# GUIDANCE ON TECHNICAL LAND-USE PLANNING ADVICE

## for planning authorities and COMAH establishment operators

*This Guidance interprets Health and Safety Authority (HSA) policy on technical land-use planning (TLUP) advice under the Seveso III Directive (Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC), as implemented by the COMAH Regulations 2015. The Guidance provides a risk-based approach and clear guidance on scenario frequencies and modelling parameters across all sectors.*

Version 3 published in [Date to be added]

# Table of Contents

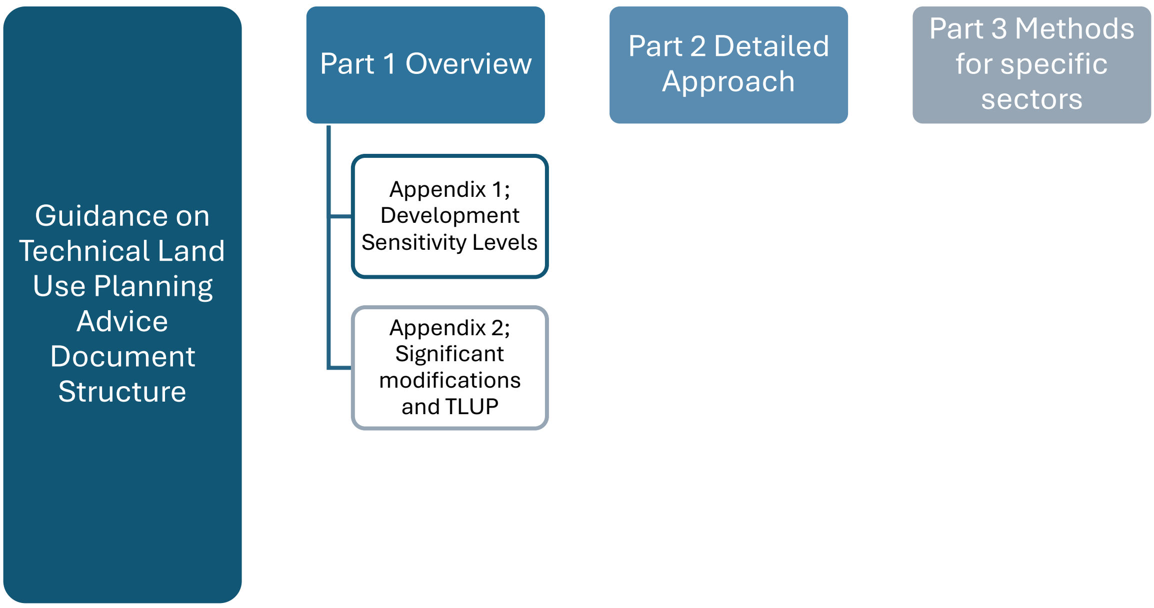
# Glossary of terms and definitions

| | |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| BAT | Best Available Technique |
| BATC | Best Available Technique Conclusions |
| BLEVE | Boiling Liquid Expanding Vapour Explosion |
| BREF | Best Available Technique Reference Document |
| CD | Consultation Distance |
| CDOIF | Chemical and Downstream Oil Industries Forum |
| CIA | Chemical Industries Association |
| CLP | Classification, Labelling and Packaging |
| COMAH | Control of Major Accident Hazards |
| cpm | chances per million (years) |
| EPA | Environmental Protection Agency |
| EV | Expectation Value |
| FGAN | Fertiliser Grade Ammonium Nitrate |
| Flash fire | Combustion of flammable gas/vapour/air mixture, no overpressure |
| Flash point | The lowest temperature at which vapours above a volatile combustible substance ignite in air when exposed to flame |
| FN curve | A cumulative frequency versus number of fatalities curve (for societal risk) |
| FSRU | Floating Storage Regasification Unit |
| FSU | Floating Storage Unit |
| HSA | Health and Safety Authority |
| HSE | Health and Safety Executive (UK) |
| LFL | Lower Flammable Limit |
| LNG | Liquified Natural Gas |
| LOC | Loss Of Containment Event |
| LPG | Liquified Petroleum Gas |
| LUP | Land Use Planning |
| MATTE | Major Accident To The Environment |
| NATECH | Major accident initiated by a natural hazard or disaster |
| PADHI | Planning advice for developments near hazardous installations |
| PIZ | Public Information Zone |
| Pool fire | Surface fire involving a pool of flammable liquid |
| QRA | Quantitative Risk Assessment |
| RTU | Road Transport Unit |
| SEP | Surface Emissive Power |
| TLUP | Technical Land Use Planning |
| TNT | Trinitrotoluene |
| VCE | Vapour Cloud Explosion |

# Executive Summary

This guidance interprets the Health and Safety Authority's (HSA) policy on the technical land use planning (TLUP) advice requirements of the Seveso III Directive (Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC), as implemented by the Chemicals Act (Control of Major Accidents Involving Dangerous Substances) Regulations 2015. This guidance has been revised and reissued as Version 3 published [date to be added].

The guidance consists of three parts:




Part 1 introduces the approach to TLUP:

- It describes the general background, as well as the risk criteria for new establishments and the nature of the advice that will be provided to planning authorities for developments in the vicinity of establishments.
- It explains how societal risk affects that technical advice.
- Section 1.8 explains where major environmental accidents fit into the LUP framework, and it also describes the frequency of natural major accident initiators.
- Section 1.9 sets out the purpose of the public information zone (PIZ).
- Section 1.10 explores the method that will be used to set the consultation distance (CD).
- Appendix 1 is closely linked to Part 1 in that it sets out the development sensitivity levels.

Part 2 includes these elements:

- The technical detail underpinning the establishment of the TLUP risk contours is described. Section 2.1 lists the sector groups for which TLUP criteria are being established.
- Risk of fatality and the use of probit equations is explained in Section 2.2.
- The derivation of fatality levels from exposure to thermal radiation is included in Section 2.3 and is expanded to address the issue of people residing/working inside structures. This is followed in Section 2.4 by an assessment of overpressure effects on people residing/working inside or outside structures, as well as the effects on the structures themselves.
- Toxicity is addressed in Section 2.5, where a table of common probit equations is provided, along with indoor/outdoor fractions, weather stability sets, and modelling temperatures.
- Domino effects are discussed in Section 2.6.
- Pool fire parameters are explained in Sections 2.7 and 2.8; jet fires are covered in Section 2.9 and ignition probability is addressed in Section 2.10.
- More complex situations and approach limitations are explored in Sections 2.11, 2.12 and 2.13.
- Section 2.14 sets out the limitations associated with a risk-based approach.

Part 3 sets out, for each of the sectors identified in Section 2.1, the scenarios to be modelled to generate the individual risk zones that form the basis of standard TLUP advice to planning authorities.

# Non-technical summary

As a result of a global history of major accidents at locations where residential development was located too close to industrial sites with major accident hazards, the Seveso Directives introduced a requirement for controls on development to be put in place. Such controls enable planning authorities to be technically informed on industrial accident risks before making decisions in relation to development near, or at, such locations.

The HSA is the statutory body providing TLUP advice in Ireland, which it does at the request of a planning authority.

This guidance document explains in detail how the HSA will go about developing the required technical advice. It identifies sector types and explains, for each sector, the nature of accidents that will be considered, along with the scientific approach to estimating the likelihood of those accidents occurring.

As computer programs of varied complexity can be employed to estimate both hazards and risks, where possible, the modelling parameters to be used are specified: these include the temperature of releases of dangerous substances from containment, wind speed, the proportion of people indoors, and the fatality thresholds for thermal radiation, overpressure and toxicity.

All of this enables lines of equal risk to be drawn on a map of the establishment and the surrounding area. Three such lines are used for standard technical advice: these risk lines represent the chance per million (cpm) per year, that a fatality will occur to a person permanently present at a location:

- 10 chances per million of fatality
- 1 chance per million of fatality
- 0.1 chance per million of fatality

As the risk decreases, more intensive and/or extensive development is unlikely to be advised against. The development types potentially suitable for each risk zone are described in general terms in the body of the guidance document and in extensive detail in Appendix 1.

Details are also provided on major accidents to the environment (MATTEs), and major accidents initiated by natural hazard or disaster events (NATECH). In addition, societal risk (risk of multiple fatalities), and how it will be considered in developing technical advice, is explained.

# Part 1: Land Use Planning Overview

## 1.1 General background

The Seveso III Directive (2012/18/EU) requires that the objectives of preventing major accidents and limiting their consequences should be taken into account in land use policy.[1]

As implemented by the Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations 2015 (S.I. No. 209 of 2015) (the 'COMAH Regulations 2015'), the objectives are to be achieved through controls on:

- the siting and development of new establishments,
- modifications to existing establishments,
- development in the vicinity of establishments.

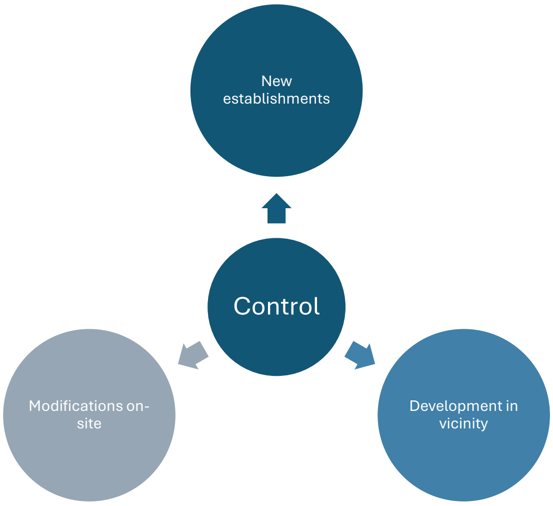



**Figure 1: Achievement of the Seveso III Directive objectives**

In applying these controls, account must be taken of the long-term requirement to maintain appropriate distances between establishments and residential areas, buildings and areas of public use, major transport routes, recreational areas and areas of particular natural sensitivity or interest.

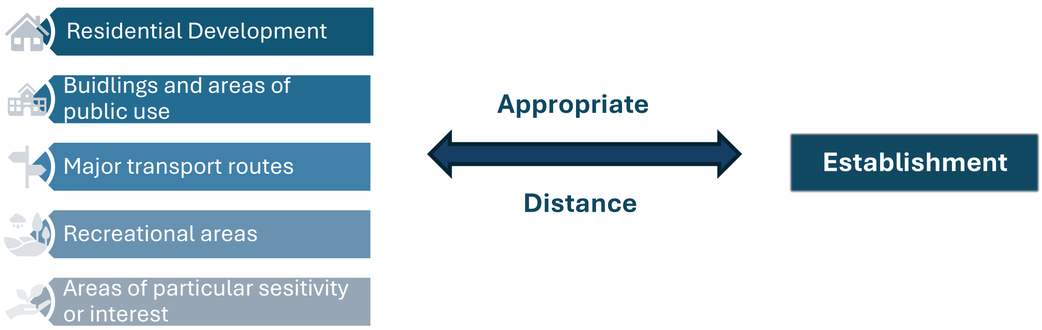



**Figure 2: Maintain appropriate distances to identified receptors**

[1] Article 13 of the Seveso III Directive

Technical advice must be available to a planning authority on the off-site risk from an establishment when decisions are being made in the planning process. The provision of this technical advice to a planning authority is referred to as 'technical land-use planning' or 'TLUP', and this advice is publicly available on the planning file.

This guidance addresses the policy and practice of the HSA in the provision of TLUP advice to planning authorities.

The TLUP requirements of the Seveso III Directive are addressed by Regulation 24 of the COMAH Regulations 2015 (and Regulation 12 for modifications to an establishment) and by the Planning and Development Regulations 2001 (S.I. No. 600 of 2001 as amended).

Regulation 24 of the COMAH Regulations 2015 requires the HSA, as the Central Competent Authority for the Seveso III Directive in Ireland, to set and review a protective consultation distance (CD) around each establishment. This CD must be formally communicated to all relevant planning authorities. Planning authorities, in turn, are required to seek technical advice for any proposed development of the specified types within the CD (see Figure 3).

When the HSA receives a formal request from a planning authority, it is obliged by the COMAH Regulations to provide TLUP advice.

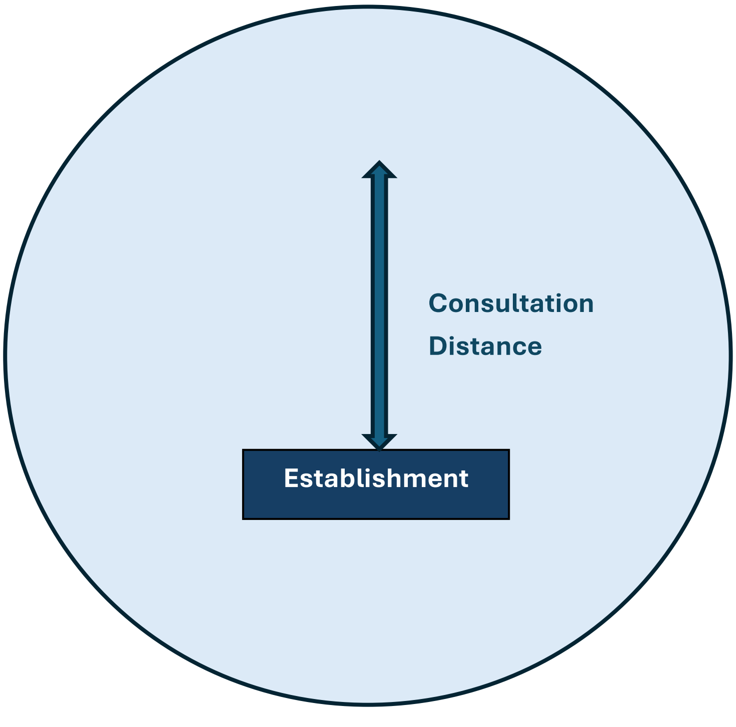



**Figure 3: Planning authority must seek technical advice for developments within the CD**
***[artwork to be amended on Fig 3 to reflect Figure 3 in version 2]***

The Planning and Development Regulations set out the overall time frames for planning processes. Regulation 24 of the COMAH Regulations 2015 sets out the time frames within which the HSA must provide technical advice to a planning authority. Planning authorities should allow for the time necessary for the provision of TLUP advice by the HSA.

The Planning and Development Regulations specify the:

- circumstances in which planning authorities are to seek TLUP advice,
- information that must be supplied to the HSA when seeking TLUP advice.

## 1.2 Best practice in land use planning

Best practice in TLUP advice systems is described in the European Guidelines on LUP[2] (see Section 4.3.1, pages 24 and 25 of those Guidelines). It advises that a TLUP advice system should apply the principles of:

- consistency (“Outcomes from broadly similar situations are broadly the same under similar conditions”),
- proportionality (“The constraint should be proportional to level of risk”),
- transparency (“Clear understanding of the decision-making process”).

Best practice also requires that account be taken of the most recent relevant technical knowledge. The system of TLUP advice set out in this guidance adheres to those principles. Also, it takes into account the publication of the more recent Handbook of Scenarios for Assessing Major Chemical Accident Risks[3] and the provision of ADAM[4] software to Central Competent Authorities by the Major Accident Hazards Bureau, along with taking account of any relevant technical knowledge in the provision of TLUP advice.

The risk-based TLUP advice methodology set out in this Guidance will be used to develop the TLUP advice required by the Seveso Directive, as well as to develop LUP zones around all establishments covered by the Directive. If the HSA engages an external body to support drawing up the LUP zones for an establishment, the approach set out in this Guidance is to be followed. Under the COMAH Regulations 2015, provision of site-specific TLUP advice by the HSA is an activity chargeable to COMAH operators, as explained on the COMAH section of the Authority's website.

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[2] MAHB (2008). Land Use Planning Guidelines in the Context of Article 12 of the Seveso II Directive 96/82/EC as amended by Directive 105/2003/EC. EC, Brussels

[3] Handbook of Scenarios for Assessing Major Chemical Accident Risks. Available at: https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/handbook_of_scenarios_for_assessing_major_chemical_accident_risksonlinepdf.

[4] Accidental Damage Analysis Module (https://adam.jrc.ec.europa.eu/en/adam/content).

## 1.3 Advice on new establishments

Regulation 24 of the COMAH Regulations 2015 refers to the siting and development of new establishments[5]. In this context, "new establishments" includes existing sites of operation that intend to increase their inventory above the COMAH threshold (thereby bringing them within the scope of the COMAH Regulations 2015) as well as newly constructed COMAH establishments.

Planning applicants for new establishments are expected to provide sufficient information to enable the HSA to apply the methods set out in this Guidance, so that the technical advice may be generated for planning authorities.

In keeping with the longer-term aims for LUP under the Seveso Directive, technical advice in relation to new COMAH establishments will be more stringent than that which applies to existing COMAH establishments. The individual location-based risk contours for new establishments, not to be exceeded, are shown in Table 1.

| | |
|---|---|
| $1 \times 10^{-6}$/year | Maximum tolerable risk to a member of the public |
| $5 \times 10^{-6}$/year | Maximum tolerable risk to a person at an off-site work location |

**Table 1: New Establishment criteria**

It is noted that these risk contours and criteria are always based on the risk to a hypothetical member of a residential population, who is always present, and is taken to be outdoors for 10% of the time and indoors for 90% of the time. The reason for this is to ensure a consistent approach to all risk criteria and contours, aligned with the fundamental basis on which the land use planning (LUP) advice for different types of development has been developed (see Appendix 1).

When the individual risk criteria in Table 1 are met for a specific development, a societal risk evaluation may also be necessary (see Section 1.6).

Note: The HSA may also advise the planning authority to consult with the principal response agencies (An Garda Síochána, fire and ambulance services) regarding emergency planning and response arrangements.

## 1.4 Advice on significant modifications to an establishment

The approach of the HSA to significant modifications is addressed in the Guidance on 'Significant Modifications' Under the COMAH Regulations (HSA, 2023).[6]

In summary, the HSA regulates the on-site risk element associated with the modification, setting limits for the tolerable level of risk increase that will be permitted and then, generally, requiring the lowest level of increased risk through the use of additional technical measures.

[5] A new establishment is defined in Regulation 2 of the COMAH Regulations 2015. It includes an establishment that enters into operation or is constructed on or after 1 June 2015, or a site of operation that falls within the scope of the Regulations, or a lower-tier establishment that becomes an upper-tier establishment, or vice versa, on or after 1 June 2015, due to modifications to its installations or activities resulting in a change in its inventory of dangerous substances.

[6] https://www.hsa.ie/eng/your_industry/chemicals/legislation_enforcement/comah/significant_modifications/guidance_on_significant_modifications_under_comah_regs.pdf

For off-site risk, the referral trigger is an off-site location fatality risk equal to or greater than $1 \times 10^{-6}$ (per year). It will then be referred to the planning authority, with technical advice consistent with the advice framework given in Section 1.5 on developments in the vicinity of COMAH establishments.

Irrespective of whether or not a modification will be subject to a planning application, the HSA must always be notified by an operator in advance of any planned significant modification and the procedures outlined in the Guidance on 'Significant Modifications' under the COMAH Regulations (HSA, 2023) must be followed. The HSA will rely on the technical information in a significant modification assessment completed in accordance this guidance when providing technical advice to a planning authority (see Appendix 2).

## 1.5 Advice on developments in the vicinity of an establishment

Within the CD around each COMAH establishment, as notified to the planning authority, three zones of risk are plotted. These are based on the location, quantity and the hazards of the dangerous substances present (taken from the formal notification required by Regulation 8 of the COMAH Regulations 2015), according to the methodology set out in Part 2 of this document, which is further elaborated on for each sector in Part 3.

The individual risk zones to be plotted on a map are shown in Table 2.

| | |
|---|---|
| $1 \times 10^{-5}$/year | Risk of fatality for the inner zone (Zone 1) boundary |
| $1 \times 10^{-6}$/year | Risk of fatality for the middle zone (Zone 2) boundary |
| $1 \times 10^{-7}$/year | Risk of fatality for the outer zone (Zone 3) boundary |

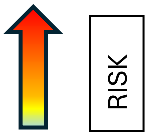



**Table 2: Risk zones for TLUP advice**

These location-based individual risk zones are always based on the risk to a hypothetical member of a residential population, who is always present, and is taken to be outdoors for 10% of the time and indoors for 90% of the time. The reason for this is to ensure a consistent approach to all risk criteria and contours, aligned with the fundamental basis on which the LUP advice for different types of development has been developed (see Appendix 1).

Associated with these zones are four levels of development, with increasing sensitivity to major hazards. A summary of these is shown in Table 3 (see Appendix1 for the complete list).

| Level | Development Type |
|---|---|
| Level 4 | Very large or sensitive development |
| Level 3 | Development for use by vulnerable people |
| Level 2 | Development for use by the general public |
| Level 1 | Workplaces, Car parks |

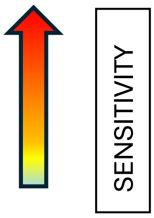



**Table 3: Summary of Development Types**

Broadly, the HSA's technical advice to planning authorities takes the form of 'Advises against'(✗) or 'Does not advise against' (✓) as illustrated in Table 4, similar to the UK HSE's Land Use Planning Methodology (UK Health and Safety Executive, 2025a), elaborated on in Appendix 1.

| | Inner Zone (Zone 1) | Middle Zone (Zone 2) | Outer Zone (Zone 3) |
|---|---|---|---|
| Level 1 | ✓ | ✓ | ✓ |
| Level 2 | ✗ | ✓ | ✓ |
| Level 3 | ✗ | ✗ | ✓ |
| Level 4 | ✗ | ✗ | ✗ |

**Table 4: TLUP advice matrix for each zone**

Therefore, for example, 'Developments for use by the general public' (Level 2) would be advised against in the inner zone, but not in the other zones. (Appendix 1 provides more detail on how developments fit into the matrix.)

The HSA's TLUP advice to planning authorities on a planning application will form part of the relevant public planning file.

## 1.6 Societal risk

A system based on the computation of individual risk has been outlined up to this point; that is, the risk to a (possibly hypothetical) person permanently located outside the establishment. The advice matrix (Table 4) takes account, to a degree, of group risk and the varied receptor sensitivities. It is applicable for the specified developments (listed in Appendix 1) that are located near a single COMAH establishment, and where the existing societal risk is well within the tolerable limit. However, there are times when the risk of multiple fatalities from an accident – the societal risk – should be taken into account more explicitly. For example, this may include where an application relates to a proposed significant off-site population density, or where there is already a significant population residing/working within the risk zone, or where the risk is emanating from more than one establishment.

To take account of societal risk in such situations, the HSA will initially obtain an estimate of the expectation value (EV)[7]. For example, for a frequency of occurrence of an accident at one chance in one million years (=1cpm), fatally affecting 120 people, the EV is the product of the two, that is, 120. However, if the frequency of occurrence of the accident is increased to once in one hundred thousand years, then in order to maintain the same EV, the number of people affected must drop to 12 (10 × 12 = 120).

EV will be relevant for TLUP advice concerning new COMAH establishments, for development near such establishments, and for significant modifications[8] to existing COMAH establishments where the risk or consequence is predicted to significantly increase.

In the HSE UK's publication on Reducing Risks, Protecting People[9] an upper limit value is provided for an intolerable societal risk criterion: for a predicted accident occurring, no more frequently than once

[7] EV is the product (multiplication) of accident frequency, expressed in chances per million, and the number of people suffering fatality in that accident.
[8] For significant modifications, an increase in EV has already been flagged as the trigger for more detailed analysis in the Guidance on 'Significant Modifications' Under the COMAH Regulations. Health and Safety Authority (2023).
[9] Reducing risks, protecting people: HSE's decision-making process, HSE Books, 2001. Paragraph 136 (on page 47): The HSE proposes that the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than once in 5,000 years.

in 5,000 years, there should be no more than 50 fatalities. This criterion has gained international acceptance as an anchor point for a line (of slope -1) to create an intolerable societal risk criterion for single accidents. An acceptable societal risk single-risk criterion line can then be drawn at frequencies that are two orders of magnitude below the intolerable line (so a frequency of $1 \times 10^{-4}$ on the intolerable line becomes $1 \times 10^{-6}$ on the acceptable line).

Between the two lines, operators and potential operators will be required to demonstrate that, in relation to proposed changes, all reasonable efforts have been made to reduce the risk to a level that is as low as reasonably practicable (ALARP).

Some establishments will have the potential for fatalities to arise from a multiplicity of accident scenarios (or there may be other establishments in the vicinity, adding to the EV). In such situations, the total off-site EV should not exceed the criterion upper limit EV of 10,000. **Between EVs of 100 and 10,000, it should be demonstrated that all practicable efforts have been made to reduce the risk to a level that is ALARP (above a developmental EV level of 450, an FN curve[10] will be required as part of the demonstration).**

For new developments near an establishment, where the calculated off-site EV at the development is greater than 2,000, further assessment of societal risk will be required and the creation of an FN curve and calculation of the total EV will be necessary.

Where the EV exceeds 10,000, the TLUP advice to the planning authority will always be 'Advise against'.

Especially large-scale or sensitive development within the CD[11] will likely require a societal risk evaluation.

[10] An FN curve is a plot of cumulative frequency versus consequences (expressed as number of fatalities).
[11] Consultation distance (CD) is the distance communicated to the planning authority by the HSA at the time of notification or subsequently. See also Section 1.10.

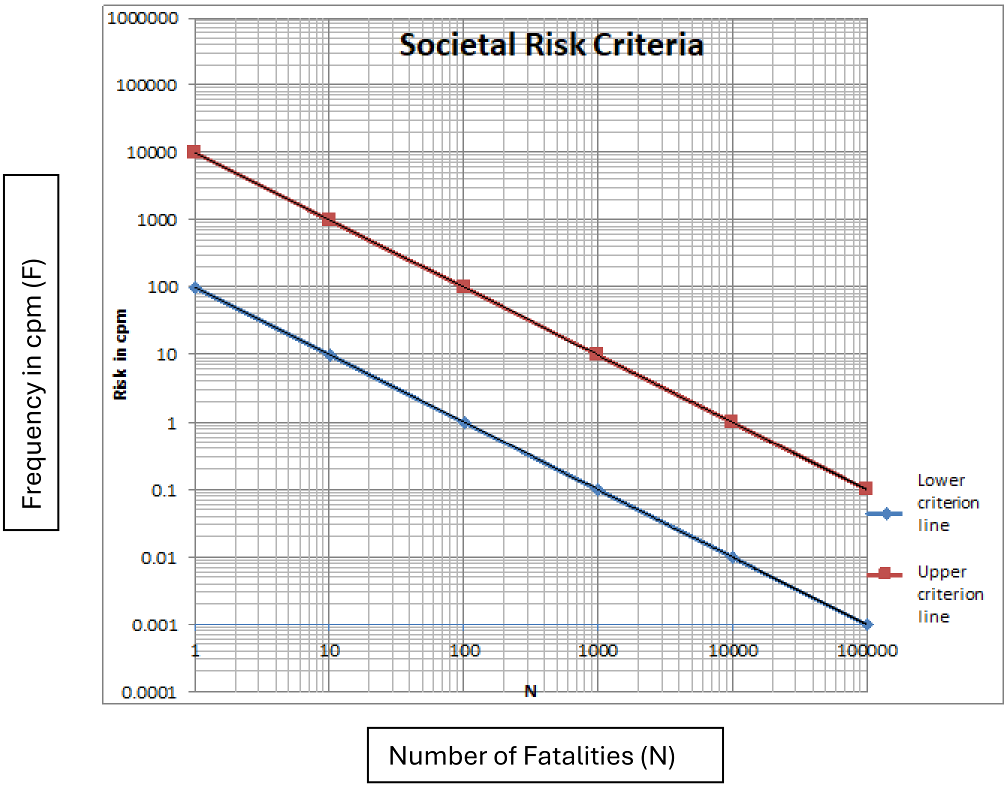



**Figure 4: Upper and lower societal risk criterion lines (log scale)**

The societal risk criterion is applied in addition to the individual risk criteria previously outlined.

Both the individual and societal risk criteria must be satisfied when considering new development, population intensification or significant modification. If the individual risk criterion is met, then the societal risk level has to be considered. If the societal risk is within the ALARP region, then an FN curve should be generated to evaluate the societal risk level (using the relevant scenarios outlined in Section 3 of this guidance).

## 1.7 Cumulative risk

The HSA approach described in this guidance provides control over the levels of individual and societal risk for a proposed development. However, it may be the case that whilst a single development may, in isolation, be considered acceptable in terms of both individual and societal risk, if several similar such developments were present adjacent to each other, then the overall societal risk may increase and become unacceptable.

In such cases, this potential 'cumulative risk' may be a reason to advise against the development. Similarly, a developer could split a large, proposed development into a number of phases or smaller incremental developments, each of which in isolation has acceptable individual risk and societal risk, but the eventual cumulative societal risk for the entire development is not acceptable.

In general, the cumulative risk is more likely to be a potential issue for small high-density developments, and less significant for low-density large developments. The HSA will use judgment in these cases, taking into account specific details for the development and published methodologies such as the UK HSE Scaled Risk Integral approach (UK HSE, 1999).

## 1.8 Environment and land use planning

Article 13 of the Seveso Directive requires European Union Member States to take account of the need, in the long term, to maintain appropriate distances between establishments and recreational areas/areas of particular natural sensitivity or interest (amongst others). A separation distance for environmental purposes will be considered appropriate if it is sufficient to enable the operation of suitable control and mitigation measures, and/or is such that the risk of serious environmental damage is low.

In the context of LUP, the prevention of Major Accidents to the Environment (MATTE) will be the primary objective, and it is expected that accident pathways will be prevented. Where this is not practicable, or in the context of significant modifications at existing COMAH establishments, the assessment of MATTEs focuses on the specific risks to sensitive receptors within the local environment, the extent of consequences to such receptors and the ability of such receptors to recover: environmental damage may be relatively long-lasting but is not necessarily irreversible. Recovery of habitats within a reasonable period of time is possible, depending on the dangerous substance involved. This information is all considered when providing advice.

While the system described in the previous sections of this guidance focused on the risk to human health, it may also be applied to other environmental receptors, with a modification factor, if necessary, in simple cases of airborne toxic releases or for the physical effects of fire and explosion. However, for accidental releases into waterways and in general, where the environmental receptors are more sensitive than human receptors, a different approach is taken.

Emphasis is initially placed on the prevention phase, the control of potential pollution routes and available response measures, rather than on the development of a quantitative risk assessment (QRA) approach and use of risk-based criteria.

Assessment is based on a Source-Pathway-Receptor model. For new establishments, the HSA requires the operator to focus on the removal of accident pathways to receptors (through the use of additional technical measures: appropriate containment, within the confines of current good practice and ALARP, for example). For significant modifications, or where necessary for a new establishment, the risk-based approach developed by the Chemical and Downstream Oil Industries Forum (CDOIF)[12] and outlined in the Guidance on 'Significant Modifications' Under the COMAH Regulations (HSA, 2023), should be used by operators.

Technical advice to a planning authority will address only the potential effects of major accidents, not routine environmental emissions. Routine environmental emissions associated with the operation of

[12] Chemical and Downstream Oil Industries Forum publication: Guideline on Environmental Tolerability for COMAH Establishments, v2.0

an establishment are a matter for the local authority or the Environmental Protection Agency (EPA), as relevant, and are subject to their permitting/licensing requirements.

Irrespective of whether the approach is qualitative or quantitative, the following are considered:

- environmentally sensitive areas in the vicinity,
- presence of endangered species,
- protected water resources/biospheres,
- types of accident that can cause environmental damage (firewater run-off, for example),
- contamination routes (watercourses, for example),
- measures in place to protect the environment and their reliability,
- hard/reliable measures in place to contain run-off in the context of internal and external emergency plans,
- recovery periods with and without intervention,
- clean-up and remediation plans and resources, and
- if necessary, tolerability of assessed risk.

Under the COMAH Regulations 2015, operators are required to use best practicable means, specifically:

- to prevent a major emission of dangerous substances resulting from uncontrolled developments in an establishment into the environment, and
- for rendering harmless and inoffensive the substances emitted.

The approach of the HSA, therefore, is to examine potential effects on the environment from the identified credible major accident hazards and to satisfy itself that appropriate 'best practicable means' are/will be in place to prevent such effects. Best practicable means may constitute adequate bunding for storage tanks containing dangerous substances for example, allied with tertiary containment to prevent migration off-site of any overtopping fraction or contaminated firefighting water.

Detail on the modelling and assessment of major accidents affecting the environment is contained in the HSA's Guidance for Inspectors on the Assessment of Safety Reports under the COMAH Regulations 2015 (HSA, 2017).

The potential for a major accident to be initiated due to natural phenomena (NATECH) is also considered.

For example, the effect of flooding, lightning, storm damage, and subsidence is considered in relation to the potential effect on storage tanks and storage areas, as well as on important site utilities. For new establishments, operators must demonstrate that other potential initiators have been considered and that appropriate prevention/control/mitigation measures will be employed.

The following events should be assessed in relation to their potential to cause or increase the likelihood of a major accident:

| NATECH Event | Frequency (per year) |
|---|---|
| Storm | 1 in 100-year event |
| Snow | 1 in 100-year event |
| Flood | 1 in 1000-year (river or coastal) event |

**Table 5: Frequency of naturally occurring potential initiators of major accidents**[13]

For environmental hazards, good practice can be found in published sources, including relevant guidance from Best Available Technique (BAT) reference documents (BREFs) and the associated BAT conclusions (BATC) documents.

While the ‘best practicable means’ standard is also applied to the control of gaseous loss of containment (LOC) events (such as suitably sized catch pots for runaway reactions), the consequences of such releases are examined as part of the general major accident scenarios for human receptors.

Where detailed risk assessment is necessary, the risk levels to be attained for new COMAH establishments in relation to MATTEs (based on the CDOIF methodology) are shown in Table 6.

| MATTE Type | Broadly Acceptable risk less than |
|---|---|
| A | $1 \times 10^{-4}$ |
| B | $1 \times 10^{-5}$ |
| C | $1 \times 10^{-6}$ |
| D | $1 \times 10^{-7}$ |

**Table 6: Broadly acceptable risk levels for MATTEs**

For sites storing dangerous liquids in bulk, which will often be located near sensitive marine environments, such as special areas of conservation and special protection areas, the prevention of a major emission into the environment will be achieved through the use of appropriate primary, secondary and tertiary liquid containment.

A lower frequency of loss (see Section 3.6.6, Table 53) will be used for double containment tanks, to reflect their contribution to prevention of damage to the environment; new establishments will be encouraged to avail of this, or equivalent, technology.

Appropriate bunds, for containing spilled liquid and any applied extinguishing or cooling media, will be required. The general requirement is for 110% of the largest tank, or 25% of the total tank volume, where more than one tank exists in the bund, whichever is the larger figure. EPA guidance on firewater retention (EPA, 2019) is relevant in this context.

Tertiary containment will be required where overtopping with potential to cause a MATTE is a credible event.

Useful information to assist in MATTE assessment can be obtained from many sources:

[13] Technical Rule on Process Safety 320: Precautions and Measures against the Hazard Sources Wind, Snow Loads and Ice Loads, 2015, German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

- Information on flood mapping for the 1 in 1,000-year return period is available at: https://www.floodinfo.ie/
- Historical rainfall information from Met Eireann https://www.met.ie/
- A national resource for environmental information is available from the EPA https://www.epa.ie/.

The site should demonstrate that it can withstand external events such as high winds, floods and earthquakes, and that any associated increase in the frequency of major accident hazard events does not lead to unacceptable risks. The site should also consider the predicted increases in the likelihood and severity of certain external events due to climate change over the facility's lifetime.

## 1.9 Public information zone

Prior to the COMAH Regulations 2015, the ‘specified area’ was defined as an area at greater risk of being affected by a major accident and within which an upper-tier establishment had to supply information directly to persons in the area on the appropriate action to take in an emergency. While this area still exists, it is no longer referred to as a ‘specified area’. The requirement to provide this information still applies under the COMAH Regulations 2015, but the area is now referred to as the Public Information Zone (PIZ). This will, at a minimum, coincide with the outer LUP zone. The HSA will use its discretion as to whether it should be enlarged further, based on the consequences of the identified major accident scenarios.

## 1.10 Consultation Distance

A consultation distance (CD) is a distance around an establishment, within which there are potentially significant consequences from major accidents to people (or to the environment). The HSA notifies the planning authority of this distance. Historically, it was based on generic categories and distances which are outlined in the planning and development legislation. Under the COMAH Regulations 2015, the HSA is required to review and update this advice as necessary. The CD will be supplied to the planning authorities as a GIS file, which is site specific and takes account of the most recent establishment notification data and related major accident hazard risks.

New establishments will be required to propose an appropriate CD to the HSA, in accordance with the methodology set out in this document and submit it to the planning authority as part of a planning application.

When establishing new CDs (or revising previously communicated CDs), the risk-based approach described in Part 3 of this guidance will be used to obtain a $1 \times 10^{-9}$ (1 in a billion) fatality risk contour. Consequences to the thresholds specified in Section 2 will also be obtained. The CD will be set at the discretion of the HSA.

## 1.11 Future technical updates

The HSA may need to update any part of this guidance, as necessary. All changes will be detailed as part of a public consultation process, prior to making updates or changes to this publication.

# Part 2: Detailed Technical Approach

## 2.1 Sectors

COMAH establishments can be treated as being in distinct sectors, each of which has characteristic dangerous substances and types of major accident. The sectors are:

- Liquefied petroleum gas (LPG) installations
- Liquefied natural gas (LNG) installations
- Renewable natural gas (RNG) installations
- Hydrogen installations
- Natural gas pipelines (within an establishment)
- Flammable liquid storage installations
- Fertiliser storage installations
- Dangerous substance warehouses
- Chemical/Pharmaceutical installations
- Gas drum and cylinder installations
- Explosives handling/storage installations
- Ammonia refrigeration plant
- Distilleries and spirit maturation warehouses.

For each of these, a method for generating TLUP risk zones is elaborated on in this guidance. Part 3 describes in detail how these LUP zones will be generated, setting out the major accident scenarios, their frequencies, and the consequences to be considered.

In Part 2 the technical background underpinning Part 3 is described.

## 2.2 Risk of fatality and the use of probit equations

The analysis requires an identification of credible major accident scenarios, followed by the likely accident consequences in terms of fatality. TLUP zones extend to a $1 \times 10^{-7}$ per year fatality contour; therefore, any scenario that can contribute to this risk level should be considered. To estimate the fatal consequences of major accidents, established probit[14] relationships for fatality are used: they are conservatively derived and help to ensure consistency in approach, resulting in a risk-based analysis that is robust and transparent.

Fatality risk increases as the level of consequence (increased concentration/intensity of effect and duration of exposure) increases. The relationship between the consequence level and the probability of fatality can be characterised by a probit relationship. A range of consequences can be expected in a population exposed to an acute hazard (dose), which can be represented mathematically by a dose-response curve, with the number of people suffering fatal effects being the response. For computational purposes, it is better to fit the relationship into the form of a straight line. Probit

[14] Probit-based models, derived from experimental dose-response data, are often used to estimate the health effect that might result based on the intensity and duration of an exposure to a harmful substance or condition (for example, exposure to a toxic atmosphere, or thermal radiation).

equations do this and can be used to estimate the proportion of a population that may be affected by exposure to a particular harm.

Examples of probits are given in Table 7:

| | |
|---|---|
| Chlorine toxicity | Probit = -11.4535 + 1.93 ln ($C^{1.04}t$) with concentration, C, in ppm and time (t) in minutes |
| Thermal radiation | Probit = -14.9 + 2.56 ln ($I^{1.33}t$) with intensity, I, in $kW/m^2$ and time (t) in seconds |
| Overpressure | Probit = 1.47 + 1.35 ln (P) with pressure, P, in psi |

**Table 7: Examples of probit equations**

The number value obtained from the probit equation can be looked up in a reference table to calculate the percentage of the population fatally affected. A probit of 5 corresponds to 50% fatality; a probit of 2.67 to 1% fatality; a probit of 7.33 to 99% fatality, and so on. Therefore, probit functions enable a consistent and transparent estimation of the fatality percentage in a standard exposed population.

The following sections will describe the probit equations to be used for estimating the consequences of specific types of major accident.

## 2.3 Consequences of thermal radiation

Thermal radiation exposure arises from fire-type events. Accidents that give rise to a thermal (heat) effect will impact differently on indoor and outdoor populations.

### 2.3.1 Thermal effects on people outdoors

The probit used for determining the fatality percentage of a population exposed to thermal radiation was developed by Eisenberg et al. (1975):

$$\text{Probit} = -14.9 + 2.56 \ln (I^{1.33} t)$$

(with I in $kW/m^2$ and t in seconds: I is the incident heat flux and t the exposure duration).

This relationship applies to a population out in the open when exposed to thermal radiation.

For fires of long duration, such as pool fires and jet fires, it is reasonable for TLUP calculations to make allowances for the fact that, unless incapacitated, people will retreat from the hazard source. Therefore, the exposure time is the time required to reach a safe place, and the default exposure time to be used is 60 seconds.

Using those parameters, the Eisenberg probit relationship implies the following fatality percentages at the heat flux levels shown in Table 8:

| | |
|---|---|
| 8.02 $kW/m^2$ | 1% fatality |
| 10.9 $kW/m^2$ | 10% fatality |
| 15.9 $kW/m^2$ | 50% fatality |

**Table 8: Heat flux and fatality levels, outdoor, for a 60-second exposure**

For TLUP, the threshold of a fatality flux level of 8.02 kW/m$^2$ can be used as a screening distance for consequence modelling, in line with the methodology described in this document.

For flash fires, fatality levels of 100% are assumed inside the lower flammable limit (LFL) envelope, with 0% fatalities outside that envelope.

### 2.3.2 Thermal effects on people inside buildings

People inside buildings will have some protection from the effects of incident thermal radiation. Therefore, a further refinement of the model is necessary. For people indoors, the relevant thermal radiation thresholds[15] are:

| | |
|---|---|
| >25.6 kW/m$^2$ | Building conservatively assumed to catch fire quickly, and therefore, there is a 100% fatality probability |
| 12.7-25.6 kW/m$^2$ | People are assumed to have escaped outdoors and therefore have a risk of fatality corresponding to that of people outdoors. |
| <12.7 kW/m$^2$ | People are assumed to be protected, and therefore there is a 0% fatality probability. |

**Table 9: Heat flux levels relevant for people within buildings**

For flash fire, within the flash fire envelope, indoor fatality levels are conservatively assumed to be 10%.

For fireballs, which have a relatively short duration, the indoor fatality level is taken to be 100% above 35 kW/m$^2$, and zero at greater distances, based on the TNO (2005) Purple Book approach.

### 2.3.3 Thermal effects and property damage

Property damage may be a relevant element of the technical advice provided to a planning authority: the Seveso Directive requires appropriate distances to be maintained to “buildings and areas of public use”. A mechanism is required to consider the risks (including economic) to property, structures, and businesses as part of any TLUP advice, where relevant (see also Section 2.4.3).

The presence of physical blocking structures can be considered when determining the areas that are likely to be subject to thermal radiation.

For thermal radiation, the key contours for structural damage will be (World Bank, 1985):

| | |
|---|---|
| 37.5 kW/m$^2$ | Sufficient to cause damage to process equipment |
| 25.6 kW/m$^2$ | Minimum heat flux to ignite wood at indefinitely long exposures (non-piloted) |
| 14.7 kW/m$^2$ | Minimum heat flux for piloted ignition of wood, melting of plastic tubing |

**Table 10: Heat Flux levels and property damage**

## 2.4 Explosion overpressure

The explosion overpressure effects in the standard model relate to vapour cloud explosions (VCEs). This refers to concentrations of flammable gas or vapour released into confined areas, which then

[15] https://www.hse.gov.uk/comah/assets/docs/methane-gas-holders.pdf and the 2006 Technical Guidance Document B on Building Fire Safety.

find an ignition source. The TNO multi-energy method (TNO, 1992) is used to estimate the level of overpressure from such events.

The flammable volume must be determined as well as the confined volume in the congested area. Explosion Strength 7 is applied to the confined volume and Explosion Strength 2 to the unconfined volume. Sometimes there will be no confined volume, but typically it is in the immediate area of the release, where there are many vessels or other obstacles.

Typically (methods for specific sectors set out in part 3), 20% of the stoichiometric cloud volume is assumed to be in the congested area – if there is one – (where the ignition is assumed to occur) and is assigned Strength 7. If the actual confined volume is bigger than this, then the actual confined volume is used.

Catastrophic failures and blasts also have the potential to generate projectiles, possibly capable of travelling several hundred metres. Whilst the risk of a particular area being hit by a projectile is usually extremely low, it may be significant if there are large numbers of cylinders, or when assessing the low levels of risk at large distances from a pressure vessel (e.g. to define the CD). Given the uncertainties associated with the prediction of these risks for LUP purposes, the HSA has adopted a simple empirical approach for the projectile risk associated with instantaneous failures of a pressure vessel (which typically has a frequency of $5x10^{-7}$/year per vessel):

- For cylinders, there is no risk to people indoors, and for people outdoors the lethality probability from projectiles decreases logarithmically from 100% at 1m to 0.01% at 200m.
- For larger pressure vessels, the outdoor and indoor lethality probability from projectiles decreases logarithmically from 100% at 1 m to 0.01% at 600 m.

These assumptions are based on historical data and the approach of Scilly and Crowther (1992). In some cases, more detailed calculations may be required.

### 2.4.1 Overpressure effects on people outdoors

The probit used for determining consequences from blast overpressure was developed by Hurst et al. (1989). The relationship is:

Probit = 1.47 + 1.35 ln (P)

with P in psi (Note: 1 psi = 68.947573 mbar).

This relationship applies only to people exposed to blast overpressure outdoor and implies the following relationship between overpressure and fatality:

| | |
|---|---|
| 2.44 psi (168mbar) | 1% fatality |
| 5.29 psi (365 mbar) | 10% fatality |
| 13.66 psi (or 942 mbar) | 50 % fatality |

**Table 11: Overpressure fatality thresholds for people outdoor**

**Caution:** This probit relationship should not be used for assessing the risk to indoor populations, as it fails to take any account of factors such as building collapse, and therefore could lead to a significant underestimation of the risk.

## 2.4.2 Blast effects on people inside buildings

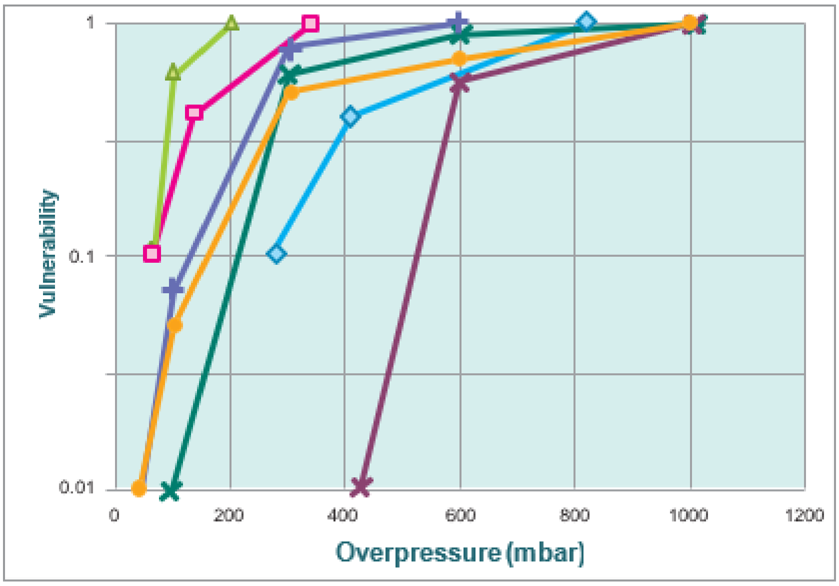
People indoors could be either more or less vulnerable to the effects of blast overpressure, depending on the blast resistance of the surrounding structure. The UK Chemical Industries Association (CIA) (Chemical Industries Association, 2020) published details of relationships between the risk of fatality for occupants and the level of blast overpressure for four different categories of building. The building categories are set out in Table 12.

| | |
|---|---|
| Category 1 | Hardened structure building |
| Category 2 | Typical office block |
| Category 3 | Typical domestic building |
| Category 4 | Portacabin-type timber construction |

**Table 12: CIA building categories**

The curves are reproduced in Figure 5. The CIA Category 3 Curve (typical domestic building: two-storey, brick walls, timber floors) will in most circumstances provide a reasonably conservative basis for assessing the risk of fatality to most residential populations and is widely used for this purpose.

It is emphasised that when calculating LUP zones (or when assessing a residential or workplace location against the risk criteria in Section 1.3) the CIA Category 3 relationship for domestic buildings must be used. Other vulnerability relationships, and occupancy details, may be more appropriate when calculating the actual individual risk for the occupants of developments or for the calculation of societal risks.



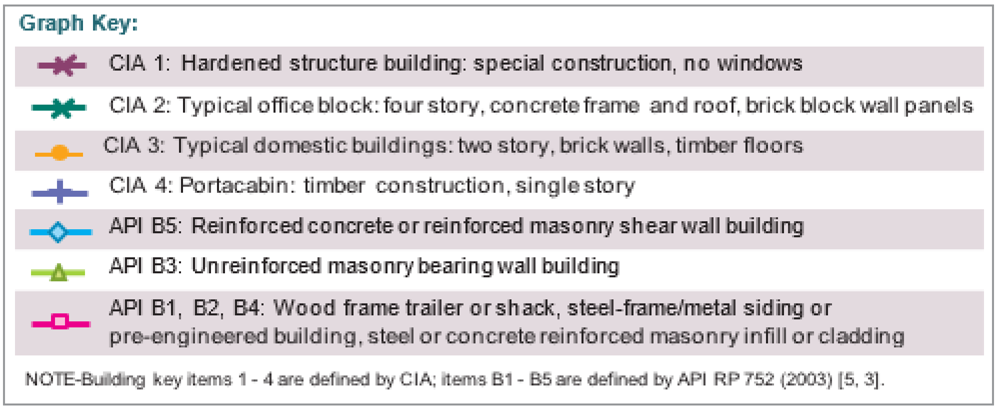



**Figure 5: Vulnerability of people in Buildings, taken from a European Industrial Gases Association publication[16].** See also Figure A2.1 in CIA (2020) Guidance**.**

## 2.4.3 Blast effects on buildings

Risks to physical structures will be taken into account as part of any TLUP advice. Landmark overpressure damage values are:

| Overpressure (kPa) | Overpressure (mbar) | Possible Damage Contours |
|---|---|---|
| 1 | >10 | Glass breakage |
| 3.5 | >35 | Light |
| 17 | >170 | Moderate |
| 35 | >350 | Severe |
| 83 | >830 | Total destruction |

**Table 13: Blast effect on buildings (extracted from Table 14)**

If it is considered necessary by the HSA, the distance to some of these key contours could be plotted on a map as part of TLUP advice addressing consequences. Table 14 provides more detail on the damage potentially resulting from overpressure.

| Overpressure (kPa) | Description of damage |
|---|---|
| 0.15 | Annoying noise |
| 0.2 | Occasional breaking of large windowpanes already under strain |
| 0.3 | Loud noise; sonic boom glass failure |
| 0.7 | Breakage of small windows under strain |
| 1 | Threshold for glass breakage |
| 2 | ‘Safe distance’, probability of 0.95 of no serious damage beyond this value; some damage to house ceilings; 10% window glass broken |
| 3 | Limited minor structural damage |
| 3.5–7 | Large and small windows usually shattered; occasional damage to window frames |
| >3.5 | Damage level for ‘light damage’ |
| 5 | Minor damage to house structures |

[16] European Industrial Gases Association, 2014: Guideline for the Location of Occupied Buildings in Industrial Gas Plants, IGC Doc 187/14/E

| | |
|---|---|
| 8 | Partial demolition of houses, made uninhabitable |
| 7–15 | Corrugated asbestos shattered. Corrugated steel or aluminium panels fastenings fail, followed by buckling; wood panel (standard housing) fastenings fail; panels blown in |
| 10 | Steel frame of clad building slightly distorted |
| 15 | Partial collapse of walls and roofs of houses |
| 15–20 | Concrete or cinderblock walls, not reinforced, shattered |
| >17 | Damage level for 'moderate damage' |
| 18 | Lower limit of serious structural damage; 50% destruction of brickwork of houses |
| 20 | Heavy machines in industrial buildings suffered little damage; steel-frame building distorted and pulled away from foundations |
| 20–28 | Frameless, self-framing steel panel building demolished; rupture of oil storage tanks |
| 30 | Cladding of light industrial buildings ruptured |
| 35 | Wooden utility poles snapped; tall hydraulic press in building slightly damaged |
| 35–50 | Nearly complete destruction of houses |
| >35 | Damage level for 'severe damage' |
| 50 | Loaded tank car overturned |
| 50–55 | Unreinforced brick panels, 25–35 cm thick, fail by shearing or flexure |
| 60 | Loaded train boxcars completely demolished |
| 70 | Probable total destruction of buildings; heavy machine tools moved and badly damaged |
| >83 | Damage level for 'total destruction' |

**Table 14: Levels of damage from overpressure from the American Institute of Chemical Engineers (1994)**

While there are no generally accepted criteria for assessing the risk to the built environment (as opposed to the risk to human health), the results of an assessment using the above criteria will be an additional factor for planning authorities to consider, although that may be of less significance than the risks to people.

## 2.5 Toxicity

### 2.5.1 Toxic effects on people out in the open

Probit equations are used for estimating the fatal toxicity effects of dangerous substances. All probits take the form Probit = a + b $\ln(C^n t)$ where a, b and n are constants, as shown in Table 15, C is the concentration value by volume (in ppm), and t is the exposure duration (in minutes).

The exposure duration is generally taken to be equal to the release duration for vapour/gas releases, up to a maximum of 30 minutes, and also a maximum of 30 minutes for toxic exposure from evaporating liquid pools or from warehouse fires (some scenarios will be of shorter duration than this maximum).

The probit equations in Table 15 will be used in TLUP risk contour generation. These are generally based on the latest available data from the Dutch National Institute for Public Health and the Environment, RIVM at: https://www.rivm.nl/probitrelaties/statusoverzicht-probitrelaties.

These latest RIVM probits are more up to date than some of those in recent publications, such as those given by RIVM (2020). To note, the probits in Table 15 are all consistent with the RIVM Toxicity Group probits included in PHAST[17] version 9.1.

| ***Substance*** | **CAS#** | **a** | **b** | **c** | **Source** |
|---|---|---|---|---|---|
| *Ammonia* | 7664-41-7 | -17.1141 | 0.99 | 2.02 | (RIVM, 2017) |
| *Bromine* | 7726-95-6 | -8.31771 | 1.57 | 1.28 | (RIVM, 2018) |
| *Chlorine* | 7728-50-5 | -11.4535 | 1.93 | 1.04 | (RIVM, 2018) |
| *Hydrazine* | 302-01-2 | -12.6499 | 1.0 | 2.0 | (RIVM, 2020) |
| *Phosgene* | 75-44-5 | -7.7840 | 2.51 | 0.80 | (RIVM, 2020) |
| *Carbon monoxide* | 630-08-0 | -15.5173 | 1.11 | 1.81 | (RIVM, 2018) |
| *Methyl bromide* | 74-83-9 | -16.2766 | 1.64 | 1.22 | (RIVM, 2017) |
| *Methylisocyanate* | 624-83-9 | -8.49645 | 1.98 | 1.01 | (RIVM, 2019) |
| *Methyl mercaptan* | 74-93-1 | -9.83727 | 1.0 | 2.0 | (RIVM, 2018) |
| *Nitrogen dioxide* | 10102-44-0 | -6.39012 | 0.5 | 3.99 | (RIVM, 2018) |
| *Nitric oxide* | 10102-43-9 | -150.838 | 15.432 | 1 | (PHAST, 2025) |
| *Hydrogen chloride* | 7647-01-0 | -16.1916 | 1.46 | 1.37 | (RIVM, 2017) |
| *Hydrogen cyanide* | 74-90-8 | -9.06052 | 1.17 | 1.71 | (RIVM, 2017) |
| *Hydrogen fluoride* | 7664-39-3 | -13.4913 | 1.83 | 1.09 | (RIVM, 2018) |
| *Hydrogen sulphide* | 7783-06-4 | -7.08847 | 0.31 | 6.52 | (RIVM, 2018) |
| *Sulphur dioxide* | 7446-09-5 | -10.56444 | 1.0 | 2.0 | (RIVM, 2018) |

**Table 15: Dangerous substances probits (concentration in ppm by volume)**

Probits are available in the published literature for other dangerous substances; where there is more than one probit, the HSA will therefore use its discretion to select an appropriate value. QRAs should provide a justification on the use of any alternative probits.

## 2.5.2 Toxic effects on people inside buildings

The risk to people indoors from a toxic vapour cloud significantly depends on the effective ventilation rate of the building they are in. Air change rates, for passively ventilated buildings, of 2.5 and 2 air changes per hour are typically assumed for $D_5$ and $F_2$ conditions. $D_5$ and $F_2$ refer to the weather/stability sets typically used in modelling releases of dangerous substances into the atmosphere. D represents typical daytime conditions, and F represents specific night-time conditions. The subscripts refer to the average wind speeds, in metres per second, associated with those atmospheric stability conditions (see also section 2.5.4).

The impact of a toxic release on an indoor population can be assessed using the same probit equations as for outdoor exposure, but it is necessary to modify the effective concentration and duration of exposure in order to take account of gas infiltration into the building. If the modelling software does not calculate indoor concentration, the approach set out in Davies and Purdy (1986) will be followed.

[17] Phast$^{TM}$ software for consequence analysis https://www.dnv.com/services/phast/

### 2.5.3 Fraction of time spent indoors/outdoors

People are assumed to be indoors 90% and outdoors for 10% of the time.

### 2.5.4 Probability of occurrence of weather stability sets

$D_5$ conditions are assumed to occur 80% of the time, with F2 occurring for the remaining 20%.

### 2.5.5 Temperature parameters

Outdoor storage vessel contents are assumed to be at ambient atmospheric temperatures. Ambient temperatures vary throughout the day and the seasons. For TLUP purposes, a temperature of 15°C is used in $D_5$ conditions and 10°C for $F_2$ conditions. Raw temperature data are available from Met Eireann at https://www.met.ie/.

### 2.5.6 Wind direction probability

The probability of a gas/vapour release (or in some cases thermal flux) being blown in any direction by the wind is taken into account, using data from the nearest suitable weather station.

### 2.5.7 Terrain

The terrain in the vicinity of the establishment, over which dispersion takes place, is carefully selected from Table 16.

| # | Short description of the terrain | Roughness length (m) |
|---|---|---|
| 1 | Open water (at least 5 km) | 0.0002 |
| 2 | Mud flats, snow; no vegetation, no obstacles | 0.005 |
| 3 | Open, flat terrain; grass, a few isolated objects | 0.03 |
| 4 | Low vegetation; large obstacles here and there, ×/h > 20 | 0.10 |
| 5 | High vegetation; distributed large obstacles, 15 < ×/h < 20 | 0.25 |
| 6 | Park, bushes; many obstacles, ×/h < 15 | 0.5 |
| 7 | Strewn with large obstacles (suburb, wood) | 1.0 |
| 8 | Town centre with high-rise and low-rise buildings | 3.0 |

**Table 16: Roughness lengths (source: Dutch National Institute for Public Health and the Environment, RIVM, 2021)**

By default, for general terrain without defining features, a value of 0.1 m will be used (a conservative approach).

### 2.5.8 Toxic effects on the environment

Where prevention measures fail and where local flora and fauna are more sensitive to toxic exposure than humans, a more relevant toxic endpoint (than those previously described) may be used to estimate consequences, where damage duration and resilience will be taken into account. See section 1.8 of this guidance for further information.

## 2.6 Domino effects

Domino effects are effects that arise when an accident event at one establishment initiates a major accident elsewhere in the establishment, or at another establishment in the vicinity. Typical examples of where domino interactions may need to be explicitly considered include:

- Where the presence of a high-frequency short-range hazard significantly increases the likelihood of a major failure of a relatively low-frequency long-range hazard. For example, small LPG storage vessels located close to a large toxic gas storage tank.
- Where the initiating event on one site (or part of the same site) could trigger a more severe than expected event on a neighbouring site. For example, a LOC and fire involving highly flammable substances on one site could spread to involve a site storing Category 3 flammable liquids, which would normally not be considered a major fire risk (due to high flash point), but which are still very likely to be ignited and become involved in escalating the fire if the initiating event is a major fire from a nearby site.
- Where an event at one site (or part of the same site) could have unexpected indirect consequences on a neighbouring site. For example, a loss of power to control and emergency shutdown systems, or toxic vapours leading to incapacity/evacuation of vital staff controlling major hazards at a nearby site. Such unexpected indirect consequences could trigger or exacerbate a potential domino event.

In most cases, domino effects can be incorporated into the risk-based assessment by simply increasing the base case frequency for the likelihood of events on one (or both) sites.

Domino effects on road tankers have been specifically accounted for in Part 3.

Often, it is found that domino effects are not significant for LUP, as the likelihood of an event at Site A triggering a major event at Site B is an order of magnitude less than the base case likelihood of the event at Site B. Nevertheless, as a rule of thumb, the potential for domino effects will always be considered at establishments within 500 m of each other. The paper by Salzano and Cozzani (2005) informs the approach that will be taken in the analysis of domino effects.

## 2.7 Unbunded pool size

Unbunded pools are given an upper limiting diameter of 100 m. Given the uncertainties regarding such events, it is generally assumed that, for the purposes of LUP, the overtop pool occurs adjacent to the bund at the nearest point to the receptor, with the wind blowing towards the receptor.

In some cases, it could happen that a pool is constrained to a particular direction, or there may be a possibility of larger pools (or even running pools). If such effects are considered to be significant, then the analysis will be adapted appropriately.

If the topography of the area surrounding the bund has any special features, such as tertiary containment, then this could be accounted for by modifying the potential location of fires outside the bund, possibly reducing the extent of the LUP zones.

## 2.8 Surface emissive power – pool fire

The scientific literature describes a number of approaches to modelling the surface emissive power (SEP) of heat radiated outwards per unit surface area of the flame from a pool fire, in units of $kW/m^2$.

Maximum SEP values from the literature are set out in the following table:

| **Substance** | **Emax** ($kW/m^2$) |
|---|---|
| Acetone | 130 |
| Crude oil | 130 |
| Diesel | 130 |
| Ethanol | 130 |
| Fuel oil, heavy | 130 |
| Gasoline | 130 |
| Heptane | 200 |
| Hexane | 200 |
| Hydrogen (Liquefied) | 70 |
| JP4 | 130 |
| Kerosine | 130 |
| LNG/Methane | 265 |
| LNG/Methane (water) | 265 |
| LPG/Propane | 250 |
| LPG/Propane (water) | 250 |
| Methanol | 70 |
| Pentane | 200 |
| Toluene | 130 |
| Xylene | 130 |

**Table 17: Maximum SEP values (Rew and Hulbert, 1996)**[18]

In practice, the actual SEP is related to the pool diameter and the flame height.

For pool fires, a two-layer solid flame model is considered to better represent the effects of pool fires than the single-point model. However, there is quite a lot of variation in methods for determining flame height, effect of soot, and the effective SEP of flames.

For consistency in TLUP advice, the following approach will be taken for pool fires and their off- site effects (which **may not be valid** for the assessment of near-field effects). The SEP of each flame layer of defined pool diameter will need to be adjusted from the maxima listed in Table 17, in order to account for the obscuration effects of soot (if any). The view factor(s) are also taken into account.

Flame height is to be calculated using a two-zone model (Rew et al., 1997) – an average surface emitted flux can be estimated based on the sum of thermal fluxes from a lower and upper layer. The emitted flux tends to decrease with increasing pool size.

For pool fire calculations, a value of 250 $kW/m^2$ for LPG and 265 $kW/m^2$ for LNG and methane gas will be used.

[18] Table B.1 of Rew and Hulbert (1996)

## 2.9 Jet fires

Jet fires are conservatively modelled as horizontal downwind releases in the standard approach, with the release direction uniformly distributed. The jet fire characteristics are based on the release being directed downwind.

A single-source release point is used for small tanks/pipelines, with risk points added as the length increases. The LOC frequency and dispersion modelling is spread over the number of release points.

## 2.10 Ignition probability

Unless otherwise indicated, the event frequencies used in the tables in Part 3 of this guidance include an assessment of the probability of ignition (that is, where the scenario includes the words ‘fire’ or ‘explosion’). Therefore, a separate ignition probability assessment is not required in the standard model. Generally, ignition probabilities (see below) and conditional event probabilities (see Part 3) are based on the Dutch National Institute for Public Health and the Environment publications (RIVM, 2009; RIVM, 2021), with a modification to take account of flammability categories changes introduced in the Classification, Labelling and Packaging Regulation (CLP)[19]. If the ignition probability for an accident scenario is not covered by the referenced publications, then other sources or expert judgement will be used.

The Guidance on the Application of the CLP Criteria (ECHA, 2024) gives this decision tree for flammable liquid classification:

[19] The Classification, Labelling and Packaging Regulation on classification, labelling and packaging of substances and mixtures amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006(EC) No 1272/2008.

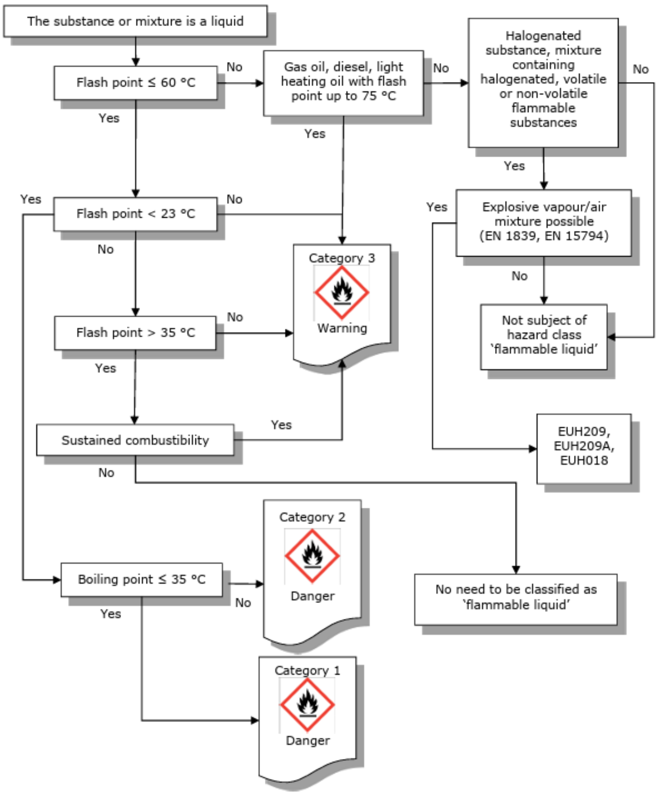



**Figure 6: GHS decision logic for flammable liquids (corresponding to Figure 2.3 from the ECHA Guidance on the Application of CLP Criteria, Version 1.0, November 2024)**

Ignition categories are then assigned as follows:

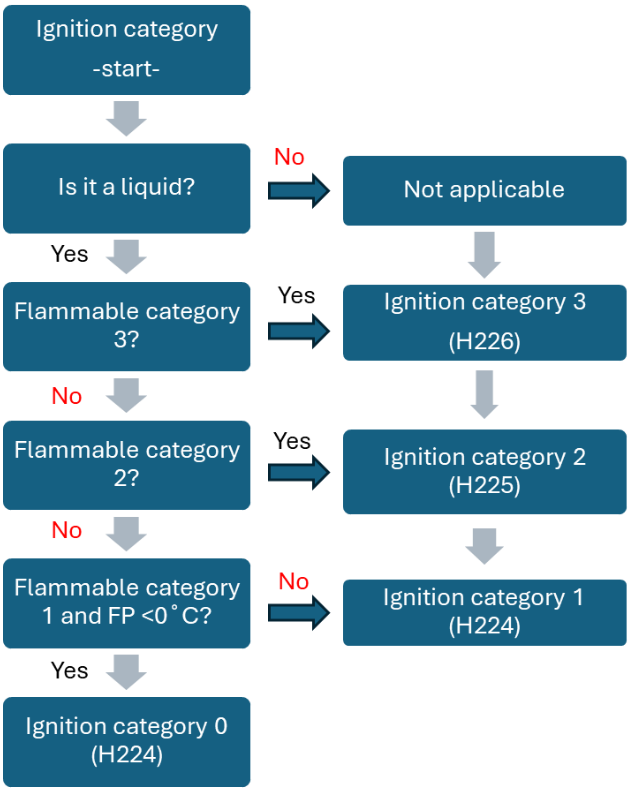



**Figure 7: Assignment of ignition category**

For the standard model, flammable liquid substances are categorised as follows:

| Ignition Category | Flash Point |
|---|---|
| 0 | FP < 0 °C, BP ≤ 35 °C |
| 1 | FP < 23 °C, BP ≤ 35 °C (excluding Category 0) |
| 2 | FP < 23 °C, BP > 35 °C |
| 3 | FP ≥ 23 °C and ≤ 60 °C* |

*For the TLUP ignition probability purposes, diesel and light heating oils having a flash point between 60°C and 75°C (inclusive) may be regarded as Ignition Category 3

**Table 18: Ignition categories for standard model**

Ignition is considered to either happen immediately or to be delayed for a short period – the modelled accident consequences reflect these two possibilities.

In the standard model, ignition probability depends on the flammability category of the dangerous substance (including flammable gases), as illustrated in Table 19 for fixed installations:

| Ignition Category | Immediate ignition | Delayed ignition |
|---|---|---|
| 0 (high reactivity) | 0.7 | 0.3 |
| 0 (low reactivity) | 0.09 | 0.91 |
| Liquid Category 1 | 0.065 | 0.935 |
| Liquid Category 2 | 0.01 | 0 |

| | | |
|---|---|---|
| Liquid Category 3 | 0 | 0 |

**Table 19: Conditional ignition probabilities for fixed installations**

Low-reactivity substances include methane, ammonia, and carbon monoxide. A substance is assigned to this category only if it is known to be of low reactivity.

Ignition probabilities for road transport unit (RTU) scenarios are treated as follows:

| Flammability | Immediate ignition | Delayed ignition |
|---|---|---|
| 0, instantaneous | 0.4 | 0.6 |
| 0, continuous | 0.1 | 0.9 |
| Liquid Category 1 | 0.065 | 0.935 |
| Liquid Category 2 | 0.01 | 0 |
| Liquid Category 3 | 0 | 0 |

**Table 20: Conditional ignition probabilities for RTU scenarios**

Note that in the above tables, for ignition categories 0 and 1, the total ignition probability is 1.

For gas (LPG/LNG) at jetties, the following are used:

| Release type | Immediate ignition | Delayed ignition |
|---|---|---|
| Continuous, large | 0.7 | 0.3 |
| Continuous, small | 0.5 | 0.5 |

**Table 11: Conditional ignition probability for gas (LPG or LNG) at a jetty**

Conditional delayed ignition probability is split into 0.4 for a VCE and 0.6 for a flash fire in the standard model.

## 2.11 BLEVEs / Fireballs

Boiling liquid expanding vapour explosions (BLEVEs) typically relate to flammable gases under excess pressure as a result of an externally applied heating source. If the containment fails catastrophically, an explosion overpressure and a fireball results.

As a result of the dominating effects of the fireball, it is used exclusively in determining BLEVE effects for TLUP. An SEP of 275 kW/m$^2$ for LPG is used in the standard model. No account is taken of fireball lift-off in the standard model calculations.

## 2.12 Flash fire

Flash fires are conservatively modelled as horizontal downwind releases in the standard approach.

The outdoor and indoor lethality for flash fires is based on the maximum extent of the LFL contour, as described in Sections 2.3.1 and 2.3.2.

## 2.13 More complex establishments

For complex sites, the installation-specific approaches, as outlined in Part 3 of this guidance, can be combined. For example, a pharmaceutical manufacturing/processing site may have a chemical warehouse, bulk flammable storage, toxic gas cylinders, and a synthesis plant and therefore each of these may have to be accounted for in the development of advice.

## 2.14 Limitations of a risk-based approach

While the risk-based approaches detailed in Part 3 of this guidance are not as comprehensive as QRAs, they are judged to fulfil the principles of robustness, consistency and transparency required for a TLUP advice system.

A risk-based approach inevitably involves assumptions concerning the frequency of accidents. However, this is preferable to the hazard-based approach, where it is implicitly assumed that the particular event chosen has a likelihood that is sufficient to be a cause for concern, but not so high as to make it unacceptable.

As the TLUP advice methodology focuses on off-site risk, it may underestimate the risk from lesser but more frequent events close to the source.

The field of risk assessment continues to develop, both in the understanding of the major accident events themselves and the criteria that should be used to assess such accidents. This guidance cannot be expected to cover every situation. It is intended to provide the basis for robust assessment, but there will, at times, be a need to refine particular aspects and to generally adapt to technical progress or to take account of particular local conditions and the HSA reserves this right for itself.

Caution is advised in attempting to use the approach described in this guidance for purposes other than TLUP advice because:

- The objective of the methodology relates to TLUP advice, which is external to the establishment and is future oriented: the assessment methods presented here are not sufficiently detailed to address risk to on-site populations and should not be used for that purpose.
- The system is designed to be used in its totality, and parts should not be mixed and matched with other systems, or be used out of this TLUP context, without clear and sufficient justification.

# Part 3: Method for specific sectors

## 3.1 LPG (Liquified Petroleum Gas) installations

### 3.1.1 Fixed installations

For fixed LPG installations, three LOC accident scenarios are modelled:

- an instantaneous loss of an entire vessel contents, resulting in a BLEVE/Fireball, a VCE and a flash fire;
- loss of the entire vessel contents over 10 minutes, resulting in a jet fire, a VCE and a flash fire;
- loss (over 30 minutes) through a hole sized to largest connection (or 10 mm hole if that is larger) resulting in a jet fire, a VCE and a flash fire.

The frequencies for each of these events (which include the ignition probabilities) are shown in Table 22.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-7}$ | BLEVE/Fireball | $3.5 \times 10^{-7}$ | 001 |
| | | VCE | $6 \times 10^{-8}$ | 002 |
| | | Flash fire | $9 \times 10^{-8}$ | 003 |
| Continuous leak over 10 minutes | $5 \times 10^{-7}$ | Jet fire | $3.5 \times 10^{-7}$ | 004 |
| | | VCE | $6 \times 10^{-8}$ | 005 |
| | | Flash fire | $9 \times 10^{-8}$ | 006 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Jet fire | $7 \times 10^{-5}$ | 007 |
| | | VCE | $1.2 \times 10^{-5}$ | 008 |
| | | Flash fire | $1.8 \times 10^{-5}$ | 009 |

**Table 22: Event frequencies for a single fixed LPG vessel**

### 3.1.2 Road transport units (RTUs)

For RTUs present in an establishment, two LOC events are considered:

- instantaneous loss of entire contents, leading to a BLEVE/fireball, a VCE, and a flash fire;
- loss of entire contents through the largest connection, resulting in a jet fire, a VCE and a flash fire.

The frequencies for each of these events (which include ignition probabilities) are shown in Table 23.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-7}$ | BLEVE/Fireball | $2 \times 10^{-7}$ | 010 |
| | | VCE | $1.2 \times 10^{-7}$ | 011 |
| | | Flash fire | $1.8 \times 10^{-7}$ | 012 |
| Loss of entire contents through largest connection | $5 \times 10^{-7}$ | Jet fire | $5 \times 10^{-8}$ | 013 |
| | | VCE | $1.8 \times 10^{-7}$ | 014 |
| | | Flash fire | $2.7 \times 10^{-7}$ | 015 |

**Table 23: Event frequencies for RTUs (per active unit on-site per year)**

The above frequencies should be adjusted for the proportion of the year that the laden RTU is present.

Some transport unit risks are also specifically associated with the on-site loading/unloading of LPG. Table 24 lists these LOC scenarios. The probabilities of jet fire, VCE and flash fire outcomes are taken as 10%, 36%, 54% respectively, based on the approach in Section 2 of this guidance.

| | Frequency ($hr^{-1}$) | | |
|---|---|---|---|
| LOC scenario | Arm | Hose | Event # |
| Rupture of loading/unloading arm/hose | $3 \times 10^{-8}$ | $4 \times 10^{-6}$ | 016 |
| Leak of loading/unloading arm/hose 10% of the diameter | $3 \times 10^{-7}$ | $4 \times 10^{-5}$ | 017 |

**Table 24: LOC scenarios for loading/unloading LPG operations**

Such leaks should be of short duration, due to blocking measures, and could be neglected on sites where the loading location is distant from the boundary. Additionally, the following domino effect should be considered for the duration of the loading operation:

| LOC scenario | Frequency ($hr^{-1}$) | Event # |
|---|---|---|
| BLEVE (hot) | $5.8 \times 10^{-10}$ | 018 |

**Table 25: BLEVE frequency for tanker loading operations**

The LOC scenarios in Table 24 and Table 25 relate to the hours engaged in actual loading/unloading activities.

### 3.1.3 Jetty

If a jetty charging/discharging LPG is within or adjacent to the establishment, a major accident during loading/ unloading operations will be taken into account. The scenarios modelled are for releases of 180 $m^3$ and 90 $m^3$ of LPG over 30 minutes.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Continuous leak of 180 $m^3$ over 30 minutes | $1.2 \times 10^{-4}$ | Jet fire | $8.4 \times 10^{-5}$ | 019 |
| | | VCE | $1.44 \times 10^{-5}$ | 020 |
| | | Flash fire | $2.16 \times 10^{-5}$ | 021 |
| Continuous leak of 90 $m^3$ over 30 minutes | $2.5 \times 10^{-2}$ | Jet fire | $1.25 \times 10^{-2}$ | 022 |
| | | VCE | $5 \times 10^{-3}$ | 023 |
| | | Flash fire | $7.5 \times 10^{-3}$ | 024 |

**Table 26: Event frequencies for an LPG jetty**

The LOC frequency figures in Table 26 are to be multiplied by $f_o$:

$f_o = N{*}T{*}t{*}6.7 \times 10^{-11}$, where T is the total number of ships on the transport route annually, t is the average unloading/loading duration (hours), and N is the number of transhipments per year.

The explosion volumes to be modelled in the multi-energy method are the stoichiometric volumes generated by these released gas volumes: 20% at strength 7 and 80% at strength 2.

### 3.1.4 Buried and fully mounded vessels

It is implicitly assumed in these figures that an establishment meets all the good practice standards required for an LPG installation (for example, by having a water deluge system or protective vessel coating) and there may be few, if any, cost-effective additional technical measures that will significantly reduce the extent of LUP risk-based zones. One possible risk reduction measure is to fully mound (or bury) the LPG vessels. In such circumstances, the likelihood of a BLEVE from an instantaneous failure is significantly reduced. This is reflected in Table 27.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-7}$ | Fireball | $1.05 \times 10^{-7}$ | 025 |
| | | Flash fire | $9 \times 10^{-8}$ | 026 |
| | | VCE | $6 \times 10^{-8}$ | 027 |
| Continuous leak over 10 minutes | $5 \times 10^{-7}$ | Jet fire | $3.5 \times 10^{-7}$ | 028 |
| | | VCE | $6 \times 10^{-8}$ | 029 |
| | | Flash fire | $9 \times 10^{-8}$ | 030 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Jet fire | $7 \times 10^{-5}$ | 031 |
| | | VCE | $1.2 \times 10^{-5}$ | 032 |
| | | Flash fire | $1.8 \times 10^{-5}$ | 033 |

**Table 27: Scenarios for mounded/buried LPG vessels**

Events # 031, 032 and 033 have lesser consequences than the other events but are more probable. It may be possible to omit them for sites where the inventory is distant from the establishment boundary.

### 3.1.5 Uncertainties in the LPG risk-based approach

The risk analysis method as described is somewhat simplistic and neglects smaller but more probable events, such as smaller vessel leaks and pipe leaks. Because the risk values generated are being used for off-site control purposes, this is considered to be a reasonable approach (and is also a reason why this methodology is not suitable for detailed on-site risk analysis).

## 3.2 LNG (Liquefied Natural Gas) installations

### 3.2.1 Fixed installations

LNG may be stored on its own or in association with LPG (see Section 3.1). Although LNG can be stored as a liquid (-161°C) at just above atmospheric pressure, it is more likely to be stored under significant pressure (up to 8–10 bar). The modelling scenarios are therefore similar to those for LPG, but greater allowance is made for pool fires because they are more probable when a LOC of cryogenic methane occurs.

This section does not address jetty operations, floating storage units (FSUs), or floating storage regasification units (FSRUs).

For fixed LNG installations (including transport containers manufactured according to the specifications outlined by the International Organization for Standardization (ISO containers) for the duration they are removed from a road transport cab), the following scenarios are modelled:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-7}$ | BLEVE/Fireball | $4.5 \times 10^{-8}$ | 034 |
| | | VCE | $9.1 \times 10^{-8}$ | 035 |
| | | Flash fire | $1.37 \times 10^{-7}$ | 036 |
| | | Pool fire | $2.28 \times 10^{-7}$ | 037 |
| Continuous leak over 10 minutes (total inventory) | $5 \times 10^{-7}$ | Jet fire | $4.5 \times 10^{-8}$ | 038 |
| | | VCE | $9.1 \times 10^{-8}$ | 039 |
| | | Flash fire | $1.37 \times 10^{-7}$ | 040 |
| | | Pool fire | $2.28 \times 10^{-7}$ | 041 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Jet fire | $9 \times 10^{-6}$ | 042 |
| | | VCE | $1.82 \times 10^{-5}$ | 043 |
| | | Flash fire | $2.73 \times 10^{-5}$ | 044 |
| | | Pool fire | $4.55 \times 10^{-5}$ | 045 |

**Table 28: Event frequencies for fixed LNG installations (per storage unit per year)**

Consideration must be given to any associated regasification units, if present, which are treated as heat exchangers. Table 29 lists the scenario and frequency.

| LOC scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Rupture of 10 pipes at the same time | $1 \times 10^{-6}$ | 046 |

**Table 29: Regasification unit scenario**

## 3.2.2 Road transport units (RTUs)

For ISO RTUs associated with delivery and transport of LNG, the scenarios are:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-7}$ | Fireball | $2 \times 10^{-7}$ | 047 |
| | | VCE | $6 \times 10^{-8}$ | 048 |
| | | Flash fire | $9 \times 10^{-8}$ | 049 |
| | | Pool fire | $1.5 \times 10^{-7}$ | 050 |
| Continuous leak over 10 minutes | $5 \times 10^{-7}$ | Jet fire | $5 \times 10^{-8}$ | 051 |
| | | VCE | $9 \times 10^{-8}$ | 052 |
| | | Flash fire | $1.35 \times 10^{-7}$ | 053 |
| | | Pool fire | $2.25 \times 10^{-7}$ | 054 |

**Table 30: Event frequencies for RTUs (per active unit on-site)**

The frequencies should be adjusted for the proportion of the year that the laden transport unit is present. RTU risks might also be specifically associated with the on-site loading/unloading of LNG. Table 31 lists the relevant LOC scenarios.

| | Frequency ($hr^{-1}$) | | |
|---|---|---|---|
| LOC scenario | Arm | Hose | Event # |
| Rupture of loading/unloading arm/hose | $3 \times 10^{-8}$ | $4 \times 10^{-6}$ | 055 |
| Leak of loading/unloading arm/hose 10% of the diameter | $3 \times 10^{-7}$ | $4 \times 10^{-5}$ | 056 |

**Table 31: LOC scenarios for loading/unloading LNG operations**

Additionally, the following domino effect must also be taken into account for loading/unloading activities:

| LOC scenario | Frequency ($hr^{-1}$) | Event # |
|---|---|---|
| Pool fire | $5.8 \times 10^{-9}$ | 057 |

**Table 32: Pool fire frequency for RTU loading operations**

The LOCs in both tables relate to the hours engaged in actual loading/unloading activities.

### 3.2.3 Uncertainties in LNG risk-based approach

The risk analysis method in Section 3.2 is somewhat simplistic, and it neglects smaller but more probable events such as smaller vessel leaks and pipe leaks. Because the risk values generated are being used for off-site control purposes, this is considered to be a reasonable approach.

## 3.3 Renewable natural gas (RNG) installations

This includes the activity of generating methane (biomethane) from anaerobic digesters. The gas within the digester should be considered as P2 Flammable Gas, and the entire volume of the digester dome should be included.

Digesters are considered to have failure frequencies equivalent to atmospheric storage vessels, since the pressure load is much less than 0.5 bar above atmospheric pressure.

Some sites upgrade and compress the gas for transport off-site. In this case, the upgraded gas should be treated as upgraded biogas in line with Note 19 to Schedule 1 of the COMAH Regulations 2015. The upgraded gas is also included in the scenarios used to develop TLUP contours.

If LPG or LNG are present on a site, then the methodology in Sections 3.1 and 3.2 must also be applied.

### 3.3.1 LOC scenarios

The following scenarios are modelled for each digester:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | Fireball* | $4.5 \times 10^{-7}$ | 058 |
| | | VCE | $1.64 \times 10^{-6}$ | 059 |
| | | Flash fire | $2.46 \times 10^{-6}$ | 060 |
| | | None | $4.55 \times 10^{-7}$ | 061 |
| Continuous leak over 10 minutes | $5 \times 10^{-6}$ | Jet fire | $4.5 \times 10^{-7}$ | 062 |
| | | VCE | $1.64 \times 10^{-6}$ | 063 |
| | | Flash fire | $2.46 \times 10^{-6}$ | 064 |
| | | Pool fire | $4.55 \times 10^{-7}$ | 065 |

**Table 33: Scenarios for flammable gas in digesters**

**For the instantaneous failure, the contents of the digester are assumed to be in a fireball centred on the digester – as the pressure drops from the initial jet fire, the flame propagates back to the digester.*

The pressure vessels containing the upgraded biogas are treated as follows:

| LOC scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Instantaneous release | $5 \times 10^{-7}$ | 066 |
| Release over 10 minutes | $5 \times 10^{-7}$ | 067 |
| Release through 10 mm pipe leak over 30 minutes | $1 \times 10^{-5}$ | 068 |

**Table 34: Scenarios for pressurised vessel of upgraded biogas**

## 3.4 Hydrogen installations

This section covers gaseous hydrogen in any type of pressurised vessel, it does not address jetty operations, or hydrogen stored as a liquid.

Hydrogen is typically stored as a compressed gas in pressurised vessels such as cylinders or tube trailers at pressures between 350 and 700 bar. Due to its small molecular size, it also has the potential to diffuse through containment structures. It has a very wide flammability range (4–75%) and extremely low minimum ignition energy.

Hydrogen is very readily ignitable (even by static spark from a person or by phenomenon such as shockwave auto ignition, where high pressure releases can self-ignite with no obvious sources of ignition) and can ignite at a wide range of concentrations and therefore, an ignition probability of 100% is considered to be a reasonable assumption for the purposes of LUP relating to major accidental releases.

A particular focus should be given to VCE consequences for hydrogen as these are expected to be more severe than other ignited events with their effects much further reaching. Explosions are also proven to be much more prevalent in hydrogen incident recordings than other types of events in comparison to conventional fuel releases.

Due to the emerging nature of the industrial scale generation, storage and use of hydrogen, it is recommended to use equipment failure frequencies described in this section, until a robust dataset specific for hydrogen is developed.

### 3.4.1 Fixed installations

For fixed hydrogen installations located outdoors (including, but not limited to, bulk storage vessels) the following scenarios should be modelled:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency ($yr^{-1}$) | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | VCE/Fireball | $5 \times 10^{-6}$ | 069 |
| Continuous leak over 10 minutes (total inventory) | $1 \times 10^{-5}$ | Jet fire | $7 \times 10^{-6}$ | 070 |
| | | VCE | $1.2 \times 10^{-6}$ | 071 |
| | | Flash fire | $1.8 \times 10^{-6}$ | 072 |
| 10 mm pipe leak over 10 minutes | $5 \times 10^{-4}$ | Jet fire | $3.5 \times 10^{-4}$ | 073 |
| | | VCE | $6 \times 10^{-5}$ | 074 |
| | | Flash fire | $9 \times 10^{-5}$ | 075 |

**Table 35: Event frequencies for outdoors bulk hydrogen storage (per vessel)**

As hydrogen is more likely to ignite immediately, in the case of an instantaneous failure, the worst-case consequence should be taken from either the fireball or VCE event.

The consequence frequencies in Table 35 for continuous leaks and pipe leaks are based upon a split of 70:30 between immediate and delayed ignition from fixed installations (given that hydrogen is best described as an ignition 0 (high reactivity) gas, with a 70% immediate ignition probability of a jet fire and a 40% probability of a VCE occurring instead of a flash fire scenario (RIVM, 2021).

For fixed hydrogen installations located indoors (including equipment such as electrolysers, heat exchangers, and compressors) the following scenarios should be modelled:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency ($yr^{-1}$) | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | VCE/Fireball | $5 \times 10^{-6}$ | 076 |
| Continuous leak over 10 minutes (total inventory) | $1 \times 10^{-5}$ | Jet fire | $7 \times 10^{-6}$ | 077 |
| | | VCE | $3 \times 10^{-6}$ | 078 |
| 10 mm pipe leak over 10 minutes | $5 \times 10^{-4}$ | Jet fire | $3.5 \times 10^{-4}$ | 079 |
| | | VCE | $1.5 \times 10^{-4}$ | 080 |

**Table 36: Event frequencies for indoor hydrogen equipment releases (per vessel/equipment)**

As hydrogen is more likely to ignite immediately, in the case of an indoor instantaneous failure, the worst-case consequence should be taken from either the fireball or VCE event.

The consequence frequencies in Table 36 are again based upon a split of 70:30 between immediate and delayed ignition from fixed installations (given that hydrogen is best described as an ignition 0 (high reactivity) gas) and 100% probability of VCE occurring instead of a flash fire scenario (which is considered reasonable given the large explosivity range of hydrogen).

It is noted that the frequency for the 10 mm pipe leak over 10 minutes includes allowance for failures from all associated pipework equipment and fittings, and hence it may be conservative for a simple installation.

### 3.4.2 Road transport units (RTUs)

For compressed gaseous hydrogen stored or transported in cylinder arrays by RTUs, the scenarios are:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency ($yr^{-1}$) | Event # |
|---|---|---|---|---|
| Instantaneous failure | N x (5 x $10^{-7}$) | VCE/Fireball | N x (5 x $10^{-7}$) | 081 |
| Loss of entire contents (complete cylinder array) through largest connection | N x (5 x $10^{-7}$) | Jet fire | N x (2 x $10^{-7}$) | 082 |
| | | Flash fire | N x (1.8 x $10^{-7}$) | 083 |
| | | VCE | N x (1.2 x $10^{-7}$) | 084 |

**Table 37: Event frequencies for RTUs on-site (per pressurised cylinder array with 'N' cylinders**)

As hydrogen is more likely to ignite immediately, in the case of an instantaneous cylinder failure, the worst-case consequence should be taken from either the fireball or VCE event.

The frequencies should be adjusted for the proportion of the year that the laden RTU is present. The consequence frequencies given in Table 37 are also applicable for hydrogen storage cylinder arrays which are not stored on RTUs.

The consequence frequencies in Table 37 for continuous releases are based upon a 60% probability of delayed ignition (in line with "Flammability 0, instantaneous" event for RTUs in Table 21) and a 40% probability of VCE occurring instead of a flash fire scenario (RIVM, 2021).

In addition to the risks associated with the presence of an RTU, as described above, there will also be risks associated with the on-site loading/unloading of hydrogen as detailed below:

| | Frequency ($hr^{-1}$) | | |
|---|---|---|---|
| LOC scenario | Arm | Hose | Event # |
| Rupture of loading/unloading arm/hose | 3 x $10^{-8}$ | 4 x $10^{-6}$ | 085 |
| Leak of loading/unloading arm/hose 10% of the diameter | 3 x $10^{-7}$ | 4 x $10^{-5}$ | 086 |

**Table 38: Event Frequencies for hydrogen loading/unloading operations**

### 3.4.3 Pipelines

LOC scenarios for hydrogen pipelines are considered to be analogous to that of natural gas due to the similarities in the way the fluids are carried in the pipeline and the likely causes of failure which could lead to pipeline LOC.

Refer to Table 39 and Table 40 covering LOC scenarios for over ground and underground natural gas pipelines within an establishment respectively.

However, consequence frequencies should assume a 100% ignition probability, 30% probability of delayed ignition, and a 40% probability of VCE occurring instead of a flash fire scenario as per Table 35 concerning outdoor releases from bulk hydrogen storage.

### 3.4.4 Hydrogen explosion modelling guidance

Given the ignitability of hydrogen (especially if it is released at high pressures), it is recommended to assume that all releases would be ignited leading to either an immediate or delayed event.

The likelihood of a significant detonation (with blast overpressures exceeding 10 bar in the near field) is much greater for hydrogen than for methane or LPG. Therefore, it is recommended to model a VCE of ignition strength 7 (with respect to the TNO multi-energy method (Van den Berg, 1985) for 40% of the total flammable cloud volume (or using a site specific estimate of volume) in an outdoors environment (i.e. representative of the outdoor scenarios listed in Table 35, Table 37, and Table 38).

The magnitude of an overpressure generated inside an enclosed space (i.e. representative of the scenarios listed in Table 36) should be based upon the entire volume of the enclosure filled at a flammable (stoichiometric) concentration with ignition strength of 7. There is potential for even small releases from hydrogen systems to fill enclosures to flammable levels especially given the high pressure at which the systems are maintained giving high release rates and hydrogen's large flammability range.

### 3.4.5 Uncertainties in the hydrogen risk-based approach

For TLUP purposes, the VCE and fireball events are located at the source. In addition, VCE consequences are expected to dominate other potential scenarios (such as jet fires or flash fires).

The risk analysis method as described in this section is somewhat simplistic and neglects smaller but more probable events, such as smaller vessel leaks and pipe leaks. Because the risk values generated are being used for off-site control purposes, this is considered to be a reasonable approach and is also a reason why this methodology is not suitable for detailed on-site risk analysis.

## 3.5 Natural gas pipelines within an establishment

This section describes the approach to be taken for establishments where there is a significant major accident risk associated with releases from on-site natural gas pipelines.

### 3.5.1 LOC scenarios and frequencies

Table 39 gives the LOC frequencies associated with pipework that will be used to develop standard TLUP advice.

| | Frequency ($m^{-1}\ yr^{-1}$) | | | |
|---|---|---|---|---|
| LOC scenario | D < 75 mm | 75 mm ≤ D ≥ 150 mm | D > 150 mm | Event # |
| Pipeline rupture | $1 \times 10^{-6}$ | $3 \times 10^{-7}$ | $1 \times 10^{-7}$ | 087 |
| Pipeline leak of 10% of the diameter (max 50 m) | $5 \times 10^{-6}$ | $2 \times 10^{-6}$ | $5 \times 10^{-7}$ | 088 |

**Table 39: LOC scenarios for overground pipes of varying diameters**

For underground pipes, an order of magnitude reduction is applied in the standard model and the following values are used:

| | Frequency ($m^{-1}\ yr^{-1}$) | | | |
|---|---|---|---|---|
| LOC scenario | D < 75 mm | 75 mm ≤ D ≥ 150 mm | D > 150 mm | Event # |
| Pipeline rupture | $1 \times 10^{-7}$ | $3 \times 10^{-8}$ | $1 \times 10^{-8}$ | 089 |
| Pipeline leak of 10% of the diameter (max 50 m) | $5 \times 10^{-7}$ | $2 \times 10^{-7}$ | $5 \times 10^{-8}$ | 090 |

**Table 40: LOC scenarios for underground pipes of varying diameters**

The concern for TLUP purposes is primarily with the effects on humans, but environmental effects should not be disregarded. Modelling will use typical atmospheric stability conditions ($D_5/F_2$).

Natural gas pipeline ruptures and leaks are assumed to be continuous rather than instantaneous. The consequences associated with the LOCs are fireballs/jet fires, flash fires, and VCEs. Because methane is categorised as being of low reactivity TNO (1997), the immediate ignition probability is low; therefore, a fireball/jet fire is a less likely event than might be expected. The conditional probabilities for a flammable gas release from a pipeline, based on the event tree in RIVM (2021), are shown in Table 41.

| Event | Conditional probability |
|---|---|
| Fireball / Jet Fire | 0.1 |
| Flash Fire | 0.9 x 0.6 = 0.54 |
| VCE | 0.9 x 0.4 = 0.36 |

**Table 41: Conditional probabilities for fire and explosion from gas release**

## 3.6 Flammable liquid storage installations

The non-environmental specific scenarios considered are pool fire, VCE, and flash fire. If the flammable substance is also toxic, then toxic effects on people must also be considered, as well as relevant environmental scenarios.

According to the CLP Regulation, flammable liquids consist of three categories with associated hazard (H) Statements. These are set out in Table 42.

| Category | Criteria | H Statement |
|---|---|---|
| 1 | Flash point < 23 °C and initial boiling point ≤ 35 °C | 224 |
| 2 | Flash point < 23 °C and initial boiling point > 35 °C | 225 |
| 3 | Flash point ≥ 23 °C and ≤ 60 °C (1) | 226 |

(1) For the purpose of this Regulation gas oils, diesel and light heating oils having a flash point between ≥ 55 °C and ≤ 75 °C may be regarded as Category 3.

**Table 42: CLP classification of flammable substances**

Ignition probabilities for flammable liquids at ambient temperature are discussed in Section 2.10 of this guidance. Figure 7 and Tables 18, 19 and 20 should be referred to for assignment of ignition category.

### 3.6.1 Ignition category 0 substances and mixtures

There are very few flammable liquids that fall into ignition category 0, but crude oil, gasoline, pentane, and diethyl ether are examples of substances that will probably fall into this category (relevant safety data sheet (SDS) should be consulted for physical data).

Operators are expected to comply with good practice and to have implemented all of the recommendations in the final report into the Buncefield accident (UK HSE, 2007)[20].

Where a storage tank has the potential for such events, based on the criteria specified in the Process Safety Leadership Group report (UK HSE, 2009), the approach adopted by the HSA for LUP purposes is to consider an additional event involving an explosion with a frequency of $10^{-5}$ per year per tank. The consequences of the explosion are based on the cloud having a radius of 150 m, a height of 3 m and centred on the nearest part of the bund to the receptor. Overpressures within the cloud radius are very high and result in 100% lethality, and beyond this distance the overpressure is based on the correlation of Johnson and Allason (2014).

Some simplification has been made in the number of LOC scenarios, with early and late pool fires being consolidated into a single event, for example. It may be possible to ignore LOC scenarios with limited off-site impact on sites with many hazard sources. However, such events should be considered when assessing significant modifications and, for TLUP, where the (initial) CD does not extend off-site.

For a single containment atmospheric storage tank storing ignition category 0 substance/mixture, the LOC event frequencies are:

[20] *The Buncefield Incident 11 December 2005 The final report of the Major Incident Investigation Board*, HSE Books (2007)

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | Pool fire | $9.96 \times 10^{-7}$ | 091 |
| | | VCE | $1.82 \times 10^{-6}$ | 092 |
| | | Flash fire | $5.46 \times 10^{-7}$ | 093 |
| | | None/toxic | $1.64 \times 10^{-6}$ | 094 |
| Failure over 10 minutes | $5 \times 10^{-6}$ | Pool fire | $9.96 \times 10^{-7}$ | 095 |
| | | VCE | $1.82 \times 10^{-6}$ | 096 |
| | | Flash fire | $5.46 \times 10^{-7}$ | 097 |
| | | None/toxic | $1.64 \times 10^{-6}$ | 098 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Pool fire | $1.99 \times 10^{-5}$ | 099 |
| | | VCE | $3.64 \times 10^{-5}$ | 100 |
| | | Flash fire | $1.09 \times 10^{-5}$ | 101 |
| | | None/toxic | $3.28 \times 10^{-5}$ | 102 |

**Table 43: Event frequencies for ignition category 0 flammable liquids**

The toxic events in Table 43 are only relevant if the substance carries a H300/310/330/370 classification.

Instantaneous tank failure will most likely lead to bund overtopping, which means that the first scenarios in Table 43 occur both inside and outside the bund. The overtopping percentage is based on actual site conditions, with 50% assumed by default. The overtop pool size is based on site conditions and modelling parameters, but the pool diameter modelled is never greater than 100 m.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure - overtop | $5 \times 10^{-6}$ | Pool fire | $9.96 \times 10^{-7}$ | 103 |
| | | VCE | $1.82 \times 10^{-6}$ | 104 |
| | | Flash fire | $5.46 \times 10^{-7}$ | 105 |
| | | None/toxic | $1.64 \times 10^{-6}$ | 106 |

**Table 44: Event frequencies for overtop scenarios, ignition category 0 flammable liquids**

The magnitude of the overpressure generated by the VCE is that arising from a cloud volume based on a stoichiometric burning ratio of the vapourised liquid, by default with an ignition strength of 7 for 20% of the volume and a combustion energy of 3.5 MJ/$m^3$, using the TNO multi-energy method (Van den Berg, 1985).

Where a failure can lead to a liquid pool spreading offsite, where there may be uncontrolled ignition sources, the pool fire approach in Section 2.7 is adopted with an ignition probability of 50% assumed for ignition category 0 substances.

### 3.6.2 Ignition category 1 substances and mixtures

The majority of CLP category 1 flammable liquids fall into ignition category 1. Operators are expected to comply with good practice and to have implemented all the recommendations in the final report into the Buncefield accident. The risks associated with potential Buncefield type events should be assessed as described in Section 3.6.1.

The scenarios to be modelled are:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | Pool fire | $8.86 \times 10^{-7}$ | 107 |
| | | VCE | $1.87 \times 10^{-6}$ | 108 |
| | | Flash fire | $5.61 \times 10^{-7}$ | 109 |
| | | None/toxic/MATTE | $1.68 \times 10^{-6}$ | 110 |
| Failure over 10 minutes | $5 \times 10^{-6}$ | Pool fire | $8.86 \times 10^{-7}$ | 111 |
| | | VCE | $1.87 \times 10^{-6}$ | 112 |
| | | Flash fire | $5.61 \times 10^{-7}$ | 113 |
| | | None/toxic/MATTE | $1.68 \times 10^{-6}$ | 114 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Pool fire | $1.77 \times 10^{-5}$ | 115 |
| | | VCE | $3.74 \times 10^{-5}$ | 116 |
| | | Flash fire | $1.12 \times 10^{-5}$ | 117 |
| | | None/toxic/MATTE | $3.37 \times 10^{-5}$ | 118 |

**Table 45: Event frequencies for ignition category 1 flammable liquids**

The magnitude of the overpressure generated by a VCE in Table 45 is that arising from a cloud volume based on a stoichiometric burning volume of the vapourised liquid, by default with ignition strength of 7 for 20% of the volume, assumed to be confined, and a combustion energy of 3.5 MJ/m$^3$, using the TNO multi-energy method (Van den Berg, 1985).

Instantaneous tank failure will most likely lead to bund overtopping, which means that the first scenarios occur both inside and outside the bund. The overtopping percentage is based on actual site conditions, with 50% assumed by default. The overtop pool size is based on site conditions and modelling parameters, but the pool diameter modelled is never greater than 100 m. The overtop scenarios are listed in Table 46.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure - overtop | $5 \times 10^{-6}$ | Pool fire | $8.86 \times 10^{-7}$ | 119 |
| | | VCE | $1.87 \times 10^{-6}$ | 120 |
| | | Flash fire | $5.61 \times 10^{-7}$ | 121 |
| | | None/toxic/MATTE | $1.68 \times 10^{-6}$ | 122 |

**Table 46: Event frequencies for overtop scenarios, ignition category 1 flammable liquids**

Where a failure can lead to a liquid pool spreading offsite, where there may be uncontrolled ignition sources, the pool fire approach in Section 2.7 is adopted with an ignition probability of 50% assumed for ignition category 1 substances.

### 3.6.3 Ignition category 2 substances and mixtures

Ignition probabilities for category 2 substances are very low. Pool fire is the only scenario of relevance for this category, provided it is not in the same bund as CLP category 1 substances. For TLUP purposes, accidents to the environment must also be considered. Other fire and explosion events are not considered for category 2 substances unless they are co-located with category 1, in which case they could be modelled as category 1.

Many flammable liquids have flash points of less than 23°C and a boiling point above 35°C.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | Pool fire | $5 \times 10^{-8}$ | 123 |
| | | None/toxic/MATTE | $4.95 \times 10^{-6}$ | 124 |
| Failure over 10 minutes | $5 \times 10^{-6}$ | Pool fire | $5 \times 10^{-8}$ | 125 |
| | | None/toxic/MATTE | $4.95 \times 10^{-6}$ | 126 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Pool fire | $1 \times 10^{-6}$ | 127 |
| | | None/toxic/MATTE | $9.9 \times 10^{-5}$ | 128 |

**Table 47: Event frequencies for ignition category 2 flammable liquids**

An overtop pool fire is also modelled at a frequency of $5 \times 10^{-8}$ per tank if the pool remains onsite.

Where a failure can lead to a liquid pool spreading offsite, where there may be uncontrolled ignition sources, the pool fire approach in Section 2.7 is adopted with an ignition probability of 10% assumed for ignition category 2 substances.

### 3.6.4 Ignition category 3 substances and mixtures

Ignition probabilities for category 3 substances are zero. Fire and explosion events are not considered for category 3 substances, unless they are co-located in the same bund as category 1 or category 2 substances, in which case they could be modelled as category 1 or category 2 substances.

Failure to retain spilled material on-site means that prevention of ignition will no longer be within the control of the operator of an establishment and therefore the approach outlined above, in relation to ignition probability, does not apply and pool fires do have to be modelled. Operators generally do not have control of areas outside the establishment, so an overtop pool running off-site means that control of ignition sources, physical effects, and effects on third parties require consideration and a pool fire and its consequences will have to be modelled.

Clearly, a MATTE is a major consideration in such circumstances. As described in Section 1.8, a preventive approach is preferred regarding MATTEs.

Provided that there are no other flammable substances on the site, or in the vicinity, close enough to initiate a major accident and it is clear that any credible spill will remain on-site, the probability of a category 3 fire will not be considered credible. However, where a failure can lead to a liquid pool spreading offsite, where there may be uncontrolled ignition sources, the pool fire approach in Section 2.7 is adopted with an ignition probability of 10% assumed for Ignition category 3 substances.

### 3.6.5 Road transport units (RTUs) in an establishment

RTUs are taken into account in the scenarios listed in Table 48 and Table 49.

For ignition category 0:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | 1 x $10^{-5}$ | Pool fire | 4.36 x $10^{-6}$ | 129 |
| | | VCE | 2.4 x $10^{-6}$ | 130 |
| | | Flash fire | 2.88 x $10^{-6}$ | 131 |
| | | None/toxic/MATTE | 3.6 x $10^{-7}$ | 132 |
| Failure over 10 minutes | 5 x $10^{-7}$ | Pool fire | 7.7 x $10^{-8}$ | 133 |
| | | VCE | 1.8 x $10^{-7}$ | 134 |
| | | Flash fire | 2.16 x $10^{-7}$ | 135 |
| | | None/toxic/MATTE | 2.7 x $10^{-8}$ | 136 |

**Table 48: Event frequencies for ignition category 0 liquid transport units, per unit per year, proportionally**

For ignition category 1:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | 1 x $10^{-5}$ | Pool fire | 1.21 x $10^{-6}$ | 137 |
| | | VCE | 3.74 x $10^{-6}$ | 138 |
| | | Flash fire | 4.49 x $10^{-6}$ | 139 |
| | | None/toxic/MATTE | 5.61 x $10^{-7}$ | 140 |
| Leak from largest connection | 5 x $10^{-7}$ | Pool fire | 6.06 x $10^{-8}$ | 141 |
| | | VCE | 1.87 x $10^{-7}$ | 142 |
| | | Flash fire | 2.24 x $10^{-7}$ | 143 |
| | | None/toxic/MATTE | 2.81 x $10^{-8}$ | 144 |

**Table 49: Event frequencies for ignition category 1 liquid transport units, per unit per year, proportionally**

For ignition category 2, only direct ignition scenarios are considered; therefore, only pool fire, toxic and MATTE risks are considered, as shown in Table 50.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | 1 x $10^{-5}$ | Pool fire | 1 x $10^{-7}$ | 145 |
| | | None/toxic/MATTE | 9.9 x $10^{-6}$ | 146 |
| Leak from largest connection | 5 x $10^{-7}$ | Pool fire | 5 x $10^{-9}$ | 147 |
| | | None/toxic/MATTE | 4.95 x $10^{-8}$ | 148 |

**Table 50: Event frequencies for ignition category 2 flammable liquid RTUs**

The frequencies should be adjusted for the proportion of the year that the transport unit is present.

The following scenarios are taken into account for all road tanker loading/unloading operations, as shown in Table 51.

| LOC scenario | Frequency ($hr^{-1}$) | | Event # |
|---|---|---|---|
| | Arm | Hose | |
| Rupture of loading/unloading arm/hose | $3 \times 10^{-8}$ | $4 \times 10^{-6}$ | 149 |
| Leak of loading/unloading arm/hose 10% of the diameter | $3 \times 10^{-7}$ | $4 \times 10^{-5}$ | 150 |

**Table 51: LOC scenarios for loading/unloading operations, road tanker**

The figures in Table 51 are for the LOC scenario only; therefore, the ignition probability then must be factored in. Additionally, failure due to a road tanker domino effect must be included, as shown in Table 52.

| Scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Pool fire | $5.8 \times 10^{-9}$ | 151 |

**Table 52: LOC related to domino effect for road tanker**

Modelled pool fire diameters for road tankers should never exceed 100 m.

### 3.6.6 Key technical measures for new installations

It is anticipated that new flammable liquid storage installations will install double-skin containment tanks or full containment tanks. Double-skinned tanks will likely represent the lowest risk and eliminate MATTEs from consideration and therefore comfortably fit within the 'all necessary measures' that COMAH operators must take. If operators choose not to take this route to compliance, they must demonstrate, through cost-benefit analysis, that all necessary measures have been achieved by alternative means.

LOCs scenarios and frequencies for double containment tanks are given in Table 53.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Event # |
|---|---|---|---|
| Instantaneous failure of primary container and outer shell | $1.25 \times 10^{-8}$ | Release of the entire contents | 152 |
| Instantaneous failure of primary container | $5 \times 10^{-8}$ | Release of the entire contents into the intact outer shell | 153 |
| Failure of primary container and outer shell | $1.25 \times 10^{-8}$ | Release of the entire contents in 10 minutes in a continuous and constant stream | 154 |
| Failure of primary container | $5 \times 10^{-8}$ | Release of the entire contents in 10 minutes in a continuous and constant stream into the intact outer shell | 155 |

| | | | |
|---|---|---|---|
| Failure of primary container | 1 x $10^{-4}$ | Continuous release from a hole with an effective diameter of the largest connection into the intact outer shell | 156 |

**Table 53: LOC scenarios for double containment atmospheric storage tanks**

### 3.6.7 Major accidents to the environment in this sector

In addition to the measures in place to minimise the risks to people, adequate tertiary containment should be provided, so that the contents of the largest tank and all the expected extinguishing media can be contained in the event of a major fire[21].

CLP category 2 and category 3 flammable liquids are generally more likely to carry an environmental hazard rating than category 1 flammables. The most important major accident consideration for category 3 storage is a LOC leading to a release of the dangerous substance into the environment.

## 3.7 Fertiliser storage installations

The main sources of off-site risk for this sector are associated with the blending/storage of fertiliser-grade ammonium nitrate (named dangerous substances 1 to 4 in Part 2 of Schedule 1 of the COMAH Regulations 2015). For TLUP purposes, the events to consider are a major fire leading to a plume of toxic smoke capable of travelling some distance off-site and also, if the fire leads on to a detonation, from blast overpressure effects.

Typically, the qualifying inventories at a fertiliser blending plant belong to ammonium nitrate named substance 2, which fulfils the resistance to detonation requirements of Regulation EU 2019/1009 (with thresholds of 1250 and 5000 tonnes). This will be referred to as fertiliser-grade ammonium nitrate (FGAN).

Ammonium nitrate named dangerous substances 1, 3 and 4 are not normally encountered and are not addressed here.

As FGAN is not combustible, a major accident would have to be initiated by other sources; this could be a fire involving contaminants such as wood or other combustible material, or a road transport vehicle, for example. Local conditions (that is, the possibility of these contaminants being present) will influence the scenario probabilities.

The effect of fire on FGAN is to cause it to decompose, releasing toxic gases. The toxic gases modelled are nitrous oxide (NO) and nitrogen dioxide ($NO_2$). Therefore, one scenario addresses off-site dispersion of these fire-generated gases.

FGAN detonation requires the formation of a pool of molten ammonium nitrate, caused by the heat input from a fire, a confined state and the initiation of an explosion by some mechanism (for

[21] EPA (2019) provides guidance on firewater retention.

example, from impact by a high-energy object). Due to the explosion resistance of FGAN, a route to detonation is extremely improbable and the accident frequencies reflect this. However, detonation following a fire on a truck is considered a more credible scenario. While missile generation following detonation is credible, the off-site risk of missile impact in any single location is judged to be small.

The most likely MATTE relates to a fire/fire-water run-off scenario, and appropriate retention facilities should be in place.

### 3.7.1 Approach to source terms

A fire scenario should be considered where FGAN is stored on palletised stacks in the yard. For fire modelling purposes, 300 tonnes (300 t) of FGAN (the maximum stack size recommended by good practice) is taken as the largest mass likely to be involved in a fire and therefore in subsequent detonation. For that purpose, it is taken to be equivalent to 42 tonnes (42 t) of trinitrotoluene (TNT). Therefore, 30 t FGAN is equivalent to 4.2 t TNT.

Generally, smaller fires (10% of total mass) are considered to be almost two orders of magnitude more likely than fires involving the full inventory. Progression to detonation is considered to be almost two orders of magnitude less likely for the full 300 t stack than for 10% of the stack.

Fertiliser truck fires are modelled as involving the maximum possible inventory (~30 t) of palletised ammonium nitrate fertiliser or, for loose material, the maximum inventory that can be carried by the truck.

When modelling the generation of fumes of toxic $NO_2$ from a fire inside a warehouse, the initial fire situation, before the roof collapses, is of most interest, due to the potential for higher ground-level concentrations. Once the fire develops and the roof collapses, the heat-induced buoyancy means that ground-level concentrations will be insignificant, except in very high winds.

The wind-stability pairs of $F_2$, $D_5$ are typically used for modelling. However, buoyancy calculations (Briggs lift-off criterion equation; Hanna *et al.*, 1998) generally allow $F_2$ conditions to be discarded for modelling purposes.

While $D_{10}$ conditions could be included to account for high winds, a somewhat simpler approach is taken in the standard model, which gives a degree of conservatism to the resulting risk figures the release is modelled as a passive dispersion in $D_5$ conditions, using a Gaussian model.

Toxic gas release rates in fires are as follows: 1.4 kg $s^{-1}$ of $NO_2$ and 2.3 kg $s^{-1}$ of NO for the worst-case (300 t) scenario.

### 3.7.2 Scenarios and frequency of occurrence

In the standard model, FGAN is considered to be present all year round. The main accident scenarios considered are shown in Table 54.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Fire started in truck | $4.02 \times 10^{-4}$ | 30 t explosion | $4.02 \times 10^{-5}$ | 157 |
| | | 30 t fire | $3.62 \times 10^{-4}$ | 158 |
| Fire started in stack | $1.98 \times 10^{-4}$ | 30 t fire | $1.94 \times 10^{-4}$ | 159 |
| | | 30 t explosion | $1.96 \times 10^{-6}$ | 160 |
| | | 300 t fire | $1.96 \times 10^{-6}$ | 161 |
| | | 300 t explosion | $1.98 \times 10^{-8}$ | 162 |

**Table 54: FGAN (ammonium nitrate, named dangerous substance 2) yard scenarios**

Truck fire frequencies are given as per truck transporting FGAN. Allowance is made for the fraction of time the activity happens during a year. For example, assuming a truck delivery of bulk FGAN takes 15 minutes (0.25 of an hour) and there are 400 transports per year, this results in a frequency figure of $((0.25 \times 400)/8760) \times (4.02 \times 10^{-4})$, or $4.59 \times 10^{-6}$ per year.

Fire frequency is per bulk stack per year, which can be adjusted for the fraction of a year that a bulk stack is present, as shown in Table 55.

For the warehouse (after assigning a frequency of $1.44 \times 10^{-4}$ per year to non-escalating events):

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Fire started in bulk stack | $4.56 \times 10^{-4}$ | 30 t fire | $4.47 \times 10^{-4}$ | 163 |
| | | 30 t explosion | $4.51 \times 10^{-6}$ | 164 |
| | | 300 t fire | $4.51 \times 10^{-6}$ | 165 |
| | | 300 t explosion | $4.56 \times 10^{-8}$ | 166 |

**Table 55: FGAN (ammonium nitrate, named dangerous substance 2) warehouse scenarios**

The fraction of the year that the bulk material is present should be factored into the calculation. Risks sources are centred on the FGAN storage and operation areas.

This guidance utilises one approach to FGAN scenario modelling. Ten consequence events are listed but, in reality, this can be reduced to four events – a 30 t fire plus explosion and a 300 t fire plus explosion – which are repeated at varying locations.

## 3.8 Dangerous substance warehouses

Generally, the off-site risks associated with the most foreseeable accidents in chemical warehouses are negligible, as the quantities involved in any LOC tend to be limited (for example, single inventory containments up to about 0.2 $m^3$ for a single drum or 1 $m^3$ for an intermediate bulk container (IBC)). Road transport containers such as ISO road transport containers can be treated as described in Sections 3.1.2, 3.2.2, and 3.6.5 as appropriate. Substances which are particularly toxic (gases or volatile liquids) may require additional consideration (see Section 3.10).

The most common off-site risk in this sector, for TLUP advice generation, is the risk associated with a major fire, involving the release of hazardous substances from multiple containers. This could lead to a plume of toxic smoke capable of travelling some distance.

Where there is significant storage of flammable substances, the near-field thermal effects of a fire should also be considered.

### 3.8.1 Approach to source terms

Assuming that the warehouse does not contain any particularly toxic materials (such as pesticides or toxic agrochemicals capable of being released unburned in the fire plume), then the main risk will be associated with dispersion of toxic combustion products.

However, it is difficult to predict the precise mix and quantity of each toxic combustion product: the approach taken is to assume that the toxicity of the fire plume can be represented by an equivalent release rate of the most significant toxic combustion product. This could be, for example, nitrogen dioxide ($NO_2$), hydrogen chloride (HCl), or sulphur dioxide ($SO_2$), hydrogen cyanide (HCN), hydrogen bromide (HBr), depending on the chemical substance composition within the warehouse.

Carbon monoxide (CO) and carbon dioxide ($CO_2$) could also be released in significant quantities, as they could in all fires involving organic substances; therefore, no emphasis is placed on assessing CO or CO2 levels.

For warehouses storing complex mixtures of dangerous substances, representative release rates for $NO_2$, HCl, $SO_2$ and any other dominant toxic combustion products must be determined. Porter *et al*. (2000) made the following useful general assumptions:

| Contains | Toxic combustion product | Conversion rate (%) |
|---|---|---|
| N | $NO_2$ | 5 |
| N | HCN | 1.5 |
| Cl | HCl | 100 |
| S | $SO_2$ | 100 |
| Br | HBr | 100 |

**Table 56: Toxic combustion conversion rates**

Therefore, in a fire involving a dangerous substance containing nitrogen, the release rate of $NO_2$ can be estimated by assuming that 5% of the nitrogen content (Table 56) of the dangerous substances stored in the warehouse is combusted to form $NO_2$ which is then dispersed.

**Example:** for a large warehouse storing 2500 tonnes of ammonium chloride ($NH_4Cl$), molecular weight (MW) = 53.49, the release rates of $NO_2$ (MW = 46) and HCl (MW = 36.46), from a major fire involving 100% of the inventory, can be calculated as follows (assuming 5% of N converted to $NO_2$, and 100% of Cl converted to HCl, as shown in Table 56):

$NO_2$ release rate = 2,500,000 × (14/53.49 × 0.05) × (46/14) = 108,000 kg

HCl release rate = 2,500,000 × (35.45/53.49 × 1.0) × (36.46/35.45) = 1,699,200 kg

In most weather conditions, the hot plume of smoke from the fire will be buoyant, and is likely to rise into the atmosphere, resulting in relatively little risk at ground level. Therefore, for the purposes of TLUP risk assessment, it is necessary only to consider relatively high wind speed conditions, which generally occur for a small percentage of the time. However, as with fertiliser fires, the simpler and more conservative standard model approach is to model as a passive Gaussian dispersion in $D_5$ conditions.

The standard model assumes that, for a large warehouse, the fire inventory is released over 2 hours (but only the first 30 minutes of this are modelled for dose calculation), using a standard Gaussian plume model, with no plume rise.

So, in this example, a fire in a large warehouse involving 100% of the inventory gives the following release rates:

$NO_2$ release = (108,000 / (2 × 60)) × 30 = 27,000 kg = 27,000 kg over 30 minutes = 15 kg/sec

HCl release = (1,699,200 / (2 × 60)) × 30 = 424,800 kg = 424,000 kg over 30 minutes = 236 kg/sec

Where several toxic combustion products arise from a fire, it will be necessary to consider the relative release rates and toxicities to determine whether a particular component is clearly dominant. Otherwise, it may be necessary to calculate an increased 'equivalent' release rate for the most significant component.

### 3.8.2 Fire frequency

The likelihood of fires starting in typical warehouses has been estimated at about $10^{-2}$ per year, based on historical evidence (Hymes and Flynn, 1982; Hockey and O'Donovan, 1997). However, the majority of such fires are relatively minor or are rapidly controlled, and only a small proportion escalate to become major fires, with data from Hockey and O'Donovan (1997), suggesting a frequency of about $10^{-3}$ per year for a large fire in a typical warehouse. However, for the warehouse type holding hazardous substances, it is assumed that the more stringent controls would result in a reduction in the likelihood of such major events (involving the entire warehouse), typically an order of magnitude lower still, at about $10^{-4}$ per year. The higher frequency of $10^{-3}$ per year is assigned to a lesser fire involving just 10% of the source term, which is the following:

| Scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Fire (10% of inventory) | $1 \times 10^{-3}$ | 167 |
| Fire (100% of inventory) | $1 \times 10^{-4}$ | 168 |

**Table 57: Fire frequency for warehouse**

Warehouses with sprinklers are considered to have a reduced frequency of fire, but data supporting reduced frequency estimation are limited (Frank *et al*., 2013). For the standard model, small fire frequency is reduced by one order of magnitude and large fires by a factor of two, as shown in Table 58.

| Scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Fire (10% of inventory) | $1 \times 10^{-4}$ | 169 |
| Fire (100% of inventory) | $5 \times 10^{-5}$ | 170 |

**Table 58: Warehouse (sprinkler) fire frequencies**

## 3.9 Chemical/Pharmaceutical installations

Chemical/pharmaceutical manufacturing/processing plants are likely to contain multiple hazard sources, often distributed around a large site. Hazards are likely to include those related to:

- bulk flammable storage

- dangerous substance warehousing
- bulk storage and processing of toxics and flammables
- overpressure and explosion related to processing
- releases from pressurised drums of toxic and flammable gases.

The risks associated with flammable storage and warehousing generally can be assessed using the methods described elsewhere in this document; therefore, only risks from process hazards are considered in more detail in this section. For sites with multiple hazards, risks should be aggregated.

A key point to note for chemical processing sites is that the dangerous substances in-process may be at elevated temperatures and pressures; therefore, the likelihood of relatively small releases leading to a significant major accident is considerably increased. Furthermore, the hazardous substances that could be released from a process may include reaction products (and by-products) and not simply the raw materials or intended final products.

The general methods outlined here can also be applied to other establishment types with process hazards and/or multiple hazards.

## 3.9.1 Risks from atmospheric bulk storage of toxic (and water-reactive) liquids

Section 3.6 addressed LOC scenarios related to the bulk storage of flammable liquids. For sites with atmospheric bulk storage of non-flammable toxic (or water-reactive) liquids, the same base LOC figures can be used, with modified consequences, as follows:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | Pool evaporation + vapour dispersion (bund) | $5 \times 10^{-6}$ | 171 |
| | | Pool evaporation + vapour dispersion (overtop) | $5 \times 10^{-6}$ | 172 |
| Failure over 10 minutes | $5 \times 10^{-6}$ | Pool evaporation + vapour dispersion | $5 \times 10^{-6}$ | 173 |
| 10mm pipe leak over 30 minutes | $1 \times 10^{-4}$ | Pool evaporation + vapour dispersion | $1 \times 10^{-4}$ | 174 |

**Table 59: LOC scenarios and frequencies for bulk toxic storage**

Adequate bunds are assumed to be present, as required by good practice. For instantaneous failure, it is assumed that a pool forms outside the bund; by default, this is assigned 50% of the tank contents. Overtop pools are assigned an upper pool diameter limit of 100 m.

Truck deliveries may also need to be considered, as described in Table 60.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $1 \times 10^{-5}$ | Pool evaporation + vapour dispersion | $1 \times 10^{-5}$ | 175 |
| | | Pool evaporation + vapour dispersion (if overtop is relevant) | $1 \times 10^{-5}$ | 176 |
| Failure over 10 minutes | $5 \times 10^{-7}$ | Pool evaporation + vapour dispersion | $5 \times 10^{-7}$ | 177 |

**Table 60: Road tanker delivery LOC scenarios**

In addition, the scenarios in Table 61 can be taken into account for loading/unloading operations:

| LOC scenario | Frequency ($hr^{-1}$) | | Event # |
|---|---|---|---|
| | Arm | Hose | |
| Rupture of loading/unloading arm/hose | $3 \times 10^{-8}$ | $4 \times 10^{-6}$ | 178 |
| Leak of loading/unloading arm/hose 10% of the diameter | $3 \times 10^{-7}$ | $4 \times 10^{-5}$ | 179 |

**Table 61: Road tanker loading/unloading LOC scenarios**

Additionally, failure due to LOC in a domino effect during unloading has to be included as in Table 62.

| Scenario | Frequency ($hr^{-1}$) | Event # |
|---|---|---|
| Pool evaporation | $5.8 \times 10^{-9}$ | 180 |

**Table 62: Road tanker domino toxic LOC**

Evaporation release rates from pools can be calculated using standard evaporation models (in $D_5$ and $F_2$ conditions). More detailed calculations may be required for water-reactive chemicals or fuming acids.

### 3.9.2 Process risks

A full QRA to consider every process and every vessel individually would entail considerable effort and analysis, which is not considered necessary for the purposes of generating TLUP advice. Many of the possible LOC events will have immediate impacts within the process building which are not relevant to LUP. Therefore, the approach taken in the standard model is to identify the process step with the greatest potential for off-site consequences and to assume that this inventory bounds all other potential toxic and flammable events from the process building. This may require detailed analysis of the toxicity, flammability, volatility, temperature, and inventory for various cases to ensure that the worst-case toxic release is identified. The frequency of this event is then multiplied by the potential number of active process reaction vessels, to get the overall frequency for the LOC event. The locus of the releases is spread across the vessels.

Processes may be at elevated temperature and/or pressure and therefore the quantity of material that may be dispersed could be much greater than for an ambient release at atmospheric pressure. In some cases, it may be appropriate to assume that 100% of the available inventory in the largest vessel is released. In other cases, it may be possible to determine a smaller 'worst-case' source term.

In the absence of more detailed information, the likelihood of such a major release from a process vessel – allowing that other items of equipment (for example, pipes, pumps, compressors, heat exchangers) could also be sources of LOC events – is assumed to be equivalent to the 10-minute or 10 mm pipe leak releases, as shown in Table 63.

| LOC scenario | Frequency per vessel ($yr^{-1}$) | Event # |
|---|---|---|
| Instantaneous release | $5 \times 10^{-6}$ | 181 |
| Release over 10 minutes | $1 \times 10^{-5}$ | 182 |
| Release through 10 mm pipe leak | $5 \times 10^{-4}$ | 183 |

**Table 63: LOC scenarios for process vessels (per vessel per year)**

For gas turbines located within enclosures, the most significant risks to people off-site are generally associated with a LOC, leading to a gas build-up within the enclosure and a subsequent explosion. Events #181 and #182 in Table 63 are assumed to lead to the enclosure being rapidly filled with a flammable gas mixture, with a high likelihood of ignition, so such events are modelled as confined explosions as described in Section 2.4 with the frequencies detailed in Table 63 (for each turbine) using an explosion volume based on the internal free volume of the enclosure. For lesser events, characterised by Event #183, it is generally reasonable to assume that gas detection, isolation and ventilation systems could reduce the likelihood of such an explosion, provided that adequate such systems are in place, and maintained accordingly, so the frequency of the event is reduced by a factor of 100 to $5x10^{-6}$ per turbine per year.

The figures are derived from the LOC frequencies in Table 30 (Module C) of RIVM (2021). The frequencies for the 10-minute release and the 10 mm release have been increased to compensate for releases from associated process equipment, which are not being separately modelled.

The LOC scenarios from Table 63 should be multiplied by the number of reactor vessels in the hall or building, as appropriate. Dispersion should be modelled in $D_5$ and $F_2$ weather conditions. In most cases, a standard Gaussian plume model will be sufficient for modelling the dispersion.

For flammable substances, fire and explosion risk must be accounted for in the event tree. Events to be considered are:

- risk of VCE due to the release of flammables in semi-confined regions, and
- flash fire.

These events will be included in the analysis unless it is clearly evident that such events are not applicable to the facility.

Therefore, the event assumed is a vapour or two-phase release external to the process building. If flammable, a flash fire is considered. If significant confinement is possible, a VCE is considered. If the substance also has toxic properties, then some of the flash fire probability is assigned to the toxic arm. For substances with a toxic hazard designation, all the risk is assigned to toxic dispersion.

A MATTE could also be an outcome. While not usually relevant in setting LUP zones or CDs, it would be relevant for a new establishment and the requirement for suitable barriers to eliminate possible accident pathways.

The risk associated with failure of pressure vessels can be calculated by assessing the blast overpressure that would be produced in the event of the worst-case pressure vessel failure (taking into account the volume and failure pressure). The failure pressure is typically taken as three times the design pressure. The overpressures will be determined using a simple TNT equivalence model, based on the release of stored energy in the vessel.

The risk associated with potential VCEs in semi-confined areas, such as might occur due to a leak of hot solvent, can be estimated simply by using the TNO VCE model, where the size of the flammable cloud is taken to correspond to the volume of the semi-confined region where the release may occur (often taken as the building volume). The ignition strength is taken as 7. For TLUP contour generation, VCEs inside some process buildings may be modelled using a TNO strength of 10, at the discretion of the HSA.

Where the potential for exothermic runaway exists, the instantaneous release LOC in Table 63 should be increased to $1 \times 10^{-5}$ per year.

## 3.10 Gas drum and cylinder installations

The risks associated with dangerous substance gas drum and cylinder stores (including acetylene ($C_2H_2$), chlorine ($Cl_2$), hydrogen chloride (HCl), and ammonia ($NH_3$)), arise from the toxic and/or flammable gas and vapour that is generated from any loss from the pressurised containment. The released inventory is limited to that of the containing cylinder or drum (a drum has a volume greater than 150 l). The likelihood of release can be relatively high due to the nature of the manual operations involved in handling drums.

RIVM (2020) suggests the following scenarios and frequencies for pressurised containment of (water) volumes up to 150 l:

| LOC scenario | Frequency per cylinder ($yr^{-1}$) | Event # |
|---|---|---|
| Instantaneous release | $5 \times 10^{-7}$ | 184 |
| Release through hole, diameter = 3.3 mm | $5 \times 10^{-7}$ | 185 |

**Table 64: LOC scenarios and event frequencies for pressurised cylinders (per cylinder per year)**

For a multiple cylinder array with Number (N) cylinders, the following applies:

| LOC scenario | Frequency per array ($yr^{-1}$) | Event # |
|---|---|---|
| Instantaneous release | N x (5 x $10^{-7}$) | 186 |
| Release through hole, diameter = 3.3 mm | N x (5 x $10^{-7}$) | 187 |

**Table 65: LOC scenarios for pressurised cylinder array with Number (N) of cylinders (per array, per year)**

Dispersion of the toxic releases will be modelled in $D_5$ and $F_2$ weather conditions, using an appropriate dispersion modelling programme (such as ADAM, ALOHA[22], EFFECTS[23], RISKCURVES[24], Phast™ , Safeti™[25]).

For pressurised flammable gas cylinders, fire/explosion events will be modelled. Conditional probabilities are taken as:

| Event | Conditional probability |
|---|---|
| Fireball / Jet Fire | 0.1 |
| Flash Fire | 0.54 |
| VCE | 0.36 |

**Table 66: Conditional probabilities for fire and explosion events**

Drums are mobile pressurised containers of greater than 150 l water volume. The drum scenarios to be considered are for those for pressurised storage units and are listed in Table 67.

| LOC scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Instantaneous release | 5 x $10^{-6}$ | 188 |
| Contents released over 10 minutes | 5 x $10^{-6}$ | 189 |
| Release through pipe, diameter = 10 mm | 1 x $10^{-4}$ | 190 |

**Table 67: LOC scenarios and event frequencies for pressurised drums (per drum per year)**

Instantaneous failures of pressurised drums and cylinders may also generate projectiles, which can be assessed as described in Section 2.4.

## 3.11 Explosives handling/storage installations

This section applies to sectors manufacturing, storing or using explosives. This includes actual explosives manufacturing sites and sites using explosives (underground mines, for example).

The major accident scenarios associated with such sites are accidental detonation, giving rise to blast overpressure. Such explosions can also generate flying debris and cause window damage, which may sometimes be important in determining the LUP risk.

[22] ALOHA https://www.epa.gov/cameo/aloha-software
[23] EFFECTS https://www.gexcon.com/software/effects/
[24] RISKCURVES https://www.gexcon.com/software/riskcurves/
[25] Safeti™ software for consequence analysis https://www.dnv.com/services/safeti/

### 3.11.1 Approach to modelling

Processing, storage and transport areas are considered as potential fire locations. Fires are considered to always lead on to an explosive event. The TNT equivalence model is used to determine the overpressure.

The risk-based approach considers the worst-case scenario for each explosives inventory and assumes the following:

| Scenario | Frequency ($yr^{-1}$) | Event # |
|---|---|---|
| Fire in process building | $1 \times 10^{-4}$ | 191 |
| Fire in storage area | $1 \times 10^{-5}$ | 192 |

**Table 68: Scenarios for explosives**

Fires involving 10% of the inventory are considered to have a probability of 0.9, with fires involving the full inventory to have a probability of 0.1.

Fatality and damage levels are calculated as described in Section 2.4.

## 3.12 Ammonia refrigeration plant

Releases can occur from vessels, pipes, pumps, condensers and evaporators in ammonia plants. Releases can be emitted into the plant building or directly into the open air.

Ammonia will be at varying pressures and temperatures in the different parts of a refrigeration system, the pressure and temperature conditions determine the source term at each potential release point.

For the standard TLUP case, a simplified approach is taken, using a limited set of scenarios. These are:

- Release of one-third of the largest inventory through a pipe over 10 minutes, outdoors, at a temperature of -12 °C and at a frequency of $5 \times 10^{-6}$ per year. The maximum pool diameter is set to 100 m.
- Failure during bulk ammonia truck delivery, taken as $1 \times 10^{-6}$ per delivery.
- The ammonia probit listed in Table 15 is used to estimate fatality risk from modelled ($D_5/F_2$) concentrations.

## 3.13 Distilleries and spirit maturation warehouses

The information in this section applies to sectors manufacturing and/or storing potable spirits. Processing, storage (including tank farms) and transport locations are considered as potential fire locations. The major accident scenarios associated with such sites are spirit warehouse fires, fire and explosion in still houses or at bulk loading/unloading points.

## 3.13.1 Approach to modelling

Uncertainty exists as to the SEP of potable spirit fires. A Swedish study[26] on large-scale ethanol fires of bulk mixtures, with added small fractions of gasoline, noted that the thermal flux to a receiver is higher than previously predicted and much higher from an ethanol fire than from an equivalent gasoline fire.

A subsequent UK Health and Safety Executive Research Report[27] agreed that the flux from ethanol fires is high and concluded that the data obtained from the Swedish project formed a reasonable basis for risk assessment.

For cask-strength whiskey (65% alcohol by volume), it concluded that the SEP of such fires is less than for 100% ethanol. It concluded that much larger experiments would be necessary to provide the data to support more realistic assessments.

Neither report provided guidance on modelling of warehouse fires in which wooden casks contribute to the fire load. Therefore, care is required in modelling fire events at distilleries and spirit warehouses.

In the standard TLUP approach, the model described by Rew *et al.* (1997) or an equivalent model will be used to determine incident heat flux from ethanol fires.

Lower SEPs will be assumed for aqueous solutions and cask-strength whiskey fires.

However, for fires in warehouses containing wooden casks, the maximum SEP used is increased to 250 kW/m$^2$ (UK Health and Safety Executive, 2025b), due to the substantial co-burning of wooden casks, which is assumed to considerably add to the fire load.

Ethanol has a flash point of 12°C and boils at 78.4°C and is therefore located in CLP category 2 at ambient temperatures: this means that it falls into ignition category 2 (see Figure 7).

[26] ETANKFIRE – Experimental results of large ethanol fuel pool fires, SP Report 15:12 (SP Technical Research Institute of Sweden, 2015)

[27] RR 1144 – Measurements of burning rate and radiative heat transfer for pools of ethanol and cask-strength whisky (UK Health and Safety Executive, 2019)

Scenarios for bulk ethanol storage are:

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | Pool fire | $5 \times 10^{-8}$ | 193 |
| | | None/toxic/MATTE | $4.95 \times 10^{-6}$ | 194 |
| Failure over 10 minutes | $5 \times 10^{-6}$ | Pool fire | $5 \times 10^{-8}$ | 195 |
| | | None/toxic/MATTE | $4.95 \times 10^{-6}$ | 196 |
| Largest connection leak over 30 minutes | $1 \times 10^{-4}$ | Pool fire | $1 \times 10^{-6}$ | 197 |
| | | None/toxic/MATTE | $9.9 \times 10^{-5}$ | 198 |

**Table 69: Bulk ethanol storage LOC scenarios**

As with all instantaneous bulk storage failures, overtopping of a bund leading to a pool fire external to the bund is a credible scenario.

Ethanol releases occurring at, or close to, the boiling point (from a still for example) are treated as being in ignition category 1. In the standard case, the failure frequencies listed in RIVM (2021) for distillation columns are, for simplicity, further increased to cover the failures of associated condensers, reboilers and pumps. The still scenarios are listed in Table 70.

| LOC scenario | Frequency ($yr^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-5}$ | Pool fire | $8.86 \times 10^{-6}$ | 199 |
| | | VCE | $1.87 \times 10^{-5}$ | 200 |
| | | Flash fire | $5.61 \times 10^{-6}$ | 201 |
| | | None/toxic/MATTE | $1.68 \times 10^{-5}$ | 202 |
| Failure over 10 minutes | $5 \times 10^{-5}$ | Pool fire | $8.86 \times 10^{-6}$ | 203 |
| | | VCE | $1.87 \times 10^{-5}$ | 204 |
| | | Flash fire | $5.61 \times 10^{-6}$ | 205 |
| | | None/toxic/MATTE | $1.68 \times 10^{-5}$ | 206 |
| 10 mm leak over 30 minutes | $1 \times 10^{-3}$ | Pool fire | $1.77 \times 10^{-4}$ | 207 |
| | | VCE | $3.74 \times 10^{-4}$ | 208 |
| | | Flash fire | $1.12 \times 10^{-4}$ | 209 |
| | | None/toxic/MATTE | $3.37 \times 10^{-4}$ | 210 |

**Table 70: Ethanol still LOC scenarios**

Potential MATTEs are spirit spills or firewater getting into watercourses. Pool fires in firewater retention facilities will also be considered.

Bulk road tanker loading/unloading is assumed to involve inventories up to 30 $m^3$. Spills during loading/unloading are credible. For resulting pool fires, the area of the largest possible pool is used (bearing in mind that this may be severely limited through kerbing and drainage and for modelling purposes never exceeds a diameter of 100 m). The event frequencies in Table 71 are applicable to bulk loading/unloading of potable spirits.

| LOC scenario | Frequency (yr$^{-1}$) | Consequence | Frequency | Event # |
|---|---|---|---|---|
| Instantaneous failure | 1 x 10$^{-5}$ | Pool fire | 1 x 10$^{-7}$ | 211 |
| | | None/toxic/MATTE | 9.9 x 10$^{-6}$ | 212 |
| Leak from largest connection | 5 x 10$^{-7}$ | Pool fire | 5 x 10$^{-9}$ | 213 |
| | | None/toxic/MATTE | 4.95 x 10$^{-8}$ | 214 |

**Table 71: Event frequencies for potable spirits road tankers**

The frequencies should be adjusted for the proportion of the year that the road tanker is present. In addition, the scenarios in Table 72 are taken into account for loading/unloading operations:

| LOC scenario | Frequency (hr$^{-1}$) | | Event # |
|---|---|---|---|
| | Arm | Hose | |
| Rupture of loading/unloading arm/hose | 3 x 10$^{-8}$ | 4 x 10$^{-6}$ | 215 |
| Leak of loading/unloading arm/hose 10% of the diameter | 3 x 10$^{-7}$ | 4 x 10$^{-5}$ | 216 |

**Table 72: Road tanker loading/unloading LOC scenarios**

Moreover, failure due to a road tanker domino effect may also be included, as Table 73 shows.

| LOC scenario | Frequency (hr$^{-1}$) | Event # |
|---|---|---|
| Pool fire | 5.8 x 10$^{-9}$ | 217 |

**Table 73: Road tanker domino effect pool fire**

Spirit warehouses are typically well protected against vandalism and arson. In addition, they are compartmented and (in most cases) they contain sprinklers.

For these reasons, and provided that such measures are in place, the major warehouse fire frequency is set at:

| LOC scenario | Frequency (yr$^{-1}$) | Event # |
|---|---|---|
| Full compartment warehouse fire | 5 x 10$^{-6}$ | 218 |

**Table 74: Spirit warehouse fire frequency (with sprinklers)**

If the warehouse is without sprinklers, the frequency is increased to 5 × 10$^{-5}$ per year.

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# Appendix 1: Development Sensitivity Levels

## Sensitivity Level 1: People at work, car parks

DT 1.1 – Workplaces

DT 1.2 – Parking Areas

| DEVELOPMENT TYPE | EXAMPLES | DEVELOPMENT DETAIL AND SIZE | JUSTIFICATION |
|---|---|---|---|
| **WORKPLACES (DT 1.1)** | Offices, factories, warehouses, haulage depots, farm buildings, non-retail markets, builder's yards, self-storage units. | Workplaces (predominantly non-retail), providing for fewer than 100 occupants in each building and fewer than three occupied storeys.<br><br>LEVEL 1 | Places where the occupants will be fit and healthy and could be organised easily for emergency action. Members of the public will not be present or will be present in very small numbers and for a short time. |
| | EXCLUSIONS | | |
| | | Workplaces (predominantly non-retail) providing for 100 or more occupants in any building or 3 or more occupied storeys in height (DT 1.1.1)<br><br>LEVEL 2<br>(except where the development is at the major hazard site itself, where it remains Level 1).<br><br>Self-storage units with 3 or more accessible storeys<br>LEVEL 2 | Substantial increase in numbers at risk with no direct benefit from exposure to the risk. |
| | Rehabilitation and training services for people with disabilities. | Workplaces (predominantly non-retail) specifically for people with disabilities **(DT 1.1.2)**<br><br>LEVEL 3 | Those at risk may be especially vulnerable to injury from hazardous events and/or they may not be able to be organised easily for emergency action. |
| **PARKING AREAS (DT 1.2)** | Car parks, truck parks, lock-up garages. | Parking areas with no other associated facilities (other than toilets) | |

| | | | |
|---|---|---|---|
| | | LEVEL 1 | |
| | Car parks with picnic areas, or at a retail or leisure development, or serving a park and ride facility. | Where parking areas are associated with other facilities and developments the sensitivity level and the decision will be based on the facility or development. (**DT 1.2.1**) | |

## Sensitivity Level 2: Developments for use by the general public

DT2.1 – Housing

DT2.2 – Hotel/Hostel/Holiday accommodation

DT2.3 – Transport links

DT2.4 – Indoor use by public

DT2.5 – Outdoor use by public

| DEVELOPMENT TYPE | EXAMPLES | DEVELOPMENT DETAIL AND SIZE | JUSTIFICATION |
|---|---|---|---|
| **HOUSING (DT 2.1)** | Houses, apartments, retirement flats/ bungalows, residential caravans, mobile homes. | Developments up to and including 30 dwelling units and at a density of no more than 40 per hectare<br><br>LEVEL 2 | Development where people live or are temporarily resident. It may be difficult to organise people in the event of an emergency. |
| | | EXCLUSIONS | |
| | Very small developments, infill, backland development (development of land at rear of existing property). | Developments of 1 or 2 dwelling units (DT 2.1.1)<br><br>LEVEL 1 | Minimal increase in numbers at risk. |
| | Larger housing developments | Larger developments for more than 30 dwelling units (DT 2.1.2)<br><br>LEVEL 3 | Substantial increase in numbers at risk |
| | Developments at high density. | Any developments (for more than 2 dwelling units) at a density of | High-density developments. |

| | | | |
|---|---|---|---|
| | | more than 40 dwelling units per hectare<br>(DT 2.1.3)<br><br>LEVEL 3 | |
| **HOTEL/HOSTEL/ HOLIDAY ACCOMMODATION (DT 2.2)** | Hotels, motels, guesthouses, hostels, youth hostels, holiday camps, holiday homes, student accommodation, accommodation centres, holiday caravan sites, camping sites. | Accommodation of up to 100 beds or 33 caravan/tent pitches<br><br>LEVEL 2 | Development where people are temporarily resident. It may be difficult to organise people in the event of an emergency. |
| | EXCLUSIONS | | |
| | Smaller guesthouses, hostels, youth hostels, holiday homes, student accommodation, holiday caravan sites, camping sites. | Accommodation of fewer than 10 beds or three caravan/tent pitches<br>(DT 2.2.1)<br><br>LEVEL 1 | Minimal increase in numbers at risk. |
| | Larger hotels, motels, hostels, youth hostels, holiday camps, holiday homes, student accommodation, holiday caravan sites, camping sites. | Accommodation of more than 100 beds or 33 caravan/tent pitches<br>(DT 2.2.2)<br><br>LEVEL 3 | Substantial increase in numbers at risk. |
| **TRANSPORT LINKS (DT 2.3)** | Motorway, dual carriageway. | Major transport links in their own right, i.e. not as an integral part of other developments<br><br>LEVEL 2 | Prime purpose is as a transport link. Potentially large numbers exposed to risk, but exposure of an individual is only for a short period. |
| | EXCLUSIONS | | |
| | Estate roads, access roads. | Single-carriageway roads, cycle paths, bridleways and footpaths without facilities for people to congregate.<br>(DT 2.3.1)<br><br>LEVEL 1 | Minimal numbers present and exposed to risk for a short time period (predominantly). Associated with other development. |

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|---|---|---|---|
| | Any rail or tram track. | Railways (DT 2.3.2)<br><br>LEVEL 1 | Transient population, exposed to risk for short time periods. Times with no population present. |
| **INDOOR USE BY THE PUBLIC (DT 2.4)** | **Food and drink:** Restaurants, cafés, drive-through fast food, pubs.<br><br>**Retail:** Shops; petrol filling stations (total floor space based on shop area, not forecourt); vehicle dealers (total floor space based on showroom/sales building not outside display areas); retail warehouses; super-stores; small shopping centres; markets; financial and professional services to the public.<br><br>**Community and adult education:** Libraries, art galleries, museums, exhibition halls, day surgeries, health centres, religious buildings, community centres. Adult education, second-level education colleges, colleges of further education.<br><br>**Assembly and leisure:** Coach/bus/railway stations, ferry terminals, airports. Cinemas, concert/bingo/dance halls. Conference centres. Sports/ leisure centres, sports halls. Facilities associated with golf courses, flying clubs (e.g. changing rooms, club house), indoor go-kart tracks. | Developments for use by the general public where total floor space is from 250m2 up to 5000m2<br><br>LEVEL 2 | Developments where members of the public will be present (but not resident). Emergency action may be difficult to coordinate. |

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|---|---|---|---|
| | EXCLUSIONS | | |
| | | Development with less than 250 m2 total floor space (of all floors)<br>(DT 2.4.1)<br><br>LEVEL 1 | Minimal increase in numbers at risk. |
| | | Development with more than 5000 m2 total floor space (of all floors)<br>(DT 2.4.2)<br><br>LEVEL 3 | Substantial increase in numbers at risk. |
| | | Self-storage units for use by members of the public to be considered as workplaces.<br>See DT1.1 and DT 1.1.1<br>(DT 2.4.3) | Members of the public will be present in very small numbers and for a short period of time |
| **OUTDOOR USE BY PUBLIC<br>(DT 2.5)** | **Food and drink:**<br>Food festivals, picnic area.<br><br>**Retail:**<br>Outdoor markets, car boot sales, funfairs.<br><br>**Community and adult education:**<br>Open-air theatres and exhibitions.<br><br>**Assembly and leisure:**<br>Coach/bus/railway stations, park and ride facilities, ferry terminals. Sports stadia, sports fields/pitches, funfairs, theme parks, viewing stands. Marinas, playing fields, children's play areas, BMX/go-<br>kart tracks. Country parks, nature reserves, picnic sites, marquees. | Principally an outdoor development for use by the general public, i.e. developments where people will predominantly be outdoors and not more than 100 people will gather at the facility at any one time<br><br>LEVEL 2 | Developments where members of the public will be present (but not resident) either indoors or outdoors.<br>Emergency action may be difficult to coordinate. |
| | EXCLUSIONS | | |

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|---|---|---|---|
| | Outdoor markets, car boot sales, funfairs. Picnic area, park and ride facilities, viewing stands, marquees. | Predominantly open-air developments likely to attract the general public in numbers greater than 100 people, but up to 1,000 people at any one time (DT 2.5.1)<br><br>LEVEL 3 | Substantial increase in numbers at risk and more vulnerable due to being outside. |
| | Theme parks, funfairs, large sports stadia and events, open-air markets, outdoor concerts, pop festivals. | Predominantly open-air developments likely to attract the general public in numbers greater than 1,000 people at any one time (DT 2.5.2)<br><br>LEVEL 4 | Very substantial increase in numbers at risk, more vulnerable due to being outside and emergency action may be difficult to coordinate. |
| | Landscaped and grassed / planted areas, sustainable drainage systems (SuDS), fields including dog walking fields, equestrian manages, nature reserves (e.g. woodlands or marshes), areas assigned to Biodiversity Net Gain (BNG), aspects of country parks with associated facilities such as cafes, play areas etc., cemeteries (excluding crematoria), remembrance gardens, allotments, golf courses (excluding club houses) | Outdoor areas where members of the public may be present in small numbers and for a short time.<br>(DT 2.5.3)<br><br>LEVEL 1 | No facilities (e.g. cafes, play areas) for people to congregate. Members of the public will be present in small numbers at very low density and often only for a short time. |

## Sensitivity Level 3: Developments for use by vulnerable people

DT3.1 – Institutional accommodation and education

DT3.2 – Prisons

| DEVELOPMENT TYPE | EXAMPLES | DEVELOPMENT DETAIL AND SIZE | JUSTIFICATION |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **INSTITUTIONAL ACCOMMODATION AND EDUCATION (DT3.1)** | Hospitals, convalescent homes, nursing homes.<br><br>Housing for elderly with warden on-site or 'on call', sheltered housing. Nurseries, crèches.<br><br>Schools and academies for children up to school-leaving age. | Institutional, educational and special accommodation for vulnerable people, or that provides a protective environment<br><br>LEVEL 3 | Places providing an element of care or protection. Due to age, infirmity or state of health, the occupants may be especially vulnerable to injury from hazardous events. Emergency action and evacuation may be very difficult. |
| | EXCLUSIONS | | |
| | Hospitals, convalescent homes, nursing homes, sheltered housing. | 24-hour care where the site on the planning application being developed is greater than 0.25 hectare (DT 3.1.1)<br><br>LEVEL 4 | Substantial increase in numbers of vulnerable people at risk. |
| | Schools, nurseries, crèches. | Day care where the site on the planning application being developed is greater than 1.4 hectares (DT3.1.2)<br><br>LEVEL 4 | Substantial increase in numbers of vulnerable people at risk. |
| **PLACES OF DETENTION (DT3.2)** | Prisons, detention facilities, remand centres. | Secure accommodation for those sentenced by court, or awaiting trial, etc.<br><br>LEVEL 3 | Places providing detention. Emergency action and evacuation may be very difficult. |

## Sensitivity Level 4: Very large and sensitive developments

DT4.1 - Institutional accommodation

DT4.2 - very large outdoor use by public

Note: All Level 4 developments are by exception from level 2 or 3. They are reproduced in this table for convenient reference.

| DEVELOPMENT TYPE | EXAMPLES | DEVELOPMENT DETAIL AND SIZE | JUSTIFICATION |
|---|---|---|---|
| **INSTITUTIONAL ACCOMMODATION (DT4.1)** | Hospitals, convalescent homes, nursing homes, sheltered housing. | Large developments of institutional and special accommodation for vulnerable people (or that provide a protective environment) where 24-hour care is provided. And where the site on the planning application being developed is greater than 0.25 hectare<br><br>LEVEL 4 | Places providing an element of care or protection. Due to age or state of health, the occupants may be especially vulnerable to injury from hazardous events. Emergency action and evacuation may be very difficult. The risk to an individual may be small, but there is a larger societal concern. |
| | Nurseries, crèches. Schools for children up to school-leaving age. | Large developments of institutional and special accommodation for vulnerable people (or that provide a protective environment) where day care (not 24-hour care) is provided. And where the site on the planning application being developed is greater than 1.4 hectares<br><br>LEVEL 4 | Places providing an element of care or protection. Due to their age, the occupants may be especially vulnerable to injury from hazardous events. Emergency action and evacuation may be very difficult. The risk to an individual may be small, but there is a larger societal concern. |
| **VERY LARGE OUTDOOR USE BY PUBLIC (DT4.2)** | Theme parks, large sports stadia and events, open-air markets, outdoor concerts, and pop festivals | Predominantly open-air developments where there could be more than 1,000 people present<br><br>LEVEL 4 | People in the open air may be more exposed to toxic fumes and thermal radiation than if they were in buildings. Large numbers make emergency action and evacuation difficult. The risk to an individual may be small, but there is a larger societal concern. |

## Notes to Appendix 1

- Where a development straddles zones, the development will be considered to belong to the zone that gives rise to the greatest expectation value (EV) – a societal risk assessment may be necessary if there is significant expectation contribution from the other zone(s).
- For developments consisting of multiple development types, a societal risk evaluation will likely be necessary.

# Appendix 2: Significant Modifications and TLUP

An operator planning significant modification must notify the HSA in advance. The simplified chart shown in Figure 8 (adapted from a chart in the Guidance on 'Significant Modifications' Under the COMAH Regulations) provides an overview of the process.

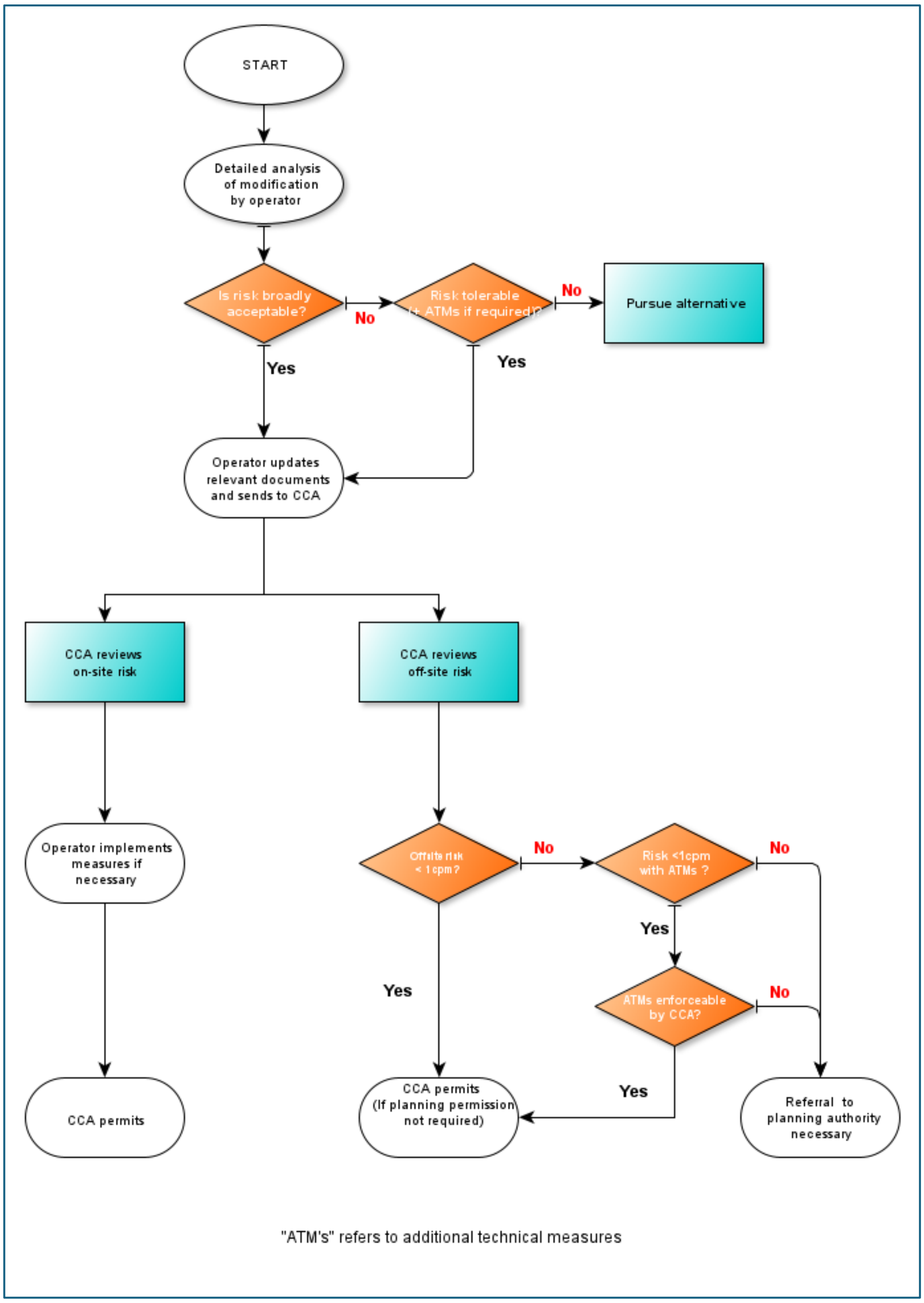


Figure 8: Significant Modifications and TLUP

To note: if planning permission is required for the modification (note that development of a new establishment or a tier-change at an existing establishment requires planning permission – see

Section 1.4), the HSA will use the data and documentation submitted in the significant modification process to develop its advice for the planning authority.