed in EIGA Doc 169 *Classification, and Labelling Guide in accordance with EC Regulation 1272/2008 (CLP Regulation)* [3].

3.2.2 Transportable toxic gas containers

Gas containers and the MEGCs and tank containers as defined in the ADR:

3.2.2.1 Cylinder

Transportable pressure receptacle of a water capacity not exceeding 150 litres.

3.2.2.2 Bundle of cylinders

An assembly of cylinders that are fastened together and which are interconnected by a manifold and carried as a unit. The total water capacity does not exceed 3 000 litres except that bundles intended for the carriage of toxic gases of Class 2 is limited to 1 000 litres water capacity.

3.2.2.3 Pressure drum

Welded transportable pressure receptacle of a water capacity exceeding 150 litres and of not more than1 000 litres, for example cylindrical containers equipped with rolling hoops, spheres on skids.

3.2.2.4 Tube

Seamless transportable pressure receptacle of a water capacity exceeding 150 litres and of not more than 3 000 litres; tubes are also called “ton containers” in the USA.

3.2.2.5 Multiple-Element Gas Container (MEGC)

Unit containing elements which are linked to each other by a manifold and mounted on a frame. The following elements are considered to be elements of a MEGC: cylinders, tubes, pressure drums and bundles of cylinders as well as tanks for the carriage of gases of Class 2 having a capacity of more than 450 litres.

3.2.2.6 Portable tank/tank container

Transport unit comprising a shell and items of equipment and when used for the carriage of gases having a capacity of more than 0.45 m^3 (450 litres). Portable tanks/tank containers are also referred to ISO Containers or ISO Modules.

NOTE Typical container sizes and their toxic gas content are listed in 10.2.

3.2.3 Transportable toxic gas container in use

Placement of the container into service by connecting it to a system. It excludes the use of the product itself downstream of the connection due to the variety of applications that would require specific risk management measures.

3.3 Safety distance

According to EIGA Doc 75, [1] the safety distance is the minimum separation between a hazard source and an object (human, equipment or environment) which will mitigate the effect of a likely foreseeable incident down to a no harm effect or to a harm effect and prevent a minor incident escalating into a larger incident.

3.4 Harm effect

EIGA Doc 75 [1] defines a harm criterion as one that would cause severe distress, a high probability of a need for medical attention, likelihood of serious injury or a probability of fatal injury. According to the available data listed in table 10.3, it could be either:

- The lethal dose for fatality to 1% of the exposed population" (LD_{01}); or
- The Emergency Response Planning Guidelines for Air Contaminants ERPG Level 3 (AEGL3) from the American Industrial Hygiene Association; or
- Data published by the Health and Safety Executive of the United Kingdom; or
- Immediately Dangerous to Life or Health (IDLH) levels from the US National Institute for Occupational Safety and Health (NIOSH).

In this publication, the LD_{01} has been used to calculate the distances for harm effect. The LD_{01} may be calculated based on the Probit function using the constants A, B and N as given in table 10.4.

3.5 No harm effect

EIGA Doc 75, [1] defines a no harm criteria as one that nearly all individuals could be exposed to without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action. According to the available data listed in table 10.3, it could be either:

- 10% of the x LD_{01} for the harm level or the LD_{001} level for the no harm level; or
- The ERPG Level 2 or AEGL2 for acceptable exposure levels.
- If ERPG Level 2 values are not available, then an equivalent concentration should be used. Useful sources for these are nationally determined guides on occupational exposure limits (OELs) such as:
    - Workplace Exposure Limits the UK (EH40);
    - Occupational exposure limit values (TLV (c), PEL,) in the US; and
    - AGW values in Germany.

In this publication, the LD_{001} has been used to calculate the distances for no harm effect. The LD_{001} is calculated based on the Probit function using the constants A, B and N as given in table 10.4.

4 Accidental toxic gas leaks from transportable containers

The EIGA Safety Advisory Council database contains more than 3 100 accident reports collected over a 35-year period from industrial gas companies in Europe. About 10% (305 reports) concern gas leaks, the majority of them related to non-toxic industrial gases: oxygen, hydrogen, nitrogen and carbon dioxide. Only 1% (31 reports) is related to toxic gas leaks, this equates to less than 1 accident per year.

This frequency is consistent with data from the BARPI database of the French Ministry of Ecology, Sustainable Development, Transport and Housing where out of 40 000 events collected since1966, the accidents involving the main toxic gases are 11 relevant leaks in 45 years.

The number of gas containers filled in toxic service in Europe is estimated to be 300 000 containers per year. The resultant frequency of an accidental toxic gas leak is therefore estimated to be less than $3x10^{-6}$ per container per year. This frequency compares with the figure of $5x10^{-7}$ (per container, per year) used by the Dutch authorities *[ref.3]* and $1.1x10^{-6}$ (per container, per year) used by the Belgian authorities [4] for gas releases from a 3.3 mm leak size.

The calculated probability of a toxic gas leak can be used to determine whether it is necessary to define a safety distance.

This probabilistic approach is proposed in EIGA Doc 75, [1] and the proposed individual harm exposure threshold frequency Ft for determining distances is Ft =< $3.5x10^{-5}$ per annum. The total frequency of a gas leak from a population of cylinders is calculated by multiplying the frequency mentioned above by the number of cylinders.

For events where the probability of a gas leak is below the threshold, (Ft,) no distance is calculated.

For events where the total frequency of a gas leak is higher than the threshold value Ft but lower than 100 X Ft the distances should be calculated based on the harm effect criteria.

For events where the total frequency of a gas leak is above 100 X Ft the distances should be calculated based on the no harm effect criteria.

In countries where probabilistic approaches are not accepted, the criteria for determining safety distances are given by the authorities.

5 Scenario definition of major possible toxic gas leak from transportable containers

5.1 Transportable toxic gas containers in storage

Containers for toxic gases have their valve outlets fitted with leak tight plugs and the valves are protected by a cap designed to resist to shocks.

The likely foreseeable incident is a leak from the container due to corrosion or from the valve. Catastrophic failures of toxic gas containers are excluded because of their low event frequency, see Section 4.

The maximum likely leak of toxic gas containers in storage is considered to be that through an orifice of 0.1mm diameter size as referenced in document EI 15*: Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids* [5] referenced in EIGA Doc 134 *Potentially explosive atmospheres – EU Directive 1999/92/EC* [6].

For liquefied toxic gases, the leak is considered to originate from the liquid phase.

5.2 Transportable toxic gas containers in use

The guillotine rupture of the valve is excluded due to the construction of the valve according to ISO standards, for example, ISO 10297: *Transportable gas cylinders, Cylinder valves, Specification and type testing* [7].

The maximum likely leak is considered to be either a rupture of a flexible hose or pigtail (semi flexible section of piping) connecting the container to the installation or an incorrect disconnection of a container in use with its valve open, due to human error.

For liquefied toxic gases, the leak is considered to originate from the liquid phase except where the container is not fitted with a dip tube and is used in the upright position.

5.2.1 Cylinders, bundles and pressure drums

For transportable toxic gas containers having a capacity of less of 1 000 litres, the maximum likely leak is considered a full bore leak through the container valve having an internal diameter of 4 mm, with no means of leak confinement and no toxic gas flow limiting device, for example, restricted flow orifice: RFO.

5.2.2 Tubes and MEGCs

For transportable toxic compressed gas tubes, with no liquid phase and having a capacity of 1 000 litres and above, the maximum likely gaseous leak is also considered to be one through an orifice of 4 mm diameter for the same reasons as indicated in 5.2.1.

5.2.3 Portable tanks/tank containers

According to ADR, transportable toxic liquefied gas tanks having a capacity of 1 000 litres and above shall be fitted with an excess flow valve or equivalent device on every piping penetration.

For example, in the case of ammonia ISO-tanks there are excess flow emergency valves which have to be opened via a manual isolation valve to put them in use. When they are manually opened, they open only partially allowing a small flow-rate of ammonia going through for building ammonia pressure downstream. When the downstream ammonia pressure equilibrates with the ISO-tank ammonia pressure, the emergency valve fully opens. In case of a connection rupture the ammonia pressure downstream of the emergency valve will decrease returning the valve automatically to its partially open position. There will be an ammonia flow rate of 920 l/min for a few seconds until the valve returns automatically to its partially open position. The liquid ammonia bleed flow rate through the excess flow emergency valve and in its partially open position is estimated at 2 l/min (or 1 kg/min or 0.016 kg/sec) and is equivalent to the flow-rate through a 1 mm orifice.

The distance calculated from a sudden release of 920 l/min for a few seconds followed by a small continuous release of 2 l/min is smaller than the distance for a continuous release through an orifice of 4mm.

6 Distances from transportable toxic gas containers

6.1 Justification of the gas dispersion modelling tool and parameters

6.1.1 Gas dispersion modelling tool

The gas dispersion is calculated by the Unified Dispersion Model (UDM) implemented in the Phast software. This modelling considers only free field dispersion, so that any local air stream effects at equipment/ buildings are not included in the dispersion calculation.

Phast is referred to in EIGA Doc 75, [1] and recognised by several regulators and authorities within the EU member states. Version 6.7 of Phast has been used to calculate the distances in this document.

Results can be unreliable when the following conditions exist:

- Very low wind speeds.
- Wind shifts and terrain steering effects. The modelling assumes that wind speed and direction are constant (at any given height) throughout the area downwind of a release. The modelling also expects the ground below a dispersing cloud to be flat and free of obstacles

The modelling assumes that a dispersing fluid does not react with oxygen and water vapour in the atmosphere. However, some toxic and flammable gases, such as phosphine, react spontaneously with oxygen and toxic and corrosive gases, for example, ammonia, hydrogen chloride, can react with moisture. The products that disperse downwind can be different from the gas that originally escaped from the containment.

Other limitations:

- Obstacles (including buildings and structures) are not taken into account in simulations; and
- The modelling assumes that any release, if not vertical, is being vented in the same direction as the wind prevailing at the time of release.

The results of the calculations depend on the parameters that have been used in the model.

6.1.2 Parameters

It is important that the input parameters are defined as proposed underneath, and the pre-installed Phast default settings are not modified, in order to obtain consistent results with those reported within this publication:

- Wind speed: 1.5, 3 and 5 m/s (reference height 10 m);
- Pasquill stability: F for 1.5 and 3 m/s; D for 5 m/s;
- Ambient temp: 15°C for F; 20°C for D;
- Surface roughness parameter: 0.1 (183 mm);
- Height of release: 1.5 m;
- Inhalation height: 1.5 m;
- Release direction: horizontal;
- Time varying release: not used;

- Core averaging time: 600 sec (identical to the toxic averaging time, per DNV recommendation);
- Toxic averaging time: 600 sec;
- Exposure time data: use “fixed averaging time”;
- Toxic result grid step in X direction: 1 m;
- Maximum release duration: 1h; and
- Container capacity according to the maximum filling ratio allowed by ADR or according to industry practices.

NOTE 1 The exposure time is a maximum of 1 hour or similar to the release time when it is less than 1 hour.

NOTE 2 In case the effect distances determined in Section 7 are not acceptable, because for instance of high societal risk (for example near to urban areas high population densities), further investigation taking into account specific site conditions, such as weather, environmental conditions, should be done.

NOTE 3 The full list of parameters that have been used in the PHAST dispersion modelling is shown in 10.8.

6.2 Harm and no harm distances from transportable toxic gas containers in storage

The distances for leaks from transportable toxic gas containers for harm and no harm effects are listed in 10.5. They have been calculated according to:

- leaks in the gaseous phase for compressed gases;
- leaks in the liquid phase for liquefied gases; and
- container sizes and their toxic gas quantities and pressures at 15°C as listed in 10.2.

NOTE Leaks are calculated at 15°C, except for hydrogen fluoride (HF), nitrogen dioxide (NO_2) and tungsten hexafluoride (WF_6) for which a temperature of 25°C was used because their vapour pressures at 15°C are below atmospheric pressure.

6.3 Harm and no harm distances from transportable toxic gas containers in use

The distances for leaks from transportable toxic gas containers for harm and no harm effects are listed in 10.6. They have been calculated according to:

- Leaks in the gaseous phase for compressed gases and for some liquefied gases, for example arsine and phosphine in cylinders used only in the upright position and where only the gas phase is withdrawn;
- Leaks in the liquid phase for liquefied gas containers not covered in 6.2;
- Container sizes and their toxic gas quantities and pressures at 15°C as listed in 10.2.

NOTE Leaks are calculated at 15°C, except for hydrogen fluoride (HF), nitrogen dioxide (NO_2) and tungsten hexafluoride (WF_6) for which a temperature of 25°C was used because their vapour pressures at 15°C are below atmospheric pressure.

7 Mitigation measures to reduce safety distances

The following mitigation measures are engineering controls. They come in addition to management controls such as leak testing, training and qualification of operators.

7.1 Mitigation measures for transportable toxic gas containers in storage

The distances and the space available at the site will determine if the storage of toxic gases can be outdoor in a secured area or indoor.

In the case of indoor storage, the area should have forced ventilation as determined by a risk assessment and equipped with a gas detection system. Any forced ventilation system should be linked to a gas detector with a suitable visual/audible alarm system to warn of toxic gas concentrations above non harmful levels. The distances can be restricted to the limits of the indoor storage by adequate design of the forced ventilation system including information contained in 7.2.1.1. If this is not feasible, other mitigation systems shall be considered.

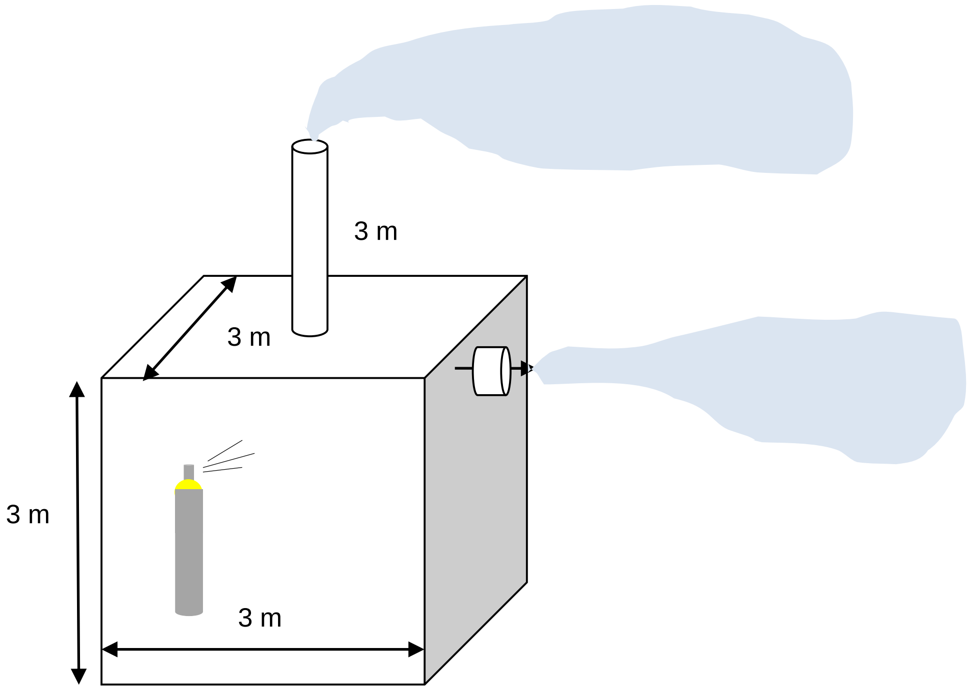
Example calculations for indoor storage of phosphine cylinder

This section compares the results of harm and no harm distance calculations for the outdoor storage of a cylinder containing 22.5 kg phosphine with the case of indoor storage that is equipped with a forced ventilation system. Phosphine has been selected as an example because of the large distances required for outdoor storage (see table 10.5) and to demonstrate that the distances can be reduced to the limits of the indoor storage area.

The storage room is 3 m x 3 m x 3 m and the forced air ventilation system has a 350 m³/h flow-rate.

The cross section of the exhaust pipe is 200 mm. This exhaust vent is located at a height of 3 m above the roof of the storage room (vertical flow) or at a height of 3 m above the ground for a wall mounted vent (horizontal flow). See the sketch below for details.

The weather category is F1.5 in both cases. The size of the leak is 0.1 mm.



In the case of outdoor storage, the distances are 53 m for harm and 69 m for no harm. In the case of indoor storage, these distances are reduced to:

- 32 m and 45 m for a horizontal vent; and

- Inside the room for a vertical vent.

A similar approach can be used for the storage of other toxic gases provided that the ventilation system is adequately designed.

For additional information concerning design and operations within storage areas, refer for example to EIGA Doc 130 *Principles for the Safe Handling and Distribution of Highly Toxic Gases and Mixtures* [8] and to the BCGA Code of Practice CP18, *The Safe Storage, Handling & Use of Special Gases in the Micro-electronics and other Industries* [9].

In any case, the storage area shall comply with local regulatory requirements.

7.2 Mitigation measures for toxic gas containers in use

The harm and no harm distances, the processes using the gas, the space available at the site and local regulations will determine if the use of toxic gases can be outdoor or indoor.

When toxic gas containers are connected to an installation, their valves should only be opened when the gas is decanted or transfilled. The valve should be closed when the containers are not in use.

Design and operations of installations to which containers are connected are out of the scope of this document. However, a proper installation design and adequate operations will decrease the likelihood of accidental toxic gas leak. They shall comply with local regulatory requirements and take into account the content of EIGA Doc 130, EIGA Doc 162 *Code of Practice – Phosphine* and EIGA Doc 163 *Code of Practice – Arsine* [8,10,11].

The following measures should be considered to reduce the risk of accidents and their frequency:

- Prevention of disconnecting cylinders in use;
- Prevention of tow away accidents of containers in use;
- Leak testing of the container connection before opening the container valve.

The following measures (not an exhaustive list) should be considered to reduce the harm and no-harm distances:

- Confinement and abatement/dilution of the toxic gas leak;
- Local Exhaust Ventilation (LEV) at the connection of the container and abatement/dilution of the toxic gas leak;
- Use of a flow limiting device.

These measures are described below.

7.2.1 Confinement and abatement/dilution of the toxic gas leak

There are two kinds of confinements:

- Installation of the toxic gas container and its connection inside a forced air ventilated enclosure, with the ventilation sized for safe dilution or the ventilation exhaust connected to an appropriate toxic gas abatement system;
- Confinement by water curtains.

7.2.1.1 Toxic gas container and connections inside forced air ventilated enclosure:

Examples of enclosures are:

- Gas cabinets used for toxic gas cylinders, mainly in semiconductor industries; and
- Rooms/containers/buildings made of non-combustible materials for pressure drums, bundles, MEGC and tanks.

When designing forced ventilation systems typically at least six to ten air changes per hour should be specified for normal operation. The actual requirement will depend on the size of the room and the layout of equipment within it and any specific mitigation measures.

Toxic gas detectors shall be located at the inlet of the ventilation system with an alarm when reaching occupational exposure threshold concentrations.

The alarm should be both visual and audible, located both inside (if relevant) and outside the enclosure for the evacuation of operators working inside and intervention of emergency team from outside.

The emergency forced air flow-rate should be sized to ensure a laminar flow through any opening inside the enclosure walls and according to the maximum toxic gas release rate that should be mitigated.

The exhaust from the ventilation system shall be connected to a toxic gas abatement system if the residual “harm” or “no-harm” distances cannot be met. The abatement system should be sized for the maximum possible toxic gas leak flow-rate indicated in the table in 10.7 diluted in the emergency forced air ventilation flow-rate. The maximum emission levels permitted by the local regulations shall be met.

In these conditions the no-harm distances can be reduced to the limits of the enclosure.

The same example as for the indoor storage of a phosphine cylinder described in 7.1, applied for use, demonstrates that there is no distance reduction using the same ventilation alone. Therefore, either the ventilation exhaust should be connected to an abatement system, or another mitigation system, as described in 7.3, should be used.

However, in the case of the use of ammonia containers, the results are the following:

Example calculations for indoor use

This example compares the results of distance calculations for the outdoor use of a cylinder containing 66 kg ammonia with that of indoor use using a forced ventilation system. Ammonia has been selected as an example because of its wide application and to demonstrate that the distances can be reduced to the limits of the indoor area.

The room is 3 m x 3 m x 3 m and the forced air ventilation system has a 1900 m^3/h emergency flow-rate.

The cross section of the exhaust pipe is 200 mm. This exhaust vent is located at a height of 3 m above the roof of the storage room (vertical flow) or at a height of 3 m above the ground for a wall mounted vent (horizontal flow).

The weather category is F1.5 in all cases. The size of the leak is 4 mm.

In the case of an outdoor use, the distances are 27 m for harm and 47 m for no harm, however in case of an indoor use, these distances are reduced to:

- 12 m and 16 m for a horizontal vent; and
- Inside the room for a vertical vent.

A similar approach can be used for other toxic gases provided that the ventilation system is adequately designed.

7.2.1.2 Local exhaust ventilation (LEV)

LEV consists of capturing the gas leak at the gas container connection with a forced air ventilation system.

The LEV should be running continuously with a flow-rate sufficient to ensure an air speed to capture the gas leak at the potential point of emission.

LEV is normally used indoor but can also be used outdoor in order to improve detection of gas leaks**.**

Toxic gas detectors should be located at the inlet of the ventilation system with an alarm when reaching threshold concentrations.

The alarm should be both visual and audible, for the evacuation of operators working inside and intervention of emergency team from outside.

The exhaust of the ventilation should be connected to a toxic gas abatement system if the resulting safety distances cannot be met. The abatement system should be sized for the maximum possible toxic gas leak flow-rate indicated in the table in 10.6 diluted in the emergency forced air ventilation flow-rate. Maximum emissions levels authorised by local regulations shall be met.

In these conditions the distances for the container in use can be reduced to the same distances as for containers in storage.

7.2.1.3 Confinement by water curtains

Water curtains are typically used for large containers located outdoor under a shelter.

When the toxic gas reacts and/or dissolves quickly in water, for example, ammonia and sulfur dioxide, and for large containers (ISO containers, portable tanks) the confinement can be achieved by the activation of water curtains above each opening on all sides below the roof of the shelter.

Toxic gas detectors should be located near the container connection with an alarm when reaching threshold concentrations. The alarm should be both visual and audible for operators to escape and intervention of emergency team.

In the case of toxic gas detection at an emergency concentration the water curtains shall be activated in order to capture toxic gases by reaction and/or dissolution.

The effluent water coming from the water curtains shall be collected to a safe place and disposed of according to regulations.

In these conditions the distances can be reduced to the limits of the shelter footprint.

7.2.2 Use of a flow limiting devices

7.2.2.1 Restricted gas flow orifices

The RFO placed inside the container valve outlet has a hole of a smaller cross-section than the container valve internal section (4mm). This decreases the gas flow-rate through the restricted flow orifice proportionally to its section compared to the 4mm diameter container valve internal section.

A commonly used RFO has a diameter of 0.25 mm. Consequently, the flow-rate of a leak and the resulting safety distance are reduced. See the example given in 7.3.

7.2.2.2 Automatic self-closing valve systems

These systems include:

- Pneumatically actuated container valves activated by a safety protection loop and gas;
- Manual container valves actuated by a pneumatic or electrical valve closing mechanism, (for example, Chlorguard^{TM}), activated by a safety protection loop and gas detectors.

They can reduce the distances by reducing the release time and consequently the exposure time. See the example given in 7.3.

7.3 Example of the effects of mitigation systems on the harm and no-harm distances

The following table gives the distances for harm and no-harm effects for a gas cylinder with a water capacity of 50L containing 22.5 kg of phosphine under the following conditions:

- Gaseous leak for the use and liquid leak for the storage;
- Outdoor storage without mitigation;
- Indoor storage with forced air ventilation;
- Outdoor use without mitigation;
- Outdoor use with 0.25 mm RFO; and
- Outdoor use with 0.25 mm RFO and the automatic self-closing valve shutting after 30 seconds.

Cylinder use conditions	Gas release conditions		Harm effect (distance to LD_{01}) [m]	No harm effect (distance to LD_{001}) [m]
	Gas state	Release rate [g/s]	F1.5	F1.5
Outdoor storage	29.83bar.g @ 15°C	0.28 g/s	53 m	69 m
Indoor storage with horizontal vent	29.83bar.g @ 15°C	0. 28 g/s	32 m	45 m
Indoor storage with vertical vent	29.83bar.g @ 15°C	0. 28 g/s	Distance restricted to the indoor storage area	Distance restricted to the indoor storage area
Outdoor use (no mitigation)	29.83 bar.g @ 15°C	100 g/s	848 m	1 093 m
Outdoor use, 0.25mm RFO	29.83 bar.g @ 15°C	0.39 g/s	61 m	80 m
Outdoor use 0.25mm RFO, the automatic self-closing valve shuts after a 30 seconds release	29.83 bar.g @ 15°C	0.39 g/s	6 m	8 m

Additional distance calculations to harm effects for outdoor use are listed for other toxic gases and containers sizes in 10.7.

8 References

Unless otherwise specified the latest edition shall apply.

[1] EIGA Doc 75, *Determination of Safety Distances*, www.eiga.eu

[2] *Classification, Labelling and Packaging Regulation*, (CLP) https://echa.europa.eu/regulations/clp

[3] EIGA Doc 169, *Classification, and Labelling Guide in accordance with EC Regulation 1272/2008 (CLP Regulation)*, www.eiga.eu

[4] Modellering gas cylinders uit Handleiding Risicoberekeningen BEVI concept versie 1.4 *(Modelling gas cylinders from the Risk Assessment tool BEVI version 1.4); 18 Jan 2008; published by the Dutch RIVM (National institute for public health and the environment)*

Handbook Failure Frequencies 2009 for drawing up a Safety Report, published by the Flemish Government, http://www.lne.be/themas/veiligheidsrapportage/rlbvr/bestanden-rlbvr/tr/vr_rlbvr_rl_hbff_EN.pdf

[5] Energy Institute, EI 15, *Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids* www.energyinst.org

[6] EIGA Doc 134, *Potentially explosive atmospheres – EU Directive 1999/92/EC* www.eiga.eu

[7] ISO 10297, *Transportable gas cylinders, Cylinder valves, Specification and type testing* www.iso.org

[8] EIGA Doc 130, *Principles for the Safe Handling and Distribution of Highly Toxic Gases and Mixtures* www.eiga.eu

[9] BCGA CP 18: *The Safe Storage, Handling & Use of Special Gases in the Micro-electronics and other Industries* www.bcga.co.uk

[10] EIGA Doc 162, *Code of Practice – Phosphine* www.eiga.eu

[11] EIGA Doc 163 *Code of Practice – Arsine* www.eiga.eu

9 Glossary

ADR	European Agreement concerning the international carriage of Dangerous goods by Road.
AEGL-2	Acute Exposure Guideline Level 2 is the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape (http://www.epa.gov/oppt/aegl/pubs/define.htm).
AEGL-3	Acute Exposure Guideline Level 3 is the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death escape (http://www.epa.gov/oppt/aegl/pubs/define.htm).
BARPI	Barpi (Bureau for Analysis of Industrial Risks and Pollutions) is an entity within the French Ministry of Ecology, Sustainable Development, transport and housing that is in charge of operating the Aria Database listing the accidental events which have, or could have damaged health or public safety, agriculture, nature or the environment.
CLP Regulation	European Community Regulation No 1272/2008 on Classification, Labelling and Packaging of Substances and mixtures,
ERPG-2	Emergency Response Planning Guideline Level 2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action (2011 Emergency Response Planning Guidelines (ERPG) and Workplace Environmental Exposure Levels (WEEL) Handbook, AIHA).
ERPG-3	Emergency Response Planning Guideline Level 3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects (2011 Emergency Response Planning Guidelines (ERPG) and Workplace Environmental Exposure Levels (WEEL) Handbook, AIHA).
IDLH	Immediately Dangerous to Life or Health concentration is the concentration that is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment. Exposure time 30 min
LC50 (1h)	LC50 for acute toxicity on inhalation is that concentration of vapour which administered by continuous inhalation to both male and female young adult albino rats, is most likely to cause death of within 14 days in one half of the animals tested (ADR 2013).
LD01	The lethal dose for fatality to 1% of the exposed population.
OEL	Occupational Exposure Limit values (OELs) are set by competent national authorities or other relevant national institutions as limits for concentrations of hazardous compounds in workplace air (https://osha.europa.eu/en/topics/ds/oel).
RFO	Restricted Flow Orifice
SLOD	Specified Level of Death (Health and Safety Executive of the United Kingdom). SLOD is defined as the dose to typically result in 50% fatality (LD50) of an exposed population.
SLOT	Specified Level of Toxicity (Health and Safety Executive of the United Kingdom). HSE has defined the SLOT as: severe distress to almost everyone in the area, substantial fraction of exposed population requiring medical attention, some people seriously injured, requiring prolonged treatment and highly susceptible people possibly being killed.

10 Attachments

10.1 List of main toxic gases with their physical and toxic data

EIGA SDS No	**Usual Name**	**Formula**	**Tcrit (°C)**	**Tboil (°C)**	**Pvap @15°C Bar (g)**	**LC50/rat 1h ppm(v)**	**Highest % for Acute Tox Cat.3**
2	Ammonia	NH_3	132	-33	6.25	4 000	80.00
5	Arsine	AsH_3	100	-62.5	12.05	20	0.40
6	Boron Trichloride	BCl_3	181.9	12.5	0.104	2,541	50.82
7	Boron Trifluoride	BF_3	-12.3	-100	Not Applicable	387	7.74
19	Carbon monoxide	CO	-140	-192	Not Applicable	3 760	75.20
22	Chlorine	Cl_2	144	-34	4.875	293	5.86
40	Diborane	B_2H_6	16.6	-92.5	35.59	80	1.60
43	Dichlorosilane	SiH_2Cl_2	176	8.4	0.282	314	6.28
56	Ethylene oxide	C_2H_4O	196	10.4	0.2	2,900	58.00
57	Fluorine	F_2	-129	-188	Not applicable.	185	3.70
68	Hydrogen bromide	HBr	90	-66.7	18.27	2,860	57.20
69	Hydrogen chloride	HCl	51.4	-85	36.34	2,810	56.20
70	Hydrogen fluoride	HF	188	19.5	0.86 bar(a)	966	19.32
72	Hydrogen selenide	H_2Se	138	-41.4	6.94	2	0.04
73	Hydrogen sulphide	H_2S	100	-60.2	14.64	712	14.24
88	Nitric oxide	NO	-93	-152	Not Applicable	115	2.30
90	(1) Nitrogen dioxide (2) Dinitrogen tetroxide	(1) NO_2 (2)N_2O_4	158	21.1	0,8 bar(a)	115	2.30
100	Phosphine	PH_3	51.6	-88	29.83	20	0.40
108	Silicon Tetrafluoride	SiF_4	-14.1	-95,2	Not Applicable	450	9.00
113	Sulphur dioxide	SO_2	158	-10	1.8	2,520	50.40
123	Tungsten hexafluoride	WF_6	195.4	17	0.513 @25°C	160	3.20
Mixt	30% Diborane in hydrogen	30% B_2H_6 in H_2	Not applicable	-	Not Applicable	267	Not applicable
Mixt	1% Arsine in hydrogen	1% AsH_3 in H_2	Not applicable	-	Not applicable	2,000	Not applicable
Mixt	1% Phosphine in hydrogen	1% PH_3 in H_2	Not applicable	-	Not applicable	2,000	Not applicable
Mixt	20%Fluorine in nitrogen	20%F_2 in N_2	Not applicable	-	Not applicable	925	Not applicable

*According to European Regulation (EC) N° 1272/2008 (CLP).

10.2 List of common transportable gas container sizes and their contents

EIGA SDS No	USUAL NAME	ADR 2017 Maximum filling ratio (Test Pressure)	Typical Cylinders		Typical Pressure drums & Bundles		Typical MEGC & Tanks	
			Capacity (Service Pressure)	Kg or Sm^3	Capacity (Service Pressure)	Kg or Sm^3	Capacity (Service Pressure)	Kg or Sm^3
2	Ammonia	0,54 kg/L	79 L 127 L	40 kg 66 kg	960 L	500 kg	21,000 L	11,000kg
5	Arsine	1,10 kg/L	10 L 50 L	0,25 kg 10,4 kg				
6	Boron trichloride	1,19 kg/L	10 L 50 L	11,9 kg 59,5 kg				
7	Boron trifluoride	0,715 kg/L (225bar)	10 L (60bar)	6 kg				
		0,86 kg/L (300bar)	50 L (60bar)	43 kg				
19	Carbon monoxide	Cylinder service pressure	40 L (200bar)	7,6 Sm^3	480 L (200bar)	91,2 Sm^3	11,600 L 24x12x40L (200 bar)	2,200 Sm^3
22	Chlorine	1,25 kg/L	52 L	65 kg	400 L 800 L	500 kg 1,000kg		
40	Diborane	0,07 kg/L	See mixture of diborane below					
43	Dichlorosilane	0,90 kg/L (10bar)	47 L	43 kg	960 L	837 kg		
		1,08 kg/L (200bar)						
56	Ethylene oxide	0,78 kg/L	50 L	39 kg	1000 L	780 kg		
57	Fluorine	30 bar	50 L	2,3 kg or 28bar	600 L	20 kg or20bar		
68	Hydrogen bromide	1,51 kg/L	10 L 50 L	12 kg 50 kg				
69	Hydrogen chloride	0,56 kg/L (120bar)			960 L	550 kg		
		0,74 kg/L (200bar)	67 L	50 kg				
70	Hydrogen fluoride	0,84 kg/L	50 L	38,5 kg	400 L	330 kg		
72	Hydrogen selenide	1,60 kg/L	44 L	45,4 kg				
73	Hydrogen sulphide	0,67 Kg/L	50 L	33,5 kg	960 L	600 kg		
88	Nitric oxide	33 bar	50 L	1,7 Sm^3				
90	(1) Nitrogen dioxide (2) Dinitrogen tetroxide	1,3 kg/L	10 L	13 kg				
100	Phosphine	0,3 kg/L (225bar)	10 L	0,5 kg				
		0,45 Kg/L (250bar)	50 L	22.5 kg				
108	Silicon tetrafluoride	0,74 Kg/L (200bar)	20 L (200bar))	10 kg or 61bar				
		1,1 Kg/L (300bar)	45 L (300bar)	49,5 kg or 131bar				
113	Sulphur dioxide	1,23 kg/L	50 L	61,5 kg	500 L 1,000 L	550 kg 1070 Kg		
123	Tungsten hexafluoride	3,08 kg/L	20 L	52 kg				
Mixt	30% B_2H_6 in H_2	Cylinder service pressure	50 L (200bar)	65 m^3 or 124 bar				
Mixt	1% AsH_3 in H_2	Cylinder service pressure	50 L (150bar)	6,8 Sm^3				
Mixt	1% PH_3 in H_2	Cylinder service pressure	50 L (150bar)	6,8 Sm^3				
Mixt	20%F_2 in N_2	Cylinder service pressure	50 L	5 Sm^3 or 100bar	600 L	60 Sm^3		

10.3 List of main toxic gases with harm effect and no harm effect levels

EIGA SDS No	USUAL NAME or FORMULA	Harm effect			No harm effect	
		ERPG3	**AEGL3**	**IDLH**	**ERPG2**	**AEGL2**
2	Ammonia	750 ppm	1,100 ppm 1,600 ppm	300 ppm	150 ppm	160 ppm 220ppm
5	Arsine	1.5 ppm	0.5 ppm 0.63 ppm	3 ppm	0.5 ppm	0.17 ppm 0.21 ppm
6	Boron trichloride	ND	ND	ND	ND	ND
7	Boron trifluoride	100 mg/m^3	88 mg/m^3 110 mg/m3	25 mg/m^3	30 mg/m^3	29 mg/m^3 37 mg/m^3
19	Carbon monoxide	500 ppm	330 ppm 600 ppm	1,200 ppm	350 ppm	83 ppm 150 ppm
22	Chlorine	20 ppm	20 ppm 28 ppm	10 ppm	3 ppm	2 ppm 2.8 ppm
40	Diborane	3 ppm	3.7 ppm 7.3 ppm	15 ppm	1 ppm	1 ppm 2 ppm
43	Dichlorosilane	ND	50 ppm 110 ppm	ND	ND	11 ppm 22 ppm
56	Ethylene oxide	500 ppm	200 ppm 360 ppm	800 ppm	50 ppm	45 ppm 80 ppm
57	Fluorine	20 ppm	13 ppm 19 ppm	25 ppm	5 ppm	5 ppm 11 ppm
68	Hydrogen bromide	ND	120 ppm 250 ppm	30 ppm	ND	25 ppm 50 ppm
69	Hydrogen chloride	150 ppm	100 ppm 210 ppm	50 ppm	20 ppm	22 ppm 43 ppm
70	Hydrogen fluoride	50 ppm	44 ppm 62 ppm	30 ppm	20 ppm	24 ppm 34 ppm
72	Hydrogen selenide	2 ppm	1.1 ppm 1.4 ppm	1 ppm	0.2 ppm	0.33 ppm 0.44 ppm
73	Hydrogen sulphide	100 ppm	50 ppm 59 ppm	100 ppm	30 ppm	27 ppm 32 ppm
88	Nitric oxide	ND	ND	100 ppm	ND	ND
90	(1) Nitrogen dioxide (2) Dinitrogen tetroxide	30 ppm	20 ppm 25 ppm	20 ppm	15 ppm	12 ppm 15 ppm
100	Phosphine	5 ppm	3.6 ppm 7.2 ppm	50 ppm	0.5 ppm	2 ppm 4 ppm
108	Silicon tetrafluoride	ND	10 ppm 13 ppm	ND	ND	3,3 ppm 4,3 ppm
113	Sulphur dioxide	25 ppm	30 ppm 30 ppm	100 ppm	3 ppm	0.75 ppm 0.75 ppm
123	Tungsten hexafluoride	ND	ND	ND	ND	ND
Mixt	30% B_2H_6 in N_2	Refer to the values of the pure gases				
Mixt	1% AsH_3 in H_2	Refer to the values of the pure gases				
Mixt	1% PH_3 in H_2	Refer to the values of the pure gases				
Mixt	20%F_2 in N_2	Refer to the values of the pure gases				

ND –Not Defined

References:

AEGL values: http://www.epa.gov/oppt/aegl/pubs/chemlist.htm (07.11.2011); two values are given – first for 60 min exposure time and second for 30 min exposure time

ERPG values: 2013 ERPG/WEEL Handbook, AIHA Guideline Foundation

IDLH: http://www.cdc.gov/niosh/idlh/intridl4.html

10.4 A, B and N constant values describing the toxicity of main toxic gases

EIGA SDS No	USUAL NAME or Formula	A ppm(v)	B	N	Reference / Remarks*
2	Ammonia	-16.21	1	2	/1/
5	Arsine	-8.78	1.61	1.24	/1/
6	Boron trichloride	-15.19	1.69	1	/2/
7	Boron Trifluoride	-10.02	1.64	1	/2/
19	Carbon monoxide	-7.21	1	1	/1/
22	Chlorine	-4.81	0.5	2.75	/1/
40	Diborane	-27.87	3.5	1	/3/
43	Dichlorosilane	-11.32	1.69	1.18	/3/, Pseudo Probit – Reference Material Hydrogen Chloride
56	Ethylene oxide	-6.03	1	1	/1/
57	Fluorine	-19.09	1.694	2	/4/
68	Hydrogen bromide	-13.11	1.68	1	/4/
69	Hydrogen chloride	-35.62	3.69	1	/1/
70	Hydrogen fluoride	-8.62	1	1.5	/1/
72	Hydrogen selenide	-5.46	1.73	1	/2/
73	Hydrogen sulphide	-10.76	1	1.9	/1/
88	Nitric oxide	-150.84	15.43	1	/2/
90	(1)Nitrogen dioxide (2)Dinitrogen tetroxide	-16.06	1	3.7	/1/
100	Phosphine	-6.026	1	2	/4/
108	Silicon tetrafluoride	-12.04	1.69	1.18	/3/, Pseudo Probit – Reference Material Hydrogen Chloride
113	Sulphur dioxide	-16.76	1	2.4	/1/
123	Tungsten hexafluoride	-10.39	1.69	1	/2/
Mixt	30% B_2H_6 in H_2	-32.08	3.5	1	/5/
Mixt	1% AsH_3 in H_2	-17.97	1.61	1.24	/5/
Mixt	1% PH_3 in H_2	-15.24	1	2	/5/
Mixt	20%F_2 in N_2	-24.54	1.694	1	/5/

(*) Because no single reference provides an exhaustive list of constant values for the pure toxic gases included in this document, different sources with indicated precedence were used:

1. Handbook for Risk Assessment BEVI (Table 15), because it is the most recognized reference for toxic gases constant values.
2. When the constant values are not listed in Table 15 of Handbook for Risk Assessment BEVI, the figures of Phast's database were used
3. When the constant values are neither in Table 15 of Handbook for Risk Assessment BEVI and in Phast database, the SLOD and SLOT values published by HSE were used. Finally, when no values could be found in the literature, constant values provided by The Linde Group were used.

References:

/1/ Handleiding Risicoberekeningen BEVI versie 3.2 (Handbook for Risk Assessment BEVI version 3.2); 01 July 2009; published by the Dutch National Institute for Public Health and the Environment (RIVM)

/2/ SLOT & SLOD data published by the Health and Safety Executive of the UK (http://www.hse.gov.uk/chemicals/haztox.htm)

/3/ Data supplied by The Linde Group

/4/ DNV Phast 6.7

/5/ Conversion based on given composition: B and N are independent from toxic concentration in mixture; $A_{mix} = A + B \ln (X^N)$ with X = mol fraction of toxic in mixture

10.5 Distances for transportable toxic gas containers in storage

Gas Name	Gas release conditions			Gas content (kg or Sm^3)	Harm effect (distance to LD$_{01}$) [m]			No harm effect (distance to LD$_{001}$) [m]		
	Gas state	Release phase	Release rate [g/s]		F1.5	F3	D5	F1.5	F3	D5
Ammonia	6.25 bar.g @ 15°C	Liquid	0.15 g/s	40 kg	1.8m	1.5m	1.5m	2.1m	1.7m	1.8m
				66 kg	1.8m	1.5m	1.5m	2.1m	1.7m	1.8m
				500kg	1.8m	1.5m	1.5m	2.1m	1.7m	1.8m
				11.000kg	1.8m	1.5m	1.5m	2.1m	1.7m	1.8m
Arsine	12.05 barg @ 15°C	Liquid	0.28 g/s	0.25kg	10m	11m	5.1m	15m	14m	6.1m
				10.5kg	29m	24m	8.7m	39m	31m	10m
Boron trichloride	0.104 barg @ 15 °C	Liquid	0.03 g/s	11.9kg	0.8m	0.8m	0.6m	1m	1m	0.7m
				59.5kg	0.8m	0.8m	0.6m	1m	1m	0.7m
Boron trifluoride	106 barg @ 15°C	Gas	0.44 g/s	6kg	12m	12m	6.4m	20m	18m	7.9m
	109 barg @ 15°C	Gas	0.46 g/s	43kg	12m	12m	6.6m	21m	18m	8.1m
Carbon monoxide	200 barg @ 15°C	Gas	0.33 g/s	7.6Sm^3	4.0m	3.1m	3.2m	4.8m	3.7m	4.0m
				91.2Sm^3	4.0m	3.1m	3.2m	4.8m	3.7m	4.0m
				2,200Sm^3	4.0m	3.1m	3.2m	4.8m	3.7m	4.0m
Chlorine	4.875 barg @ 15°C	Liquid	0.18 g/s	65kg	6.7m	7.1m	3.7m	12m	11m	4.7m
				500kg	6.7m	7.1m	3.7m	12m	11m	4.7m
				1,000kg	6.7m	7.1m	3.7m	12m	11m	4.7m
Dichlorosilane	0.282 barg @ 15°C	Liquid	0.042 g/s	43kg	3.6m	3.3m	1.9m	4.6m	3.9m	2.2m
				837kg	3.6m	3.3m	1.9m	4.6m	3.9m	2.2m
Ethylene oxide	0.2 barg @ 15°C	Liquid	0.03 g/s	39kg	2.3m	2m	1.5m	3.6m	3.1m	2m
Fluorine	28 barg @ 15°C	Gas	0.05 g/s	2.3kg	3.1m	2.9m	2.4m	3.5m	3.6m	2.6m
	20 barg @ 15°C		0.039 g/s	20kg	2.7m	2.6m	2.1m	3.1m	3.2m	2.3m
Hydrogen bromide	18.27 barg @ 15°C	Liquid	0.39 g/s	12kg	3.3m	2.7m	2.8m	3.9m	3.6m	3.4m
Hydrogen chloride	36.34barg @ 15°C	Liquid	0.42 g/s	50kg	3.1m	2.5m	2.5m	3.4m	2.7m	2.8m
				550kg	3.1m	2.5m	2.5m	3.4m	2.7m	2.8m
Hydrogen fluoride	0.209barg @ 25°C	Liquid	0.05g/s	38.5kg	9.6m	7.3m	2.3m	12m	9.6m	3m
				330kg	9.6m	7.3m	2.3m	12.2m	9.6m	3m
Hydrogen selenide	6.94 barg @ 15°C	Liquid	0.24g/s	45.4kg	90m	65m	19m	119m	84m	23m
Hydrogen sulphide	14.64barg @ 15°C	Liquid	0.24g/s	33.5kg	4.5m	5.1m	3.8m	6.1m	7.5m	4.5m
				600kg	4.5m	5.1m	3.8m	6.1m	7.5m	4.5m
Nitric oxide	33 barg @ 15°C	Gas	0.06g/s	1.8kg	1.5m	1.5m	1.4m	1.9m	1.5m	1.5m
Nitrogen Dioxide	0.198barg @ 25°C	Liquid	0.04g/s	13kg	3.2m	3m	2.1m	3.6m	3.4m	2.3m
Phosphine	29.83barg @ 15°C	Liquid	0.28g/s	22.5kg	53m	40m	14m	69m	51m	16m
Silicon Tetrafluoride	61 barg @ 15°C	**Gas**	0.25g/s	10kg	4.5m	4.8m	3.7m	5.8m	7.1m	4.4m
	131 barg @ 15°C	**Gas**	0.63g/s	49.5kg	6.6m	7.5m	5.5m	11.1m	11m	6.6m
Sulphur dioxide	1.8 barg @ 15°C	Liquid	0.11g/s	61.5kg	1.5m	1.3m	1.2m	1.7m	1.5m	1.3m
				550kg	1.5m	1.3m	1.2m	1.7m	1.5m	1.3m
				1,070kg	1.5m	1.3m	1.2m	1.7m	1.5m	1.3m
Tungsten hexafluoride	0.513 bar.g @ 25°C	Liquid	0.09g/s	52kg	2.5m	2.6m	1.6m	3.4m	3.4m	2.9m
30% B_2H_6 inH2	124 barg @ 15°C	Gas phase	0.12g/s	6Sm^S	3.9m	3.4m	3.2m	4.3m	4.1m	3.5m
1% AsH_3 inH2	150ba.g @ 15°C	Gas phase	0.074g/s	6.8 Sm^3	3.1m	2.9m	2.6m	3.8m	4.1m	3.1m
1% PH_3 inH2	150 barg @15°C	Gas phase	0.067 g/s	6.8 Sm^3	3.4m	3.7m	2.9m	4.4m	5.3m	3.4m
20% F_2inN2	100 barg @ 15°C	Gas phase	0.17g/s	5 Sm^3	0.1m	0.1m	0.1m	0.1m	0.1m	0.1m

10.6 Distances for transportable toxic gas containers in use - outdoor without mitigating measures

Gas Name	Gas release conditions			Gas content (kg or Sm³)	Harm effect (distance to LD$_{01}$) [m]			No harm effect (distance to LD$_{001}$) [m]		
	Gas state	Release phase	Release rate [g/s]		F1.5	F3	D5	F1.5	F3	D5
Ammonia	6.25 barg @ 15°C	Gas	15 g/s	40 kg	12m	9m	8m	19m	11m	9m
				66 kg	14m	9m	8m	22m	13m	10m
		Liquid	236 g/s	40 kg	20m	19m	15m	31m	26m	22m
				66 kg	27m	23m	19m	47m	36m	28m
				500 kg	83m	62m	49m	118m	90m	61m
				11000 kg	103m	80m	57m	162 m	121m	70 m
Arsine	12.05 barg @ 15°C	Gas	58 g/s	0.25 kg	8m	6m	7m	11m	9m	8m
				10.5 kg	118m	98m	36m	177m	139m	45m
Boron trichloride	0.104 barg @ 15 °C	Gas	2.5 g/s	11.9 kg	4m	3m	4m	5m	4m	4m
				59.5 kg	4m	3m	4m	5m	4m	4m
Boron trifluoride	106 barg @ 15 °C	Gas	697 g/s	6 kg	11m	13m	8m	17m	13m	11m
	109 barg @ 15 °C	Gas	733 g/s	43 kg	39m	46m	40m	55m	76m	60m
Carbon monoxide	200 barg @ 15 °C	Gas	529 g/s	7.6 Sm³	4m	5m	3m	8m	10m	6m
				91.2 Sm³	28m	23m	16m	84m	76m	51m
				2 200 Sm³	473m	424m	220m	917m	750m	294m
Chlorine	4.875 barg @ 15°C	Gas	24 g/s	65 kg	157m	108m	34m	255m	167m	48m
		Liquid	292 g/s	65 kg	391m	299m	95m	595m	456m	129m
				500 kg	698m	524m	143m	1 031m	763m	194m
				1 000 kg	843m	627m	165m	1 227m	900m	223m
Dichloro-silane	0.282 barg @ 15°C	Gas	4 g/s	43 kg	60m	38m	16m	83m	52m	19m
		Liquid	66 g/s	837 kg	457m	326m	70m	559m	398m	83m
Ethylene Oxide	0.2 barg @ 15°C	Gas	2.2 g/s	39 kg	26m	20m	11m	55m	38m	16m
		Liquid	49 g/s	39 kg	128m	91m	23m	171m	125m	38m
				780 kg	332m	233m	51m	497m	354m	76m
Fluorine	28 barg @ 15°C	Gas	86 g/s	2.3 kg	46m	44m	21m	51m	56m	28m
	20 barg @ 15°C	Gas	62 g/s	20 kg	124m	103m	42m	150m	126m	48m
Hydrogen bromide	18.27 barg @ 15°C	Gas	91 g/s	12 kg	7m	6m	5m	8m	7m	6m
				50 kg	17m	12m	10m	29m	23m	12m
Hydrogen chloride	36.34 barg. @ 15°C	Gas	129 g/s	50 kg	12m	9m	8m	14m	11m	9m
		Liquid	669 g/s	50 kg	8m	7m	7m	9m	10m	9m
				550 kg	96m	72m	59m	115m	85m	73m
Hydrogen fluoride	0.21 barg @ 25 °C	Gas	2.6 g/s	38.5 kg	44m	38m	16m	72m	56m	20m
		Liquid	47 g/s	330 kg	467m	28m	71m	633m	230m	95m
Hydrogen selenide	6.94 barg @ 15°C	Gas	35 g/s	45.4 kg	1032m	695m	157m	1 362m	905m	202m
Hydrogen sulphide	14.64 barg @ 15°C	Gas	46 g/s	33.5 kg	98m	80m	31m	138m	112m	39m
		Liquid	378 g/s	600 kg	540m	427m	156m	743m	578m	192m
Nitric Oxide	33 barg @ 15°C	Gas	91 g/s	1.7 m³	3m	2m	2m	3m	2m	2m
Nitrogen Dioxide	0.2 barg @ 25°C	Gas	2.2 g/s	13 kg	48m	34m	14m	57m	40m	16m

Gas Name	Gas release conditions			Gas content (kg or Sm^3)	Harm effect (distance to LD_{01}) [m]			No harm effect (distance to LD_{001}) [m]		
	Gas state	**Release phase**	**Release rate [g/s]**		**F1.5**	**F3**	**D5**	**F1.5**	**F3**	**D5**
Phosphine	29.83 barg @ 15°C	Gas	100 g/s	0.5 kg	110m	110m	65m	145m	139m	77m
				22.5 kg	848m	627m	163m	1 093m	795m	199m
Silicon tetra-fluoride	61 barg @15°C	Gas	402 g/s	10 kg	16m	16m	12m	24m	21m	15m
	131 barg @ 15°C	Gas	1 015 g/s	49.5 kg	45m	47m	38m	53m	63m	58m
Sulphur dioxide	1.8 barg @ 15°C	Gas	10 g/s	61.5 kg	9m	7m	7m	13m	8m	8m
		Liquid	179 g/s	61.5 kg	15m	18m	14m	23m	26m	19m
				550 kg	86m	68m	30m	123m	95m	36m
				1 070 kg	93m	73m	31m	134m	102m	38m
Tungsten hexafluoride	0.513 barg @ 25°C	Gas	3.2 g/s	52 kg	18m	17m	8m	32m	25m	11m
30 % B_2H_6 in H2	124barg@15°C	Gas	192 g/s	6.2 Sm^3	4m	4m	4m	5m	4m	4m
1% AsH_3 in H2	150barg@15°C	Gas	118 g/s	6.8 Sm3	3m	3m	3m	5m	4m	4m
1% PH_3 in H2	150barg@15°C	Gas	109 g/s	6.8 Sm^3	12m	12m	11m	13m	14m	13m
20% F_2 in N2	100barg@ 15°C	Gas	273 g/s	5 Sm^3	n/r	n/r	n/r	n/r	n/r	n/r
				60 Sm^3	n/r	n/r	n/r	n/r	n/r	n/r

10.7 Distances for transportable toxic gas containers in use - outdoor with mitigating measures (for F1.5 weather conditions)

Gas Not applicable	Gas release conditions			Gas content (kg or Sm^3)	Harm effect (distance to LD$_{01}$)	
	Gas state	Release phase	Release rate (g/s)		4mm & closing after 30sec [a]	4mm (without mitigation) [b]
Ammonia	6.25 barg @ 15°C	Gas	15g/s	40 kg	2.4m	12m
				66 kg	2.4m	14m
		Liquid	236g/s	40 kg	11m	20m
				66 kg	11m	27m
				500 kg	11m	83m
				11,000 kg	11m	103m
Arsine	12.05 barg@ 15°C	Gas	58g/s	0.25 kg	8.2 m	8 m
				10.5 kg	8.2 m	118m
Boron trichloride	0.104 barg@ 15°C	Gas	2.5g/s	11.9 kg	0.2m	2m
				59.5 kg	0.2m	4m
Boron trifluoride	106 barg@ 15°C	Gas	697 g/s	6 kg	11m	11m
	109 barg@ 15°C	Gas	733 g/s	43 kg	26m	60m
Carbon monoxide	200 barg @ 15°C	Gas	529g/s	7.6 Sm^3	4m	4m
				91.2 Sm^3	6.3m	28m
				2.200Sm^3	6.3m	473m
Chlorine	4.875 barg @ 15°C	Gas	24g/s	65 kg	30m	157m
				500 kg	30m	173m
				1000 kg	30m	173m
		Liquid	292g/s	65 kg	181m	391m
				500 kg	181m	698m
				1000 kg	181m	843m
Dichlorosilane	0.282 barg @ 15°C	Gas	4g/s	43 kg	2.8m	60m
		Liquid	66g/s	837 kg	8m	457m
Ethylene oxide	0.2 barg @ 15°C	Gas	2.2g/s	39 kg	1.1m	128m
		Liquid	49g/s	780 kg	3m	26m
Fluorine	28 barg @ 15°C	Gas	86g/s	2.3 kg	46m	46m
	20 barg@ 15°C	Gas	62g/s	20 kg	43m	124m
Hydrogen bromide	18.27 barg@ 15°C	Gas	91g/s	12 kg	2m	7m
				50 kg	2m	17m
Hydrogen chloride	36.34 barg@ 15°C	Gas	129g/s	50 kg	2m	12m
			129g/s	550 kg	2m	113m
		Liquid	669g/s	50 kg	3.2m	8m
			669g/s	550 kg	3.2m	96m
Hydrogen fluoride	0.21 barg @ 25°C	Gas	2.6g/s	38.5 kg	4.1m	44m
		Liquid	47g/s	330 kg	35m	467m
Hydrogen selenide	6.94 barg @ 15°C	Gas	35g/s	45.4 kg	31m	1032m
Hydrogen sulphide	14.64 barg @15°C	Gas	46g/s	33.5 kg	17m	98m
		Liquid	378g/s	600 kg	59m	540m
Nitric oxide	33 barg @ 15°C	Gas	91 g/s	1.7Sm^3	3m	3m
Nitrogen dioxide	0.2 barg @ 25°C	Gas	2.2g/s	13 kg	11m	48m
Phosphine	29.83 barg @ 15°C	Gas	100 g/s	0.5 kg	110m	110m
				22.5 kg	250m	848m
Silicon tetrafluoride	61 barg @ 15°C	Gas	402g/s	10 kg	16m	16m
	131 barg @ 15°C	Gas	1.015g/s	49.5 kg	29m	45m
Sulphur dioxide	1.8 barg @ 15°C	Gas	10g/s	61.5 kg	2.8m	9m
		Liquid	179g/s	61.5	7.5m	15m
				550 kg	7.5m	86m
				1.070 kg	7.5m	93m
Tungsten hexafluoride	0.513 barg @ 25°C	Gas	3.2g/s	52 kg	1.4m	18m
30 % B_2H_6 in	124 barg @ 15°C	Gas	192g/s	6.2Sm^3	3.1m	4m
1% AsH_3 in H_2	150barg @ 15°C	Gas	118g/s	6.8Sm^3	3m	3m
1% PH_3 in H_2	150barg @ 15°C	Gas	109g/s	6.8Sm^3	12m	12m
20% F_2 in N_2	100barg @ 15°C	Gas	273g/s	5Sm^3	n/r	n/r
				60Sm^3	n/r	n/r

[a] Distance to harm for leaks through a 4mm diameter container valve with an automatic self- closing valve system stopping the leak within 30 seconds.

[b] Distance to harm for leaks through a 4mm diameter container valve without an automatic self-closing valve system.

10.8 List of parameters used in Phast for modelling

Parameters	Values/comments	Units
Discharge parameters		
Continuous critical Weber number	12.5	
Instantaneous critical Weber number	12.5	
Venting equation constant	24.82	
Critical pressure greater than flow phase	0.3447	bar
Maximum release velocity	500	m/s
Minimum drop diameter allowed	0.01	um
Maximum drop diameter allowed	1E4	um
Default liquid fraction	100	%
Continuous drop slip factor	1	
Instantaneous drop slip factor	1	
Number of time steps	100.00	
Maximum number of data points	1,000.00	
Tolerance	0.0001	
Thermal coupling to the wall	No modelling of heat transfer	
Use Bernoulli for forced -phase liq-liq discharge	Use compressible flow eqn	
Velocity capping method	Fixed velocity	
Droplet method - continuous only	Modified CCPS	
Air changes	3	/hr
Elevation	1	m
Atmospheric expansion method	Closest to initial conditions	
Mechanism for forcing droplet breakup - Inst.	Use flashing correlation	
Mechanism for forcing droplet breakup - Cont	Do not force correlation	
Flashing in the orifice	No flashing in the orifice	
Handling of droplets	Not trapped	
Dispersion parameters		
Expansion zone length/source diameter ratio	0.01	
Near field passive entrainment parameter	1	
Jet model	Morton et.al.	
Jet entrainment coefficient alpha1	0.17	
Jet entrainment coefficient alpha2	0.35	
Drag coefficient between plume and air	0	
Dense cloud parameter gamma - continuous	0	
Dense cloud parameter gamma - instant	0.3	
Dense cloud parameter K - continuous	1.15	
Dense cloud parameter K - instantaneous	1.15	
Modelling of instantaneous expansion	Standard method	
Maximum cloud/ambient velocity difference	0.1	
Maximum cloud/ambient density difference	0.015	
Maximum non-passive entrainment fraction	0.3	
Maximum Richardson number	15	
Distance multiple for full passive entrainment	2	
Core averaging time	600	s
Ratio instantaneous/continuous sigma-y	1	
Ratio instantaneous/continuous sigma-z	1	
Droplet evaporation thermodynamics model	Rainout, Non-equilibrium	
Ratio droplet/ expansion velocity for inst. release	0.8	
Expansion energy cut-off for droplet angle	0.69	kJ/kg

Coefficient of Initial Rainout	0	
Flag to reset rainout position	Do not reset rainout position	
Richardson number for passive transition above pool	0.015	
Pool vaporization entrainment parameter	1.5	
Richardson number criterion for cloud lift-off	-20	
Flag for heat/water vapour transfer	Heat and water	
Surface over which the dispersion occurs	Land	
Minimum temperature allowed	-262.1	deg C
Maximum temperature allowed	626.9	deg C
Minimum release velocity for cont. release	0.1	m/s
Minimum continuous release height	0	m
Maximum distance for dispersion	5E4	m
Maximum height for dispersion	1000	m
Minimum cloud depth	0.02	m
Treatment of top mixing layer	Constrained	
Model in use	Best estimate	
Lee length	Calculate	
Lee half-width	Calculate	
Lee height	Calculate	
K-Factor	Calculate	
Switch distance	Calculate	
Maximum initial step size	10	m
Minimum number of steps per zone	5.00	
Factor for step Increase	1.2	
Maximum number of output steps	1,000.00	
Flag for finite duration correction	QI without duration adjustment	
Quasi-instantaneous transition parameter	0.8	
Relative tolerance for dispersion calculations	0.001	
Relative tolerance for droplet calculations	0.001	
Initial integration step size - Instantaneous	0.01	s
Initial integration step size - Continuous	0.01	m
Maximum integration step size - Instantaneous	100	s
Maximum integration step size - Continuous	100	m
Impingement Option	Use velocity modification factor	
Impinged velocity limit	500	m/s
Impinged velocity factor	0.25	
Dispersion model to use	Version 2 model	
Fixed step size - Instantaneous	0.01	s
Fixed step size - Continuous	0.1	m
Number of fixed size output steps	20.00	
Multiplier for output step sizes	1.2	
Pool vaporization parameters		
Toxics cut-off rate for pool evaporation	1	g/s
Concentration power to use in pool rate load calculation	1	
Maximum number of pool evaporation rates	10.00	
Pool minimum thickness	5	mm
Surface thermal conductivity	0.00221	kJ/m.s.degK
Surface roughness factor	2.634	
Surface thermal diffusivity	9.48E-7	m2/s

Type of bund surface	Concrete	
Bund height	0	m
Bund failure modelling	Bund cannot fail	
Toxic Parameters		
Toxics: minimum probability of death	0.001	
Toxics: height for calculation of effects	1.5	m
Toxics: results grid step in Y-direction	1	m
Toxics: results grid step in X-direction	1	m
Multi-comp. toxic calc. method	Mixture Probit	
Toxic averaging time - New parameter	600	s
Probit calculation method	Use Probit	
Building exchange rate	4	/hr
Tail time	1800	s
Indoor calculations	Unselected	
Wind dependent exchange rate	Case specified	
Set averaging time equal to exposure time	Use a fixed averaging time	
Cut-off fraction of toxic load for exposure time calculation	5	%
Cut-off concentration for exposure time calculations	0	%
Weather parameters		
Atmospheric pressure	1.013	bar
Atmospheric molecular weight	28.97	
Atmospheric specific heat at constant pressure	1.004	kJ/kg.degK
Wind speed reference height	10	m
Temperature reference height	0	m
Cut-off height for wind speed profile	1	m
Wind speed profile	Power Law	
Atmospheric T and P profile	Temp.logarithmic; pres.linear	
Atmospheric temperature	9.85	degC
Relative humidity	70	%
Parameter	0.1	
Length	183.2	mm
Surface roughness	Use parameter	
Surface temperature for dispersion calculations	9.85	degC
Surface temperature for pool calculations	9.85	degC
Solar radiation flux	0.5	kW/m2
Building exchange rate	4	/hr
Tail time	1800	s
Surface type	User-defined	
Mixing layer height for Pasquil stability D	800	m
Mixing layer height for Pasquil stability F	100	m