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Re: Notice of Draft Variation (No.3) of the Navan Development Plan 2009-2015.

Dear Sir/Madam,

The Health & Safety Authority (the Authority) is an Authority prescribed under Article 13 of the Planning & Development Regulations 2001-2015 and as such is required to be consulted in relation to Development Plans under sections 11-13 & 24 of the Act.

The approach of the Authority to Land-use Planning is set out in the document 'Policy & Approach of the Health and Safety Authority to COMAH Risk-based Land-use Planning'. It is available from our website at:
https://www.hsa.ie/eng/Your_Industry/Chemicals/Legislation_Enforcement/COMAH/Land_Use_Planning/.

The document should be consulted to fully understand the advice given in this letter.

The Authority would expect the planning guidelines to contain:

1. An indication of planning policy in relation to major accident hazard sites notified under the regulations, which reflects the intentions of Article 13 of Directive 2012/18/EU.
2. The consultation distances and generic advice, where applicable, supplied by the Authority to Fingal County Council in relation to such sites. These distances to be indicated on the various maps included in the plan, as well as any more specific distances and advice supplied by the Authority .
3. A policy on the siting of new major hazard establishments, taking account of Article 13 and the published policy of the Authority in relation to new developments, including developments in the vicinity of such establishments.

4. There are currently three COMAH establishments in the county of Meath which are as follows:

Xtratherm Ltd.,
Liscarton Industrial Estate,
Kells Road,
Co. Meath

Irish Industrial Explosives,
Clonagh,
Enfield,
Co. Meath

Grassland Agro
The Pound Road
Slane
Co. Meath

If you have any queries please contact the undersigned.

Yours sincerely

Tara Horigan

Tara Horigan
Inspector,
COMAH, Chemical Production & Storage (CCPS)

Encl: Note on the Approach of the HSA to the Provision of Land-use Planning Advice

Note on the Approach of the HSA to the Provision of Land-use Planning advice.

The Authority, acting as the Central Competent Authority under the Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations 2015 (S.I. 209 of 2015), gives technical advice in response to a notice sent by a planning authority under Part 11 of the Planning and Development Regulations 2001-2015. Under Regulation 24(2) of S.I. 209 of 2015, the technical advice on the effects of a proposed development on the risk or consequences of a major accident relates to the following types of developments within the consultation distance for an establishment:

(a) the siting and development of new establishments;

(b) modifications to establishments of the type described in Regulation 12(1);

(c) new developments including transport routes, locations of public use and residential areas in the vicinity of establishments, where the siting, modifications or developments may be the source of, or increase the risk or consequences of, a major accident.

The advice given is for the purposes of assessing new development only. A full explanation of the Authority's Land Use Planning advice system can be found at https://www.hsa.ie/eng/Your_Industry/Chemicals/Legislation_Enforcement/COMAH/Land_Use_Planning/.

Your attention is drawn to Regulation 24(3) of S.I. 209 of 2015:

(3) The technical advice provided by the Central Competent Authority to a planning authority pursuant to paragraph (2) may be generic or case specific in nature and shall be so formulated that it will assist the planning authority to take into account the need, in the long term—

(a) to maintain appropriate safety distances between establishments covered by these Regulations and residential areas, buildings and areas of public use, recreational areas, and, as far as possible, major transport routes;

(b) to protect areas of particular natural sensitivity or interest in the vicinity of establishments, where appropriate through appropriate safety distances or other relevant measures; and

(c) for the operator to take additional technical measures, in the case of existing establishments, in accordance with Regulation 7, so as not to increase the risks to human health and the environment.

In giving its advice the Authority does not deal with routine emissions. Such emissions will be subject to EPA or Local Authority scrutiny and control.

The operator of an establishment covered by S.I. 209 of 2015 is also required to take all necessary measures to prevent major accidents occurring and to limit the consequences of any such major accidents for human health and the environment

Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning (19 March 2010)

Including Detailed Implementation by Sector

This document sets out the policy of the Authority on the Land-use Planning requirements of the European 'Seveso' Directive [2003/105/EC] on the control of major accident hazards and includes the sector-by-sector implementation of the December 2008 Atkins Ltd., report on risk-based Land-use Planning advice, as approved by the Authority in February 2009.

1 Policy in Relation to Land-use Planning

1.1 GENERAL BACKGROUND

Article 12 of the Seveso Directive [2003/105/EC] requires that for Member States 'the objectives of preventing major accidents and limiting the consequences of such accidents are taken into account in their land use policies and/or other relevant policies'.

It states that this is to be achieved by controls on the siting of new establishments and modifications to existing establishments, as well as developments in the vicinity of such establishments.

Member States are required to ensure that account is taken of the long-term need to maintain appropriate distances between establishments and residential areas, buildings and areas of public use, major transport routes as far as possible, recreational areas and areas of particular natural sensitivity or interest.

The Member States are also required to ensure that technical advice on the risks from an establishment is available when planning decisions are being made.

This aspect of the Directive is implemented in Ireland through regulation 27 of SI 74 of 2006 and the Planning and Development Regulations 2001-2006. The Planning and Development Regulations specify when planning authorities should seek technical advice in this area and the information that must be supplied to the HSA when seeking the advice.

Regulation 27 of SI 74 allows the Authority to give the technical advice and sets out the appropriate timeframes within which this is to be done.

Neither the Regulations nor the Directive set out how the appropriate distances are to be established, this being left up to the individual states to decide, based on their particular circumstances.

The recent European Guidelines [1] describe the ideal LUP technical advice system:

> 4. 2. Best Practice in Risk Assessment
>
> In principle all risk assessment methods without regard to individual applications have the same relevant elements; these are[2]:
>
> > Definition of scope, objectives and risk criteria
> >
> > Description of the object or area of concern
> >
> > Identification of hazards
> >
> > Identification of vulnerable targets
> >
> > Assumption of source terms or hazardous incidents
> >
> > Development of escalation scenarios
> >
> > Estimation of consequences

[1] *Land use Planning Guidelines in the Context of Directives 96/82/EC and 105/2003/EC*, Christou et al, 2006. ISBN 978-92-79-09182-7

[2] Taken from *Mannan/Lees* "Loss Prevention in the Process Industry", 2005

Estimation of likelihood

Presentation of resulting risk and comparison with established tolerability criteria

Identification of mitigation measures

Acceptance of result, modification or abandoning

Besides these elements a proper risk assessment should furthermore ensure a level of detail proportional to the severity of consequences;

the use of acknowledged methods (or it must be demonstrated that these are equivalent);

reliability of data and relevant information and transparency of the process.

The best practice in the application of the general principles of consistency, proportionality and transparency for Land-use Planning advice are set out by the European Guidelines (see section 4.3.1, pages 24 & 25).

The system of land-use Planning advice described in this document applies the principles of those guidelines and also takes account of recent major industrial accidents in Europe.

The Authority will use the general risk based LUP methodology and approach set out in this document to develop the technical LUP advice required by article 12 of the Directive. It is based on the report of WS Atkins, carried out for the Authority in 2008 (Atkins Ltd., 2008).

1.2 NEW ESTABLISHMENTS

Planning applicants for new establishments are required to submit a QRA to the Authority. The Authority will evaluate the submitted QRA before advising the planning authority.

In relation to new establishments it will be necessary for them to demonstrate that they do not present a risk of fatality greater than 5×10^{-6} (per year) to their current non-residential type neighbours or a risk of fatality greater than 1×10^{-6} (per year) to the nearest residential type property. This may be relaxed in respect of neighbours where the new development is the same/similar to the existing neighbours; for example new oil storage depot being set up in a location already occupied by tank farms.

The Authority will seek from the operators of proposed establishments a detailed risk assessment in order to help it formulate a response to a request for advice on a planning application for a new establishment. The approach described in this document is one such way of doing this that would be acceptable to the Authority. The Authority will bring to the attention of the Planning Authority the need to consult with the local authority emergency services on any potential impact on local access/egress arrangements in the context of public behaviour in the event of an emergency and access for emergency services.

1.3 SOCIETAL RISK

Societal Risk is examined as part of the assessment and this may be by the use of screening tools - such as the ARI as a screening tool in relation to the siting of new establishments. Where further assessment of societal risk is necessary, Expectation Value (EV)/Potential Loss of Life (PLL) or an FN curve will be used to determine the level of societal risk as considered appropriate. Where societal risk is in the intolerable region (an upper societal risk criterion value of 1 in 5000 for 50 fatalities will be used) the advice should be ‘against’, in the broadly acceptable region (1 in 100,000 for 10 fatalities) it should be ‘not against’ and in the significant risk region (which is between these 2 values) the planning authority should be advised of that fact and the need for the planning authority to weigh this into their planning decision, using Cost Benefit Analysis (CBA) and taking into account any socioeconomic benefits as necessary.

1.4 ENVIRONMENT & LUP

The Authority will continue to use the position papers (in appendix 4) as the basis for advice on LUP matters relating to the environment.

1.5 SPECIFIED AREA

The Authority are withdrawing the previous position paper on setting the specified area and will now set the specified area based on the outer fatality risk zone of 1×10^{-7} per year, obtained from the LUP methodology. Existing zones to continue until replaced.

1.6 FORM OF ADVICE

The Authority will put its case-by-case LUP advice to planning authorities in the form 'Advises Against' or 'Does Not Advise Against'.

Where Generic advice is provided it will consist of risk-based contours using a 3 zone traffic-light system, advising on suitable developments in each zone, according to the system set out in this document (see also appendix 1)

10^{-5}/year	• Risk of fatality for Inner Zone (Zone 1) boundary
10^{-6}/year	• Risk of fatality for Middle Zone (Zone 2) boundary
10^{-7}/year	• Risk of fatality for Outer Zone (Zone 3) boundary

To assist planning authorities apply the advice given, the detail of advice for each zone has now been considerably expanded based on the UK HSE PADHI model (see appendix 1). PADHI sets 4 sensitivity levels, with the sensitivity increasing from 1 to 4, to describe the development-types in the vicinity of a COMAH establishment.

A matrix will be used to advise on suitable development for technical LUP purposes, as follows:

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

So, for example, level 2 development (developments for use by the general public) would be advised against in the inner zone, but not in the other zones.

If the individual risk dictates an 'advise against' response to the planning authority then societal risk issues will not be explored by the Authority. However, for some types of development, particularly those involving large numbers of people, it is likely that the deciding factor is the societal risk, i.e. the risk of large numbers of people being affected in a single accident. Therefore for large scale developments, including those outside zone 3 but within the consultation distance[3] set out in the Planning and Development Regulations 2001-6 and notified to the planning authority by the HSA at the time of notification of the establishment, estimations of societal risk will be undertaken.

In addition to providing risk-based advice, the Authority will advise the planning authority of the consequences of worst case major accidents in relation to overpressure, thermal or toxic effects as appropriate, without further comment, for their consideration.

Where the Authority advises against a development, a planning applicant may in consultation with the PA submit a QRA to the planning authority. It will be a matter for the PA to consider the applicability or otherwise of this QRA in their planning decision process. The Authority will not make an assessment of such QRA's unless a new planning application is made and the planning authority seeks further advice from the Authority on the new material submitted.

There may be establishments where the technical assessment may show that there are either no consequences or risks off-site from the identified major accident hazards. In situations where there are consequences but the risk offsite is below the threshold 1×10^{-7} per year risk of fatality then no separation distance will be advised to the planning authority.

Generic advice generated by the Authority and given to planning authorities will be placed on the HSA website.

[3] Consultation Distance is the distance set out in the Planning and Development Regulations for the type of establishment at the time of Notification and which was communicated to the planning authority at that time.

2 Introduction to the Technical Aspects

The types of major hazard establishment considered in this methodology are grouped as follows:

i) LPG Installations

ii) Large Scale Flammable Storage Sites (VCE Risk)

iii) Large Scale Flammable Storage Sites (No VCE Risk)

iv) Storage of Class III (1) Petroleum Products (Diesel, Gas Oils)

v) Sites with Gas Pipelines

vi) Fertilizer Blending/Storage Sites

vii) Warehouses

viii) Chemical/Pharmaceutical Plants

ix) Toxic Gas Drum & Cylinder Stores

x) Sites Handling/Storing Explosives

The risk based approaches described here are not intended to be as detailed as those required for a full Quantified Risk Assessment, but are relatively simple approaches, based on the consideration of a smaller number of representative events which are the most significant in terms of off-site land use planning.

As the objective relates to land use planning advice, the assessment methods presented here are generally not sufficiently detailed to deal with on-site populations.

The field of risk assessment is constantly developing, both in terms of our understanding of major accident events and in terms of the criteria which should be used to assess the results. This document cannot be expected to cover every situation. It is intended to provide a robust initial basis for assessment, but there will sometimes be a need to update and refine particular aspects and to generally adapt to technical progress.

The policy of the HSA is that a simplified application of a risk based approach is the most appropriate for land use planning. The difficulties associated with the complexity of analyzing many scenarios can be avoided by considering a small number of carefully chosen representative events, whose frequency has been estimated conservatively.

A risk based approach inevitably involves some assumptions concerning the likelihood of events. This is considered to be preferable to the hazard based approach where it is implicitly assumed that the particular event chosen has a likelihood which is sufficient to be a cause for concern, but not so high as to make it unacceptable.

The likelihoods of events and assumptions relating to probit relationships are estimated conservatively and consistently in our approach, resulting in a risk based approach that is robust and transparent.

The risk of fatality increases with the level of consequence. The relationship between the level of consequence and the probability of fatality is generally characterized by a probit relationship (A range of responses can be expected in a population exposed to an acute hazard. This can be represented mathematically by a dose-response curve with the response classified in a number of categories. For calculation purposes it is better to try to fit the relationship into a straight line form. Probit equations do this and can be used to estimate the proportion of the population that may be affected by exposure to a particular harm. The probit number obtained from the probit equation can be looked up in a table to give the % of the population affected) e.g.

Chlorine toxicity	• Probit = -8.29 + 0.92 ln (C^2t) with concentration, C, in ppm and t in minutes
Thermal radiation	• Probit = -14.9 + 2.56 ln ($I^{1.33}$ t) with Intensity, I, in kW/m^2 and t in seconds
Overpressure	• Probit = 1.47 + 1.35 ln (P) with pressure, P, in psi

There is an exponential relationship between the probit and the probability of fatality, which is defined as:

$$\text{Probability} = \frac{1}{\sqrt{2\pi}} \int_{u=-\infty}^{u=Y-5} \exp\left(-\frac{u^2}{2}\right) du \quad \text{where u is an integration variable}$$

This implies that a probit of 5 corresponds to 50% fatality, a probit of 2.67 to 1% fatality, a probit of 7.33 to 99% fatality, etc.

2.1 INDIVIDUAL RISK CRITERIA

HSA has defined the boundaries of the Inner, Middle and Outer LUP zones as:

10^{-5}/year	• Risk of fatality for Inner Zone (Zone 1) boundary
10^{-6}/year	• Risk of fatality for Middle Zone (Zone 2) boundary
10^{-7}/year	• Risk of fatality for Outer Zone (Zone 3) boundary

For some types of development, particularly those involving large numbers of people, it is likely that the deciding factor from the point of view of land use planning is the societal risk, i.e. the risk of large numbers of people being affected in a single accident.

2.2 SOCIETAL RISK AND INDICES

There are relatively few widely accepted societal risk criteria for land use planning, as it is generally considered that, if the individual risks for particular types of development are adequately controlled, then the societal risks will also be controlled adequately. However, this is not always the case, particularly for hazards such as pipelines or some major toxic risks, where the societal risks may be significant even though the individual risks are relatively low.

The methodology for calculating the Societal Risk Index (SRI) is described by Carter (1995) and Hirst and Carter (2000) as follows:

$$SRI = \frac{P \times R \times T}{A}$$

Where,	P	= population factor, defined as $(n + n^2)/2$
	n	= number of persons at the development
	R	= average estimated level of individual risk in cpm
	T	= proportion of time development is occupied by n persons
	A	= area of the development in hectares

Carter (1995) recommends the following occupation factors (T):

Houses	1
Hotels	1
Hospitals and nursing homes	1
Factories	0.75
Places of entertainment	0.5
Shops and supermarkets	0.5
Warehouses	0.5
Offices	0.3
Schools	0.25
Sunday market/car boot sales	0.075

It is sometimes possible to make more appropriate estimates using data for the actual development under consideration. Some allowance for the sensitivity of different population groups is incorporated by scaling 'n' by, for example, 0.25 for a working population, and 4 for a sensitive population.

The SRI as described above is best used as an initial screening tool in relation to societal risk to new developments in the vicinity of existing establishments.

The Risk Integral (RI) concept has been developed and used in the UK. It can be used when assessing major hazard installations (see Hirst and Carter, 2002 and Carter et al, 2003). The risk integral is defined as:

$$RI = \sum_{N=1}^{Nmax} f(N).N^a$$

Where f(N) is the frequency of events leading to N fatalities (in units of cpm), and 'a' is a constant.

When assessing COMAH (Seveso) establishments, a value of a = 1.4 is used, and the result (RI_{COMAH}) can be judged against criteria of 2000 (broadly acceptable) to 500,000 (significant).

The Approximate RI (ARI) can be determined based simply on a knowledge of the frequency and number affected in the worst case event:

If the consequences of the worst case event are omni-directional, then:

$$ARI_{COMAH} = f(N_{max})N_{max}\left[\sum_{N=1}^{N_{max}-1}\frac{N^{a-1}}{N+1} + N_{max}^{a-1}\right]$$

And if the consequences are uni-directional, then:

$$ARI_{COMAH} = f(N_{max})N_{max}^{2}\sum_{N=1}^{N_{max}} N_{max}^{a-2}$$

The ARI_{COMAH} gives a rough but rapid indication of Societal Risk around Seveso establishments and can be used in Safety Report estimations.

For land use planning purposes, the UK HSE has also defined an RI_{LUP}, with a greater degree of scale aversion than the RI_{COMAH}. The RI_{LUP} is defined as:

$$RI_{LUP} = \sum(F \times N) = \sum\left(f \times \frac{n+n^2}{2}\right)$$

Again, in those cases where a full FN curve has not been calculated, the Approximate RI_{LUP} (ARI_{LUP}) can be determined based simply on knowledge of the frequency and number affected in the worst case event:

If the consequences of the worst case event are omni-directional, then:

$$ARI_{LUP} = f(N_{max}) \times N_{max}^{2}$$

And if the consequences are uni-directional, then:

$$ARI_{LUP} = 0.5 \times f(N_{max}) \times N_{max}^{3}$$

A value of ARI_{LUP} = 10,000 corresponds to the broadly acceptable area, below which the societal risks are not considered to be an issue for the purposes of land use planning (in relation to the location of new establishments).

Whilst the SRI or ARI_{LUP} are used to provide a rapid initial assessment of the societal risk, it must be emphasized that a full consideration of the FN curve is probably a more robust approach. Also, there is ongoing debate as to whether scale-aversion should be included at all in societal risk measures for land use planning, and so such risk integrals are only used as screening aids.

While more detailed analysis (such as an FN curve) may provide more accurate representation of societal risk it will not be undertaken by the Authority, but will be accepted as part of the QRA submitted for new establishments.

2.3 THERMAL RADIATION

2.3.1 Persons Outdoors

The probit most commonly used to determine the risk from thermal radiation is the Eisenberg et al (1975) probit, i.e.

Probit = $-14.9 + 2.56 \ln (I^{1.33} t)$ with I in kW/m^2 and t in seconds

This relationship applies to people exposed outdoors. However, it can be reasonably applied for most exposed populations (whether indoor or outdoor).

For long duration fires, such as pool fires and jet fires, it is generally reasonable to assume an effective exposure duration of 75 seconds (to take account of the time required to escape).

The Eisenberg probit relationship then implies:

1% fatality	• 6.8 kW/m^2
10% fatality	• 9.23 kW/m^2
50% fatality	• 13.4 kW/m^2

2.3.2 Persons Indoors

Since people indoors may have some protection, it is sometimes necessary to make some further refinement and assumptions for people indoors, based on Crossthwaite et al (1988), namely:

>25.6 kW/m^2	• Building conservatively assumed to catch fire quickly and so 100% fatality probability
12.7-25.6 kW/m^2	• People are assumed to escape outdoors, and so have a risk of fatality corresponding to that outdoors
<12.7 kW/m^2	• People are assumed to be protected, so 0% fatality probability

The 12.7 kW/m^2 criterion above is based on the figure used in the Building Regulations of 2006 Technical Guidance Document B on Building Fire Safety

2.3.3 Property Damage

For some types of major hazard installation, damage contours associated with various levels of harm to property and buildings will be produced and provided to the planning authority, showing the maximum possible extent of any particular level of damage.

This will enable them to take the economic risks to property, structures and businesses into account as part of any land use planning decision (see also 2.4 below).

In terms of 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 kW/m^2	• Minimum heat flux to ignite wood at indefinitely long exposures (non piloted)
12.5 kW/m^2	• Minimum heat flux for piloted ignition of wood, melting of plastic tubing

2.4 BLAST OVERPRESSURE

2.4.1 Persons Outdoors

One of the most commonly used probits to determine the risk from blast overpressure is the Hurst, Nussey and Pape (1989) probit. The probit relationship is generally quoted as:

Probit = 1.47 + 1.35 ln (P) with P in psi (NB 1 psi = 68.947573 mbar)

This relationship only applies to people exposed outdoors, and implies:

1% fatality at	• 2.44 psi	or 168 mbar
10% fatality at	• 5.29 psi	or 365 mbar
50% fatality at	• 13.66 psi	or 942 mbar

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 underestimate of the risk.

2.4.2 Persons Indoors

People indoors could be either more or less vulnerable, depending on the blast resistance of the structure. The Chemical Industries Association (CIA, 2003) has published relationships between the risk of fatality for occupants and the level of blast overpressure for 4 different types of building, namely:

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

The CIA Category 3 Curve (typical domestic building: two-storey, brick walls, timber floors) provides a reasonably conservative basis for assessing the risk of fatality to most residential populations.

The table below gives the risk of fatality associated with various levels of overpressure.

Overpressure (mbar)	Outdoor Risk	Indoor Risk (Category 3)
3000	94.10%	100%
1000	53.21%	100%
600	27.12%	70%
300	6.12%	50%
100	0.12%	5%
50	0%	1%
10	0%	0%

Property Damage

For some types of major hazard installation, damage contours associated with various levels of harm to property and buildings will be produced and provided to the planning authority, showing the maximum possible extent of any particular level of damage.

This will enable them to take the economic risks to property, structures and businesses into account as part of any land use planning decision.

The table below summarizes the effect of various levels of overpressure.

Overpressure (kPa)	Description of Damage
0.15	Annoying noise
0.2	Occasional breaking of large window panes 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
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"

Key contours that could be plotted on maps are the maximum range at which the following overpressures occur:

1 kPa	(10 mbar)	Threshold for glass breakage
3.5 kPa	(35 mbar)	Damage level for "Light Damage"

17 kPa	(170 mbar)	Damage level for "Moderate Damage"
35 kPa	(350 mbar)	Damage level for "Severe Damage"
83 kPa	(830 mbar)	Damage level for "Total Destruction"

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

2.5 TOXICITY

2.5.1 Persons Outdoors

Appendix 3 includes probit equations for the toxicity of a number of substances. For example, for Chlorine the Withers and Lees (1985) probit for a regular population with a standard level of activity is:

Probit = $-8.29 + 0.92 \ln (C^2 t)$ with concentration C, in ppm and t in minutes

The exposure duration is generally taken to be equal to the release duration for vapour/gas releases, and 30 minutes for exposure from evaporating liquid pools or fires.

A variety of probits exist in the published literature for some substances; therefore it is often necessary to make a selection. In general, it is currently recommended that probits be selected from the most well established sources[4], namely:

TNO

AIChE

HSE

Persons Indoors

The risk to persons indoors from a toxic vapour cloud depends on the effective ventilation rate of the building, which may depend on the wind speed. Air change rates of 2.5 and 2 air changes per hour are typically assumed for D_5 and F_2 conditions (F_2 and D_5 refer to the weather/stability sets typically used in modeling releases of dangerous substances to the atmosphere. D represents typical day- time conditions and F represents appropriate night-time conditions. The subscripts refer to the average wind speeds, in metres per second, associated with those stability conditions). The impact of a toxic release on an indoor population can be assessed using the same probit equations, but it is necessary to modify the effective concentration and duration of exposure to take account of infiltration into the building. The most widely used approach is that of Davies and Purdy (1986).

Property Damage

The major concern generally relates to whether any toxic liquid spill (or firewater) could escape and pollute water courses and the environment.

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[4] TNO is a Dutch technical research organisation, AIChE is the American Institute of Chemical Engineers and HSE is the UK Health and Safety Executive.

Property damage is rarely an issue for toxic vapour releases, although acid gases can cause damage to crops and buildings, and deposition/washout of toxic material from fire plumes can be significant.

2.6 DOMINO EFFECTS

Domino effects are the effects arising from an event at one establishment which could initiate a major accident 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, e.g. small LPG storage vessels located close to a large toxic gas storage tank.
- Where the initiating event on one site could trigger a more severe than expected event on a neighbouring site, e.g. a release and fire involving highly flammables on one site could spread to involve a site storing Class III(1) petroleum products which would normally not be considered a major fire risk (because of their 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 could have unexpected indirect consequences on a neighbouring site, e.g. loss of power for 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.

In many cases, however, it is found that domino effects are not significant in terms of land use planning as the likelihood of an event at Site A triggering a major event at Site B is an order of magnitude or more less than the base case likelihood of the event at Site B. Nevertheless, as a general rule of thumb, the potential for domino effects should always be considered for any sites within about 500 m of each other.

3 METHODOLOGIES FOR RISK-BASED LUP ASSESSMENT OF MAJOR HAZARD INSTALLATIONS

3.1 LPG INSTALLATIONS

It is reasonable to assume that the off-site risks for LPG storage will generally be dominated by large BLEVE events, as the majority of lesser events have much less impact (even though they may be somewhat more likely).

A frequency of 10^{-4}/year is deliberately chosen as being relatively high as it is intended to cover sites with more than one LPG vessel (up to about 10). If there are only a few vessels, and the HSA is satisfied that there is a high probability that the measures in place at the site would mitigate against BLEVEs occurring, then a lower frequency of 10^{-5}/year **per vessel** may be adopted.

If there are several vessels of different size, perhaps some distance apart, then the risks from each vessel should be aggregated (taking account of location as well as event size).

Other events (such as VCEs and BLEVEs of a road tanker) may also be significant, and these should be included as part of the aggregation if they are considered to be credible events.

In some cases HSA may provide information to the Planning Authority on the level of thermal radiation and blast overpressure/damage that could be generated from BLEVEs and VCEs, such as producing blast overpressure and thermal radiation contours, although it is noted that (for BLEVEs) such pressure effects are generally less significant than the thermal radiation

3.1.1 Potential for Risk Reduction

It is implicitly assumed that a site meets all the normal standards required for an LPG installation (e.g. having water deluge etc), and so there is probably not much more that can be done which is sure to lead to a significant reduction in risk, or a reduction in the extent of risk based zones. However, some possible risk reduction measures are outlined below, together with an indication of how they would change the risk based approach.

3.1.2 Fully Mounded Vessels

If the LPG vessels are fully mounded (or buried) then the likelihood of a BLEVE becomes negligible, and the risk based zones should be based on a BLEVE of 50% of the full contents of the road tanker, with a frequency of 1.3×10^{-7}/delivery. It may also be necessary to consider a VCE based on twice the flash fraction (e.g. flash fraction is 29% for propane and 9% for butane) for the vessel inventory with a frequency of 2×10^{-6}/year per vessel (cold catastrophic failure), with approximately 10% of the flammable material in vapour cloud contributing to the VCE. The extent of the Inner Zone should be at least as large as the road tanker BLEVE fireball radius.

3.1.3 Intumescent Coating of Vessels

Intumescent coating, if properly applied and maintained, should significantly reduce the likelihood of a BLEVE. For the purposes of LUP, the reduction in likelihood is taken to be an order of magnitude, i.e. to 10^{-6}/year per vessel. Again, it may now also be necessary to include the risk associated with road tankers, and also with potential VCE events, as these may now be the dominant contributors to risk. The extent of the Inner Zone should be at least as large as the road tanker BLEVE fireball radius (based on 50% of full contents).

3.1.4 Uncertainties in LPG Risk Based Approach

It is acknowledged the risk based assessment is relatively simplistic. It might be argued that it was overly conservative to use a frequency as high as 10^{-4}/year for the representative BLEVE event (or 10^{-5}/year per tank), but this is deliberately chosen to bound other events, which would have lesser consequences but could have higher frequencies. Also, it is noted that the risks fall off quite rapidly with distance, and so the distances to the risk criteria are relatively insensitive to this choice of frequency.

If an establishment wished to refine this risk based assessment, taking into account site specific factors, then they would be free to do so once sufficient justification is provided. If the HSA is satisfied that such an assessment still provided a reasonably cautious assessment of the risks for the purposes of land use planning, then the results of the more detailed assessment could be adopted. The key requirements of any such more detailed assessment would have to include:

- Consideration of a comprehensive set of representative events, including, but not limited to the worst case events.
- Clear definition of the event frequencies based on data from reputable sources.
- Consequence assessment methods which are well established or err on the side of caution.
- Suitable choice of harm and vulnerability criteria.

The weight that HSA will give to any assessment will depend on the above issues being dealt with satisfactorily.

3.1.5 Examples of risk-based LPG zones

These 3 examples illustrate the zones that can be expected around LPG sites. The distances are set out in increments of 20m, beginning at a value of 60m, with the colours below indicating the extent of the zones.

Site 1 has 20 vessels containing LPG varying between 90 and 100 tonnes, all are over-ground and have no protective coating.

The risk zones are as follows (zones are from the centre of the storage area):

Distance	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540
Zone																									

Site 2 has 16 vessels containing LPG varying between 100 and 275 tonnes, all are over-ground and 6 of the vessels have a protective coating. The risk zones are as follows:

Distance	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560
Zone																										

Site 3 has 8 vessels containing LPG varying between 100 and 150 tonnes; all are over-ground and have no protective coating. The risk zones are as follows:

Distance	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440
Zone																				

3.2 LARGE SCALE FLAMMABLE STORAGE SITES (VCE RISK)

The UK HSE have concluded (see Buncefield Standards Task Group Report 2007) that any site which meets the following conditions should be considered as having a significant risks associated with potential vapour cloud explosions (VCEs).

COMAH Upper- and Lower-tier sites, storing:

1. gasoline (petrol) as defined in Directive 94/63/EC [European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations], in:
2. vertical, cylindrical, non-refrigerated, above-ground storage tanks typically designed to standards BS 2654, BS EN 1401:2004, API 620, API 6508 (or equivalent codes at the time of construction); with
3. side walls greater than 5 metres in height; and at
4. filling rates greater than 100 m^3/hour (this is approximately 75 tonnes/hour of gasoline).

It is assumed that the principal off site risk associated with such sites is taken to be a large vapour cloud explosion, such as occurred at Buncefield.

In relation to point 1, at present, the HSA recommends that all low flash materials of the type typically found in large petroleum stores (with flash point less than 21°C) should be considered as being capable of leading to a VCE.

3.2.1 Risk Based Approach

The approach here is essentially identical to that adopted by Atkins in RR 512 (HSE, 2007), which was commissioned by the UKHSE in order to help understand the levels of risk associated with VCEs at large scale petroleum storage depots.

The methodology is based on the following assumptions:

1. The likelihood of a VCE event at a large scale petroleum storage depot is conservatively taken as 10^{-4}/year per installation.
2. The VCE event could be centred anywhere on site (for practical purposes, the frequency can be uniformly distributed between the locations close to all the main fuel storage tanks).
3. The magnitude of the overpressure generated by the VCE is defined as that arising from a 50,000 m^3 VCE with an ignition strength of 7 and a combustion energy of 3.5 MJ/m^3 using the TNO multi-energy method (Van den Berg, 1985). Within RR 512 it was concluded that these assumptions were broadly consistent with the observed damage at Buncefield.
4. Individual risks of fatality can be calculated using a probit of $Y = 1.47+1.35\ln(P)$, with P in psi (Hurst, Nussey and Pape, 1989) for the risk to people outdoors, and the Chemical Industries Association (CIA, 2003) vulnerability curves for the risk to people indoors.
5. It is noted that, for a site with many vessels, it may sometimes be preferable to assume a lower frequency (e.g. 10^{-5}/year) for each Buncefield-type tank, rather than 10^{-4}/year for an entire site or vessel storage area.
6. It is emphasised that, in addition to the VCE risks, there will also be risks associated with large pool fires. Therefore, the risk assessment for these sites should also include the risks associated with the events described in Section 3.3, as these are likely to dominate the near field risks, and may be responsible for defining the Inner zone boundary.

3.2.2 Potential for Risk Reduction

If a site can demonstrate that it has implemented all the recommendations arising from the Buncefield investigations (in terms of overfill protection etc.), then it would be justifiable to reduce the likelihood of major VCEs by an order of magnitude (i.e. 10^{-5}/year for a site, or 10^{-6}/year per tank).

However, if there are particular areas of a site which are congested and where releases are likely to occur (such as road tanker loading bays), then the risk of VCEs in these regions should also be included in the risk assessment using a similar approach to that described above, but using the volume of the congested area and a suitable frequency (perhaps 10^{-3}/year depending on the site specific circumstances). Typically, the volume of a congested area such as a loading bay would be simply based on its total area times its height.

In some cases it may be worthwhile to determine the damage contours associated with various levels of harm, showing the maximum possible extent of any particular level of harm, using the criteria set out for thermal radiation and overpressure. These may be provided to the planning authority, as such issues may be additional factors which those involved in making land use planning decisions may wish to take into account, in addition to the direct risks to people.

3.2.3 Key Considerations for New Installations

It is expected that any new Buncefield-type storage installations would include:

- Compliance with S.I. 313 of 1979 – Dangerous Substances (Petroleum Bulk Stores) Regulations 1979.
- Compliance with the HSA Guidelines on Bulk Stores & LUP (see appendix 4)
- Compliance with HS(G)176 The storage of flammable liquids in tanks.
- Implementation of all the recommendations arising from the Buncefield investigation

3.2.4 Examples of risk-based zones

These 2 examples illustrate the zones that can be expected around large scale flammable storage sites. The distances are set out in increments of 20m, beginning at a value of 60m, with the colours below indicating the extent of the zones.

In a Site with <10 vessels, some containing Class I petroleum in tanks of volume > 175m^3, in one bund, the risk zones are as follows (zones are from the bund wall and include the pool fire risk):

Buncefield recommendations **not** implemented:

Distance	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500	520	540	560
Zone																										

Buncefield recommendations implemented:

Distance	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440
Zone																				

3.3 LARGE SCALE FLAMMABLE STORAGE SITES (NO VCE RISK)

These are sites which do not meet the definitions in Section 3.2 for VCE-type sites, and where the likelihood of a major VCE is considered to be so low as to be negligible for the purposes of land use planning.

The major off-site risks associated with such sites are generally taken to be associated with large pool fires, following a loss of containment.

The worst case event is taken to be a circular pool fire located adjacent to the storage bund (i.e. due to bund overtopping or bund failure). The radius (R) of the fire is taken to be given by:

$$R = 6.85\ V^{0.44537}$$

with R in metres and V (volume of liquid in pool) in cubic metres, subject to a maximum diameter of 100 m (which occurs when V = 87 m^3), which should not normally be exceeded (unless there are special circumstances). It is typically assumed that 50% of the maximum vessel contents may overtop the bund, which implies that the maximum 100 m pool size occurs for vessels of over 175 m^3.

The distances to thermal doses of 1800, 1000 and 500 tdu (thermal dose units –see appendix 2) can be modeled using any suitable pool fire model such as PHAST (in PHAST the value for the SEP of Xylene (surrogate for all hydrocarbons other than class I) should be set at 25 kW/m^2 and at 52 kW/m^2 in the case of Pentane (surrogate for class I)).

3.3.1 Risk Based Approach

A simple approach is taken which considers two events:

1) A major unbunded pool fire extending up to 100 m from the bund wall, with a total frequency of at least 10^{-4}/year (for a small installation, and increasing for larger installations to ensure that the risks close to large sites are not less than those for small sites, e.g. based on an event frequency of $10^{-4}/(100\pi)$ per metre/year along a locus 50 m from the vessel storage area).
2) A pool fire which covers the entire surface of the bund with a higher frequency of 10^{-3}/year.

The levels of thermal radiation as a function of distance from the centre of the pool can be calculated using any standard pool fire model. The calculations are undertaken for 5 m/s wind speed, and that the radiation levels taken are those calculated in the downwind direction (this will be conservative). Risks of fatality are then calculated using the standard Eisenberg probit and an assumption that people would be exposed for a period of 75 seconds (at a constant thermal radiation level).

For the purposes of risk assessment calculations, Event 1 is generally taken to be centred on a locus at a distance of 50 m from the bund, with the frequency distributed equally along this locus with a frequency of $10^{-4}/(100\pi)$ per metre/year. This approach implies a frequency approaching 10^{-4}/year for a very small vessel storage area, and ensures that the risks associated with larger sites are increased appropriately (e.g. a total frequency of 1.27×10^{-4}/year for a 100 m square site) to ensure that the risks close to a large site are not less than for a small site. Event 2 is taken to be centred in the middle of the bund area.

In some cases, it may be that a pool would be constrained in 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 could be adapted appropriately.

3.3.2 Potential Risk Reduction Measures

The fire frequencies quoted above are considered to be reasonable estimates for an installation which complies with current standards and guidance. However, if it can be shown that the fire risk at an installation is significantly lower, either due to the nature of the materials stored, the design of the installation, or other measures in place, then it may be appropriate to reduce these frequencies by up to an order of magnitude. For example, if the material has a high flashpoint then the likelihood of a fire is reduced (e.g. kerosene with a flashpoint >38°C is less likely to ignite than petrol with a flashpoint of -40°C (but see 3.4)). Similarly, if the tanks are located in a large sunken bund, with little danger of overtopping, then it would be reasonable to adopt a lower frequency for large fires outside the bund.

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 land use planning zones.

3.3.3 Other Issues

In addition to all the measures which should be in place to minimize the risks to people, it may also be worth considering whether there is adequate tertiary containment, and whether this would contain catastrophic bund failures and all the firewater in the event of a major fire.

The HSA policy in relation to tertiary containment and LUP is set out in appendix 4.

3.3.4 Examples of risk-based zones

In a Site with <10 vessels, some containing Class II petroleum in tanks of volume > 175m^3, in one bund, the risk zones are as follows (zones are based on pool fire risk, and are from the bund wall):

Distance	60	80	100	120	140	160	180	200
Zone								

3.4 STORAGE OF CLASS III (1) PETROLEUM PRODUCTS (DIESEL, GAS OILS)

Ordinarily, an isolated site storing class III(I)petroleum i.e. storing material classified as combustible (FP>55°C) rather than flammable, would not have a hazard zone around it because the pool fire event is not credible. However, there are a number of issues which need to be considered before such a decision can be made.

3.4.1 LUP Advice for Establishments Storing only Class III (I)

Petroleum liquids of this type are not classified as flammable liquids. They are combustible liquids which under normal storage conditions present only environmental hazards should a loss of containment occur.

The only circumstances where it is envisaged that they could be considered flammable would be following a loss of containment as an aerosol, mist or spray, or as a thin film on a surface. For a storage site with good control of ignition sources this should not alter the assessment process proposed in this document.

Provided the Safety Data Sheet confirms that the Flash Point of the product stored is above 55°C (and the storage tank that contains it is not capable of being heated) the approach described in 3.4.2 can be taken.

3.4.2 Standard Establishments

The most important major accident consideration in relation to Class III (I) storage is a loss of containment leading to a release into the environment.

The extent of any major accident should be fully described in either the company major hazard identification documents or planning submissions, where the applicant is the establishment.

Where the applicant is in the vicinity, the Authority, after engaging in consultation with the Operator on the potential consequences of this type of major accident at the establishment, must come to a view as to the likelihood and extent.

Provided there are no other flammable substances on the site or in the vicinity close enough to initiate a major accident on the site and it is clear that any credible spill will remain on site, the probability of a Class III (I) Fire should not be considered credible.

3.4.3 Establishments Where a Spill Cannot be Contained On Site

Operators generally do not have control of the areas outside of the establishment. Therefore, a release off-site raises many possibilities, especially in relation to control of ignition sources, physical effects, effects on third parties etc.

In these circumstances the modelling of a Class III (I) pool fire is appropriate.

3.4.4 Other Flammable Substances in the Vicinity (On or Off-Site)

While Class III (I) product in itself in normal circumstances is not considered flammable, the presence of flammable substances does raise the possibility of a fire or explosion involving those substances initiating a Class III (I) fire. The consequences of such events must be considered.

Additional fire protection arrangements for Diesel tanks may be appropriate and advice based on the modelling of Class III (I) fires may be justified in these circumstances.

3.4.5 Sites with Gas Pipelines

There are some sites (e.g. Power Stations) where the most significant major hazard risk is associated with potential jet fires from gas pipelines.

Therefore, on these sites, the risks from aboveground gas pipelines must be considered in developing LUP advice. A very simple method for assessing the risks associated with natural gas pipelines is provided by Jo and Ahn (2005) which essentially assumes that the risk can be determined using a point source thermal radiation model (see API RP 521 (1997) or IChemE (1989)).

The heat flux (I) can be calculated as:

$$I = \frac{\eta \, \tau_a \, Q \, H_c}{4 \pi r^2}$$

Where η is the ratio of the radiated heat to total heat released from the fire, τ_a is the atmospheric transmissivity, Q the gas release rate (kg/s), H_c the heat of combustion (J/kg) and r is the radial distance (m) to the point of interest.

Assuming a radiation fraction η of 0.2, an atmospheric transmissivity of 1, $H_c = 50.02\text{x}10^6$ J/kg for Methane and conservatively taking a 30 second exposure duration (based on Rausch et al, 1977) in the thermal radiation probit (see Section 2.3), leads to the following results for a point source:

99% fatality at	•3.9 $Q^{0.5}$ m
50% fatality at	•5.5 $Q^{0.5}$ m
10% fatality at	•6.7 $Q^{0.5}$ m
1% fatality at	•7.8 $Q^{0.5}$ m

Jo and Ahn (2005) provide a formula to calculate the effective gas release rate for natural gas pipelines, but no information is provided on the likely failure rates. However, such failure rate data is provided by Carter (1991) and in the Purple Book (1999) for various diameters of pipe.

The above information could simply be used to define hazard ranges (and hazard based zones), or the risk could be integrated along the pipelines to produce risk contours.

It is noted that the approach described above is relatively simplistic, and that risk assessments are often undertaken using more sophisticated jet fire models, such as that of Chamberlain (1987), and that rather than use a point source model, the risks are generally calculated taking account of the flame length and direction, as well as transmissivity. However, the results are likely to depend primarily on the choice of hole sizes and associated frequencies.

3.5 FERTILIZER BLENDING/STORAGE SITES

The main off-site risks associated with fertilizer blending/storage sites handling various grades of Ammonium Nitrate Fertilizer covered by the COMAH regulations are the risks associated with a major fire, leading to a plume of toxic smoke which could travel many kilometers, and the risk of an Ammonium Nitrate explosion.

3.5.1 Risk Based Approach

The two main types of event which could be considered are:

- Fire in vicinity of Ammonium Nitrate Fertilizer leading to the decomposition products Nitric Oxide and Nitrogen Dioxide being released.
- Explosion of molten/decomposing Ammonium Nitrate

The risk of fatality simply by using the appropriate probit relationships for the toxic and explosion effects, e.g.

Nitrogen dioxide :	Probit = $-13.79 + 1.4\ln(c^2t)$	(AIChE, 2000)
Nitric oxide :	Probit = $-150.838 + 15.432\ln(ct)$	(PHAST, 2006)
Overpressure :	Probit = $1.47 + 1.35\ln(P)$	(Hurst, Nussey and Pape (1989))

Where C is in ppm, t in minutes and P in psi.

It may also be necessary to take account of the effect of being indoors, using appropriate air change rates for the toxic hazards and vulnerability relationships for the overpressure hazards.

The full details of such an approach are set out in appendix 5.

Alternatively a simplified risk assessment can then be undertaken based only on the explosion scenarios below:

30t explosion of Truck outside warehouse, per site,	4×10^{-5} per year
300t explosion of Stack outside warehouse, per site,	2×10^{-8} per year
30t explosion of Stack outside warehouse, per site,	1.98×10^{-5} per year
30t explosion of Stack inside warehouse, per site,	6×10^{-5} per year
300t explosion of Stack inside warehouse, per site,	6×10^{-7} per year

The Warehouse risks are calculated from the wall of the warehouse nearest to the receptor. The outside risks from the edge of the storage area nearest the receptor. The levels of overpressure can be calculated using the method for condensed phase explosives in Appendix 2.3, or any standard TNT equivalence model.

For a typical site this gives the following profile:

Distance	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
Zone																											

3.6 WAREHOUSES

In general, the off-site risks associated with most accidents in warehouses are negligible, as the quantities involved in any loss of containment tend to be very limited (e.g. up to about 200 kg for a single drum or 1 m^3 for an IBC). The only exceptions are any particularly toxic substances (gases or volatile liquids), which need to be considered individually.

Therefore, the main concern in terms of off-site risk and land use planning is the risk associated with a major fire, involving the release of hazardous materials from several containers. This could lead to a plume of toxic smoke which could travel many kilometers.

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

3.6.1 Risk Based Approach

Assuming that the warehouse does not contain any particularly toxic materials, such as pesticides or some agrochemicals (e.g. Phorate, Lindane, etc) capable of being released unburned in the fire plume, then the main risk will be associated with toxic combustion products. However, it is impossible to predict the precise mix and quantity of each toxic combustion product, and so the approach adopted here 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. In many cases, this turns out to be Nitrogen Dioxide, which is one of the more toxic combustion products that is likely to be released in large quantities in most warehouse fires. However, in other cases it might be HCl, SO_2, etc, depending on the chemical mix within the warehouse.

The release rate of NO_2 , for example, can be estimated by assuming that 5% (see table below) of the nitrogen content of the hazardous substances stored in the warehouse is combusted to form NO_2, and that this is released over 2 hours for a small warehouse, or 4 hours for a large warehouse. For example, for a large warehouse storing 2500 tonnes of Ammonium Chloride (NH_4Cl, MW = 53.49), the release rates of NO_2 (MW = 46) and HCl (MW = 36.46) in a major fire can be calculated as follows (assuming 5% of N converted to NO_2, and 100% Cl converted to HCl):

$$NO_2 \text{ release rate} = 2{,}500{,}000 \times (14/53.49 \times 0.05) \times (46/14) / (4 \times 3600) = 7.5 \text{ kg/s}$$

$$HCl \text{ release rate} = 2{,}500{,}000 \times (35.45/53.49 \times 1.0) \times (36.46/35.45) / (4 \times 3600) = 118 \text{ kg/s}$$

For warehouses storing a more complex mix of hazardous substances, a judgment will need to be made to determine the representative release rates of NO_2, HCl, SO_2 and any other dominant toxic combustion products. Porter et al (2000) makes the following useful general assumptions:

Toxic Combustion Product	From Porter et al (2000)
CO	9.7% C to CO
CO2	5% C to CO_2
NO_2	5% N to NO_2
HCN	1.5% N to HCN
HCl	100% Cl to HCl
SO_2	100% S to SO_2
HBr	100% Br to HBr

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 risk assessment, it is only necessary to consider relatively high wind speed conditions (i.e. >10 m/s), which generally occur for rather less than 10% of the time. The dispersion of a release can therefore be simply modeled using a standard Gaussian plume model (e.g. TNO, 1979), with no plume rise.

For cases where several toxic combustion products are produced, it is 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. Hence, in the example above, the equivalent release rate of NO_2 in a major fire can be increased from 7.5 to about 20 kg/s to take account of the HCl and any other less toxic combustion products. This is based on a conservative assessment of the relative toxicity of HCl and NO_2 for a 30 minute exposure.

The likelihood of fire starts in typical warehouses is estimated at about 10^{-2}/year, based on historical evidence (see Hymes and Flynn (1982) and 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}/year for a large fire in a typical warehouse. However, for the type of warehouses holding hazardous substances, it is assumed that the more stringent controls would result in the likelihood of such major events involving the entire warehouse being typically an order of magnitude lower still, at about 10^{-4} per year, with the higher frequency of 10^{-3}/year being associated with a lesser fire involving just 10% of the source term. i.e.

- Minor fire involving 10% of inventory at a frequency of 10^{-3}/year
- Major fire involving 100% of inventory at a frequency of 10^{-4}/year

The risk of fatality can then be calculated using standard probit equations (e.g. that of AIChE for NO_2), using an exposure duration of 30 minutes.

In reality, such high wind speeds of over 10 m/s are only likely to occur for a few percent of the time at most locations. However, the conservatism in assuming 10% is intended to cover other uncertainties in the analysis, such as the variable degree of fire plume entrainment in the building wake which may occur at lower wind speeds.

Example

A warehouse storing ~350 tonnes of dangerous substances would have the following zones around it:

Distance	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310
Zone																											

3.7 CHEMICAL/PHARMACEUTICAL PLANTS

Chemical/pharmaceutical manufacturing/processing plants are likely to involve a variety of different hazards, often located in different parts of the site. Hazards are likely to include those related to:

- Bulk Flammable storage
- Warehouse fires
- Toxic hazards from bulk storage and process activity
- Explosion related to processing activity
- Presence of pressurized drums of toxic gases

The large scale storage hazards associated with flammable storage and warehouses can generally be assessed using the methods described elsewhere in this document (3.2/3.3 & 3.8), and so it is the process hazards which are considered in more detail in this section. If a site includes more than one of the above hazards, then the risks will need to be aggregated.

The key point with processing sites is that the material in process may be handled at elevated temperatures and pressures, and so the likelihood of relatively small releases leading to significant major accidents is considerably increased. Furthermore, the hazardous materials that could be released from process may be reaction products and not simply raw materials.

The general methods recommended here can be applied to a wide variety of other types of site, such as biodiesel manufacturing, distilleries, etc.

3.7.1 Risk Based Approach

3.7.1.1 Toxic (and Water Reactive) Risks from Bulk Storage

For sites with atmospheric bulk storage of toxic (or water reactive) liquids, the risks can generally be represented by 3 scenarios:

1. Major failure leading to the bund area being covered (frequency 10^{-4} per year per vessel).
2. Catastrophic failure leading to larger spillage (frequency 10^{-5} per year per vessel).
3. Failure during road tanker on/off-loading (frequency 3×10^{-7} per operation).

If the vessel is not bunded, then Scenario 1 can be omitted, but the likelihood of Scenario 2 should be increased to 10^{-4} per year per vessel.

The source term release rate (due to evaporation or reaction with water) will depend on the pool area. For Scenarios 2 and 3 the pool radius can be estimated using $R = 6.85 \times V^{0.44537}$ m (where V is the vessel or tanker volume), up to a maximum of $R = 50$ m. Some allowance for partial retention within the bund in Scenario 2 can be made by reducing V by about half (or doing more detailed bund overtopping calculations).

Evaporation release rates from pools can be calculated using standard evaporation models (in D5 and F2 conditions). More detailed calculations may be required for water reactive chemicals or fuming acids.

The risks should be calculated using D5 and F2 weather conditions. In most cases, a standard Gaussian plume model will be sufficient for modeling the dispersion. Appendix 3 provides probit data for all the most likely substances which may need to be considered.

3.7.1.2 Toxic Risks from Process

A full QRA would need to consider every process and every vessel individually and this would entail considerable effort and analysis which is not considered necessary for the purposes of land use planning. The approach recommended here is to identify the largest process vessel for the most toxic material being handled, and assume that a release of this inventory bounds all other potential toxic releases. This may require some analysis of the toxicity, volatility, temperature and inventory for various cases in order to ensure that the worst case toxic release is identified. For example, a reactor vessel containing 1 tonne of Methyl Iodide above its boiling point (42.5°C) would pose a more significant potential release than a similar vessel at the same temperature with 10 tonnes of a less volatile substance such as Ethylene Dibromide (BP = 131.6°C).

Releases from a process may be hot and under pressure, and so the quantity of material that may become airborne can 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 becomes airborne. In other cases it may be possible to determine a smaller worst case source term.

In the absence of any more detailed information, the likelihood of such a major toxic release from a process should conservatively be taken as 10^{-4}/year.

The risks should be calculated using D5 and F2 weather conditions. In most cases, a standard Gaussian plume model will be sufficient for modeling the dispersion. Appendix 3 provides probit data for all the most likely substances which may need to be considered. Where several probits exist for a substance then a reasonably conservative choice should be made. Generally, the probits quoted by AIChE and TNO tend to be the most appropriate.

If there are several process areas handling toxics, then worst case events should be identified for each area.

3.7.1.3 Explosion Risks

There are two main types of explosion risk which need to be considered for most process plants:

- Risks associated with failure of pressure vessels (exothermic reactions)
- Risks associated with VCEs due to release of flammables in semi-confined regions

Each of these should be included in the analysis unless it can be demonstrated that such events are not applicable for the facility.

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 3 times the design pressure. The overpressures can be determined using a simple TNT equivalence model based on the release of stored energy in the vessel, and the risks associated with the overpressure can be calculated as in Section 3.2. Details of the calculation method are given in Appendix 2.

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 vapour cloud explosion 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 should be taken as 7.

In the absence of any more detailed information (such as historical data or more detailed fault tree analysis etc), the likelihood of either of the above types of explosion in a process area should be taken as 10^{-4}/year. This is considered to be a conservative approach.

3.7.2 Uncertainties

The greatest uncertainties probably relate to the likelihood of the postulated representative scenarios. These frequencies could be refined if there is site specific or industry specific historical data, or if more detailed studies (such as fault tree analysis) are able to demonstrate lower frequencies.

3.8 PRESSURISED TOXIC GAS DRUM & CYLINDER STORES

The risks associated with toxic gas drum & cylinder stores, storing substances such as Chlorine, HCl, Ammonia etc., arise from the toxic vapour that is generated in any loss of containment. Although the inventory involved is generally limited to that of a drum (typically 1 tonne), the likelihood of release can be relatively high due to the nature of the manual operations involved in handling drums.

The table below provides a simple set of representative events and frequencies that can be used as the basis for a risk assessment for a Chlorine drum store. For other similar installations or for other substances it may necessary to revise these events and release rates/durations accordingly.

Table: Representative Events for a Chlorine Drum Store

Scenario	Description	Release Quantity or Rate	Release Duration (minutes)	Likelihood (Annual Frequency in cpm)
1	Drum dropping (large 13 mm hole in drum)	2.84 kg/s	5	1.2 cpm per drum movement
2	Drum dropping (small 7 mm hole in drum)	0.7 kg/s	20	4.8 cpm per drum movement
3	Valve damage (sheared liquid valve)	0.45 kg/s	30	22.5 cpm per drum movement

The table above indicates that key parameter in this case is the number of drum movements, although a more detailed assessment would include consideration of the number of drums on site, the number of drums used, the length of vapour pipework and whether releases would be controlled by an automatic isolation system. Clearly, this type of risk assessment methodology could be refined by defining additional scenarios as appropriate, but it provides an indication of the type of approach that could be adopted for a particular type of installation.

The Purple Book suggests the following scenarios and frequencies for more general application:

Installation	G1 Inst.	G2 continuous 10 min	G3 Continuous 10mm
Pressure Vessel	$5x10^{-7}$ y^{-1}	$5x10^{-7}$ y^{-1}	$1x10^{-5}$ y^{-1}
Pipe	G1 Full-bore	G2 Leak 10% D	
Pipe nominal dia. < 75mm	$1x10^{-6}$ m^{-1} y^{-1}	$5x10^{-6}$ m^{-1} y^{-1}	
Pipe nominal dia. ><	$3x10^{-7}$ m^{-1} y^{-1}	$2x10^{-6}$ m^{-1} y^{-1}	
Pipe nominal dia. > 150mm	$1x10^{-7}$ m^{-1} y^{-1}	$5x10^{-7}$ m^{-1} y^{-1}	

The dispersion of the releases should be modeled in D5 and F2 weather conditions, using an appropriate dispersion model (e.g. a dense gas dispersion model such as in PHAST or HGSYSTEM would be required for Chlorine releases). Alternatively, for some substances there are published correlations giving the extent of various fatality envelopes for any release rate and duration (see for example HSE RR283).

The risks can be calculated using appropriate probits (see Appendix 3) and wind rose data.

3.9 SITES HANDLING/STORING EXPLOSIVES

The major risk associated with such sites arises from the blast overpressure associated with potential accidental detonations. Such explosions can also generate flying debris and cause glass damage, which may sometimes be important in determining the risk.

3.9.1 Risk Based Approach

The simplest risk based approach is to consider the worst case event for each explosives inventory and assume a generic frequency of 10^{-4}/year, based on the recommendation by HSE (2002) which was derived from historical accident records. In some cases, the likelihood of explosions involving process inventories may be somewhat higher (typically an order of magnitude). These frequencies could be reduced for a particular site if there is sufficient justification.

In many cases, it may be sufficient to perform a simpler analysis using the TNT equivalence model, where the analysis should be based on each explosive inventory with an appropriate likelihood. Merrifield (1993) suggests a value of 10^{-3} for process buildings and 10^{-4} for Storage areas.

The level of blast overpressure can be calculated using a simple TNT equivalence model and overpressure probit, although it may be more appropriate to derive fatality estimates using more bespoke models such as the MoD ESTC models, as described by HSE (2002).

It is noted that HSE (2002) provides detailed risk assessment methods for a variety of explosive stores, and these approaches could be used where appropriate.

It may be useful to also supply to the planning authority the Inhabited Building Distance.

The Inhabited Building Distance for Hazard Type 1 explosives is calculated according to the following formula (HSE, 2002):

$$\mathrm{IBD} = \frac{22.4\,Q^{1/3}}{[1+(3175/Q)^2]^{1/6}}$$

where IBD is the inhabited building distance (m) and Q is the net explosives quantity (kg).

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5 Glossary

AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonably Practicable
ALARA	As Low As Reasonably Achievable
An BP	An Bord Pleanala
ARI	Approximate Risk Integral
ARAMIS	Accidental risk assessment Methodology for Industries
BLEVE	Boiling Liquid Expanding Vapour Explosion
CBA	Cost Benefit Analysis
CD	Consultation Distance
CIA	Chemical Industries Association
COMAH	Control of Major Accident Hazards
cpm	Chances per million (years)
DD	Dangerous Dose (or worse)
EV	Expectation Value
HSA	Health and Safety Authority
F-N curve	A Frequency-Number curve (for Societal Risk)
HSE	Health and Safety Executive UK
LUP	Land Use Planning
Nmax	Maximum number of people affected
PA	Planning Authority
PADHI	Planning Advice for Developments near Hazardous Installations
PLL	Potential Loss of Life
QRA	Quantified Risk Assessment
R2P2	Reducing Risks, Protecting People (HSE publication, 2001
RI	Risk Integral
RHAD	Risk Hazard Assessment Database (an EU LUP initiative)
SRI	Scaled Risk Integral
TOR	Tolerability of Risk
VCE	Vapour Cloud Explosion

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Appendix 1- HSA advice matrix and Padhi sensitivity levels

HSA Individual Risk Matrix

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

HSA has defined the boundaries of the Inner, Middle and Outer LUP zones as:

10^{-5}/year	• Risk of fatality for Inner Zone (Zone 1) boundary
10^{-6}/year	• Risk of fatality for Middle Zone (Zone 2) boundary
10^{-7}/year	• Risk of fatality for Outer Zone (Zone 3) boundary

For some types of development, particularly those involving large numbers of people, it is likely that the deciding factor from the point of view of land use planning is the societal risk, i.e. the risk of large numbers of people being affected in a single accident. Therefore for large scale developments, including those outside Zone 3 but within the consultation distance set out in the Planning and Development Regulations 2001-6 and notified to the planning authority by the HSA at the time of notification of the establishment, estimations of societal risk will be undertaken.

Padhi sensitivity levels

SENSITIVITY LEVEL 1: People at work, Parking

DT1.1 – Workplaces

DT1.2 – Parking Areas

DEVELOPMENT TYPE	EXAMPLES	DEVELOPMENT DETAIL AND SIZE	JUSTIFICATION
DT1.1 - WORKPLACES	Offices, factories, warehouses, haulage depots, farm buildings, non-retail markets, builder's yards.	Workplaces (predominantly non-retail), providing for less than 100 occupants in each building **and** less than 3 occupied storeys - **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	
		DT1.1 x1 Workplaces (predominantly non-retail) providing for 100 or more occupants in any building **or** 3 or more occupied storeys in height - **Level 2** (except where the development is at the major hazard site itself, where it remains Level 1).	Substantial increase in numbers at risk with no direct benefit from exposure to the risk.
	Sheltered workshops, Remploy.	**DT1.1 x2** Workplaces (predominantly non-retail) specifically for people with disabilities - **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.
DT1.2 - PARKING AREAS	Car parks, truck parks, lock-up garages.	Parking areas with no other associated facilities (other than toilets) - **Level 1**	
		EXCLUSIONS	
	Car parks with picnic areas, or at a retail or leisure development, or serving a park and ride interchange.	**DT1.2 x1** Where parking areas are associated with other facilities and developments the sensitivity level and the decision will be based on the facility or development.	

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
DT2.1 - HOUSING	Houses, flats, 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 - **Level 2**	Development where people live or are temporarily resident. It may be difficult to organise people in the event of an emergency.
		EXCLUSIONS	
	Infill, backland development.	**DT2.1 x1** Developments of 1 or 2 dwelling units - **Level 1**	Minimal increase in numbers at risk.
	Larger housing developments.	**DT2.1 x2** Larger developments for more than 30 dwelling units - **Level 3**	Substantial increase in numbers at risk.
		DT2.1 x3 Any developments (for more than 2 dwelling units) at a density of more than 40 dwelling units per hectare - **Level 3**	High-density developments.
DT2.2 - HOTEL/HOSTEL/ HOLIDAY ACCOMMODATION	Hotels, motels, guest houses, hostels, youth hostels, holiday camps, holiday homes, halls of residence, dormitories, accommodation centres, holiday caravan sites, camping sites.	Accommodation up to 100 beds or 33 caravan / tent pitches - **Level 2**	Development where people are temporarily resident. It may be difficult to organise people in the event of an emergency.
		EXCLUSIONS	
	Smaller - guest houses, hostels, youth hostels, holiday homes, halls of residence, dormitories, holiday caravan sites, camping sites.	**DT2.2 x1** Accommodation of less than 10 beds or 3 caravan / tent pitches - **Level 1**	Minimal increase in numbers at risk.
	Larger – hotels, motels, hostels, youth hostels, holiday camps, holiday homes, halls of residence, dormitories, holiday caravan sites, camping sites.	**DT2.2 x2** Accommodation of more than 100 beds or 33 caravan / tent pitches - **Level 3**	Substantial increase in numbers at risk.
DT2.3 - TRANSPORT LINKS	Motorway, dual carriageway.	Major transport links in their own right; i.e. not as an integral part of other developments - **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.	**DT2.3 x1** Single carriageway	Minimal numbers present and

		roads - **Level 1**	mostly a small period of time exposed to risk. Associated with other development.
	Any railway or tram track.	**DT2.3 x2** Railways - **Level 1**	Transient population, small period of time exposed to risk. Periods of time with no population present.
DT2.4 - INDOOR USE BY PUBLIC	**Food & Drink:** Restaurants, Cafes, drive-through fast food, pubs. **Retail:** Shops, petrol filling station (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. **Community & adult education:** Libraries, art galleries, museums, exhibition halls, day surgeries, health centres, religious buildings, community centres. Adult education, 6th form college, college of FE. **Assembly & 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 250 m^2 up to 5000 m^2 - **Level 2**	Developments where members of the public will be present (but not resident) Emergency action may be difficult to co-ordinate.
	EXCLUSIONS		
	Outdoor markets, car boot sales, funfairs. Picnic area, park & ride interchange, viewing stands, marquees.	**DT2.5 x1** Predominantly open-air developments likely to attract the general public in numbers greater than 100 people but up to 1000 at any one time - **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.	**DT2.5 x2** Predominantly open-air developments likely to attract the general public in numbers greater than 1000 people at any one time - **Level 4**	Very substantial increase in numbers at risk, more vulnerable due to being outside and emergency action may be difficult to co-ordinate.
DT2.5 - OUTDOOR USE BY PUBLIC	**Food & Drink:** Food festivals, picnic area. **Retail:** Outdoor markets, car boot sales, funfairs. **Community & adult education:** Open-air theatres and exhibitions. **Assembly & leisure:** Coach / bus / railway stations, park & ride interchange, ferry terminals. Sports stadia, sports fields / pitches, funfairs, theme parks, viewing stands. Marinas, playing fields, children's play areas, BMX/go-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 - **Level 2**	Developments where members of the public will be present (but not resident) either indoors or outdoors. Emergency action may be difficult to co-ordinate.

	EXCLUSIONS		
	Outdoor markets, car boot sales, funfairs. Picnic area, park & ride interchange, viewing stands, marquees.	**DT2.5 x1** Predominantly open-air developments likely to attract the general public in numbers greater than 100 people but up to 1000 at any one time - **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.	**DT2.5 x2** Predominantly open-air developments likely to attract the general public in numbers greater than 1000 people at any one time - **Level 4**	Very substantial increase in numbers at risk, more vulnerable due to being outside and emergency action may be difficult to co-ordinate.

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
DT3.1 - INSTITUTIONAL ACCOMMODATION AND EDUCATION	Hospitals, convalescent homes, nursing homes. Old peoples homes with warden on site or 'on call', sheltered housing. Nurseries, crèches. Schools and academies for children up to school leaving age.	Institutional, educational and special accommodation for vulnerable people, or that provides a protective environment - **Level 3.**	Places providing an element of care or protection. Because of 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, old peoples homes, sheltered housing.	**DT3.1 x1** 24-hour care where the site on the planning application being developed is larger than 0.25 hectare - **Level 4**.	Substantial increase in numbers of vulnerable people at risk.
	Schools, nurseries, crèches.	**DT3.1 x2** Day care where the site on the planning application being developed is larger than 1.4 hectare – **Level 4**.	Substantial increase in numbers of vulnerable people at risk.
DT3.2 - PRISONS	Prisons, remand centres.	Secure accommodation for those sentenced by court, or awaiting trial etc. – **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

DEVELOPMENT TYPE	EXAMPLES	DEVELOPMENT DETAIL AND SIZE	JUSTIFICATION
[Note: All Level 4 developments are by exception from Level 2 or 3. They are reproduced in this table for convenient reference.]			
DT4.1 - INSTITUTIONAL ACCOMMODATION	Hospitals, convalescent homes, nursing homes, old peoples 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 larger than 0.25 hectare - **Level 4**.	Places providing an element of care or protection. Because of 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 larger than 1.4 hectare - **Level 4**.	Places providing an element of care or protection. Because of 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.
DT4.2 - VERY LARGE OUTDOOR USE BY PUBLIC	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 1000 people present - **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.

Appendix 2 Details of Consequence and Risk Assessment Modeling

A2.1 - LPG FIREBALL MODELLING

The fireball is assumed to be just touching the ground and has a diameter (D) given by the standard Roberts (1982) model, which is defined by AIChE (1994) as:

$$D = 5.8\, M_F^{1/3} \qquad \text{(metres)}$$

Where M_F = Mass of fuel involved (kg)

The fireball duration (T) in seconds is given by Cook et al (1990) as:

$$T = 0.45\, M_F^{1/3} \qquad \text{for } M_F < 37{,}000 \text{ kg}$$

$$T = 2.59\, M_F^{1/6} \qquad \text{for } M_F > 37{,}000 \text{ kg}$$

The intensity of thermal radiation is based on the solid flame model as described by Crossthwaite (1988). The thermal radiation is given by:

$$I = F\, E\, \tau_a$$

Where I = Thermal radiation intensity (kW/m^2)

F = View factor (for vertical target)

E = Surface emissive power (kW/m^2)

τ_a = Atmospheric transmissivity, taken as $\tau_a = 1 - 0.0565 \ln (x - R)$ for $x > R$ [note that 100% fatality is assumed within the fireball radius]

x = Horizontal distance between receptor and fireball centre (m)

R = Fireball radius (m)

The surface emissive power is conservatively taken as 270 kW/m^2 (for propane).

The view factor for a vertical target is:

$$F = \frac{x\,(D/2)^2}{\left(x^2 + (D/2)^2\right)^{3/2}}$$

Where F = View factor

x = Horizontal distance between receptor and fireball centre (m)

D = Fireball diameter (m)

The level of harm associated with thermal radiation depends on both the radiation intensity (I) and the duration of exposure (t). The radiation is generally assumed to take the form of a square wave pulse. The thermal dose outdoors is defined as:

$$V = I^{4/3}\, t$$

Where V = Thermal dose $((kW/m^2)^{4/3}$.seconds

I = Radiation intensity (kW/m^2)

T = Duration of exposure (seconds)

The thermal dose is measured in $(kW/m^2)^{4/3}$.seconds, which is usually abbreviated to thermal dose units (tdu). The probit equation most commonly used to assess the probability of fatality associated with thermal radiation is that of Eisenberg (see Lees, 1996), which is quoted as:

$$\text{Probit} = -14.9 + 2.56 \ln (V)$$

A thermal dose of 1000 tdu would give a probit of 2.78, which implies about a 1% level of fatality.

A 2.2 VAPOUR CLOUD EXPLOSION MODELLING

Using the TNO vapour cloud explosion model, the vapour cloud is assumed to be a stoichiometric mixture of volume V (m^3) with a heat of combustion (H) of 3,500,000 J/m^3 and an ignition strength of 7.

The scaled distance R at a distance r (m) is defined as:

$$R = r\left(\frac{101325}{V\,H}\right)^{\frac{1}{3}}$$

The level of overpressure (P in atm) as a function of scaled distance is given by TNO as a graphical correlation, which can be represented as follows:

Define $x = \log_{10}(R)$
For R <= 0.4 P = 1
For 0.4 < R < 4 $P = 10^{(-0.2211x^6 - 2.1917x^5 - 0.1924x^4 + 2.2432x^3 - 0.7044x^2 - 1.4617x - 0.3465)}$
For R >= 4 $P = 10^{(-1.1113x - 0.5178)}$

P can be converted to mbar by multiplying by 1013.25. To convert mbar to psi divide by 68.947573.

The outdoor risk associated with any level of overpressure can be calculated using the HSE probit defined by Hurst, Nussey and Pape (1989):

Probit = 1.47 + 1.35 ln(P) with P in psi

Levels of risk to people indoors can be calculated using vulnerability relationships such as those presented by the CIA (2003).

A2.3 - CONDENSED PHASE EXPLOSIONS

The TNT equivalence model can be used for modelling condensed phase explosions such as explosives, and also for assessing events such as pressure vessel bursts. The TNT equivalent mass m (kg) for the explosion must be estimated using Prugh's or Baker's method, and then standard correlations can be used to determine the level of overpressure at a distance r.

The surface burst correlations given in Lees (p17/132, 1996), based on the work of Kingery and Bulmash, are generally the most appropriate.

R (the scaled distance) = $r/m^{1/3}$

For R > 40 the overpressure is not significant, otherwise

Define a = -0.214362789151
Define b = 1.35034249993
If R < 0.0674 Then define R = 0.0674
Define $u = a + b \log_{10}(R)$
Define $x = \sum_{i=0}^{i=11} c_i u^i$
Where $c_0 = 2.78076916577$
$c_1 = -1.6958988741$
$c_2 = -0.154159376846$
$c_3 = 0.514060730593$
$c_4 = 0.0988534365274$
$c_5 = -0.293912623038$

$c_6 = -0.0268112345019$
$c_7 = 0.109097496421$
$c_8 = 0.00162846756311$
$c_9 = -0.0214631030242$
$c_{10} = 0.0001456723382$
$c_{11} = 0.00167847752266$

$P = 10^x$ (kPa)

Outdoor and indoor risks can be calculated as for VCEs.

Appendix 3 Probit Relationships

The table below lists a number of published (and a few unpublished) probits for a variety of toxic, fire and blast hazards, which can be used to relate the level of accident consequences to a predicted probability of harm. All probits are of the form Probit = a + b ln ($V^n t$), where a, b and c are constants as given in the table, V is the value of the consequence in the units specified, and t is the duration of exposure (in the units specified). The original source references for each probit relationship are also given. It is noted that there are often several relationships for the same hazardous phenomenon, and so care should be taken in choosing an appropriate relationship.

PHENOMENON AND TYPE OF INJURY	a	b	n	Hazard	Unit	Time	Reference
Acrolein (AIChE)	-9.931	2.049	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Acrolein (World Bank 1988)	-9.93	2.05	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)
Acrolein (TNO 1999)	-4.1	1	1	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Acrolein (TNO 2000)	-9.83	1	2	Toxic	mg/m3	Minutes	TNO Effects Version 4.0 (2000)
Acrylamide (PHAST)	-10.2622	1.677894	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Acrylonitrile (AIChE)	-29.42	3.008	1.43	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Acrylonitrile (TNO 1999)	-8.6	1	1.3	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Acrylonitrile (TNO 2000)	-8.6	1	1.4	Toxic	mg/m3	Minutes	TNO Effects Version 4.0 (2000)
Allylalcohol (TNO 1992 n=1)	-5.1	1	1	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992)
Allylalcohol (TNO 1999)	-11.7	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Ammonia (AIChE)	-35.9	1.85	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Ammonia (World Bank 1988)	-9.82	0.71	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988); ACDS p135 (1991) based on (see Lees (1996) pA17/7)
Ammonia (TNO 1999)	-15.6	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999)
Ammonia (TNO)	-15.8	1	2	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (2000)
Ammonia (ACDS 1991)	-12.2	0.8	2	Toxic	ppm	Minutes	ACDS p185 (1991)
Ammonia (Eisenberg et al 1975)	-30.57	1.385	2.75	Toxic	ppm	Minutes	J. Loss Prev. Process Ind. p170 Vol. 3 January 1990; Lees (1980) p208; Lees (1996) p18/37
Ammonia (USCG 1980)	-28.33	2.27	1.36	Toxic	ppm	Minutes	Perry W.W. and Articola W.J., US Coast Guard 1980 & Lees p18/60 1996
Ammonia (Canvey 1978 Case A)	1.14	0.782	2.75	Toxic	g/m3	Minutes	Canvey Report (1978) (see Lees (1996) pA7/21
Ammonia (Canvey 1978 Case B)	-7.41	2.205	2.75	Toxic	g/m3	Minutes	Canvey Report (1978) (see Lees (1996) pA7/21

PHENOMENON AND TYPE OF INJURY	a	b	n	Hazard	Unit	Time	Reference
Azinphosmethyl (TNO 1992)	-1.6	1	1	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992)
Azinphosmethyl (TNO)	-4.8	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Benzene (AIChE)	-109.78	5.3	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Benzyl chloride (PHAST)	-10.2772	1.677892	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Bromine (AIChE)	-9.04	0.92	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Bromine (TNO)	-12.4	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); Effects Version 4.0 (2000)
Carbon disulphide (PHAST)	-16.5246	1.673501	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Carbon monoxide (AIChE)	-37.98	3.7	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Carbon monoxide (TNO)	-7.4	1	1	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); Effects Version 4.0 (2000)
Carbon tetrachloride (AIChE)	-6.29	0.408	2.5	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Carbon tetrachloride (World Bank 1988)	0.54	1.01	0.5	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)
Chlorine (IOM 2004)	-19.7	3.8	0.64	Toxic	ppm	Minutes	IOM 2004 (Confidential information provided by Peter Ridgway of HSE)
Chlorine (TNO 1999)	-6.35	0.5	2.75	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999)
Chlorine (Franks Harper Bilo 1996)	-13.855	1.455	2	Toxic	ppm	Minutes	Franks, Harper and Bilo (1996)
Chlorine (TNO 1992)	-14.3	1	2.3	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (2000)
Chlorine (van Heemst 1990)	-10.1	1.11	1.65	Toxic	ppm	Minutes	van Heemst (1990; used in PHAST Version 6.3
Chlorine (Purdy et al 1988)	-4.4	0.52	2.75	Toxic	ppm	Minutes	J. Loss Prev. Process Ind. p51 Vol. 4 January 1991; ACDS (1991)
Chlorine (Zwart & Woutersen 1988)	-23.76	2.78	1.04	Toxic	ppm	Minutes	Zwart & Woutersen (1992)
Chlorine (World Bank 1988)	-5.3	0.5	2.75	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)
Chlorine (ten Berge 1986)	-19.05	1.1	3.5	Toxic	ppm	Minutes	ten Berge (1986)
Chlorine (Withers and Lees 1985 Reg pop - Std level of activity)	-8.29	0.92	2	Toxic	ppm	Minutes	Withers and Lees (1985); Lees p18/57 (1996); AIChE Guidelines for CPQRA p156 (1989) & p259 (20
Chlorine (Withers and Lees 1985 Reg pop - Base level of activity)	-9.57	0.92	2	Toxic	ppm	Minutes	Withers and Lees (1985); Lees p18/57 (1996)

PHENOMENON AND TYPE OF INJURY	a	b	n	Hazard	Unit	Time	Reference
Chlorine (Withers and Lees 1985 Vul pop - Std level of activity)	-6.61	0.92	2	Toxic	ppm	Minutes	Withers and Lees (1985); Lees p18/57 (1996)
Chlorine (Withers and Lees 1985 Vul pop - Base level of activity)	-7.88	0.92	2	Toxic	ppm	Minutes	Withers and Lees (1985); Lees p18/57 (1996)
Chlorine (ten Berge 1983)	-5.04	0.5	2.75	Toxic	ppm	Minutes	ten Berge (1983)
Chlorine (Rijnmond 1982)	-11.4	0.82	2.75	Toxic	ppm	Minutes	J. Loss Prev. Process Ind. p50 Vol. 4 January 1991
Chlorine (ten Berge & van Heemst 1982)	-6.5	0.5	2.75	Toxic	ppm	Minutes	J. Loss Prev. Process Ind. p57 Vol. 4 January 1991
Chlorine (Nussey et al 1986 version of ten Berge & van Heemst 1982)	-4.92	0.5	2.75	Toxic	ppm	Minutes	J. Loss Prev. Process Ind. p50 and p57 Vol. 4 January 1991
Chlorine (USCG 1980)	-36.45	3.13	2.64	Toxic	ppm	Minutes	Perry W.W. and Articola W.J., US Coast Guard 1980 & Lees p18/60 (1996)
Chlorine (Eisenberg et al 1975)	-17.1	1.69	2.75	Toxic	ppm	Minutes	J. Loss Prev. Process Ind. p54 Vol. 4 January 1991; Lees p208 (1980); Lees p18/37 (1996)
Chlorine (Eisenberg et al 1975 - Injuries)	-2.4	2.9	1	Toxic	ppm	n/a	Lees p208 (1980); Lees p9/64 & p18/37 (1996)
Ethylene oxide (TNO)	-6.8	1	1	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Formaldehyde (AIChE)	-12.24	1.3	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Hydrazine (PHAST)	-13.4523	1.675894	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Hydrogen chloride (AIChE)	-16.85	2	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Hydrogen chloride (World Bank 1988)	-21.76	2.65	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)
Hydrogen chloride (TNO 1999)	-37.3	3.69	1	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999)
Hydrogen chloride (TNO)	-6.7	1	1	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (2000)
Hydrogen chloride (PHAST)	-15.6891	1.69	1.18	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Hydrogen cyanide (AIChE)	-29.42	3.008	1.43	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Hydrogen cyanide (Harris)	-29.4224	3.008	1.43	Toxic	ppm	Minutes	Harris 1987
Hydrogen cyanide (TNO)	-9.8	1	2.4	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (200
Hydrogen cyanide (PHAST)	-5.79563	1.08	1.85	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)

PHENOMENON AND TYPE OF INJURY	a	b	n	Hazard	Unit	Time	Reference
Hydrogen cyanide (ten Berge)	-15.5	1.37	2.05	Toxic	mg/m3	Minutes	Dr W.F. ten Berge, DSM, Heerlen, The Netherlands. Based on 'The acute inhalation to xicity of hyd January 2002.
Hydrogen fluoride (AIChE)	-25.87	3.354	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on US Coast Guard (1980)
Hydrogen fluoride (World Bank 1988)	-26.4	3.35	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)
Hydrogen fluoride (Mudan)	-25.8689	4.853	1	Toxic	ppm	Minutes	Mudan 1989
Hydrogen fluoride (TNO)	-8.4	1	1.5	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (200
Hydrogen fluoride (USCG 1980)	-25.8689	3.3545	1	Toxic	ppm	Minutes	Perry W.W. and Articola W.J., US Coast Guard 1980; quoted in Lees p18/60 1996 and Harris 1987
Hydrogen peroxide (PHAST)	-16.3905	1.677894	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Hydrogen sulphide (AIChE)	-31.42	3.008	1.43	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Hydrogen sulphide (TNO)	-11.5	1	1.9	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); TNO Yellow Book Annex 37 (Version 4.0 (2000)
Hydrogen sulphide (TNO ppm)	-10.833752	1	1.9	Toxic	ppm	Minutes	TNO Yellow Book Annex 37 (2005)
Hydrogen sulphide (Rogers AEUB 1990)	-36.2	2.366	2.5	Toxic	ppm	Minutes	Rogers, 'Toxicological Justification of the Triple Shifted Rijnmond Equation', Alberta Energy and Ut
Hydrogen sulphide (HSE AEUB 2004)	-30.023	1.154	4	Toxic	ppm	Minutes	Alberta Energy and Utilities Board, 'Proposed Hydrogen Sulphide Endpoints for Emergency Respor Discussion Paper for the November 26 Stakeholder Meeting', October 2004
Hydrogen sulphide (HSE AEUB 2006)	-29.415	1.443	3.5	Toxic	ppm	Minutes	Alberta Energy and Utilities Board, 'EUBH2S A Model for Calculating Emergency Response and Plar Gas Facilities. Volume 2:Emergency Response Planning Endpoints, December 2006
Hydrogen sulphide (PHAST 6.51)	-8.5306	0.44	4.55	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Methanol (PHAST)	-6.34734	0.66358	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Methyl bromide (AIChE)	-56.81	5.27	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Methyl bromide (World Bank 1988)	-19.92	5.16	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)

PHENOMENON AND TYPE OF INJURY	a	b	n	Hazard	Unit	Time	Reference
Methyl bromide (TNO)	-7.3	1	1.1	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (200
Methyl isocyanate (AIChE)	-5.642	1.637	0.653	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Methyl isocyanate (TNO)	-1.2	1	0.7	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Methyl isocyanate (ten Berge 1985)	-6.64	1.637	0.653	Toxic	mg/m3	Minutes	J. Loss Prev. Process Ind. p54 Vol. 4 January 1991
Nitric oxide (PHAST)	-150.838	15.43222	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Nitrogen dioxide (AIChE)	-13.79	1.4	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Nitrogen dioxide (TNO)	-18.6	1	3.7	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (200
Parathion (TNO 1992 n=1)	-2.5	1	1	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992)
Parathion (TNO 1999)	-6.6	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Phenol (PHAST)	-13.4604	1.677894	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Phosgene (AIChE)	-19.27	3.686	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Phosgene (World Bank 1988)	-19.27	3.69	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p259 (2000) based on World Bank (1988)
Phosgene (Harris)	-19.2736	3.6861	1	Toxic	ppm	Minutes	Harris (1987)
Phosgene (TNO)	-0.8	1	0.9	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992); Effects Version 4.0 (2000)
Phosgene (IChemE)	-27.2	5.1	1	Toxic	ppm	Minutes	IChemE, 'Phosgene toxicity', Major hazards monograph, 1993
Phosgene (PHAST)	-7.69037	2	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Phosphamidon (TNO)	-2.8	1	0.7	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Phosphine (TNO n=1)	-2.6	1	1	Toxic	mg/m3	Minutes	TNO Green Book Table 5.3 (1992); TNO Effects Version 4.0 (2000)
Phosphine (TNO n=2)	-6.8	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)
Propylene oxide (AIChE)	-7.415	0.509	2	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Sulphur dioxide (AIChE)	-15.67	2.1	1	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Sulphur dioxide (TNO)	-19.2	1	2.4	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992); Effects Version 4.0 (2000)
Tetraethyllead (TNO)	-9.8	1	2	Toxic	mg/m3	Minutes	TNO Purple Book Table 5.2 (1999); TNO Green Book Table 5.3 (1992)

PHENOMENON AND TYPE OF INJURY	a	b	n	Hazard	Unit	Time	Reference
Toluene (AIChE)	-6.794	0.408	2.5	Toxic	ppm	Minutes	AIChE Guidelines for CPQRA p156 (1989) & p259 (2000) based on US Coast Guard (1980)
Vinyl chloride (PHAST)	-22.5019	1.674336	1	Toxic	ppm	Minutes	PHAST Version 6.51 (2006)
Burn deaths from BLEVE fireball (HSE)	-14.9	2.56	1.33	Fire	kW/m3	Seconds	Crossthwaite, Fitzpatrick and Hurst (1988)
Burn deaths from flash fire (Lees)	-14.9	2.56	1.333	Fire	kW/m3	Seconds	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Burn deaths from pool burning (Lees)	-14.9	2.56	1.333	Fire	kW/m3	Seconds	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
First degree burns (TNO 1989)	-39.83	3.0186	1.333	Fire	W/m3	Seconds	TNO Green Book Table p20 (1989); [NB Typo in Pietersen 1990 as units given as kW/m3]
Second degree burns (TNO 1989)	-43.14	3.0186	1.333	Fire	W/m3	Seconds	TNO Green Book Table p20 (1989); [NB Typo in Pietersen 1990 as units given as kW/m3and b as 3.
Lethality - unprotected (TNO 1989)	-36.38	2.56	1.333	Fire	W/m3	Seconds	TNO Green Book Table p20 (1989); [NB Typo in Pietersen 1990 as units given as kW/m3]
Lethality - protected (Pietersen 1990)	-37.23	2.56	1.333	Fire	W/m3	Seconds	Pietersen C.M., J. Loss Prev. Process Ind., p139 Vol 3 January 1990 [NB Typo in paper as units given
Lethality - nuclear weapons (TNO 1989)	-38.48	2.56	1.333	Fire	W/m3	Seconds	TNO Green Book Table p19 (1989) based on Eisenberg et al (1975)
Overpressure fatality (HSE)	1.47	1.35	1	Blast	psi	n/a	Hurst, Nussey and Pape (1989)
Deaths from lung haemorrhage (Lees)	-77.1	6.91	1	Blast	N/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Eardrum ruptures (Lees)	-15.6	1.93	1	Blast	N/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Structural damage (Lees)	-23.8	2.92	1	Blast	N/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Glass damage (Lees)	-18.1	2.79	1	Blast	N/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Window-panes in older buildings before 1975 (TNO 1989)	-11.97	2.12	1	Blast	N/m3	n/a	TNO Green Book Table p50 & p73 (1989)
Window-panes in newer buildings after 1975 (TNO 1989)	-16.58	2.53	1	Blast	N/m3	n/a	TNO Green Book Table p50 & p73 (1989)
Deaths from impact (Lees)	-46.1	4.82	1	Impulse	Ns/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Injuries from impact (Lees)	-39.1	4.45	1	Impulse	Ns/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)
Injuries from flying fragments (Lees)	-27.1	4.26	1	Impulse	Ns/m3	n/a	Lees p208 (1980); Lees p9/64 (1996) based on Eisenberg et al (1975)

Appendix 4: LUP and the Environment

Major Accidents, Land-use Planning Advice and Environmental Effects

The Authority's technical advice to the planning authority deals with the potential effects of major accidents. In relation to the environment the advice is concerned only with those environmental effects that are related to major accidents and it does not consider routine emissions, which are within the remit of the local authority or EPA, and subject to license.

Currently, there is no common approach within the EU on suitable scenarios or endpoints for the assessment of Major Accidents to the Environment (MATTEs) within the framework of the Seveso II directive. Consequently, such assessment tends to be more qualitative than the approach concerning major accidents and the potential effect on human receptors. This qualitative approach is due to the highly variable nature and sensitivity of environmental receptors, allied to the lack of suitable sensitivity data for all receptors, and the multiplicity of such receptors in the environment.

The European Guidelines on LUP of 2007 address the environmental issues in a very general way (in part C) noting:

'The issue of environmental vulnerability may concern a broad scope of issues and related acceptability criteria together with vulnerability indices that do not yet exist at the same level of acknowledgement as in the area of human health. Nevertheless the issue needs to be addressed in the LUP risk assessment procedure if it is carried out in the context of Article 12 of Seveso II. It goes on

Summarizing, it should be concluded that a uniform and comprehensive method for Environmental Risk Assessment is presently not available because of:

- advanced complexity of modeling and lack of agreement on basic assumptions;
- lack of data, with regards to response of environmental receptors to toxic loads;
- lack of understanding and difficulty of modeling of the reactions within the components of the ecosystem.

For that reason, emphasis is usually put on the prevention phase, control of the potential routes of pollution and response measures, rather than to the development of a quantitative risk assessment approach and introduction of risk-based criteria.

Nevertheless, systematic (qualitative, semi-quantitative or quantitative) approaches to assess the environmental risk may address the following issues, some of those may also be addressed performing an Environmental Impact Assessment:

- Are there any environmentally sensitive areas in the vicinity of the establishment?
- Are there any endangered species?
- Are there protected water resources/biospheres?
- How can the environment around the establishment be contaminated and the ecosystem be destroyed? What environmental compartments are in risk? What types of accident can cause this environmental damage (e.g. fire fighting water)?
- Which are the possible routes of contamination (e.g. water courses)?
- What measures are in place in order to protect the environment? Are they sufficient?
- If release and contamination occurs, what measures are in place in order to contain it? What emergency actions are foreseen and have they been included in the internal and external emergency plan (e.g. collection of fire fighting water)?
- What is the estimated recovery period (even qualitatively) with and without interventions?
- If the environmental risk is assessed in quantitative or semi-quantitative terms (even as an index), is the assessed risk "desirable"?

The approach of the HSA, in the consideration of environmental effects associated with Seveso II establishments, is also conscious of the requirements placed on operators (current or proposed) by Regulation 9 of S.I. No. 74 of 2006. In assessing the consequences of potential worst-case credible accidents and their impacts on the environment, the HSA concentrates on Regulation 9(2)(e), requiring operators to use best practicable means –

- to prevent a major emission into the environment from any part of the establishment of dangerous substances resulting from uncontrolled developments in that establishment, and
- for rendering harmless and inoffensive such substances as may be so emitted.

The Seventh Schedule to S.I. 74 of 2006 lists the criteria for notification of accidents to the Commission. Major accident hazards should have this type of potential in order to be considered.

A major accident to the environment will occur as a result of a major emission, fire or explosion resulting from uncontrolled developments in the course of the operation of any establishment and resulting in significant damage to the natural or man-made environment. This damage could be relatively long lasting but not necessarily irreversible. Recovery of habitats can take considerably longer depending on the dangerous substance in question. The assessment of major accidents to the environment focuses on the specific risks to sensitive receptors within the local environment, the extent of consequences to such receptors, and on the ability of such receptors to recover.

HSA Approach

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

The potential for initiating a major accident due to natural phenomena is also examined. For example, the effect of flooding, storm damage, subsidence is considered in relation to the potential effect on storage tanks and storage areas, as well as important site utilities. The operator must demonstrate that other potential initiators have been considered (lightning for example) and control/mitigation measures employed where required

While the 'best practicable means' standard is also applied to control of gaseous loss of containment events (e.g. suitably-sized catch pots for reaction vessels), the consequences of such releases are examined as part of the general major accident scenarios for human receptors.

Article 12 of the amended Seveso II Directive [2003/105/EC] requires Member States to 'take account of the need, in the long term, to maintain appropriate distances between establishments covered by this Directive and residential areas, buildings and areas of public use, major transport routes as far as possible, recreational areas and areas of particular natural sensitivity or interest...'

Where the Authority notes such areas in the vicinity of an establishment it undertakes further analysis to satisfy itself that an appropriate distance can be maintained. Appropriate distances are not specified in the Directive. However a separation distance will be considered appropriate if it is sufficient to enable the installation and operation of suitable control and mitigation measures, and/or is such that the risk of serious damage is low in the event of a major release.

Petroleum Bulk Stores, Land Use Planning and Environmental Criteria

Background

The main text has set out the general approach of the Authority regarding the provision of Land Use Planning (LUP) advice and the previous section elaborates further in relation to the environment.

This document sets out the Authority's position in formulating land-use planning advice for new petroleum bulk store installations with particular consideration of appropriate environmental criteria.

In the case of new installations at existing establishments, a similar approach will be adopted. In some instances, due to spatial constraints on older sites, or other considerations relating to their layout, particular site-specific measures may have to be designed in order to fulfill the 'best practicable means' criteria: Consultation with the Authority at an early stage in the design process is recommended, with the emphasis on how the proposed design will meet the 'best practicable means' criteria.

Legislative basis

Under the Seveso II Directive [2003/105/EC] there is a requirement to ensure that the objectives of preventing major accidents and limiting the consequences of such accidents are taken into account in the land use policy of member states. Furthermore, there is a requirement to take account of the need, in the long term, to maintain appropriate distances between establishments covered by the Directive and residential areas, areas of public use and areas of particular natural sensitivity or interest. Such appropriate distances are not specified in the Directive or transposing Regulations, but would generally be considered sufficient if they allow the installation of suitable control and mitigation measures to provide adequate protection to the environment, or if their extent is such that the risk of serious damage to the environment is low in the event of a major release. Under the EC (Control of Major Accident Hazards involving Dangerous Substances) Regulations, 2006 [SI 74 of 2006], which transpose the Seveso II Directive, and specifically relating to the general duties of operators, Reg. 9(1)(b) requires the operator to take all necessary measures to limit the consequences of any major accident to man and the environment, while 9(2)(c) further qualifies this by stating that such necessary measures shall include the making of arrangements to ensure that the use, handling, storage, and transport of dangerous substances in the establishment are, so far as is reasonably practicable, without risk for man and the environment, and 9(2)(e) that the use of best practicable means to prevent a major emission into the environment from any part of the establishment of dangerous substances resulting from uncontrolled developments in that establishment, and for rendering harmless and inoffensive such substances as may be so emitted.

Petroleum Bulk Stores & Major Accidents to the Environment

The Directive specifically applies to "major accidents" as defined. That is to say, an occurrence such as a major emission, fire or explosion resulting from uncontrolled developments in the course of the operation of any establishment, leading to a serious danger to human health or the environment, whether immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances. By definition therefore, a major accident can only be considered under the terms of the Directive, if it is caused by a dangerous substance as defined under Parts 1 and 2 of Annex 1 of the Directive. Various petroleum products are listed as named substances in Part 1 of the First Schedule of S.I. 74 of 2006 and as such are dangerous substances. In addition, other relevant substances are classified under the generic category of Dangerous to the Environment, and are therefore also considered dangerous substances under the terms of the Directive. Materials not so classified as a dangerous substance, or not provisionally classified as a dangerous substance, though they may possess other properties that could cause ecological disruption, are outside the scope of the Seveso II Directive.

Many of the larger petroleum bulk stores are located adjacent to areas of natural sensitivity (ports, etc.). Such locations may also be designated as candidate Special Areas of Conservation (cSAC's), or by virtue of populations of significant bird populations, as Special Protection Areas (SPA's). As such, the potential consequence to the natural environment as a result of a major spillage event to that environment is likely to be severe. However, the long-term (and perhaps even short-term) consequences associated with some materials may be less significant. Non-persistent oils, such as kerosene for example, by virtue of their relatively quick degradation rate, will pose a lesser danger to the environment than the more persistent oils (crude oil for example). Along with spillage of inventory, the generation of contaminated firewater in the event of a major fire must also be considered.

Bunds

Prevention of a major emission into the environment, in the context of petroleum bulk stores, is generally provided by bunding. 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. The statutory requirements of S.I. No. 313 of 1979 (Dangerous Substances [Petroleum Bulk Stores] Regulations) must be complied with. In addition, the UK's HSE publication "The Storage of Flammable Material in Tanks (HSG 176)" provides further guidance on an appropriate approach to spillage containment.

Risk Assessment

In terms of site-specific environmental risk assessment, the EPA's 'Guidance Note on the Storage and Transfer of Scheduled Activities' (available from EPA website http://www.epa.ie/) provides a detailed approach (under Section 5 of that document). Additionally, it sets assessment criteria based on the German Environment Agency's approach of using water hazard classes – i.e. either non-hazardous or one of the following classes: WHC 1 – low hazard, WHC 2 – hazardous, or WHC 3 – severe hazard. Assignment of the WHC class is based on the risk phrases of the materials involved, and other considerations such as biodegradation rate, bioaccumulation etc. The full detail of how this class is assigned can be obtained directly from the German Environment Agency website at http://www.umweltbundesamt.de/wgs-e/index.htm, (where a search can be made using CAS numbers or the substance name). In addition, the downloads section demonstrates how substances and mixtures can be self-classified based on the risk phrase. Furthermore, EPA's Guidance Note goes on to provide a simple risk category table based on this risk classification criteria and associated quantities stored –

WHC Class			
Vol. (m3) or mass T	1	2	3
<0.1	A	A	A
0.1 – 1	A	A	B
1 – 10	A	B	C
10 – 100	A	C	D
100 – 1000	B	D	D
>1000	C	D	D

Generally, category A equates to low risk, B to medium risk, while categories C and D equate to higher risk. Particular consideration needs to be given in relation to sensitive environmental receptors in cases of overground facilities of category D and underground facilities of categories C and D. Section 5.3 of the guidance note provides detail on retention requirements associated with each WHC class while Section 6 provides guidance on the design and operation of retention facilities (bunds), which are categorized as Class 1, 2 or 3 on the basis of low, moderate, or high hazard potential. The EPA Guidance note should be consulted for further detailed information. It should be noted that the nature of dangerous substances and their associated volumes stored at petroleum bulk stores is likely to classify such sites as category C or D, that is to say possessing a high potential for pollution in the event of a major release, and would ordinarily require containment systems to be designed to a high standard. Provision for holding contaminated firewater should be facilitated into the overall containment design. Key activities with major accident potential should be provided with independent levels of protection (e.g. independent high level alarms and leak detection system, allied with physical secondary and tertiary containment). Again, referral is made to the EPA guidance for specific detailed design criteria appropriate to these categories.

Bund Overtopping

The issue of bund overtopping is not dealt with specifically in the EPA guidance document. It is examined by the HSA as a potential scenario with respect to Seveso II establishments in terms of the provision of LUP advice. Such a scenario is considered highly unlikely but credible, and the consequences in terms of the Seventh Schedule of the Regulations (i.e. will a major accident to the environment ensue?) and the receptors that will be affected, have to be considered. Again, referring to those sites that would qualify as possessing a higher potential for pollution, then provision for containment of the overtopping fraction in the event of catastrophic failure must also be considered in the overall design to take account of this scenario. For example, the provision of tertiary containment and associated drainage systems to contain and hold up to 110% of the maximum calculated overtopping fraction is considered by the Authority to be one appropriate approach. How tertiary containment is provided will very much depend on site-specific conditions, with risk assessment and possibly Cost Benefit Analysis being required. Therefore, consultation should be made early at the design stage with the Authority in order to ensure that the proposed approach is satisfactory.

References Cited in this Section

1. The Storage of Flammable Liquids in Tanks – HSG 176 – Health and Safety Executive
2. S.I. 74 of 2006 – European Communities (Control of Major Accident Hazards Involving Dangerous Substances) Regulations
3. Directive 2003/105/EC of the European Parliament and of the Council of 16 December 2003 amending Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances
4. S.I. 313 of 1979 – Dangerous Substances (Petroleum Bulk Stores) Regulations 1979
5. Environmental Protection Agency IPC Guidance Note on Storage and Transfer of Materials for Scheduled Activities, May 2003
6. Environmental Protection Agency (Draft) Guidance Note to Industry on the Requirements for Fire-Water Retention Facilities, 1995 ISBN 1 899965 165

Appendix 5: Ammonium Nitrate Fertilizer (ANF): Risk-based Approach to LUP

Introduction

This appendix sets out the detailed approach of the HSA in relation to the provision of land-use planning advice in regard to establishments storing ANF.

Although not itself combustible, when exposed to an external source of heat AN can decompose to various oxides of Nitrogen, usually considered as NO and NO_2.

The 'dangerous phenomena' to be considered are:

- Fire and toxic cloud
- explosion overpressure,
- missiles
- environmental damage

Looking briefly at each of these in turn:

Fire of ANF as such can be ruled out because ANF is not combustible.

As ANF is not combustible, other sources of combustibles must be looked for. If these are potentially present, the effects of fire must be considered. The effect of fire on ANF is to cause it to decompose, releasing toxic gases. Therefore the first consequence to look at is the off-site dispersion of these gases.

The most plausible (but very unlikely!) route to an explosion is firstly the formation of a pool of molten AN from a heat input source (e.g. following a very large fire), in a confined state, followed by initiation of an explosion from the falling of a high-energy object or some other source. Explosion overpressure effects could then be considered.

While missile generation is possible, the probability in terms of off-site effects is judged to be small and can therefore usually be neglected in these situations.

The most likely MATTE relates to a fire/fire-water run-off situation. This will only become an LUP issue for new establishments – see appendix 4 for more details.

HSA APPROACH

For the purpose of generating LUP advice, the HSA assume the following:

- All ANF, provided it is of the type set out in annex 1 of the Directive, is treated in the same way.
- Modelling of toxic fumes will be to the fatality endpoint (see probit list in appendix 3) for Nitic Oxide and Nitrogen Dioxide.
- 300t of ANF is equivalent to 41 tonnes of TNT, for explosion modelling purposes.
- The frequency of an explosion is related to the initial fire frequency, and is much more likely from a truck fire than from pallet or mass storage. In the case of pallet and mass storage, a smaller explosion (10% of the mass) is assumed to be more likely (by an order of magnitude) than an explosion involving the whole mass.
- If contaminated ANF is also stored at the establishment, a special assessment will be required.

The model uses an initial fire frequency, which can be modified based on the factors such as co-storage with other dangerous substances, security, location, and fire response measures in place, either at the beginning of the assessment or during it. For a typical site, the fire frequency is taken as 6 x 10^{-4} per warehouse building per year. For simplicity, the whole outside storage area is treated as having the same fire frequency.

Event Trees are then created to estimate the likelihood of the various downstream events. These are shown below:

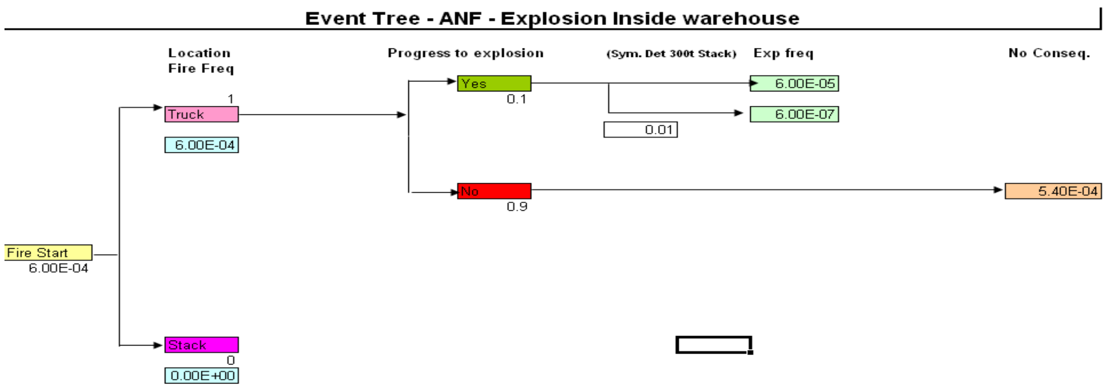

Fig.1 Event Tree for Fire/Explosion in Warehouse

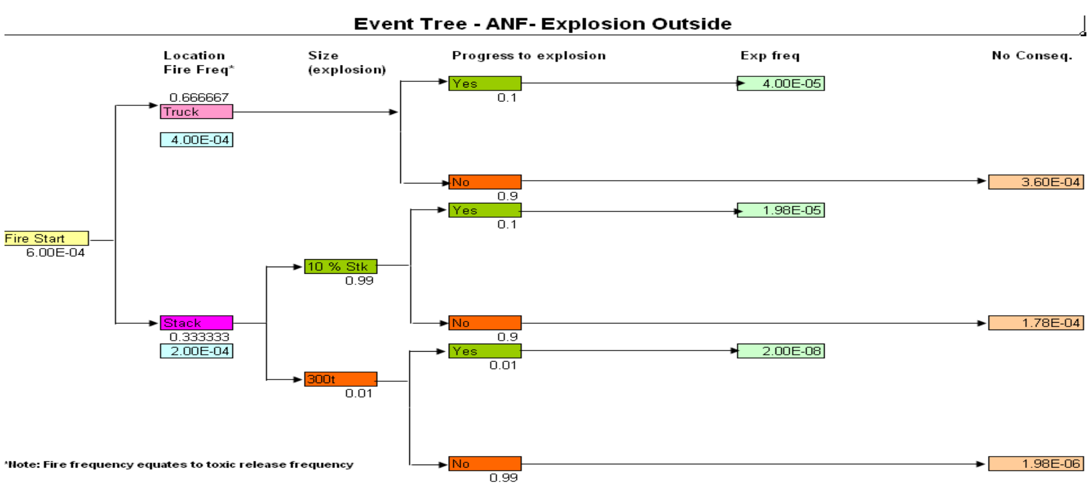

Fig. 2 Event Tree for Fire/Explosion in Outside Storage Area

The likelihood of a truck catching fire is considered to be twice that for a stack. The probability that a fire will escalate to an explosion is considered to be an order of magnitude greater for a truck than for a stack. The probability that the quantity involved in the stack explosion is up to 10% of the nominal 300 tonne stack quantity is taken as being 100 times more likely than an event involving the full 300 tonnes.

The consequences of a fire involving AN in the outside storage area will be greater than that from the inside storage. In relation to 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, because of the potential for higher ground-level concentrations. Because of the heat-induced buoyancy, such concentrations are considered to be insignificant in the event of roof collapse, except in very high windspeed conditions.

The usual local wind-stability pairs of F_2, D_5 and D_{10} are initially considered for modelling. A buoyancy check is carried out using the Briggs lift-off criterion equation, with the heat content of the plume and release height being required as inputs. In very many cases this will allow F_2 conditions to be discarded for modelling purposes. In any case the modelling of these scenarios in PHAST will show negligible consequences.

Generally, HSA selects 3 scenarios for modelling. These are:

- Outside Stack Fire
- Outside Truck fire
- Inside Truck Fire

A fire frequency, as described above, is applied to each of these scenarios. Using the rates of NO/NO_2 generation specified in the HSL paper *'Ammonium Nitrate: Toxic Risk from Fires in Storage' Atkinson & Adams, International Fertilizer Society at a meeting in London in 2002*, the extent of the fatality zones are estimated in PHAST (or other suitable software programme).

The risk zones are visualised on a map of the area.

It is then conservatively assumed that these fires could result in an explosion at the probabilities set out in the event trees above.

Factory Mutual suggest in *FM 7/89* that 10% of the stored quantity of ANF could be used for explosion modelling, up to a maximum of 45 tonnes of AN. The HSA has chosen to model the full quantity up to 300t for bagged AN, as set out in the event trees.

In the case of bulk AN, the quantities subjected to heating and decomposition will be smaller than 300t, and these are selected for modelling purposes.

The overpressure effects are estimated using the TNT equivalency method. The efficiency of AN follows the HSE approach with 300 tonnes of AN being equivalent to 41 tonnes of TNT (based on 56% equivalence and 25% efficiency).

Given the low probability of explosion, the risk associated with missiles is so low as to be deemed not credible for modelling purposes.

The explosion risks are summed with the toxic risks to generate the final risk contours that are overlaid on the local map.