Assessment Guideline

Multi-level Risk Assessment

May 2011

Multi-level Risk Assessment

23–33 Bridge Street
Sydney NSW Australia 2000
www.planning.nsw.gov.au

ISBN 978-1-74263-153-0
DOP HAZ_003

Foreword

Since the 1980s, the New South Wales Department of Planning & Infrastructure has promoted and implemented an integrated approach to the assessment and control of potentially hazardous development. The approach has been designed to ensure that safety issues are thoroughly assessed during the planning and design phases of a facility and that controls are put in place to give assurance that it can be operated safely throughout its life.

Over the years, a number of Hazardous Industry Advisory Papers and other guidelines have been issued by the Department to assist stakeholders in implementing this integrated assessment process. With the passing of time there have been a number of developments in risk assessment and management techniques, land use safety planning and industrial best practice.

In recognition of these changes, new guidelines have been introduced and all of the earlier guidelines have been updated and reissued in a common format.

I am pleased to be associated with the publication of this new series of Hazardous Industry Advisory Papers and associated guidelines. I am confident that the guidelines will be of value to developers, consultants, decision-makers and the community and that they will contribute to the protection of the people of New South Wales and their environment.

SHaddad

Director General

Contents

List of Tables and Figures

Executive Summary

Background

The orderly development of industry and the protection of community safety necessitate the assessment of hazards and risks. The Department of Planning & Infrastructure has formulated and implemented risk assessment and land use safety planning processes that account for both the technical and the broader locational safety aspects of potentially hazardous industry. These processes are implemented as part of the environmental impact assessment procedures under the Environmental Planning and Assessment Act 1979.

The Department has developed an integrated assessment process for safety assurance of development proposals, which are potentially hazardous. The integrated hazards-related assessment process comprises:

- a preliminary hazard analysis undertaken to support the development application by demonstrating that risk levels do not preclude approval;
- a hazard and operability study, fire safety study, emergency plan and an updated hazard analysis undertaken during the design phase of the project;
- a construction safety study carried out to ensure facility safety during construction and commissioning, particularly when there is interaction with existing operations;
- implementation of a safety management system to give safety assurance during ongoing operation; and
- regular independent hazard audits to verify the integrity of the safety systems and that the facility is being operated in accordance with its hazards-related conditions of consent.

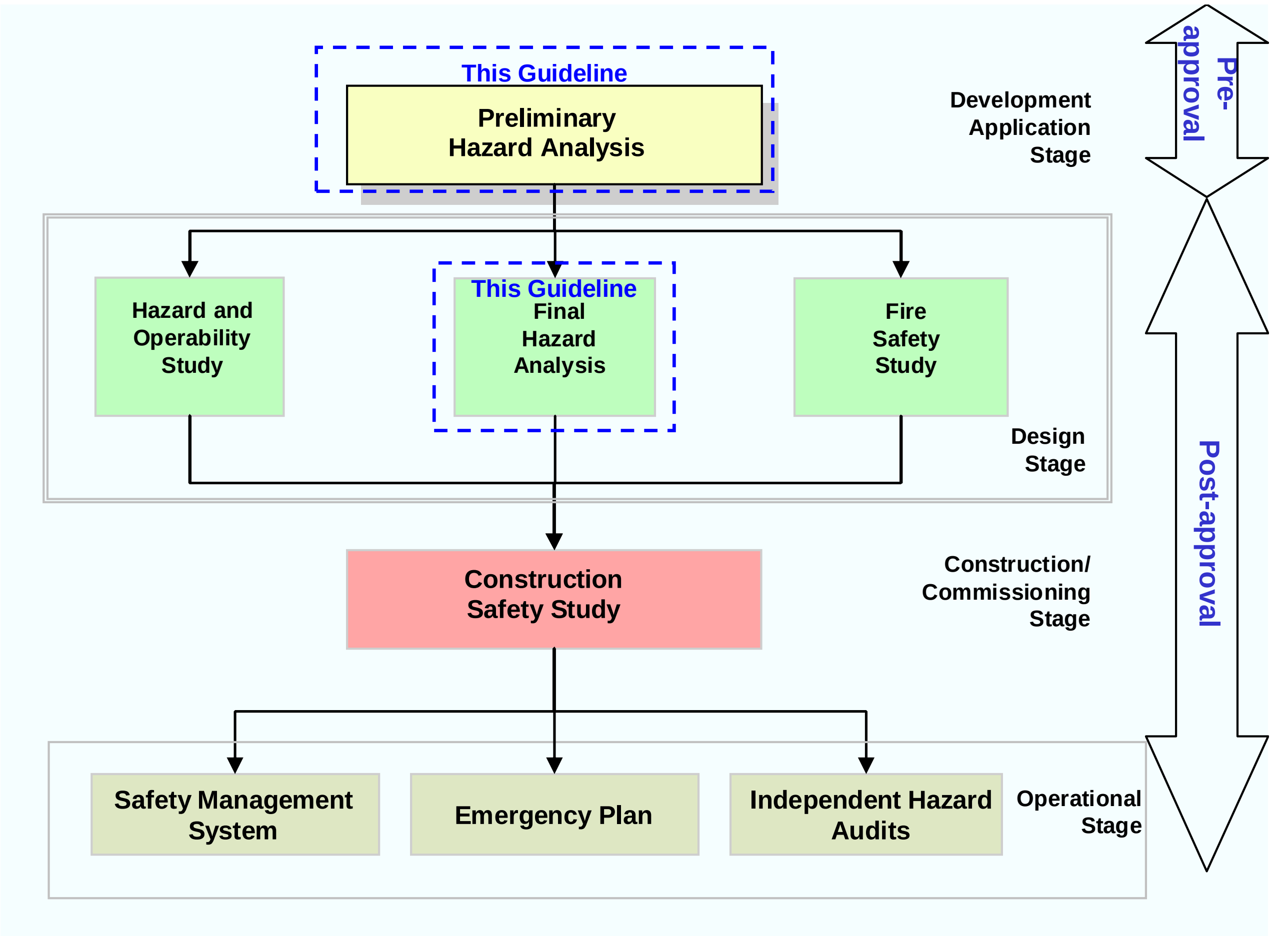
The process is shown diagrammatically in Figure 1.

A number *of Hazardous Industry Advisory Papers (HIPAPS)* and other guidelines have been published by the Department to assist stakeholders in implementing the process. All existing HIPAPs have been updated or completely rewritten and three new titles (HIPAPs 10 to12) have been added.

A full list of HIPAPs is found at the back of this document.

The part of the process covered by this guideline is highlighted in Figure 1.

Figure 1: The Hazards-Related Assessment Process



Multi-level Risk Assessment

In implementing its requirements for risk assessment, the Department of Planning & Infrastructure (the department) advocates an approach where the level and extent of the analysis should reflect the nature, scale and location of each development. In many cases however, the department’s experience has been that full risk quantification has been unnecessarily carried out in order to demonstrate that a systematic and analytical risk analysis process has been followed.

These guidelines propose a graded or multi-level framework aimed at ensuring a consistent approach. In each case, the objective is to progress the analysis and its assessment only as far as is needed to demonstrate that the operation being studied does not or will not pose a significant' risk to surrounding land uses. This may be achieved by using a combination of qualitative and quantitative approaches.

Three stages in the assessment process are suggested:

- preliminary screening
- risk classification and prioritisation
- risk analysis and assessment.

The multi-level approach is built around a consequence-based screening method set out in these guidelines and a rapid risk classification technique described in the United Nations *Manual for the classification and prioritization of risks due to major accidents in process and related industries* (the IAEA method).

The guidelines set out criteria for using the results of the screening, classification and prioritisation steps to determine which of three levels of further analysis is appropriate.

Level 1 is an essentially qualitative approach based on comprehensive hazard identification to demonstrate that the activity does not pose a significant off-site risk.

Level 2 supplements the qualitative analysis by sufficiently quantifying the main risk contributors to show that risk criteria will not be exceeded.

Level 3 is a full quantitative analysis.

A ***qualitative*** assessment may suffice provided all or most of the following conditions are met:

- screening and risk classification and prioritisation indicate there are no major off-site consequences and societal risk is negligible;
- the necessary technical and management safeguards are well understood and readily implemented; and
- there are no sensitive surrounding land uses.

If the qualitative analysis cannot demonstrate there will be no significant risk, a further level of analysis will be required.

Partial quantification would normally be applied to developments where screening, hazard identification and/or risk classification and prioritisation has identified one or more risk contributors with consequences beyond the site boundaries but with a low frequency of occurrence. Otherwise, a full ***quantitative analysis*** should be carried out.

The framework is described in chapter 2.

The guidelines are intended to assist industry, consultants and consent authorities in NSW to carry out and evaluate risk assessments at an appropriate level. While they have been written in the context of the NSW regulatory framework, in that they refer to NSW specific legislation and guidelines, the basic principles are more generally applicable.

The principles in the guidelines may be used when considering risks from new facilities, and additions or modifications to existing facilities.

They may also be used in the analysis and assessment of the risk from existing facilities, and in making comparative studies of alternative processes and locations.

These guidelines specifically cover risks from fixed installations and do not encompass transportation by pipeline, road, rail or sea.

To maximise their usefulness for a broad readership, the guidelines are divided into two parts. Part A (chapters 0 and 2) deals with general principles, while Part B(chapters 0 and 4) covers the risk assessment and management methodologies.

Appendix 1 covers the techniques of multi-level risk analysis in greater depth, while Appendix 2 gives a worked example, illustrating the application of the approach.

Note that this May 2011 printing corrects some minor table numbering errors in the January 2011 edition. The general content remains unchanged.

Part A – General Principles

1 Introduction

1.1 Background

Since the early 1980s, the New South Wales Department of Planning & Infrastructure (the department) has advocated and practised an integrated approach to land use safety planning. This approach is set out in *Hazardous Industry Planning Advisory Paper (HIPAP) No. 3 - Risk Assessment*.

The approach considers a development in the context of its location and its technical and safety management controls.

In addition, *State Environmental Planning Policy (SEPP) No. 33 - Hazardous and Offensive Development* requires that a preliminary hazard analysis (PHA) be conducted at an early stage of a development involving potentially hazardous industry. The purpose of the PHA is to:

- identify all potential hazards associated with the proposal
- analyse both their consequences (effects) on people and the environment, and their probability (likelihood or frequency) of occurrence
- estimate the resultant risk to the surrounding land uses and environment
- ensure that the proposed safeguards are adequate, and thus demonstrate that the operation will not impose a level of risk which is intolerable with respect to its surroundings.

HIPAP No. 6 - Hazard Analysis explains the hazard analysis process.

These multi-level risk assessment guidelines are intended to assist industry, consultants and consent authorities in NSW and elsewhere to carry out and evaluate risk assessments at an appropriate level. The principles in the guidelines may be used when considering risks from new facilities and additions, and when making comparative studies of alternative processes and locations. They may also be used in the analysis and assessment of risks from existing facilities.

While the principles are broadly applicable, these guidelines specifically cover risks from fixed installations and do not encompass transportation by pipeline, road, rail or sea.

1.2 The Land Use Safety Planning Context

It is important to recognise that the preparation of a PHA is only one element of the integrated planning approach to land use safety. The progressive assessment process in Figure 1 includes a number of studies which need to be carried out at various stages of the development process. These are usually required as part of comprehensive conditions of consent set by the consent authority.

The approach has come to be known as the seven stage approval process due to the seven broad assessment elements. The main components of this process are a hazard and operability study, final hazard analysis, fire safety study, emergency plan, construction safety study and safety management system.

The level of detail and the depth of assessment in each study are designed to be appropriate to the stage of the development proposal. For example, while a PHA would be expected to cover principles of fire safety, emergency planning and safety management in sufficient detail to allow the merits of a proposal to be assessed, fine detail would not be expected until the later studies. These studies are described in more detail in the department's various HIPAPs.

Within this context, the primary role of the PHA is to demonstrate that residual risk levels are tolerable in relation to surrounding land use, and that risk can and will be appropriately managed.

A risk analysis will only be valid to the extent that its assumptions, with respect to technical and organisational safety, are backed up by a comprehensive safety assessment and management regime as set out in Figure 1.

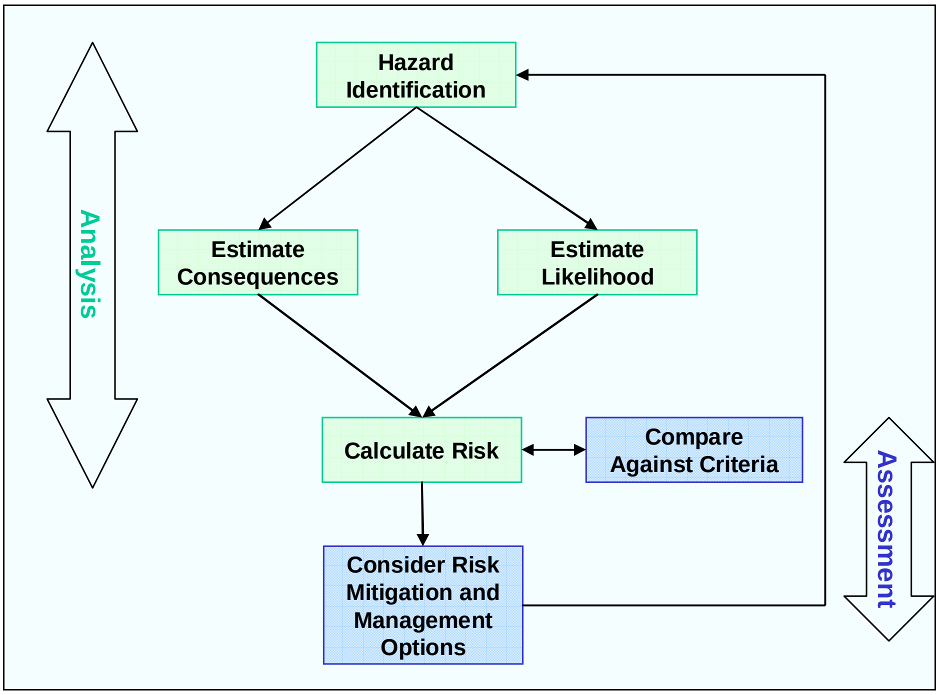
The concepts presented in these guidelines should not, therefore, be considered in isolation. In particular, these guidelines should be read in conjunction with *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning* and *HIPAP No. 6 - Hazard Analysis*.

2 Framework

The hazard analysis and quantified risk assessment framework adopted in NSW relies on a systematic and analytical approach to the identification and analysis of hazards, and the quantification of off-site risks to assess risk tolerability and land use safety implications.

This process is shown schematically in Figure 2.

Figure 2: The Risk Analysis and Assessment Process



Two key objectives have been emphasised in the implementation of this process:

- **objective 1** - the systematic and analytical nature of the assessment process enables the nature of the hazards, and the leading risk contributors and events, to be identified and understood from design, operational and organisational viewpoints; this provides a sound opportunity for focusing safety management and control, irrespective of the quantification aspects of the analysis, and is complementary to adherence to the requirements of codes and standards
- **objective 2** - the quantification of off-site risks, where applicable, enables judgements to be made on locational safety implications in regard to people, the biophysical environment and other land uses; risk quantification also enables appropriate land use safety planning.

In applying requirements for hazard analysis and quantified risk assessment, the department has advocated a merit-based approach. That is, that the level and extent of analysis must be appropriate to the hazards present and therefore, need only progress to the extent necessary for the particular case.

Experience with previous implementations of hazard analysis and risk assessment in NSW (and elsewhere) indicates that the analyses have often proceeded to full quantification of risks, irrespective of the varying circumstances of the different cases.

This may have incurred extensive resource commitments and, in some cases, a dilution of the full benefits of the analytical advantages of these tools. The reason for this may have been the lack of framework guidance on the extent of the analysis and level of quantification that is necessary. The main purpose of these guidelines is to provide such guidance, consistent with the objectives above.

The conceptual rationale for the multi-level risk assessment regime is that:

- preliminary analyses which indicate minor land use safety implications may justify a qualitative level of assessment (level 1 below) - the emphasis for such cases should be on the identification of key risk elements and optimising safety management regimes, thus fulfilling objective 1
- preliminary analyses which indicate significant potential risk impacts to surrounding land uses should be subjected to a more detailed level of analysis, including partial or total quantification (levels 2 or 3 below) - for such cases, there is increased emphasis on objective 2, relating to land use safety and risk tolerability,

2.1 The Multi-Level Risk Assessment Framework

This section highlights the key features of the multi-level risk assessment framework. The details are elaborated in the subsequent sections.

There are three levels of assessment, depending on the outcome of preliminary analysis, as shown in Figure 3:

- **level 1 - qualitative analysis**, primarily based on the hazard identification techniques (for details, see section A1.3.2)
- **level 2 - partially quantitative analysis**, using hazard identification and the focused quantification of key potential off-site risk contributors (see section A1.3.1 for the principles)
- **level 3 - quantitative risk analysis (QRA)**, based on the full and detailed quantification of risks, consistent with *HIPAP No. 6 -Hazard Analysis*.

The level of assessment is determined by the outcome of the preliminary analysis, as follows:

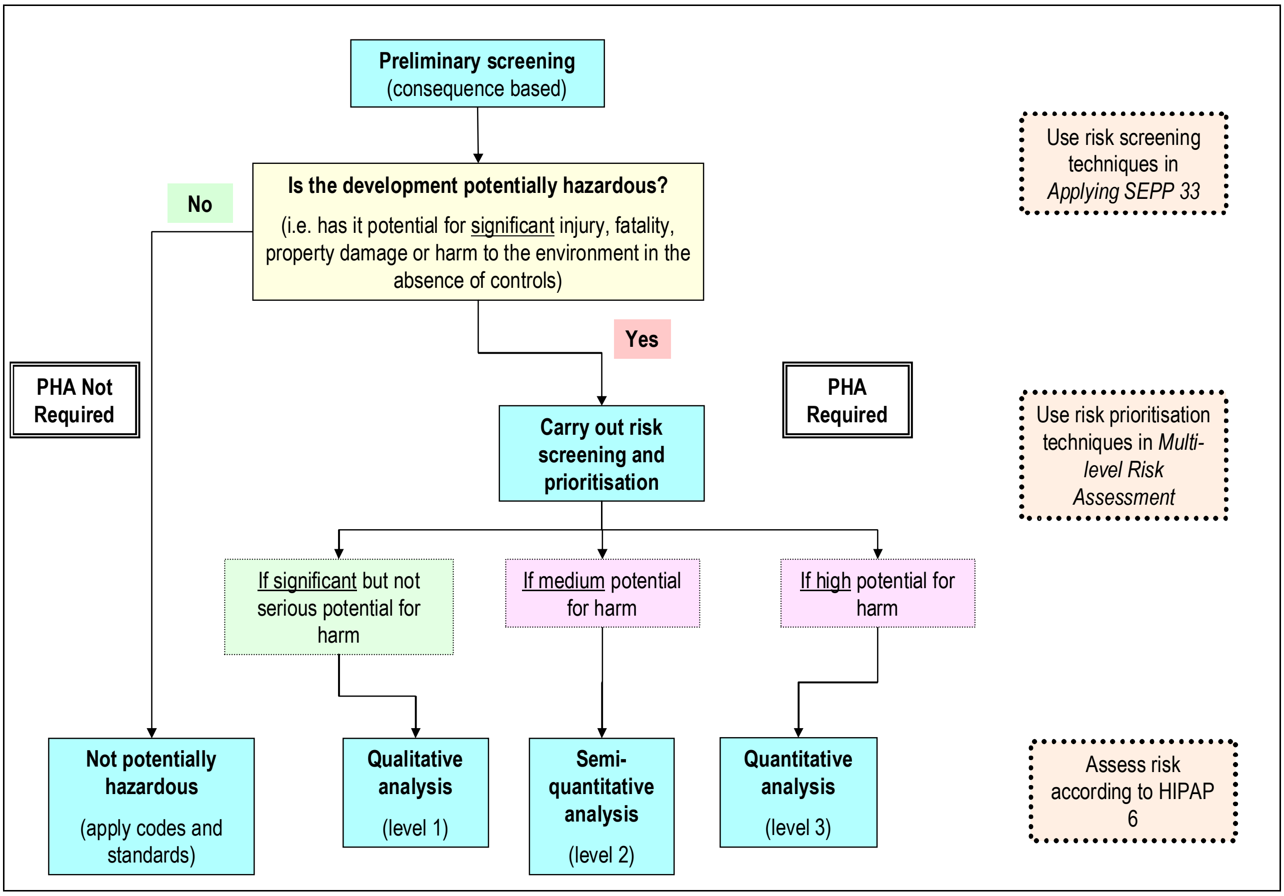
- **step one - preliminary screening**

  The screening method set out in Applying SEPP 33 (Department of Planning & Infrastructure, 1997) provides the first step in the analysis. The screening method, (which is described in section Al, Appendix A), is based on broad estimates of the possible off-site effects or consequences from hazardous materials present on site, taking into account locational characteristics.

  If the quantity is less than the screening threshold, then no further analysis is necessary. The safety management regime in this case relies on observance of the requirements of engineering codes and standards.

  If the quantities exceed the screening threshold, further analysis is necessary.

Figure 3: The Multi-Level Risk Assessment Approach



- **step two - risk classification and prioritisation**

  The next step in the analysis involves a risk ranking of the facility using a risk classification and prioritisation technique (as described in section A1.2). The method nominated in these guidelines is based on the *Manual for the classification and prioritisation of risks due to major accidents in the process and related industries* (IAEA, rev. ed. 1996). This method is risk-based and relies on broad estimations of consequences and likelihood of accidents. The outputs may be expressed in terms of individual and societal fatality risk which can be compared against criteria for determining the appropriate level of further assessment.

Societal risk is generally expressed in the form of an F-N curve, which is a plot of the frequency (F) at which N or more people are predicted to be killed. Figure 6 shows the typical format of a societal risk plot. The graph relates the total number of people that may be killed by an accident to the frequency of its occurrence.

There are three criteria regions. Above the upper criterion line, the risk would usually be regarded as intolerable, while below the lower criterion line, it would be considered to be negligible. In between, while the risk may be tolerable,

depending on the evaluation of other risk criteria, measures should be taken to reduce the risk level to as low as reasonably practicable (ALARP). The criteria for determining the level of analysis are discussed in greater depth in section 3.1.

It should be noted that the regions of Figure 6 as used in these guidelines are intended to be a pointer to the type of analysis that is required and not as a measure of acceptability of an activity in terms of risk.

Using these criteria, the indicative level of risk, as determined in the risk classification and prioritisation stage, may lead to three possible outcomes:

- **a level 1 assessment** can be justified if the analysis of the facility demonstrates societal risk in the negligible zone and there are no potential accidents with significant off-site consequences (the consequence estimations can be based on the broad estimations indicated in the classification and prioritisation manual]
- **a level 2 assessment** can be justified if the societal risk estimates fall within the middle ALARP zone and the frequency of risk contributors having off-site consequences is relatively low - a level 2 assessment must demonstrate that the facility will comply, at least in principle, with the department's risk criteria, based on a broad quantification of the risk (see section A1.3.1)
- **a level 3 assessment** is required where the societal risk from the facility is plotted in the intolerable zone or where there are significant off-site risk contributors, and a level 2 assessment is unable to demonstrate that the risk criteria will be met.

There are some substances which are not covered by the standard classification and prioritisation method. These include dangerous goods of classes 4 and 5 and classes 6.2-8. For such materials, the criteria in section 3.1 should be consulted for guidance as to the appropriate level of assessment.

2.2 The Three Levels of Analysis and Assessment

Table 1 summarises the three levels of risk analysis and assessment. Section A1.3.1 provides details on the minimum requirements of each level of assessment. Guidance on the evaluation of study adequacy is given in section 4.

Table 1: Levels of Analysis and Assessment

Key Elements	Assessment Basis
Level 1 – Essentially Qualitative	
• hazard identification using summary diagram, FMEA, fault and event trees, HAZOP etc. • identification of key scenarios and qualitative estimate of risks • comparisons with qualitative criteria. • thorough discussion of protective technical and management measures, including codes and standards	• appropriate methods used for identification • all key scenarios thoroughly examined • realistic estimates of risk • relevant qualitative criteria met • proposed measures appropriate and sufficient • compliance with all relevant codes and standards
Level 2 – Partially Quantitative	
• qualitative elements as for level 1 • rigorous quantification of consequences of all events with significant off-site effects • quantification of the likelihood of events with significant off-site' consequences • indicative estimate of risk vs. criteria • thorough discussion of technical controls, risk reduction and management measures	• qualitative elements as for level 1 • sound consequence methodology used and appropriate failure data used • technical methods and results appropriately documented • relevant criteria shown to be met • appropriate controls and safeguards
Level 3 – Fully Quantitative	
• qualitative elements as for level 1 • comprehensive quantification of significant consequences and their likelihood • evaluation of risk against all relevant criteria • thorough discussion of technical controls, risk reduction and management measures	• qualitative elements as for level 1 • sound consequence methodology used • appropriate failure data used • technical methods and results well-documented • all relevant criteria met • ALARP principles followed • appropriate technical and procedural controls and safety management system

The requirements may be expressed as follows:

2.2.1 Level 1 Assessment

A level 1 assessment is essentially qualitative in nature and should as a minimum incorporate:

- a formalised hazard identification, using such tools as word diagrams, simplified fault/event trees and checklists
- a generalised consequence analysis of the key risk contributors (using, for example, the results of the screening and risk classification and prioritisation stages), to demonstrate that such consequences are kept within site boundaries
- an evaluation of the risks against the **qualitative** criteria in *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*
- a demonstration of the adequacy of proposed technical and management controls to ensure ongoing safety of the proposed development.

2.2.2 Level 2 Assessment

A level 2 assessment is semi-quantitative, in that it should, in addition to all the elements of the level 1 analysis, include sufficient quantification of risk contributors to demonstrate that risk criteria will be met.

In particular:

- appropriate modelling tools should be used to calculate the consequences of all events shown by the preliminary assessment to have the potential for harmful off-site effects
- there should be an estimate of likelihood for each event confirmed by the consequence modelling to have significant off-site effects, using appropriate failure data and techniques, such as fault and event trees
- there should be an indicative estimate of the off-site risk, taking into account the cumulative impact of multiple events
- the study must demonstrate that all relevant numerical risk criteria will be met (see also section 2.2.4).

2.2.3 Level 3 Assessment

This is a full quantitative risk assessment, the techniques of which are outlined in section A1.3.

HIPAP No. 6 - Hazard Analysis should be consulted for details of the requirements for such a study.

2.2.4 Risk Criteria

Having identified the hazards and estimated their risks, it is necessary to compare the results against appropriate criteria in order to form a judgement on whether or not the risk is tolerable.

The criteria take into account the nature of surrounding land uses and the category of risk. They encompass such elements as injury/ irritation, individual and societal risk of fatality, property damage and harm to the biophysical environment. Criteria may be expressed in qualitative or quantitative terms.

The department's approach to the setting of criteria for acceptable risk is set out in *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*. The main criteria are set out in section 3.3.

It is not possible to apply the full range of numerical criteria to level 1 and level 2 analyses, since the risk results are not fully quantified. The following principles should be followed in these cases.

Level 1 (Qualitative) Analysis

While the criteria that will be applied to a level I assessment will mostly be qualitative, some broad quantification arises out of the preliminary screening and risk classification and prioritisation stages.

These results should be used, in conjunction with the hazard identification, to demonstrate that the following broad criteria have been satisfied:

- containment of significant consequences within the site
- compliance with relevant codes and standards
- satisfaction of the principle of avoidance of avoidable risk.

Level 2 (Partially Quantitative) Analysis

The criteria noted above for level 1 analyses also generally apply to level 2 assessments. Level 2 assessments must also demonstrate that the relevant numerical criteria will not be exceeded. This requires that the cumulative effects of those sources of risk with significant consequences beyond the site boundary will have been quantified and shown to be below the appropriate criteria. Specifically, this means that:

- no **individual** event should have off-site consequences (such as fatality or injury) at a frequency greater than that appropriate for the exposed land use
- at any point outside the site, there should be no **combination of events** which cumulatively will cause the individual risk criteria to be exceeded.

The use of generalised off-site risk contours, when they are available, may be useful in demonstrating that these requirements have been met.

2.3 Risk Reduction and Management

Even when it has been demonstrated that risk criteria have been satisfied, there is need for an ongoing program of risk minimisation and risk management. Three basic principles apply:

- as noted in the previous section, all `avoidable' risks should be avoided; risk contributors should be eliminated wherever technically and economically feasible'
- risks from major hazards should be reduced wherever practicable, irrespective of their numerical contribution to the cumulative risk from the installation; the likelihood of major accidents should be reduced as far as possible
- every facility should have a strong safety management system to ensure safe operation throughout its life; risk reduction and management are described in greater detail in section 3.4.

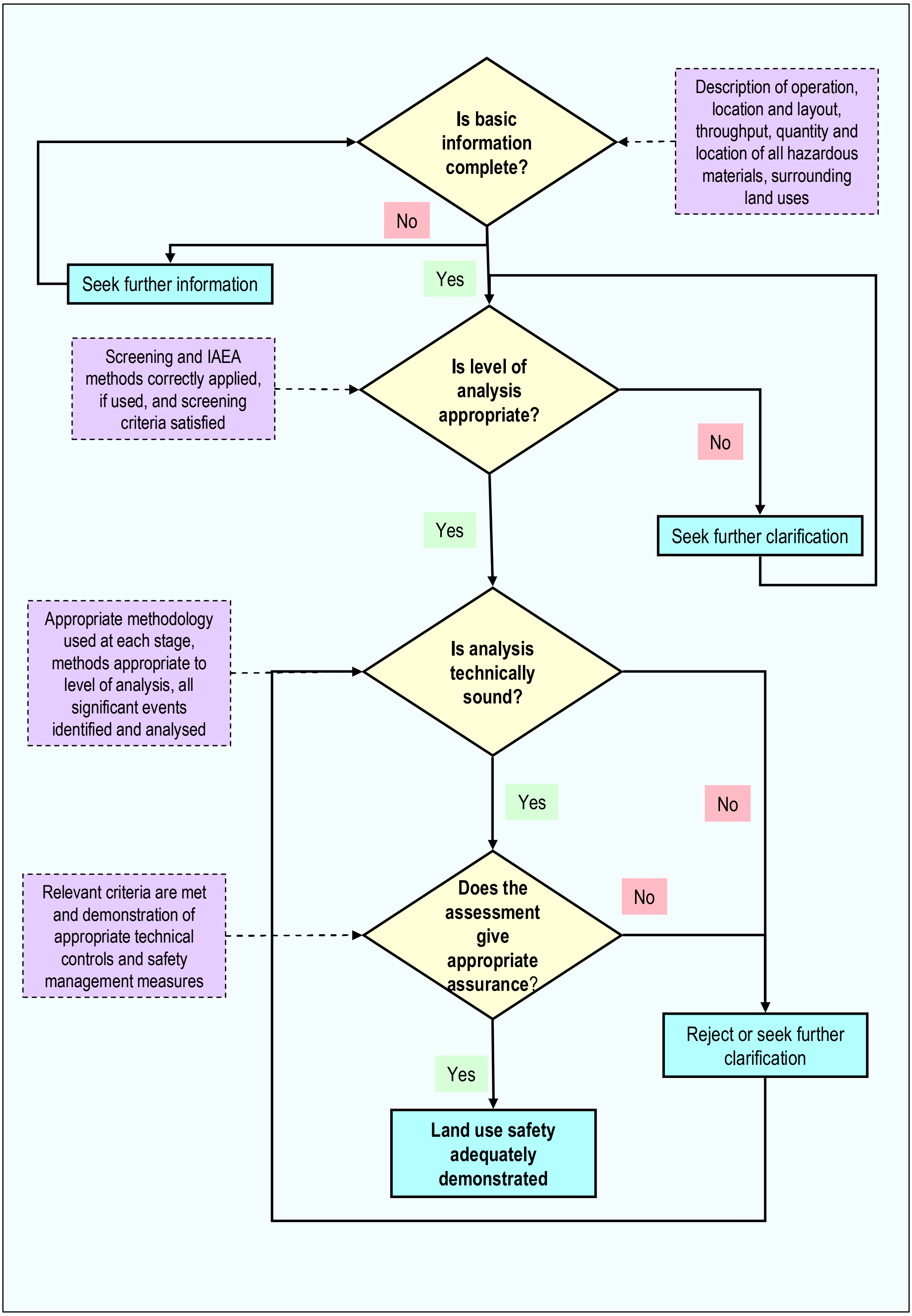
2.4 Evaluation Principles

A multi-level approach should also be used by any consent authority or other reviewer considering the adequacy of a PHA in terms of the requirements of *HIPAP No. 6 - Hazard Analysis*).

The approach to evaluating the adequacy of a hazard analysis and risk assessment essentially parallels the process of analysis outlined in the earlier sections. A generalised approach to evaluation steps is shown diagrammatically in Figure 4. More specific tests of adequacy, relating to the various levels of assessment, are given in the right hand column of Table 1.

Further guidance on evaluating a risk assessment report is given in section 4.

Figure 4: Evaluating a Risk Assessment



Part B - Methodologies

3 Risk Assessment

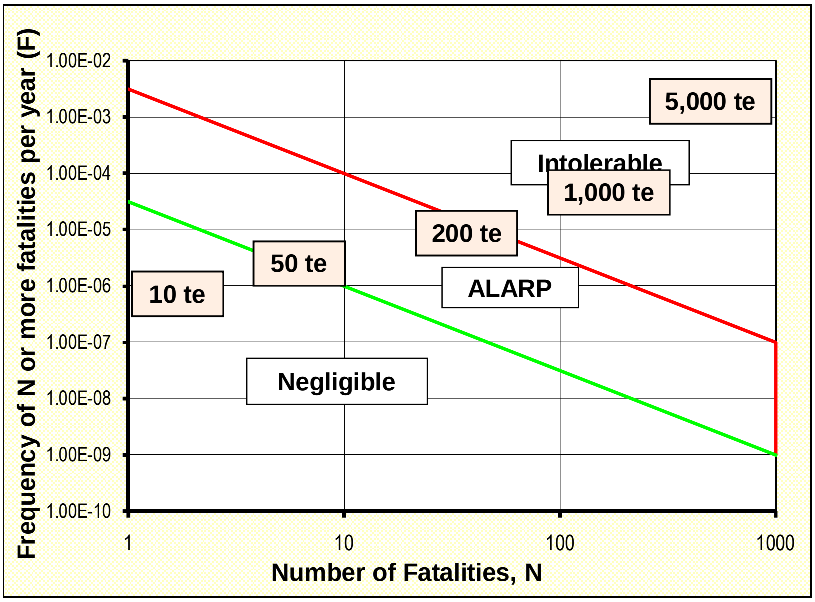
3.1 Determining the Level of Analysis

3.1.1 Background

As indicated in section 2, the level of analysis should be determined by the likely level of risk. This is related to the type and size of the activity, its location and the sensitivity of the surrounding land uses. Provided significant consequences can be shown to be largely contained within the site or, at the most, cause limited off-site effects, a level 1 or level 2 analysis will usually suffice.

The significance of size in relation to determining an appropriate level of analysis is illustrated in Figure 5, which shows the effect of the size of a typical storage facility, located close to a site boundary, on the societal risk of fatality, estimated using the risk classification and prioritisation approach.

Figure 5: Illustration of the Effect of Size on Societal Risk - Flammable Liquids



In this example, a residential population of 35 people per hectare has been used. Figure 5 shows that, for small-scale facilities, the societal risk is limited by the size of the maximum area of effect, even if the risk source is located relatively close to the site boundary, in this case, falling below the negligible line for inventories of less than 50 tonnes.

Figure 5 indicates that there is typically a size of facility below which a qualitative or semi-quantitative approach to risk analysis is likely to give an adequate degree of safety assurance (assuming adequate separation distances between the source of the risk and the exposed land uses).

The following guidance on choosing the level of analysis generally draws on the results of the risk classification and prioritisation method. However, this technique does not cover all dangerous goods classes (see the final paragraph of section 2.1) and alternative approaches are suggested for considering materials for which that method does not apply.

3.1.2 Level 1 Analysis (Qualitative)

A qualitative analysis is one in which risk is primarily expressed and analysed in non-numeric terms and assessed against qualitative criteria. At the very least, a qualitative analysis should be carried out on all facilities for which the initial screening thresholds have been exceeded (see section A1.1).

Whether or not a higher level of analysis is also required will depend on the potential of the facility to cause an accident of a scale which is significant in terms of risk to people or property, or harm to the biophysical environment.

Both the qualitative analysis and the risk classification and prioritisation step (where relevant) should be used to assess the accident potential. In some cases, risk classification and prioritisation may show a low potential but the qualitative assessment may identify particular factors such as environmental sensitivity, which would indicate the need for further analysis. In deciding whether or not to proceed further, a conservative approach should be adopted.

The following guidance on level of analysis is grouped by dangerous goods class, taking into account both the applicability of the risk classification and prioritisation method, and specific class characteristics.

Dangerous Goods Classes 1-3 and 6.1

These dangerous goods classes are those explosive, flammable and toxic materials which are covered by the risk classification and prioritisation method.

A QRA may not be required if the risk classification and prioritisation stage indicates a negligible level of societal risk. However, risk classification and prioritisation is imprecise and only considers one aspect of risk (human fatality). Other factors need also to be taken into account.

It is suggested that four conditions need to be satisfied before no further quantification of risk would be required:

- all points on the indicative societal risk curve produced from the risk classification and prioritisation should be below the negligible line
- there should be no events with consequences extending significantly beyond the site boundary at a frequency of greater than 1×10^{-7}
- the process or operation should be well understood and covered by established and recognised standards and codes of practice
- if there are any off-site consequences these will not impact on any sensitive adjoining land use.

If the essentially qualitative analysis cannot demonstrate there will be no significant risk (i.e. that risk criteria would be satisfied), a higher level of analysis will be required.

Dangerous Goods Classes 4 and 5

These classes cover flammable solids and oxidising agents to which the risk classification and prioritisation technique does not apply. While their potential for off-site impact is generally lower than for dangerous goods of classes 1-3 and 6.1, the significance of the risk is highly dependent on the quantity stored or handled and the location in relation to the site boundary.

Accordingly, for these classes, it is recommended that there should be a quantification of consequences of all credible accidents. This should include consideration of toxic reaction and combustion products. A qualitative analysis should only be considered to be sufficient when there are no harmful consequences extending significantly beyond the site boundary.

If there are significant off-site consequences, a higher level of analysis will be required.

Dangerous Goods Classes 6.2-8

These classes cover infectious, radioactive and corrosive substances to which the risk classification and prioritisation technique does not apply. Their storage and handling are generally either covered by stringent standards and codes (radioactive substances) or have limited potential for off-site harm (corrosive and infectious substances), provided appropriate technical and management controls are observed.

Consequently, a qualitative analysis, which includes a demonstration of compliance with all relevant standards and codes, should normally suffice. In particular, adequate measures to protect the biophysical environment should be clearly demonstrated.

If the qualitative analysis cannot demonstrate there will be no significant risk (i.e. that risk criteria would be satisfied), a higher level of analysis will be required.

3.1.3 Level 2 Analysis (Partial Quantification)

Partial quantification would normally be applied to small- to medium-scale proposals where screening, hazard identification or risk classification and prioritisation has identified one or more events with off-site consequences but where their consequences and likelihood are low. Otherwise, a full-scale QRA should be carried out.

In deciding what should be quantified, a conservative approach needs to be adopted, in view of the approximations involved in estimating both consequences and likelihood using the risk classification and prioritisation method.

Quantification should be carried out on any component of the risk classification and prioritisation which has off-site consequences at a frequency of greater than 1×10^{-7} per year, as determined using the risk classification and prioritisation method.

If the results of partial quantification indicate that any of the risk criteria could be exceeded, a detailed analysis will be required.

Where the risk appears to be low, quantification need only be continued to the extent needed to demonstrate that no combination of events is possible that would lead to relevant risk criteria being exceeded. For example, the modelling of the main events may show that all consequences are confined within the site or that the events with off-site consequences are sufficiently unlikely to pose a significant risk.

3.1.4 Level 3 Analysis (Full Quantitative Risk Analysis)

A full quantitative risk analysis (QRA) is advisable whenever the scale and nature of an activity creates a significant potential for a major accident. Examples of such activities would include large scale manufacture of chemicals, petroleum refining, and storage and distribution terminals involving large quantities of dangerous goods.

A full analysis should also be carried out if partial quantification cannot sufficiently demonstrate that relevant criteria will be met.

For proposals of this scale, it is important that the risk assessment also includes a sensitivity analysis covering assumptions and data used in the analysis which, if varied, could significantly affect the results.

A detailed analysis may also be desirable even when the risk of fatality is low, if there is significant potential for personal injury, property damage or harm to the biophysical environment. The choice is a matter for experienced judgement.

The techniques used in carrying out a detailed quantitative hazard analysis are described in *HIPAP No. 6 - Hazard Analysis* and summarised in section A1.3.

3.2 Presentation of Risk Results and Broad Assessment Principles

Risk results should be presented to enable assessment against all relevant qualitative and quantitative criteria for risk to people, property and the environment. Both individual and societal risk should be considered.

In presenting the results, it is essential that the potential extent of uncertainty and the sensitivity of the results to changes in assumptions are discussed and, if possible, quantified. It is important that the major risk contributors are highlighted.

In assessing the tolerability of the overall risk, account should be taken of the guidance notes in *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*. As emphasised in that paper, because of the probabilistic nature and uncertainties of the risk analysis, there needs to be a degree of flexibility in the implementation and interpretation of the risk criteria. The assessment should consider, among other things:

- qualitative as well as quantitative outputs of the analysis
- the consequences and likelihoods of hazardous events
- the vulnerability of people in the area
- the sensitivity of the affected environment
- the potential benefits of the development
- variations in local conditions
- existing risk exposures
- the likely future use of surrounding lands
- interaction with adjoining facilities.

The quantitative risk criteria should not be treated as being absolute. Where the calculated risk levels exceed the established criteria, the acceptability of the facility may nevertheless be justifiable in terms of expected economic or social benefits.

Quantitative risk measures can also be used to demonstrate the benefits of risk reduction that can be achieved if recommendations arising out of the hazard analysis are implemented.

The implementation of the risk criteria should differentiate between existing land use situations and new situations where stricter locational and technological standards would usually apply.

The complexities of assessing risk to the biophysical environment and case-to-case differences make it inappropriate to specify precise risk criteria in these cases. The acceptability of the risk will ultimately depend on the value of the potentially affected area or system to the local community and wider society. Relevant factors in the capacity of the population or ecosystem to recover should be considered, including the extent of other stresses and the possibility of repopulation of affected areas.

3.3 Risk Criteria

3.3.1 The Setting of Quantitative Risk Criteria

In setting risk criteria, the underlying principle is that people should not involuntarily be subject to a risk from a development which is significant in relation to the background risk associated with the exposed land use.

The frequency with which a particular consequence will be tolerated also depends on its severity. For example, injury or irritation will usually be tolerated at a higher frequency than fatality. Thus, in developing criteria, both severity and frequency need to be taken into account.

Some of the effects of heat radiation and explosion overpressure are given in *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*

The department normally assumes fatality levels of 12.6 kW/m2 and 14 kPa, respectively, although some analysts use a probit approach to the effects of heat radiation to account for exposure duration.

3.3.2 Risk of Fatality

The department's approach to the setting of criteria for acceptable risk is set out in HIPAP No. 4.

Two key principles are followed:

- when a risk is to be imposed on an individual or a group of people, the concept of acceptability is that it should be low relative to other known and tolerated risks
- individual and societal risk should be considered separately - while an individual's concern about their life or safety is largely independent of whether the risk is from an isolated incident or a major disaster, society’s risk perception is strongly influenced by events with potential for multiple injuries or fatalities.

HIPAP No. 4 provides a summary of fatality risks to individuals in New South Wales from various sources against which the suggested criteria may be compared.

Individual Fatality Risk Criteria

Criteria recommended by the department for individual fatality risk are set out in Table 2.

Table 2: Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk in a million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels, motels, tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open space	10
Industrial	50

These criteria have been set on the basis that they represent very low risks compared to other everyday risks associated with the various land uses.

Societal Fatality Risk Criteria

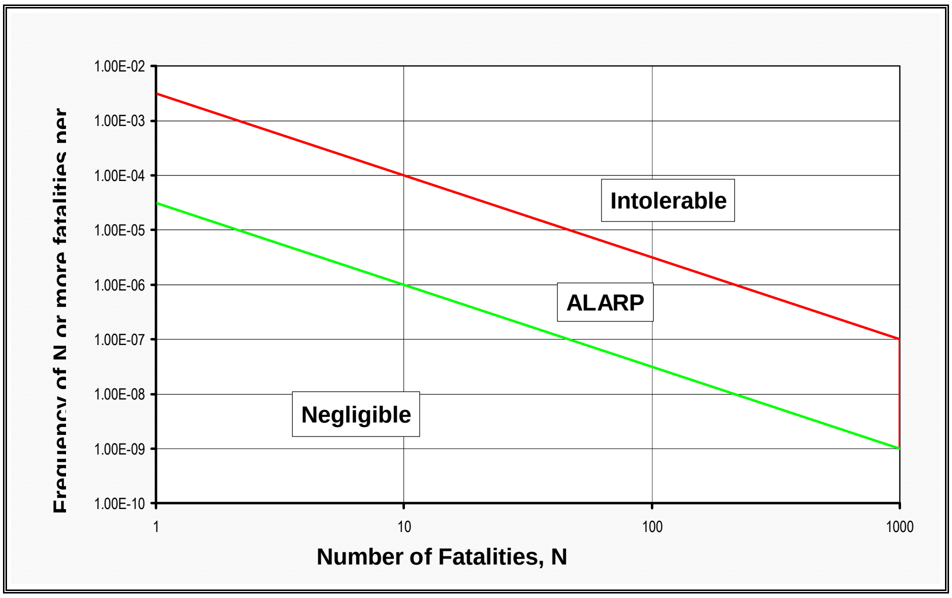
Developing criteria on tolerability of risks for hazards giving rise to societal concerns is difficult. Hazards giving rise to such concerns often involve a wide range of events with a range of possible outcomes.

Nevertheless, the Department has provisionally adopted indicative criteria as shown in Figure 6 (see section 2.1) for addressing societal concerns arising when there is a risk of multiple fatalities occurring in one event. These were developed through the use of so-called FN-curves (obtained by plotting the frequency at which such events might kill N or more people, against N). The technique provides a useful means of comparing the impact profiles of man-made accidents with the equivalent profiles for natural disasters with which society has to live. The method is not without its drawbacks but in the absence of much else it has proved a helpful tool if used sensibly.

The suggested criteria take into account the fact that society is particularly intolerant of accidents, which though infrequent, have a potential to create multiple fatalities. The indicative societal risk criteria incorporate an ALARP (As Low As Reasonably Possible) approach. The criteria are shown as three societal risk bands: negligible, ALARP and intolerable, as shown in Figure 6.

It should be emphasised that the criteria in Figure 6 are indicative and provisional only and do not represent a firm requirement in NSW.

Figure 6: Indicative Societal Risk Criteria



Below the negligible line, provided other individual criteria are met, societal risk is not considered significant. Above the intolerable level, an activity is considered undesirable, even if individual risk criteria are met. Within the ALARP region, the emphasis is on reducing risks as far as possible towards the negligible line. Provided other quantitative and qualitative criteria of HIPAP 4 are met, the risks from the activity would be considered tolerable in the ALARP region.

3.3.3 Injury and Irritation Risk Levels

Relying entirely upon fatality risk criteria may not account for the following factors:

- Society is concerned about risk of injury as well as risk of death.
- Fatality risk levels may not entirely reflect variations in people's vulnerability to risk. Some people may be affected at a lower level of hazard exposure than others.

It is therefore appropriate that risk criteria also be set in terms of injury, i.e. in terms of levels of effects that may cause injury to people but will not necessarily cause fatality.

Recommended injury risk criteria are summarised in Table 3.

Table 3: Injury Risk Criteria

Risk Type	Suggested Criteria (risk in a million per year)
Heat radiation in residential areas (at 4.7 kW/m^2)	50
Explosion overpressure in residential areas (at 7 kPa)	50
Injury to sensitive members of the community from toxic gas/smoke/ dust exposure	10
Irritation to sensitive members of the community from toxic gas/ smoke/dust exposure	50

3.3.4 Risk of Property Damage and Accident Propagation

The siting of a hazardous installation must account for the potential of an accident at the installation causing damage to buildings and propagating to a neighbouring industrial operations and hence initiating further hazardous incidents - the so-called ‘domino effect’. The siting process must also account for existing risk conditions at the proposed site.

The principle of setting risk criteria to reflect the potential for accident propagation is that the risk of an accident at one plant triggering another accident at another neighbouring plant should be low and that adequate safety separation distances should be provided as part of siting and layout of plant and equipment.

Recommended property damage and accident propagation criteria are summarised in Table 4.

Table 4: property damage and accident propagation criteria

Risk Type	Suggested Criteria (risk in a million per year)
Incident heat radiation (at 23 kW/m^2)	50
Explosion overpressure (at 14 kPa)	50

3.3.5 Criteria for Risk Assessment to the Biophysical Environment

In addition to the risk to people and property, the siting and impact assessment process for potentially hazardous installations must consider the risk from accidental releases to the biophysical environment.

In the case of the biophysical environment, fire and explosion hazards are of less relevance in comparison to the effect of these hazards on people. Acute and chronic toxicity impacts are those which must be chiefly addressed. Generally, there is less concern over the effects on individual plants or animals. The main concern is instead with whole systems or populations.

The assessment of the ultimate effects from toxic releases into the natural ecosystem is difficult, particularly in the case of atypical accidental releases. Data are limited and factors influencing the outcome variable and complex. There may be no immediate loss of plants or animals or other observable effects from single releases but there may be cumulative and synergistic effects. It is therefore appropriate to ensure that a thorough review of available data is undertaken and best available information used in the assessment process. The assessment should err on the conservative side.

Because of the complexities of such assessment and case-to-case differences, it is inappropriate to specify hard and fast criteria. The acceptability of the risk will ultimately depend on the value of the potentially affected area or system to the local community and wider society.

The Department suggests the following broad criteria:

- Industrial developments should not be sited in proximity to sensitive natural environmental areas where the effects (consequences) of the more likely accidental emissions may threaten the long-term viability of the ecosystem or any species within it.
- Industrial developments should not be sited in proximity to sensitive natural environmental areas where the likelihood (probability) of impacts that may threaten the long-term viability of the ecosystem or any species within it is not substantially lower than the background level of threat to the ecosystem.

3.4 Management of Residual Risk

3.4.1 Risk Reduction

Risk analysis and assessment are not ends in themselves. As well as demonstrating that particular numerical criteria have been met, it is important that every opportunity is taken to avoid or reduce risk and to ensure that residual risk is managed throughout the life of a facility.

These aspects are considered in the following sections.

Risk reduction strategies may be developed by first inspecting and ranking the risk results, to identify the major contributors. Cost-effective risk reduction measures can then be considered. Possible approaches to risk reduction will vary depending on whether the assessment is for an existing facility or a new development. They may include:

- an alternative technology or location
- a reduction in inventories
- modification of process or storage conditions
- early detection, control and cleanups of releases and provision for containment of spillages
- changes to site layout
- improvements to operability
- technical improvements to emergency systems
- improvement to safety management systems
- land use controls.

3.4.2 Safety Management

An integrated approach to the assessment and management of risk from potentially hazardous industry involves the complementary implementation of the three main types of safeguards:

- technical - such as the design and layout of plants and equipment
- operational - such as clear safety accountabilities; well-developed operating, maintenance and emergency procedures; and training of personnel
- locational - such as siting and land use controls; safety separation distances; and control of population densities and surrounding land uses.

One of the most effective means of ensuring the ongoing safe operation of a facility is through a comprehensive, well-documented and thoroughly implemented safety management system (SMS). Such a system will cover such diverse aspects as safety policy, organisational structure and responsibilities, operating and emergency procedures and procedures for document control, change management and performance auditing.

The SMS should be tailored to the facility in which it will be used. A simple plant may only require a simple SMS, while a complex or more hazardous plant may need a more extensive one. The adequacy of the safety management system should also be considered in the context of the initial and subsequent risk assessments.

The purpose of a SMS is to provide a management framework for:

- safely undertaking potentially hazardous activities
- minimising the likelihood of incidents
- managing occupational health and safety
- assisting in protecting people, property and the biophysical environment.

The SMS ensures that hazards are identified and managed, so that all activities are conducted safely. It is an integral part of the overall management system within a facility, and should complement other management systems, controlling such aspects as:

- production processes
- environmental protection
- marketing and finance
- human resources.

improved safety management will invariably lead to tangible benefits for the operator through the reduction of disruptive incidents and accidents. For public authorities, the knowledge that an operator has an effective SMS in place gives assurance that safety assumptions made during the development approval stage of a project will remain valid in an ongoing operation.

Because of the diverse nature of hazardous facilities, each safety management system should be appropriately comprehensive to cover the full range of activities at the facility which could have a significant safety impact.

The SMS generally should contain four elements:

- Safety Policy and Commitment to Policy;
- Management and Administration of the SMS;
- Operational Controls that include all the elements of an efficient Process Safety System; and
- Safety Assurance.

The SMS is discussed in *HIPAP No. 9 - Safety Management.*

4 Assessment

4.1 General Considerations

This section amplifies the basic principles outlined in section 2.4.

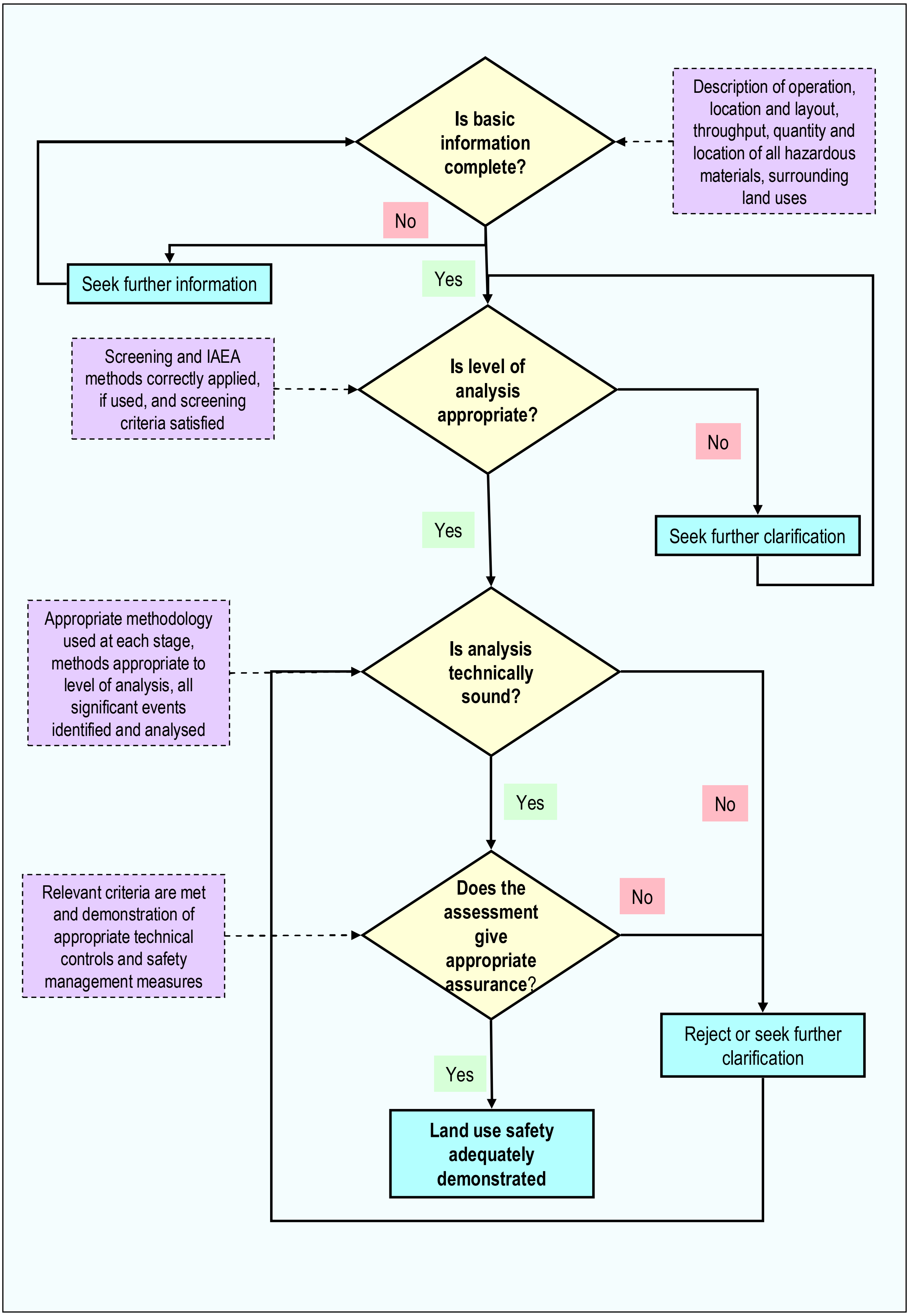
A multi-level approach should be used by a consent authority or other reviewer considering the adequacy of a PHA in terms of the requirements of *HIPAP No. 6 - Hazard Analysis.*

There may be a number of instances in which some elements of the process set out in HIPAP No. 6 are not included in an analysis. This should not necessarily be taken to mean that the study is inadequate, since there is no useful purpose served by including information which is not relevant to the end result. Where off-site consequences are clearly minor, full quantification of risk should not be required for land use safety planning purposes.

The purpose of assessment is to ensure that the study adequately demonstrates the level of risk to an extent that will allow determination of the acceptability or otherwise of the proposal. A graded approach will ensure that the degree and rigour of the assessment is neither too superficial nor greater than is needed to demonstrate the adequacy of the study,

The general approach to evaluation of the adequacy of a hazard analysis and risk assessment is shown diagrammatically in Figure 7. Level specific aspects are considered in section 4.2.

Figure 7: Evaluating a Risk Assessment



The main steps outlined in Figure 7 are amplified in the following paragraphs,

4.1.1 Completeness of Basic Information

Certain basic information requirements are common to all levels of analysis. As a minimum, there should be:

- a site location map, showing details of adjacent land uses
- a site drawing, showing manufacturing and storage locations in sufficient detail to at least allow screening and risk classification and prioritisation steps to be carried out
- a description of the nature and scale of the proposal, including throughput, storage quantities and conditions, types of manufacturing operation, and transport arrangements for significant movements of dangerous goods
- the quantity and location of all dangerous goods stored and handled on site.

4.1.2 Appropriate Level of Analysis

If a level of analysis less than a full QRA (i.e. a level 3 assessment) has been employed, the reviewer should check the screening and risk classification and prioritisation calculations against the basic data to ensure the methodology has been correctly followed.

Once the methodology has been confirmed to be correct, the level of analysis may be considered to be appropriate, assuming the criteria detailed in section 3.1 have been satisfied.

4.1.3 Technical Soundness of Analysis

Although checking the technical adequacy of a full QRA (i.e. a level 3 assessment) will generally require specialised expertise, there are a number of checks of the analysis that can be carried out by a lay person. In straightforward cases, more specialised evaluation may not be needed, particularly with respect to a qualitative (i.e. level 1) assessment.

The soundness of the analysis can be judged by comparing the approach taken against the techniques set out in section A1.2. In particular, where less than a full QRA has been carried out, the evaluator should ensure the principles set out in sections A1.3.1 and A1.3.2 have been followed in the study.

The characteristics of an adequate analysis are described in section 3 of *HIPAP No. 6 - Hazard Analysis* and summarised in the following paragraphs.

Hazard Identification

The methods used for hazard identification should be documented, together with justification of their appropriateness. Examples should be provided in cases where techniques such as fault and event trees have been used.

The results should include a brief description of possible incident initiating events, consequences and existing or proposed safeguards. The analysis should comment on the adequacy of the considered safeguards.

The hazard identification should consider possible ways of reducing or eliminating hazards, such as changes in site location or technology.

Those events that will be carried forward for more detailed analysis should be clearly identified, and the basis for screening out other lesser incidents stated.

Consequence Analysis

Methodology and results should be described in sufficient detail to allow the consequences of the various possible accidents to be clearly understood. The extent to which detailed calculations are included will depend on the size and complexity of the analysis, but details should be available if required.

Description of the methodology should include the types of calculations carried out, the models used and underlying assumptions. Where nonstandard calculation methods have been used, details of their validation and any limitations should be provided.

Opportunities for reducing or eliminating high consequence events should he discussed, even if later analysis indicates a low likelihood.

Estimation of the Likelihood of Hazardous Events

The calculation of the likelihood of hazardous events is often subject to considerable uncertainty due to the limited availability of relevant data. Hence, care needs to be taken in thoroughly documenting information sources and the way in which the data are used. The analysis should show:

- the various methods used to assess likelihood
- the failure data used and their sources
- relevant fault and event trees
- details of wind, weather, topographical, population and other data used in the calculations
- the names and purposes of computer software used in calculations
- relevant results.

Presentation and Assessment of Risk Results

Risk results should be presented in a way that will allow assessment against all relevant qualitative and quantitative criteria. The following elements should be considered:

- individual and societal risk
- injury and irritation as well as fatality risk
- property damage
- damage to the biophysical environment.

Major risk contributors should be highlighted. Additionally, there should be an analysis of the degree of sensitivity to changes in key data and assumptions with respect to the main risk contributors. The effects of possible risk reduction measures should also be shown.

The results of the analysis should be compared with appropriate qualitative and quantitative criteria such as those shown in *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*.

Specific considerations relating to the various study levels are outlined in the following section.

4.2 Level-Specific Considerations

For any level of study, the analysis should meet the requirements set out in section 4.1. Where less than a full QRA has been carried out, the evaluator should ensure the principles set out in section A1.3.1 have been followed in the study.

Their application to a multi-level assessment regime is shown diagrammatically in Table 5.

Table 5: Levels of Analysis and Assessment

Key Elements	Assessment Basis
Level 1 – Essentially Qualitative	
• hazard identification using summary diagram, FMEA, fault and event trees, HAZOP etc. • identification of key scenarios and qualitative estimate of risks • comparisons with qualitative criteria. • thorough discussion of protective technical and management measures, including codes and standards	• appropriate methods used for identification • all key scenarios thoroughly examined • realistic estimates of risk • relevant qualitative criteria met • proposed measures appropriate and sufficient • compliance with all relevant codes and standards
Level 2 – Partially Quantitative	
• qualitative elements as for level 1 • rigorous quantification of consequences of all events with significant off-site effects • quantification of the likelihood of events with significant off-site' consequences • indicative estimate of risk vs. criteria • thorough discussion of technical controls, risk reduction and management measures	• qualitative elements as for level 1 • sound consequence methodology used and appropriate failure data used • technical methods and results appropriately documented • relevant criteria shown to be met • appropriate controls and safeguards
Level 3 – Fully Quantitative	
• qualitative elements as for level 1 • comprehensive quantification of significant consequences and their likelihood • evaluation of risk against all relevant criteria • thorough discussion of technical controls, risk reduction and management measures	• qualitative elements as for level 1 • sound consequence methodology used • appropriate failure data used • technical methods and results well-documented • all relevant criteria met • ALARP principles followed • appropriate technical and procedural controls and safety management system

Section A1.3.1 sets out the principles which should have been adopted by the person carrying out the study.

The following notes focus on the requirements from the standpoint of the reviewer.

4.2.1 Level 1 Assessment (Qualitative)

The key requirements of a level 1 assessment are that all significant hazards should be identified and shown not to pose significant risks. Furthermore, the means by which risks will be managed during design, construction and ongoing operations must be clearly stated.

Hazard Identification

The methods used for the hazard identification should be documented, together with justification of their appropriateness. Examples should be provided in cases where techniques such as fault and event trees are used.

The results should include a brief description of possible incident-initiating events, consequences and existing or proposed safeguards. The analysis should comment on the adequacy of the considered safeguards.

The hazard identification should consider possible ways of reducing or eliminating hazards, such as changes in site location or technology.

Presentation and Assessment of Risk Results

While a level 1 analysis is qualitative in nature, it should still include an indicative consequence analysis of the key risk contributors (using, for example, the results of the screening and risk classification and prioritisation stages), to demonstrate that such consequences are kept within site boundaries.

If spot calculations have been done to confirm that the consequences of specific events are contained within the site, they should be shown.

Results should be presented in a way that will allow assessment against the relevant criteria. Particular attention should be given to demonstrating how the principle of avoiding avoidable risk has been implemented, and to discussing the proposed design and operational safeguards assumed in the assessment.

4.2.2 Level 2 Assessment (Partially Quantitative)

Hazard Identification

The requirements are as for a level 1 assessment. In addition, those events that will be carried forward for more detailed analysis should be identified and the basis for screening out other lesser incidents stated.

Consequence Analysis

Methodology and results should be described in sufficient detail to allow the reviewer to appreciate the consequences of the various possible accidents. Consequence results for all scenarios with harmful effects extending significantly beyond the site boundary should be included. The extent to which detailed calculations are also included will depend on the size and complexity of the analysis but details should be available, if required.

Description of the methodology should include the types of calculations carried out, the models used and underlying assumptions. Where significant non-standard calculation methods have been used, details of their validation and any limitations should be provided.

The analysis should show which events were not carried forward for further analysis because they did not have significant off-site impacts, either individually or collectively.

Estimation of the Likelihood of Hazardous Events

The calculation of the likelihood of hazardous events is often subject to considerable uncertainty due to the limited availability of relevant data. Hence, care should be taken in thoroughly documenting the relevant failure frequency data, information sources and the way in which the data were used.

Particular aspects which need to be addressed are set out in section 4.2.3, under Estimation of the Likelihood of Hazardous Events.

Presentation and Assessment of Risk Results

The requirements noted for level 1 assessments also apply here. Additionally, the results should be presented in a way that demonstrates that no combination of events can cause the numerical risk criteria to be exceeded.

In simple cases, this may only require simple tabulations of the effect distances and frequency of the relevant cases. Alternatively, generalised off-site risk contours may be shown.

It is particularly important that the analysis demonstrates that all relevant events have been included in the partial quantification.

4.2.3 Level 3 Assessment (Full Quantification)

Hazard Identification

The requirements are as for a level 2 assessment.

Consequence Analysis

The requirements are generally as for a level 2 assessment, although greater detail will usually be required.

Estimation of the Likelihood of Hazardous Events

Because a level 3 analysis is dealing with events with significant off-site consequences, particular care should be taken in the selection and use of failure and other data, and in the assumptions used to develop fault and event trees. Information sources and the methodology used for likelihood estimation should be thoroughly documented. Information should be included on:

- the various methods used to assess likelihood
- the failure data used and their sources
- relevant fault and event trees
- details of wind, weather, topographical, population and other data used in the calculations
- the names and purposes of computer software used in calculations.

Presentation and Assessment of Risk Results

Risk results should be presented in a way that will allow assessment against all relevant qualitative and quantitative criteria. The following elements should be considered:

- individual and societal risk
- injury and irritation as well as fatality risk
- property damage
- damage to the biophysical environment.

Major risk contributors should be highlighted. Additionally, any uncertainties in the results and the degree of sensitivity to changes in data and assumptions should be covered. The effects of possible risk reduction measures should also be discussed.

The results of the analysis should be compared with the appropriate qualitative and quantitative criteria in *HIPAP No. 4 - Risk Criteria for Land Use Safety Planning*

4.3 Conditions of Consent

For new development, it is usual for a number of conditions of consent to be set which include additional safety studies covering the ongoing safety of a development, and require potential hazards to be specifically considered. The framework in which the conditions are applied, which is known as the Seven Stage Approval Process, is shown diagrammatically in Figure 1 on page viii.

Each case should be considered on its merits and only those conditions relevant to the particular development applied. As an example, it would not be appropriate to require a fire safety study in cases where there are essentially no flammable materials used as part of the development.

The most applicable conditions are those relating to the final hazard analysis, emergency plan, safety management system and hazard audit. The suggested conditions of consent fall into three groups:

1. Studies to be submitted at least one month prior to commencement of construction:

- construction safety
- fire safety
- hazard and operability (HAZOP)
- final hazard analysis

2. Studies to be submitted at least one month prior to commissioning:

- transport of hazardous materials
- emergency plan
- safety management

3. Reports to be submitted during ongoing operation:

- periodic hazard and safety management audit
- incident reporting.

Appendix 1

Methodology

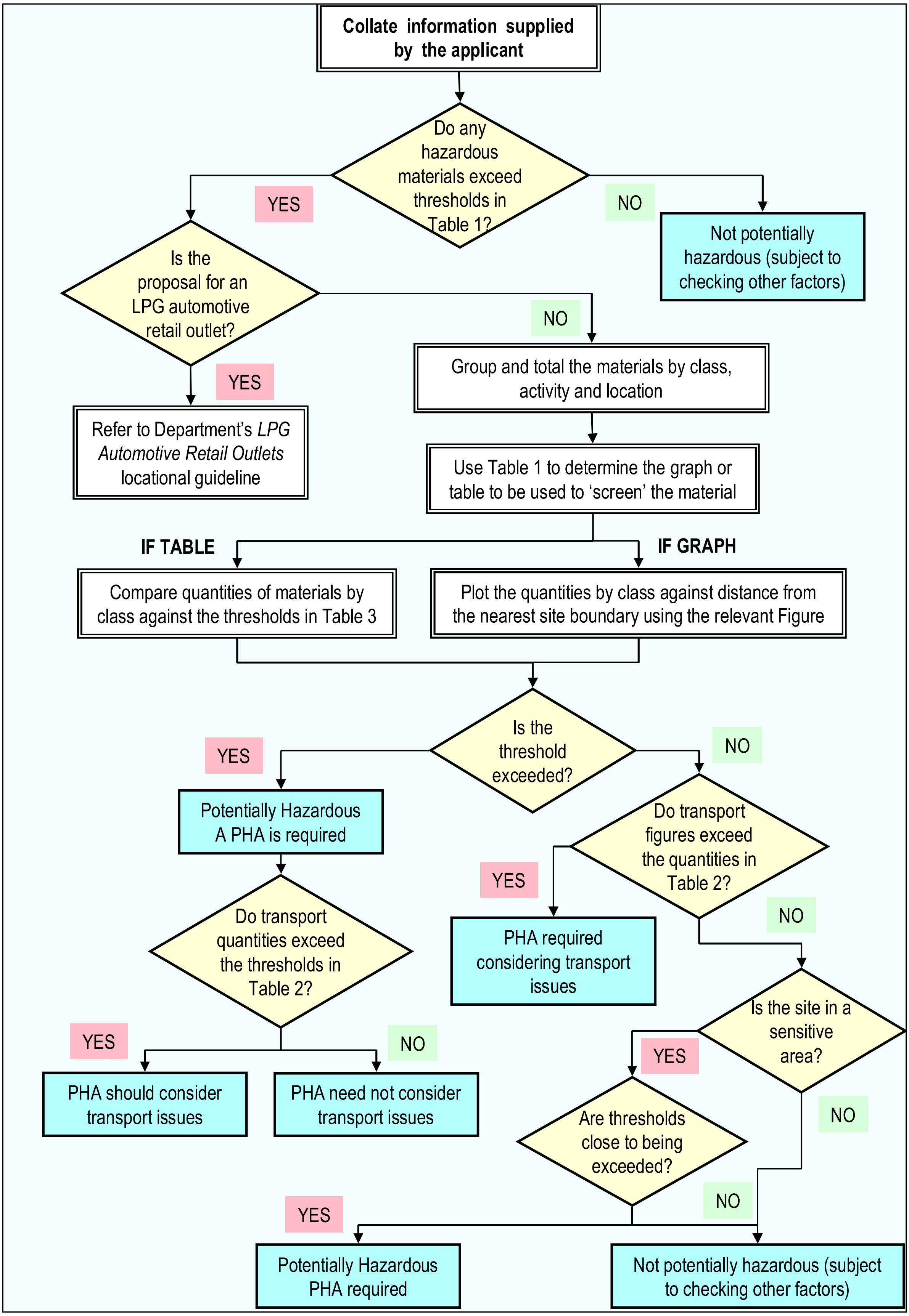
A1.1 Preliminary Screening

A1.1.1 Principles

The purpose of initial screening is to exclude from more detailed study those developments which do not pose significant risk. Because the screening is relatively crude, the underlying assumptions used are conservative, and consider the consequences of hazards in the absence of safeguards. The method used is described in *Applying SEPP 33*. A simplified representation of the screening logic is given in SEPP 33 Figure 4. The method is discussed in the remainder of this section, and illustrated by the example in Appendix 2.

Note that where figures and tables are quoted from *Applying SEPP 33*, the *Applying SEPP 33* numbering is used and the words 'table' and 'figure' are preceded by 'SEPP 33' to distinguish them from other tables and figures used throughout these guidelines.

SEPP 33 Figure 4: The Risk Screening Process



In broad terms, the method divides dangerous goods into three main categories:

- explosives
- flammable gases and liquids
- others (such as toxics and corrosives).

In the case of explosives and flammable gases and liquids, it is assumed the entire inventory is involved in an accident, resulting in an explosion overpressure or heat radiation which will vary with distance. If, at the site boundary, explosion overpressure is less than 7 kPa or heat radiation is below 12.6 kW/m^2 for 30 seconds, then it is assumed that there is minimal likelihood of death or serious injury. Above those levels, the risk may be significant and further analysis is warranted.

Since the threshold is dependent on both quantity and distance, a graphical approach, combining both factors, is used in the screening method for these materials.

For other classes of dangerous goods, such as corrosive or toxic materials, it is not easy to establish a clear-cut relationship between distance and the level of harm. For example, the effects of a toxic gas release will vary markedly depending on wind and weather patterns. For this reason, thresholds are based on quantity only. The values chosen are such that there is little likelihood of harm outside the site boundary below the threshold, even when the material is kept relatively close to the site boundary (it is assumed that normal separation distances required by relevant codes and standards will apply). The steps in the screening process, which are more fully explained later and in *Applying SEPP 33* are:

- collation of information
- identification of the types of hazard
- grouping of similar substances
- choosing the screening method
- comparing with screening thresholds
- determining the need for further analysis.

Each of these steps is described on the next page.

A1.1.2 Screening Steps

Collation of Information

The first, and most important, step in the screening process is to gather background information on the general nature of the site and its operations, including the type, quantity and location of hazardous materials present and how they are used or stored on-site. The following tasks are relevant:

- listing and classifying, by dangerous goods code, all hazardous materials on-site, together with the quantities of each
- recording the distance from the site boundary of all dangerous goods of classes 1.1, 2.1 and 3, since the screening threshold for these materials varies with distance
- recording whether the materials are above or below ground, in bulk or packed form.

While substances of dangerous goods classes C1 and C2 (combustible liquids) are not classed as hazardous when stored alone, they should be treated as class 3PGIII if they are stored together with other class 3 substances.

Subsidiary classes should be noted as well as the main class to ensure that all relevant risks are considered.

Identification of the Types of Hazard

The collated information should be carefully reviewed to ensure that both the main class and any, subsidiary classes obtained from the dangerous goods code or from information provided in the material safety data sheets are recorded, so that all relevant hazards are considered during the screening Process.

Grouping of Similar Substances

When there are several substances of the same class and form of storage in a given general location, they may be grouped together to give totals by class, type of storage and location. This approach simplifies calculations when a large number of similar substances are being considered. In carrying out the grouping, all relevant subsidiary classes should be taken into account, so that if a substance is both flammable and toxic, it should be included in the group totals for both classes.

In those cases where several sub-classes are stored together, the total should be treated as though it represents the most hazardous sub-class.

The end results of the process will be a series of totals which can be compared with the screening thresholds. In general, if quantities fall below the threshold levels the off-site risk is likely to be minimal and further formal analysis will not be required.

Choosing the Screening Method

SEPP 33 Table 1 has two columns and is used to choose the appropriate screening method. The left hand column lists the various substance groupings considered. The right hand column indicates whether the tabular or graphical method is appropriate. For the latter, a minimum quantity is also shown, below which it is considered that the off-site risk is likely to be insignificant, so that no graphical reference is required.

The quantities used in SEPP 33 Table 1 should be the total for that class, as discussed above. The shortest distance to the boundary for that class should be used.

As previously noted, if SEPP 33 Table 1 indicates that a graph is to be used but the quantity is below the minimum quantity shown in the table, the inventory is not considered to be potentially hazardous and there is no need to apply the graph.

Using the appropriate graph, the group total quantity should be plotted against the distance from the nearest boundary. If the point lies below the screening threshold line, the proposed development is potentially hazardous.

For Class 3 materials only, if storage is underground, the capacity of the tank should be divided by five prior to assessing it against the screening threshold. This adjustment accounts for the significant hazard reduction for underground storage, compared with above ground storage, for flammable substances. Effect distances should be measured from directly connect exposed fittings and pipeworks.

The foregoing procedure should be repeated until all hazardous materials have been assessed.

SEPP 33 Table 1: Screening Method to be used

Class	Method to Use/Minimum Quantity
1.1	Use graph at SEPP 33 Figure 5 if greater than 100 kg
1.2-1.3	SEPP 33 Table 2
2.1 — pressurised (excluding LPG)	SEPP 33 Figure 6 graph if greater than 100 kg
2.1 — liquefied (pressure) (excluding LPG)	SEPP 33 Figure 7 graph if greater than 500 kg
LPG (above ground)	SEPP 33 Table 2
LPG (underground)	SEPP 33 Table 2
2.3	SEPP 33 Table 2
3PGI	SEPP 33 Figure 8 graph if greater than 2 tonne
3PGII	SEPP 33 Figure 9 graph if greater than 5 tonne
3PGIII	SEPP 33 Figure 9 graph if greater than 5 tonne
4	SEPP 33 Table 2
5	SEPP 33 Table 2
6	SEPP 33 Table 2
7	SEPP 33 Table 2
8	SEPP 33 Table 2

Note: *Classes 1.4, 1.5, 1.6, 2.2, 7 and 9 are excluded from the risk screening. Classes used are those referred to in the Dangerous Goods Code*

Applying SEPP 33 also considers transportation issues. These are set out in 0 (which is not shown in this guideline), which relates primarily to risks from fixed installations).

Comparing With Screening Thresholds

Three categories of substances are considered in the screening:

- explosives
- flammable gases and liquids
- others (such as toxics and corrosives).

The need for a risk assessment is indicated by one or more of the screening threshold quantities being exceeded. The level of analysis required will depend on the results of the risk ranking and prioritisation described in section A1.2. The criteria used for determining the level of analysis are set out in section 3.1 in the body of the guidelines.

Where a good relationship can be established between quantity, distance from an incident and likely harm (such as class 1.1 explosives and flammable gases and liquids), a graphical approach is adopted in determining the screening threshold. Otherwise a table is used which applies a conservatively derived threshold quantity to each substance category.

If a graphical method is required, the threshold quantity corresponding to the distance of the inventory from the site boundary should be read from the appropriate graph. For example, from SEPP 33 Figure 5, the threshold quantity for Class 1.1 explosives situated 200 metres from the boundary is approximately 3.5 tonnes.

When the tabular method is used, the threshold quantity can be read directly from the table.

For each substance, or group of substances, the actual quantity should be then compared against the threshold. If any threshold has been exceeded, off-site effects may be significant and a risk assessment is therefore warranted. Further, where there are a number of classes posing a similar hazard (e.g. fire and explosion), it is advisable to total the proportion of the threshold of each class to see whether or not the cumulative effects may be significant. In carrying out this step it is important, however, not to aggregate dissimilar effects, since fire and explosion hazards and toxic hazards are not cumulative.

In particular cases, such as where the facility adjoins or is close to a sensitive land use, a risk assessment may be desirable, even when the thresholds have not been exceeded.

SEPP 33 Table 2: General Screening Threshold Quantities

Class	Screening Threshold	Description
1.2	5 tonne	or are located within 100 m of a residential area
1.3	10 tonne	or are located within 100 m of a residential area
2.1	(LPG only — not including automotive retail outlets[1])	
	10 tonne or16 m^3	if stored above ground
	40 tonne or 64 m^3	if stored underground or mounded
2.3	5 tonne	anhydrous ammonia, kept in the same manner as for liquefied flammable gases and not kept for sale
	1 tonne	chlorine and sulfur dioxide stored as liquefied gas in containers <100 kg
	2.5 tonne	chlorine and sulphur dioxide stored as liquefied gas in containers >100 kg
	100 kg	liquefied gas kept in or on premises
	100 kg	other poisonous gases
4.1	5 tonne	
4.2	1 tonne	
4.3	1 tonne	
5.1	25 tonne	ammonium nitrate — high density fertiliser grade, kept on land zoned rural where rural industry is carried out, if the depot is at least 50 metres from the site boundary
	5 tonne	ammonium nitrate — elsewhere
	2.5 tonne	dry pool chlorine — if at a dedicated
		pool supply shop, in containers <30 kg
	1 tonne	dry pool chlorine — if at a dedicated pool supply shop, in containers >30 kg
	5 tonne	any other class 5.1
5.2	10 tonne	
6.1	0.5 tonne	packing group I
	2.5 tonne	packing groups II and III
6.2	0.5 tonne	includes clinical waste
7	all	should demonstrate compliance with Australian codes
8	5 tonne	packing group I
	25 tonne	packing group II
	50 tonne	packing group III

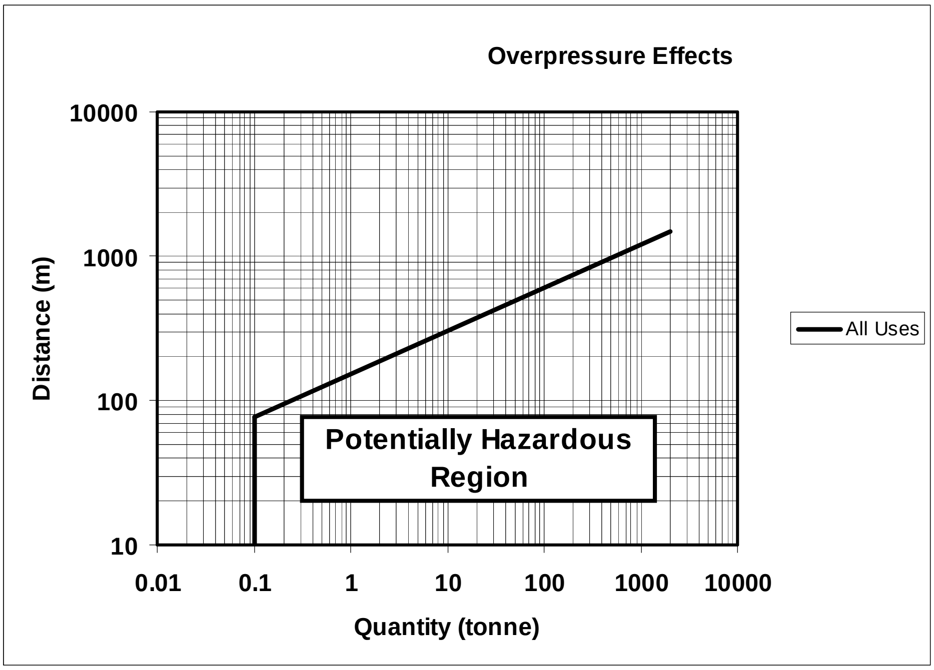
Note: *The classes used are those referred to in the Australian Dangerous Goods Code*

---

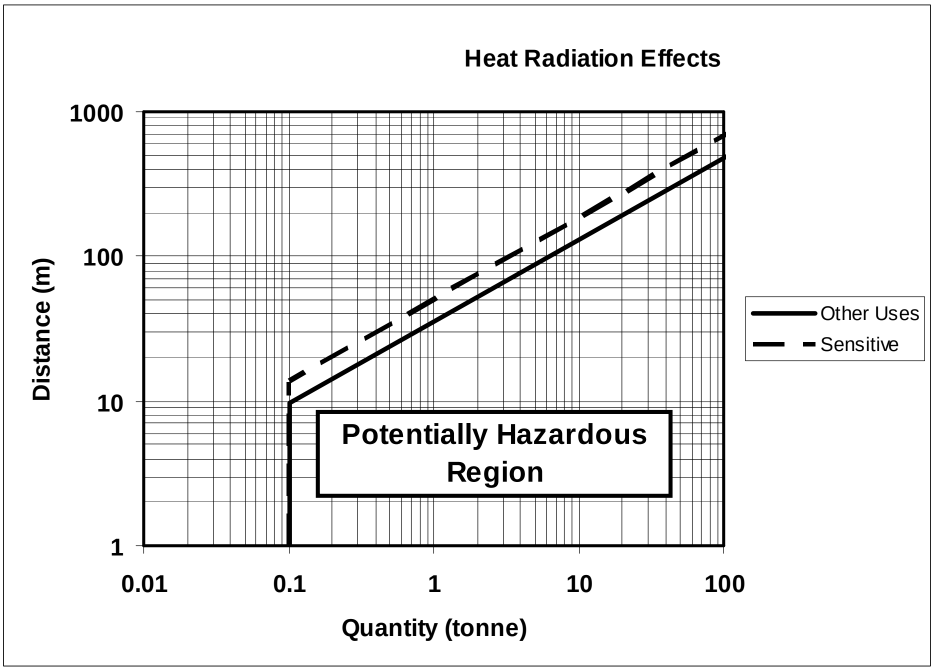
[1] These are covered by the department's *Locational Guidelines No 1 – LPG Automotive Retail Outlets.*

Note: In the following figures, the term ‘sensitive’ refers to residential or other more sensitive land uses. ‘Other’ applies to all other land uses (e.g. commercial or industrial).

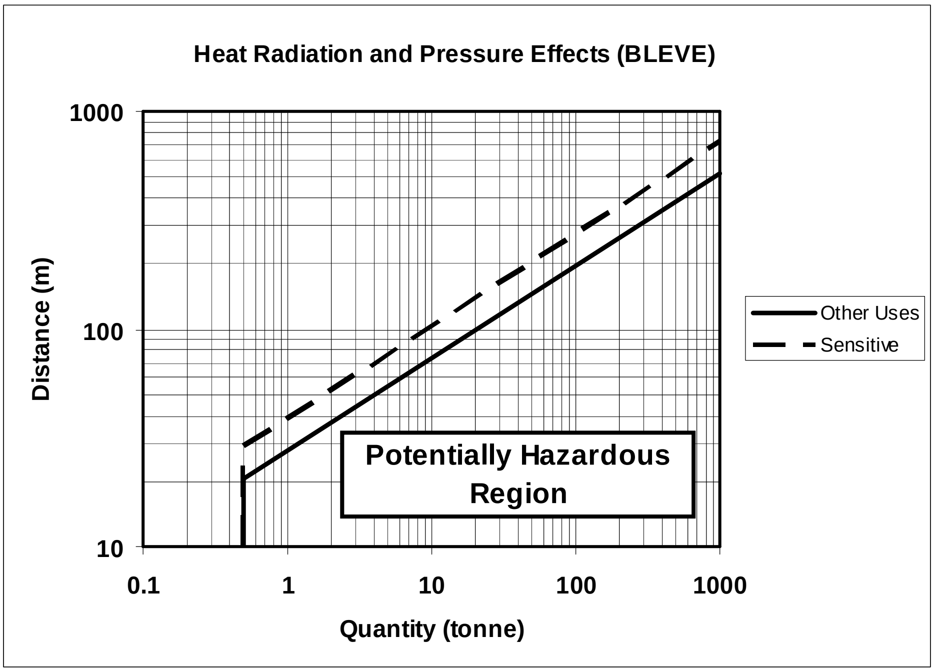
SEPP 33 Figure 5: Class 1.1 Explosives



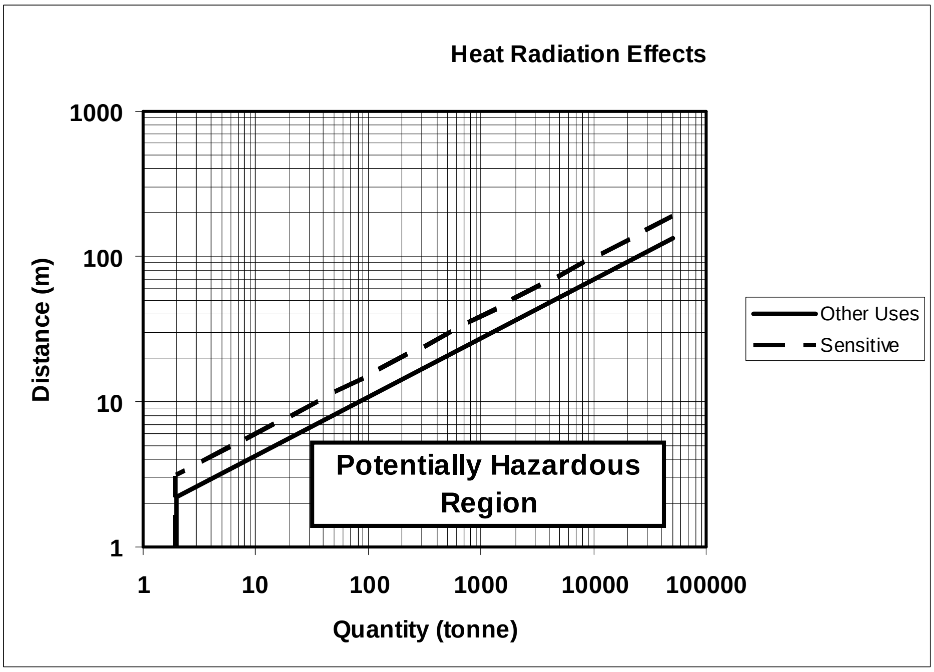
SEPP 33 Figure 6: Class 2.1 Flammable Gases Pressurised (Excluding LPG)



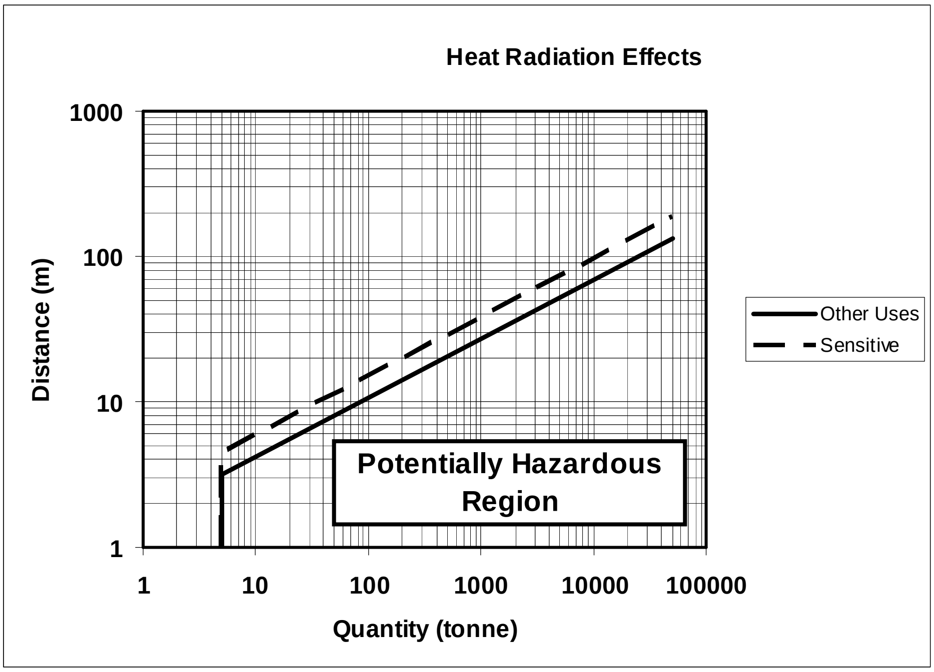
SEPP 33 Figure 7: Class 2.1 Flammable Gases Liquefied Under Pressure (Excluding LPG)



SEPP 33 Figure 8: Class 3PGI Flammable Liquids



SEPP 33 Figure 9: Class 3PGII and 3PGIII Flammable Liquids



Determining the Need for Further Analysis

If any of the thresholds are exceeded in aggregate, this is an indication that further risk assessment is warranted. However, it is important to recognise that the screening test is conservative and it should not automatically be assumed that exceeding the threshold means there is a significant risk.

Section 3.1.2 in the body of the guidelines provides guidance on criteria that can be used to decide whether a further level of analysis is required or whether a qualitative approach will suffice.

A1.2 The Risk Classification and Prioritisation Method

A1.2.1 Principles

This section describes the technique of risk classification and prioritisation used during the preliminary analysis stage outlined in section 2.1 in the body of the guidelines. This is further illustrated in the example in Appendix 2. The technique used is a modified version of the *Manual for the classification of risks due to major accidents in process and related industries* (IAEA, Rev. 1. 1996). It should be noted that the full IAEA method covers fixed installations and transport (including by waterways and pipeline). For simplicity, only the part of the method dealing with fixed installations is covered here.

The IAEA method was developed to produce a broad estimate of the risks due to major accidents From the manufacture, storage, handling and transport of hazardous materials.

As published, the method covers only off-site risks arising from explosion, fire or release of toxic substances. The results are expressed in terms of societal risk, rather than individual risk. Societal risk of death is defined in the IAEA method as the relationship between the number of people killed in a single accident and the chance or likelihood that this number will be exceeded.

The method uses a number of simplifying assumptions, the most important being:

- only the most important variables are used in assessing risk (such as population density, frequency of loading/unloading operations)
- estimates of probability and consequences are rounded to the nearest order of magnitude
- the entire inventory is initially assumed to be involved
- for physical and toxic effects, 100 percent fatality is assumed within an area where 50-100 percent lethality would be expected; outside this range, no fatalities are assumed
- no explosion overpressure or heat radiation calculations are carried out - the lethal radius is assumed to be the distance to the lower flammable limit (LFL) in the case of explosion and the actual fire area in the case of flammables
- only one weather pattern is used
- basic probabilities are generic but are modified later.

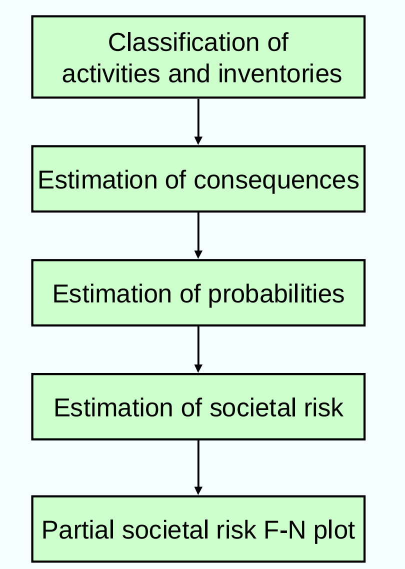
The basic estimates are modified to take into account mitigating factors and corrections for various types of industrial activities.

The use of such simplifications means that, while the method is very useful for gaining an overview of risks and for prioritising them for further study, the results should not be used in absolute terms. In particular, the authors of the method state that it should not be used for:

- risk assessment of individual facilities, or as a basis for risk management
- decision-making on siting of installations when fine judgement between alternatives is required
- emergency planning
- decisions as to whether or not the risk from an installation is acceptable.

The procedural steps are outlined in Figure A1.1.

Figure A1.1: Steps in the IAEA Method



A description of the IAEA method, as implemented in this guideline, follows. Where figures and tables are based on those in the *Manual for the classification and prioritisation of risks due to major accidents in process and related industries*, the IAEA numbering is used and the words 'table' and 'figure' are preceded by 'IAEA' to distinguish them from other tables and figures used throughout these guidelines.

A1.2.2 Defining the Scope of the Study

The boundaries of the study area should be defined and maps and drawings obtained, showing the site location in relation to its locality, and the site layout itself. The area chosen should generally be of sufficient size to encompass the consequence distance of the worst credible accident. The site layout should be in sufficient detail to allow the locations of all storage and processing areas to be identified to a precision that will allow consequence distances to be clearly represented.

It will also be necessary to obtain details of the surrounding land use and estimates of the population in the area.

A1.2.3 Classification of Type of Activities and Inventories

Much of the information required at this point will have been collected as part of the initial screening. For each potentially hazardous activity, information is required on the location, type, production and storage conditions which apply to the activity and the name, physical state and amount of hazardous substances involved. The checklist shown inIAEA Table II serves as a guide to give an indication of potentially hazardous industries and correspondingly their most important substances likely to be handled. It should be noted that transport-related activities have been omitted from the table in these guidelines.

IAEA Table I: Not used in these guidelines

IAEA Table II: Checklist

Activity		**Most important substances**	**Reference numbers (Table IV)**
Fuel storage	Delivery station	Petrol	6
	Car station	Petrol and LPG	7
	Intermediate depot	Petrol	6
		LPG	7, 9
	Main storage	Oil	1, 3
		Petrol	4, 6
		LPG	7, 9,10,11
		Natural gas	10, 11
	Gas cylinder storage	Various gases	13
Processing and storage of fuel	Refinery	LPG propane	7, 9
	Alkylation process	Hydrogen fluoride	31
	Naphtha cracker	Butylene	7, 9
		Ethylene	12
		Ethylene oxide	30
		Propylene	7, 9
		Vinyl chloride	7, 9
Transport of fuel	Pipeline	LPG, propane	8
		Natural gas	12
		Petrol	5
		Oil	2
	Water (inland waterways)	LPG (by pressure)	9
		LPG (by cooling)	11
		Petrol	6
		Oil	3
	Rail/road	LPG	7
		Petrol	6
		Oil	4
Extensive cooling installation	Abattoir, dairy, brewery, margarine, ice-cream, chocolate industries, storage of meat, fish, fruit, flowers, ice rink	Ammonia	31
Food and stimulants	Sugar industry	Sulphur dioxide	31
	Flour industry	Methyl bromide	32
	Extraction of oils/fats	Hexane	1, 3

Activity		Most important substances	Reference numbers (Table IV)
	Yeast factory, spirit distillery	Flammable liquids	4, 6
	Cocoa industry	Hexane	1, 3
Specific basic products	Leather industry	Acroleine acids	18, 21
	Wood industry	Formaldehyde	32
	Paper industry	Ethylene oxide	30
		Epichlorohydrine	16, 17
	Rubber industry	Styrene	4, 6
		Acrylonitrile	18, 21
	Textile auxiliaries	Ethylene oxide	30
		Formaldehyde	32
		Alkyl phenols	
Metallurgical, electronic	Blast furnaces	Carbon monoxide	31
		Ammonia	
			31
industries	Surface treatment	Arsine	34
Specific Chemicals	Fertilizers	Ammonia	31, 36
		Combustion products	43
	Sulphuric acid	Sulphur oxides	45
	Synthetic resins	Ethylene oxides	30
		Chlorine	32
		Acrylonitrile	18, 21
		Phosgene	33
		Formaldehyde	32
	Plastics/synthetics	Vinyl chloride	7, 9
		Acrylonitrile	18, 21
		Chlorine	32
		Combustion products	46
	Paints/pigments	Phosphene	33
		Solvents	4, 6
		Combustion products	46
	Chloro-fluorocarbons (CFCs)	Hydrogen chloride	40, 42
		Chlorine	32
		Hydrogen fluoride	31
	Chlorine	Chlorine	32, 37
	Vinyl chloride	Chlorine	32
		Vinyl chloride	7, 9
		Hydrogen chloride	40, 42
	Ammonia	Ammonia	31, 36
	Hydrogen chloride	Hydrogen chloride	40, 42
		Chlorine	32
	Fibres	Carbon disulphide	18
		Hydrogen sulphide	32
	Drugs/pharmaceuticals	Chlorine	32
		Solvents	4, 6
	Polymerization	Butylene	7, 9
		Ethylene	12
		Propane	7, 9
		Vinyl acetate	1, 3
	Synthetic fibre	Methanol	1, 3
	Chlor alkali	Chlorine	32
		Hydrogen	12
Pesticides	Raw material production	Phosgene	33
		Isocyanates	26, 29
		Chlorine	32

Activity		**Most important substances**	**Reference numbers (Table IV)**
		Combustion products	43
	Formulation and storage	Combustion products	43
	Retail and storage	Combustion products	43
		Methyl bromide	32
Explosives	Production and storage	Various	14
	Storage of ammunition	Various	14, 15
Public places and utilities	Waterworks	Chlorine	32
	Storage of pesticides	Combustion products	43

IAEA Table III: Not used in this guideline

IAEA Table IV(a): Classification of Substances by Effect Categories

Ref. No.	Type of substance	Description of substance	Activity	Quantity (t)								
				0.2-1	1-5	5-10	10-50	50-200	200-1000	1000-5000	5000-10000	>10000
1	Flammable liquid	Vapour pressure <0.3 bar at 20℃	Storage with tank pit	-	-	-	-		AI	BI	BI	CI
2			Pipeline	-	_	-	-	-	-	-	-	-
3			Other	-	-	-	AI	BI	CI	DII	X	X
4		Vapour Pressure 0.3 bar at 20℃	Storage with tank pit	-	-	-	-	-	BI	CII	CII	DII
6			Other	-	-	-	BII	CII	DII	E II	X	X
7	Flammable gas	Liquefied by pressure	Rail, road, overground storage	-	AI	BI	C I	D I	E I	X	X	X
9			Other	-	BII	CIII	CIII	DIII	E III	X	X	X
10		Liquefied by cooling	Storage with tank pit	-	-	-	-	-	BI	CII	CII	DII
11			Other		-	-	BII	CII	DII	E II	X	X
13		Under pressure > 25 bar: high toxicity	Storage of cylinders (25-100kg)	-	-	CIII	CII	CI	CI	X	X	X
14	Explosive	In bulk (causing single explosion)		AI	BI	BI	CI	CI	DI	X	X	X
15		In packages (e.g. shells)		BIII	BIII	CIII	CI	CI	DI	X	X	X
16	Toxic liquid	Low toxicity	Storage with tank pit	-	-	-	-		A II	A II	B II	C III
17			Other	-	-	-	A III	A II	B II	C II	C II	C II
18		Medium toxicity	Storage with tank pit	-	-	-	A III	B III	D III	E III	F III	F III
21			Other	-	BII	C III	D III	E III	F III	F III	X	X
22		High toxicity	Storage with tank pit	-	-	A II	B III	C III	E III	F III	G III	G III
25			Other	BII	CII	D III	E III	F III	F III	G III	X	X
26		Very high toxicity	Storage with tank pit	AII	BII	C III	E III	F III	G III	G III	H III	H III
29			Other	CIII	DIII	E III	F III	G III	H III	H III	X	X
30	Toxic gas	Liquefied by pressure: low toxicity		AII	BII	B II	CIII	C II	DIII	D III	D III	E III
31		medium toxicity		BII	CII	C II	DIII	E III	F III	F III	G III	H III
32		high toxicity		CII	DIII	E III	E III	F III	G III	G III	X	X
33		very high toxicity		DIII	EIII	F III	G III	G III	H III	.	X	X
34		extreme toxicity		EIII	FIII	G III	H III	H III	X	X	X	X
35		Liquefied by cooling: low toxicity	In the case of activities on water use 30-34 instead of 35-39	-	-	-	A II	A II	B II	B II	C II	DIII
36		medium toxicity		-	AII	B II	C II	D III	D III	E III	F III	G III
37		high toxicity		BII	CII	D III	E III	E III	F III	F III	G III	H III
38		very high toxicity		DIII	EIII	F III	F III	G III	G III	X	X	X
39		extreme toxicity		EIII	FIII	G III	H III	H III	X	X	X	X

***Note**: For flammable liquids in underground tanks, the quantity should be divided by 5 and the substance treated as 'other' i.e. Refs 3 or 6.*

***Symbols**: 'X' means the combination of that substance and that amount does not usually exist in practice. It is suggested that a full QRA should be carried out in any such case. '-' means that the effects are small enough to be ignored.*

It is then necessary to consider the site layout and the location of the various inventories, and estimate conservatively the maximum amount of hazardous substances from each activity which could be released in an accident.

As a convention (and a modification of the IAEA method) the Department suggests that for underground storage of flammable liquids, the quantity be divided by 5 and the substance treated as 'other'. This is consistent with the screening approach set out in section A1.1.2 for Class .3 dangerous goods.

If a facility has effective physical isolation and separation between the storage vessels of a particular substance, then the quantity used in estimating the effect of an incident would typically be the content of the largest storage vessel.

A1.2.4 Estimation of Consequences

Consequences of an accident depend on the type of substance and activity and the quantity involved, as well as the exposed population.

After excluding those substances or activities which neither present a significant off-site risk potential (using, for example, the screening method outlined in section A1.1) nor could potentially affect adjacent inventories, the following steps should be undertaken for each activity:

Classify the Activity Using IAEA Table IV(a)

The substances in the table are subdivided by:

- the type of physical harm (flammability, explosibility and toxicity)
- the general physical and chemical characteristics
- the type of activity.

The substances can then be classified according to the maximum quantity likely to be involved in an accident.

Where a substance can cause more than one type of effect (for example it may be both explosive and toxic), the evaluation should be separately carried out for each type of effect.

IAEA Table V shows how the effect categories are defined. The letters (A-H) are related to maximum likely effect distances, while the Roman numerals (I-III) relate to effect areas, which vary depending on the type of accident. Explosion effect areas are typically circular (Category I), while toxic releases often cover an area that corresponds to a sector of a circle (Category III). Category II represents a semicircular effect zone, such as may be produced by evaporation from a large pool.

IAEA Table V: Effect Categories: Maximum Distance and Area of Effect (*A*)

Effect distance (m)		Effect area category (ha)		
Category	**Max. Distance (m)**	**I**	**II**	**III**
A	0-25	0.2	0.1	0.02
B	25-50	0.8	0:4	0.1
C	50-100	3	1.5	0.3
D	100-200	12	6	1
E	200-500	80	40	8
F	500-1000	-	-	30
G	1000-3000	-	-	300
H	3000-10 000	-	-	1000

Estimate the Effect Distance and Area

The first stage of the estimation is to use the classification determined from IAEA Table IV(a) to look up the distance and area in IAEA Table V. This is then subjected to correction to take into account the fraction of the effect area which is actually populated, as described in the next section.

Estimate the Population Distribution

The population distribution within the circular area, whose radius is the maximum distance of effect, should first be estimated. If the value is not known, an estimation of the population density can be made using IAEA Table VI, on the basis of a generic description of the area. This needs to be used with some care in Australian conditions where the population distribution patterns may differ significantly from those assumed in the original method. If only part of the effect area is populated, the population figures should be corrected on the basis of IAEA Table VII.

IAEA Table VI: Population Density (d)

Description of the area	Density (persons/ha)
Farmland, scattered houses	5
Individual dwellings	10
Village, quiet residential area	20
Residential area	40
Busy residential area	80
Urban area, shopping centres, centre of city	160

IAEA Table VII: Population Correction Factor (f_A)

Effect area	Populated fraction (%) of circular area				
Category	100%	50%	20%	10%	5%
I	1	0.6	0.2	0.1	0.05
II	1	1	0.4	0.2	0.1
III	1	1	1	1	1

Consider Mitigation Correction Factors

IAEA Table VIII provides a correction factor for mitigation, which takes into account possible mitigatory actions that people could take, such as evacuation and sheltering. These actions are highly dependent on the type of accident and the substance involved.

Small values for toxic substances take into account:

- the time a person needs to be exposed before the effect is lethal
- the time required for dispersion over long distances
- warnings from odour, etc

IAEA Table VIII: Correction Factor for Mitigation (f_m)

Substances (reference numbers)	Factor
Flammables (1-12)	1
Flammables (13)	0.1
Explosives (14, 15)	1
Toxic liquid (16-29, 43-46)	0.05
Toxic gas (30-34, 37-39, 40-42)	0.1
Toxic gas (35-36)	0.05

Estimate the External Consequences

The method uses a formula which takes into account:

- the affected area (A)
- the population density (d) in the populated areas within the affected zone
- the correction factor (f_A) for the distribution of population in the affected zone.
- the correction factor (f_m) for mitigation effects.

The external consequences $C_{a,s}$ are given by the formula:

$$C_{a,s} = A \bullet d \bullet f_A \bullet f_m$$

where subscript *s* represents a particular hazardous substance and *a* is the activity.

In the case of categories II and III it may be possible to count the maximum number of people N in the effect area, considering the shape of the area and the worst case wind direction. In this case, the external consequences are given by the formula:

$$C_{a,s} = N \bullet f_m$$

Repeat the Above Steps for each Activity and Substance

Where a number of substances are associated with a given activity, they can be grouped and treated as a single (equivalent) substance, provided their effects are similar.

If a flammable substance is also toxic, both effects have to be accounted for.

Calculation Example

The following example of the calculation is taken from the IAEA manual

Description

A storage of petrol contains 2000 tonnes. It is provided with a bund. A village could be affected by a major accident; its population density is about 20 persons/ha. The minimum distance of the village from the storage is 30 m. The village extends beyond the distance of 100m from the storage. The village occupies 20 percent of the area within 100 m from the storage.

Estimation

The checklist indicates bunded petrol storage is reference number 4.

From IAEA Table IV(a), 2000 tonne is effect category C II.

From IAEA Table V, the maximum effect distance is 100 m and the affected area is 1.5 ha.

Since there is only rough information about the village, generic correction factors are used:

From IAEA Table VI, population density in the village is 20 persons/ha.

From IAEA Table VII, the correction factor for the distribution of population is 0.4.

From IAEA Table VIII, the correction factor for mitigation is 1.

This yields an overall estimate of:

1.5 (ha) • 20 (persons/ha) • 0.4 • 1 = 12 fatalities.

A1.2.5 Estimation of Probabilities of Major Accidents

The method used for estimating probability is based on probability numbers related to the type of installation and substance involved, together with correction factors for:

- the frequency of loading/unloading operations (n_l)
- safety systems associated with flammable substances (n_f)
- organisational and management safety (n_o)
- wind direction towards the populated area (n_p).

The probability number is given by the formula:

$$N_{i,s} = N^*_{i,s} \bullet n_l \bullet n_f \bullet n_o \bullet n_p$$

Where $N^*_{i,s}$ is the average probability number for the installation and the substance. The relationship between the probability number N and the frequency value P is given by the formula:

$$N = | \log_{10} P |$$

The procedural steps for each activity are as follows:

Select the Average Probability Number

For each hazardous substance, or group of hazardous substances, the average probability number is selected using IAEA Table IX.

IAEA Table IX: Average Probability Number ($N^*_{i,s}$)

Substances	**Activity**	
(reference numbers)	**Storage**	**Plant**
Flammable liquid (1-3)	8	7
Flammable liquid (4-6)	7	6
Flammable gas (7)	6	5
Flammable gas (9)	7	6
Flammable gas (10,11)	6	-
Flammable gas (13)	4	-
Explosive (14,15)	7	6
Toxic liquid (16-29)	5	4
Toxic gas (30-34)	6	5
Toxic gas (35-39)	6	-
Toxic gas (42)	5	4
Combustion products (43-46)	3	-

The various probability number correction factors are then taken from IAEA Table X to IAEA Table XIII inclusive.

IAEA Table X(a): Probability Number Correction Parameter (n_l) For Loading/Unloading Operations Frequency

Frequency of loading/ unloading (per year)	**Parameter**
1-10	+0.5
10-50	0
50-200	-1
200-500	-1.5
500-2000	-2

Note *that this does not apply to cylinders (Ref No 13)*

IAEA Table XI: Probability Number Correction Parameter (n_f) for Flammables

Substance	**Safety measures**	**Factor**
Flammable gas (7, 13)	Sprinkler system	+0.5
Flammable gas (10)	Double containment	+1
Flammable gas (13)	Fire wall	+1
	Sprinkler system	+0.5
	5-50 stored cylinders	+1
	50-500 stored cylinders	0
	>500 stored cylinders	-1

IAEA Table XII: Probability Number Correction Parameter (n_o) for Organisational Safety

Above average industry practice	+0.5
Average industry practice	0
Below average industry practice	-0.5
Poor industry practice	-1
Non-existent safety practices	-1.5

Note: *Several factors are included: safety management, age of the plant, maintenance, documentation and procedures, safety culture, training, emergency planning etc.*

In the case of organisational and management safety, it would usually be considered inappropriate to make a positive correction unless superior systems had been clearly demonstrated by, for example, an audit of the safety management systems. This would only apply to existing plants or to new plants established by an operator with a strong track record.

IAEA Table XIII: Probability Number Correction Parameter (n_p) for Wind Direction Towards Populated Area(s) in the Affected Zone

Effect area category	**Part of the area (%) where people are living**				
	100%	**50%**	**20%**	**10%**	**5%**
I	0	0	0	0	0
II	0	0.5	0.5	0.5	0.5
III	0	0.5	0.5	1	1.5

Having calculated an adjusted probability number N, this is converted to a frequency of occurrence by means of IAEA Table XIV.

IAEA Table XIV: Conversion of Probability Numbers (N) Into Frequencies (P, event/year)

N	***P***	***N***	***P***	***N***	***P***
0	1×10^{0}	5	1×10^{-5}	10	1×10^{-10}
0.5	1×10^{-1}	5.5	1×10^{-6}	10.5	1×10^{-11}
1	1×10^{-1}	6	1×10^{-6}	11	1×10^{-11}
1.5	1×10^{-2}	6.5	1×10^{-7}	11.5	1×10^{-12}
2	1×10^{-2}	7	1×10^{-7}	12	1×10^{-12}
2.5	1×10^{-3}	7.5	1×10^{-8}	12.5	1×10^{-13}
3	1×10^{-3}	8	1×10^{-8}	13	1×10^{-13}
3.5	1×10^{-4}	8.5	1×10^{-9}	13.5	1×10^{-14}
4	1×10^{-4}	9	1×10^{-9}	14	1×10^{-14}
4.5	1×10^{-5}	9.5	1×10^{-10}	14.5	1×10^{-15}

Note: N is the abs of the logarithm of $P(N = | \log_{10} P |)$

Repeat the Preceding Steps

The steps are repeated until all activities and substances have been covered.

Calculation Example

The following example is drawn from the IAEA manual.

Description

A storage of 1700 cylinders, each weighing 40 kg and containing propane and butane has a fire protection wall and a sprinkler system. The minimum distance between the storage and the populated area is 10m. The populated area occupies about 15 percent of the circular area between 10 m and 100 m from the storage.

Estimation

From the check list and IAEA Table IV(a), storage of flammable gas is reference number 13.

From IAEA Table IV(a) and IAEA Table V, the total mass of gas is 68 tonne. Effect category is C I (effect distance 100 m; effect area 3 ha).

From IAEA Table IX, the standard probability number is 4.

From IAEA Table IX, correction parameters are:

fire protection wall (+1)
sprinkler system (+0.5)
more than 500 stored cylinders (-1).

The overall correction parameter is +0.5.

From IAEA Table XII, the probability correction for management is assumed to be -0.5.

From IAEA Table XIII, the correction for distribution of population within the area is 0.

From IAEA Table XIV, the frequency of occurrence is 4 + 0.5 - 0.5 + 0 = 4 which corresponds to one accident in every 10,000 years.

Estimation of Societal Risk

At this stage, pairs of numbers have been calculated for each activity, comprising the number of fatalities per accident and the expected frequency of the accident.

These are grouped into consequence and probability classes. For each consequence class, frequencies for all events in that class are summed and the result transferred to a plot of frequency versus consequence. This yields a direct estimate of societal risk that can be used in the final prioritisation stage. The steps are:

Classify each Activity

Each activity is classified using a scale of consequence classes and a scale of probability classes.

The consequence classes are (fatalities per accident):

0-25
26-50
51-100
101-250
251-500
>500.

Adjacent probability classes differ by one order of magnitude of the number of accidents per year.

Group and Tabulate the Results

If an activity presents risks from different substances which can cause accidents independently of each other, it is necessary to sum the risks from substances which have the same consequences class.

All classified activities can then be converted to a plot of frequency versus consequence for risk prioritisation. This is shown in the following example, adapted from the IAEA manual.

Example

An area has been analysed using the above methodology. Two activities have been identified to present a risk to the public: an LPG storage tank and the processing of four different hazardous substances (identified by the symbols S1, S2, S3, and S4).

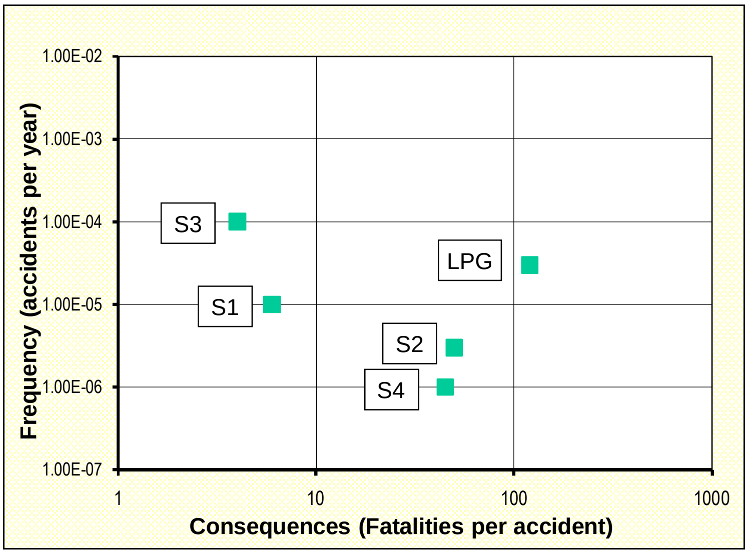
The calculated consequence/frequency pairs (C = fatalities/ accident and P = yearly frequency of that accident) are shown in Table A1.1.

Table A1.1: Consequence and Frequency Pair Example

Scenario	C, fatalities/ accident	P, accidents/ year
LPG storage	120	3 x 10^{-5}
Processing Si	6	1 x 10^{-5}
Processing 52	50	3 x 10^{-6}
Processing 53	4	1 x 10^{-4}
Processing S4	45	1 x 10^{-6}

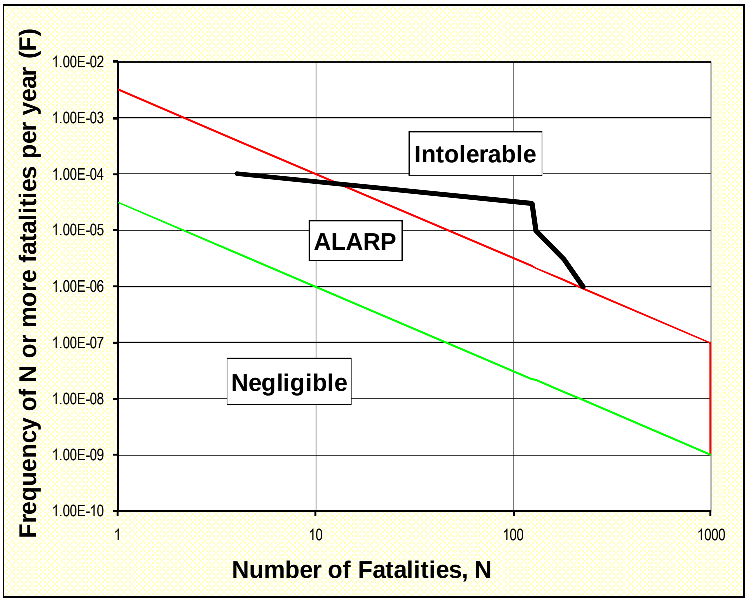
The pairs may be plotted, as shown in Figure A1.2, to highlight the main risk contributors. This is a useful guide in screening out minor contributors when partial quantification is being used.

Figure A1.2: IAEA Risk Plot Example



The cumulative results can also be plotted, in the form of an F-N curve. This gives an overall picture of the risk, as shown in the example in Figure A1.3, which also shows the indicative criteria shown in Figure 6 in the body of the guidelines.

Figure A1.3: IAEA F-N Curve Example



Rank and Prioritise the Results

The prioritisation step is carried out in two parts. The first is the setting of criteria, and the second is the identification of all elements which do not meet those criteria.

While the criteria may be thought of in terms of establishing levels of acceptable risk, this is an over-simplification. The criteria should be set at a conservative level that will ensure that only minor contributors are excluded from more detailed study. The objective is not to pass judgement on the overall acceptability of the risk at this stage, but rather to direct the priority of further work.

No firm criteria are suggested in the IAEA method, but as a general rule, it is noted that activities with risks of relatively high consequences usually warrant further study, even when the probabilities are relatively low. It is usually reasonable to place less emphasis on low consequence activities, even when frequencies are higher, since there is less potential for major harm,

If, as a result of the criteria that have been initially set, there is no clear differentiation of the results, it may be necessary to consider modifying the criteria to allow priorities to be identified more readily.

The IAEA manual suggests a number of options for approaching acceptability criteria for societal risk. However, the general approach used in these guidelines is that shown above in Figure A1.3, because it is consistent with the typical presentation of societal risk results from a detailed QRA.

A1.2.6 Calculation of Individual Risk

Although the IAEA method, as presented in its manual, focuses on societal risk, it is possible to generate individual fatality risk estimates using the area of effect and the frequencies of each event, since the method assumes that fatalities will always occur inside the effect area.

While imprecise, using an individual risk approach facilitates comparison with established individual risk criteria and provides further guidance as to degree of quantification required in the overall risk analysis. For example, if the IAEA method clearly indicates a small number of dominant risk contributors, a limited (level 2) analysis concentrating on those contributors may suffice, rather than a fully detailed (level 3) quantified risk analysis.

A1.2.7 Evaluation of Alternatives

The risk assessment process often involves the evaluation of alternatives in terms of:

- plant or equipment siting
- choice of technology
- risk reduction measures.

Detailed analysis and assessment of all alternatives may be impractical and may not be warranted, particularly in the early stages of evaluation.

The multi-level approach outlined in these guidelines can be used to advantage in such cases. For example, the risk classification and prioritisation method can be used to quickly evaluate alternatives. A simple case, comparing two LPG installations of similar capacity is illustrated below in Table A1.2 and Table A1.3. The only difference between the two is that one installation uses above ground tanks and the other uses buried or mounded tanks.

Table A1.2: Classification and Consequences (LPG)

	Above ground	**Below ground**
Activity reference no.	7	9
Inventory	1000 t	1000 t
Classification	E I	E III
Effect category	500 m, 80 ha	500 m, 8 ha
Correction factor	1	underground
Population density (residential)	40 / ha	40 / ha
Population correction (50 percent populated fraction)	0.5	1
External consequences (fatalities)	1600	320

Table A1.3: Frequency Determination (LPG - Fixed Equipment Only)

	A	**B**
	Above ground	**Below ground**
$N_{i,s}$ ave probability	6	7
n_l load/unloading operations	-1.0 200 trucks/yr	-1.0 200 trucks/yr
n_f flammables safety system factor	+0.5	0
n_o organisational safety factor	0.5 above average	0.5 above average
n_p wind factor	0 50% Cat I	0.5 50% Cat III
$N_{i,s}$ calculation	6	7
Frequency of occurrence	10^{-6} p.a.	10^{-7} p.a.

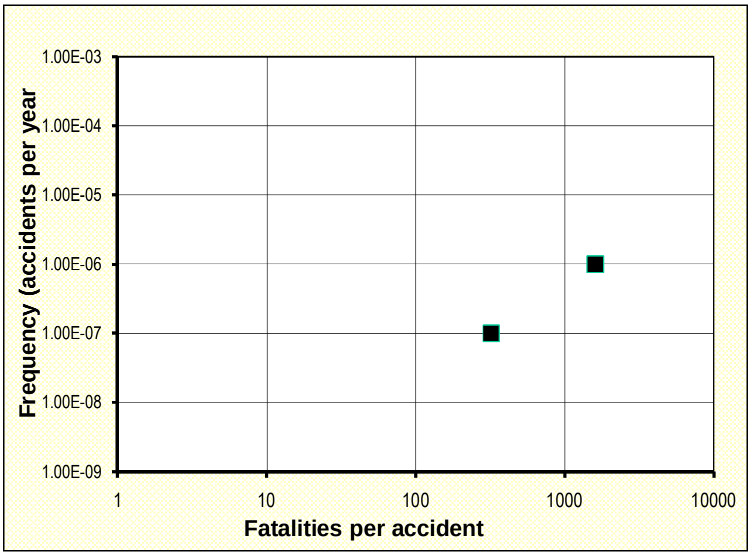
The frequency and consequence pairs for the two LPG installations are compared in Figure A1.4.

The example shows that the above ground storage of LPG poses a significantly higher risk than the below ground installation. Other alternatives which could be evaluated might include:

- a site with lower population density

- a reduced inventory
- the use of refrigerated storage.

Figure A1.4: Risk Comparison of LPG Storage Methods



A1.3 Techniques of Analysis

A1.3.1 Application Principles

The methodologies of hazard analysis and risk assessment are clearly described in *HIPAP No 6 - Hazard Analysis*. Consequently, this section concentrates on the main principles only, working through the procedural steps of the analysis.

The whole of section A1.3 applies to a full QRA (level 3). The simplifying modifications which apply in the case of a qualitative (level 1) or partially quantitative (level 2) analysis are described in the following paragraphs.

Level 1 - Qualitative Analysis

The hazard identification step should be completed as detailed in section A1.3.2. Whatever other methods of hazard identification are employed, construction of a hazard identification summary diagram, similar to the example in Table A1.4, is a valuable basis for systematically identifying possible failures, their consequences and the prevention and protection measures.

The failure scenarios and their consequences should be carefully scrutinised to ensure that all incidents with possible off-site consequences are identified. In those cases for which off-site consequences could be significant, the adequacy of proposed prevention and protection measures should be considered. In cases of uncertainty about consequences or the efficacy of protective measures, consequence effect distances should be calculated to determine whether or not some risk quantification should be carried out.

In the absence of quantification, a qualitative analysis should still include a thorough consideration of relevant qualitative criteria, together with a discussion and evaluation of risk reduction and management measures.

Level 2 - Partially Quantitative Analysis

Partial quantification is undertaken when risk classification and prioritisation indicates that off-site risks may be significant but are likely to be well within the quantitative criteria outlined in section 4.2 in the body of the guidelines. The purpose of partial quantification is to carry out a more detailed examination of the consequences and likelihood of those events which could contribute to off-site risk, in order to clearly demonstrate that quantitative risk criteria will not be exceeded.

Partial quantification utilises the techniques of consequence and likelihood estimation outlined in section A1.3.3 to examine significant failure scenarios identified as part of the qualitative analysis, and to refine the approximate results of the classification and prioritisation stage.

In addition to including all elements of the qualitative analysis, partial quantification should include:

- modelling of the consequences of all events for which hazard identification, screening, or classification and prioritisation indicate there could be credible effects beyond the site boundary
- estimation of the likelihood of each event which detailed modelling confirms would have significant off-site consequences
- an assessment of the results of the preceding estimation steps, which confirms that the overall effect of all events considered would not cause risk criteria to be exceeded.

It should be noted that these steps do not necessarily require formal calculation of risk contours. The analysis only needs to be taken far enough to conservatively demonstrate that there are no combinations of likelihood and consequences that could lead to risk criteria being exceeded. For example, the analysis could show that there are no events with significant off-site consequences, or that any off-site consequences occur at such a low frequency that the risk could be regarded as negligible.

The study should be documented in a way that will satisfy the evaluation principles of sections 2.4 and 4.2.2 in the body of the guidelines, in terms of demonstrating that: the analysis has been carried out at an appropriate level; the methods used have been technically sound; and the results have been systematically and adequately assessed.

A1.3.2 Hazard Identification

Hazard identification is a key step in the process of hazard analysis since incomplete identification of hazards could lead to invalid conclusions, no matter how sophisticated the risk estimation techniques are. The process of hazard identification looks at the facility being studied and attempts to systematically identify all significant hazards. Natural hazards and those arising from other nearby sites are considered, in addition to those which are inherent in the facility.

The identification process should incorporate:

- an appraisal of the plant and process design and construction standards, including site surveys of all process plants, feedstock and inventory; the operating parameters used; the specific safeguards built in the design; and availability of emergency equipment to control or mitigate impacts from chemical incidents
- an appraisal of safety management systems including evaluation of training and performance of staff
- a study of relevant incidents that have occurred
- an assessment of hazards that could be initiated due to neighbouring activities such as existing plant, nearby airports, public highways.

There is no comprehensive single method of hazard identification. Some of the more structured techniques for the identification of hazards include hazard and operability studies (HAZOPs), failure modes and effect analysis (FMEA), fault tree analysis and event tree analysis. These techniques are described in *HIPAP No. 6 - Hazard Analysis* and *HIPAP No. 8 - Hazard and Operability Studies*. Sample event and fault trees are given in section A1.3.2 of this appendix. The more specialised techniques are generally of greater value during the final hazard analysis stage. For example, at the approval or pre-design stage, there is usually insufficient detailed information available for a HAZOP.

One useful way of presenting hazard identification results is by use of a hazard identification summary diagram, as illustrated in Table A1.4. In a relatively simple study, the analyst should include a comprehensive list of cases. However, for a more complex case, only those events which may be significant contributors to risk need to be included. Such a screening process requires a good appreciation of the likely magnitude of the risks of each event, prior to undertaking the detailed analysis.

Consequence Estimation

In a QRA, consequence calculations are carried out on each of the scenarios developed in the hazard identification stage. The most common incidents with off-site effects are explosions, fires and toxic releases. A number of mathematical models have been developed to estimate the consequences of such events and their effects. These include:

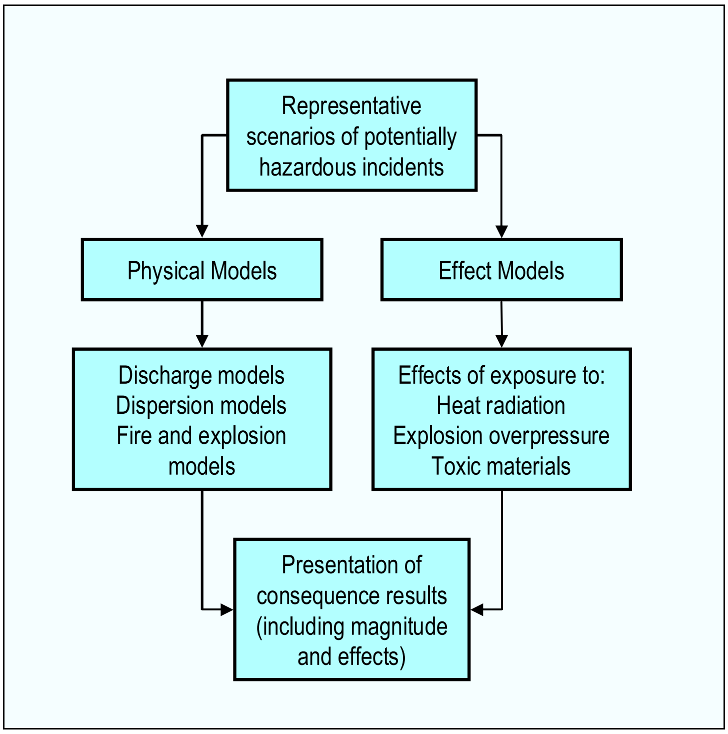
- discharge models (loss of containment)
- dispersion models (flammable and toxic gas releases)
- consequence models (the effect on people, property and the environment as a result of the incident); models cover various types of fires, explosions and toxic effects.

As an example, the various stages involved in the evaluation of consequences from the release of a hazardous materials are illustrated in Figure A1.5.

Table A1.4: Typical Hazard Identification Summary Diagram

System studied and item description	Failure mode identified	Possible consequence	Prevention/protection measures
Tanks containing flammable liquids	• Tank roof collapse • Ignition during maintenance • Lightning • Ignition by static electricity	• Tank fire or rim fire • Possible escalation to other tanks or bund fire • Explosion of vapours in tanks • Pollution via fire fighting water	• Regular maintenance • Foam injection systems • External water cooling systems • Flame arresters on vents • Earthing straps • Control of ignition sources • Adequate pigging prior to maintenance • Adequate bunding
Bunds containing flammable liquids tanks	• Leak from tank or pipeworks • Tank overfill	• Pool fire or full bund fire • Possible propagation to other tanks/bunds • Ground contamination • Possible evolution of toxic fumes • Watercourse pollution via bund drainage system • Pollution via fire fighting water	• Regular inspection and maintenance of tanks and Pipeworks • Loss detection systems • High level alarms/overfill protection • Remote isolation systems • Foam monitors • Water cooling of tanks • Control of ignition sources • Adequate bunding • Impermeable bund floors/walls • Separator pits
Rail or road tanker loading bays for flammable liquids	• Tanker overfill • Flexible hose failure • Driver uncouples hose before isolating • Driver fails to disconnect before driving off • Collision	• Spillage of fuel with pool fire if ignited • Possible propagation to involve entire tanker contents or other tankers • Ground contamination • Watercourse pollution via drainage system • Pollution via fire fighting water	• Tanker overfill protection • Regular inspection/maintenance of hoses • Drive away protection through brake interlocks or boom gates • Control of ignition sources • Remote isolation systems • Adequate bunding/drainage systems • Foam monitors/deluges • Adequate emergency egress routes

Figure A1.5: Typical Consequence Evaluation



The use of physical models involves considering release and discharge rates of hazardous materials, estimating dispersion of hazardous gases and vapours, modelling fires such as pool, jet and flash fires and fireballs. Explosion impacts may be estimated from vapour cloud explosions, failure of vessels under pressure and condensed phase explosions such as from TNT, RDX, ammonium nitrate and a variety of organic peroxides. Consideration may also be given to incident propagation from high momentum projectiles.

Physical models provide information on the dispersion of airborne flammable or toxic materials, the creation of thermal radiation from fires, the production of overpressures from explosions and the propagation of accidents due to generation of projectiles. However, they do not convert the physical consequence of a hazardous incident into information relating to the effect those consequences have upon people, property and the environment.

Effects models estimate the degree of harm to people, property and the biophysical environment arising out from the physical effects. Simple models may select a particular consequence level to represent a particular outcome (e.g. a heat radiation level of 12.6 kW/m^2 to represent death). While this approach is easy to understand, it is limited in that it does not take into account the effects of very short or very long exposures or the varying susceptibility of people to exposure. To overcome this, more sophisticated techniques, such as probit equations can be adopted. These allow the prediction of the outcome to be adjusted for the exposure conditions.

Consequence Modelling Programs

Because of the complexity of many calculations, computer software packages have been developed and are widely used for consequence analysis.

In using any of these packages, it is important that they not be used simply as a ‘black box’. The analyst needs to understand the underlying methodologies and their limitations. A model should not be used outside of the range for which validation against actual field data has been carried out. Extreme caution needs to be taken in using any software if the extent of validation is not clearly understood and recognised.

Likelihood Estimation

Risk requires consideration of how often an event will occur as well as the magnitude of the consequences. A number of sources of information may be used in making such an estimate. It is important to note that data used should, as far as possible, relate directly to the process under study. Generic data should not be used without an understanding of their source and relevance to the study in hand.

Two types of information usually need to be considered when estimating the likelihood of particular outcomes of hazardous incidents. The first is the likelihood of the initiating event. The second is the probability of the initiating event developing by means of the various event sequences identified in the earlier stages of the analysis.

Sources of Failure Data

The likelihood of potentially hazardous incidents arising out of identified hazards may be determined from generic or specific historical plant failure data, or by using an analytical technique such as fault tree analysis.

Failure data are usually presented in one of two forms, depending on the nature of the equipment and the way it is used. For equipment in continuous use, they are usually expressed as failures per unit time (e.g. failures per million hours). Systems or components which are not normally in use, but which are required to operate infrequently (e.g. protective systems may have their failure rates expressed as probability of failure upon demand. In order to predict such probabilities, a knowledge of testing and maintenance schedules is essential.

Generic failure data are those which have been collected from a wide range of sources representing many item-years of operation. Generic data can give a good first estimate of the likelihood of failure. Specific plant failure data derived from an organisation's or industry's own records would usually be preferable to generic data, provided that the item population and time period of data collection are sufficiently large to be statistically significant.

In cases where plant specific data are not available, it may be appropriate to modify the best data available in order to reflect the operational and organisational practices of the company concerned. The analyst may have to use a degree of judgement in these cases, although more formal techniques are available to assess a company's overall safety performance and may be appropriate in some circumstances. Any adjustment of generic data should be conservative and its basis carefully documented.

Initiating event likelihood might be estimated directly through the consideration of historical failure data. If these are unavailable, the likelihood may need to be derived through the consideration of the failure of sub-components, using logic models such as fault trees or event trees. The latter approach allows for the consideration of:

- specific operating conditions
- organisational factors
- preventative maintenance programs
- operator capabilities
- manual/automatic intervention systems
- other technical, organisational and operational safety controls.

The likelihood of each of the identified final outcomes may be quantified by combining the initiating event likelihood with the various probabilities associated with each branching of the event tree. If event tree probabilities cannot be estimated directly, fault trees may be used to derive an estimate through analysis of sub-system failures.

For example, to estimate the likelihood of a release of flammable material, the analyst may start with an estimate of the likelihood of loss of coolant to a reactor, which may lead to a runaway exothermic reaction. The likelihood of release would then depend on such factors as:

- the probability that safety interlocks fail to shut down the reactor
- the probability of failure of emergency protection systems
- the probability that the operator fails to appropriately intervene.

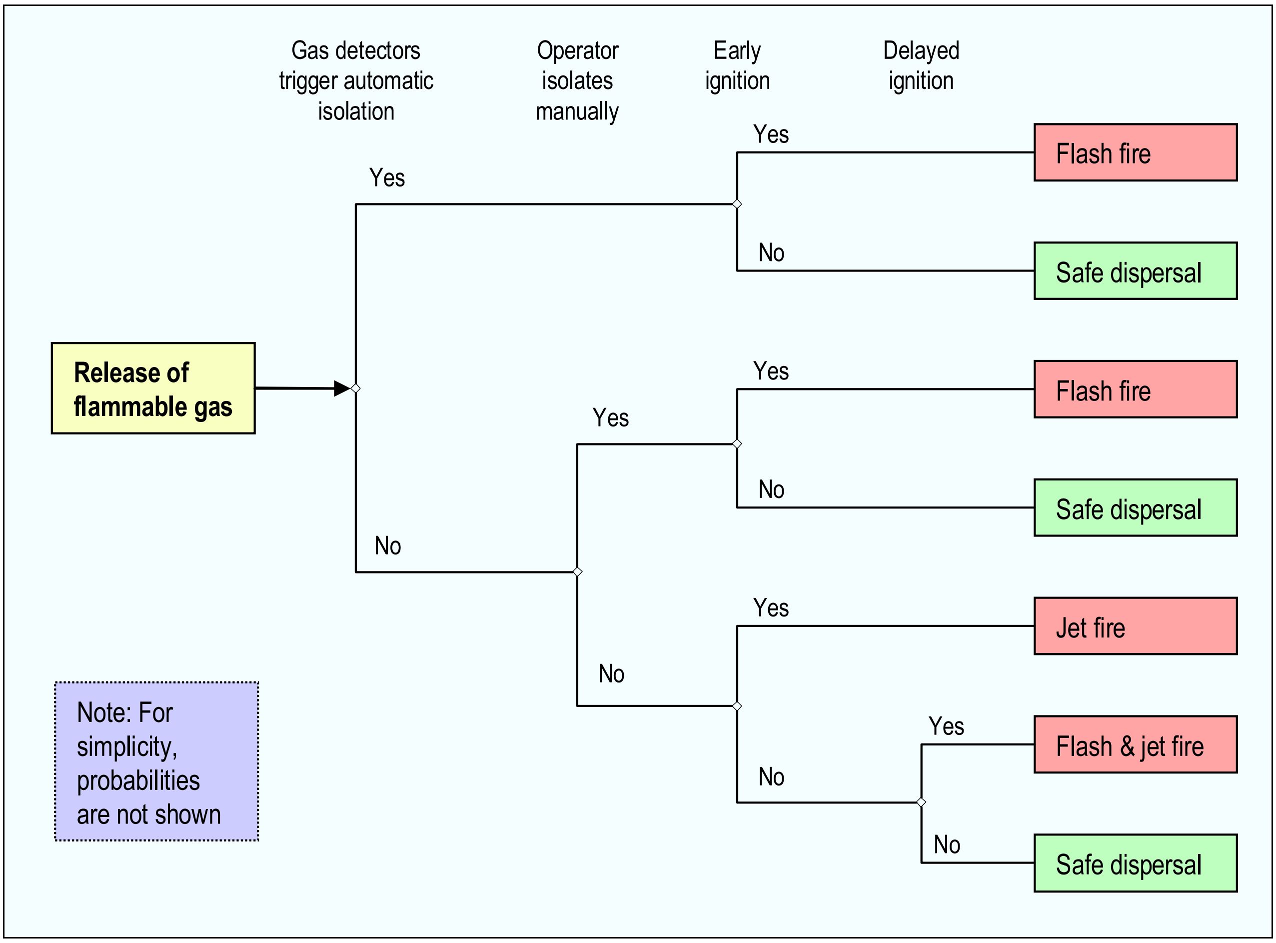
Subsequent to the release, other factors which may need to be considered in estimating the likelihood of the various outcomes are the relative likelihood of various meteorological conditions, ignition probabilities for releases in various directions, and the probability of ignition, leading to explosion or flash fire.

Event Trees

An event tree starts with a single initiating event and the subsequent event sequence possibilities are represented by branching of the trees, leading to a number of possible final outcomes.

A likelihood can be established for the initiating event. Any point in the tree can be characterised by a particular consequence and an associated likelihood. Hence, event trees are important for both consequence and frequency analysis. To obtain likelihoods within the tree, conditional probabilities need to be determined wherever branching occurs. These probabilities may be available directly, or they may to be estimated using an analytical method such as a fault tree. A typical simple event tree structure is shown in Figure A1.6.

Figure A1.6: Example Event Tree



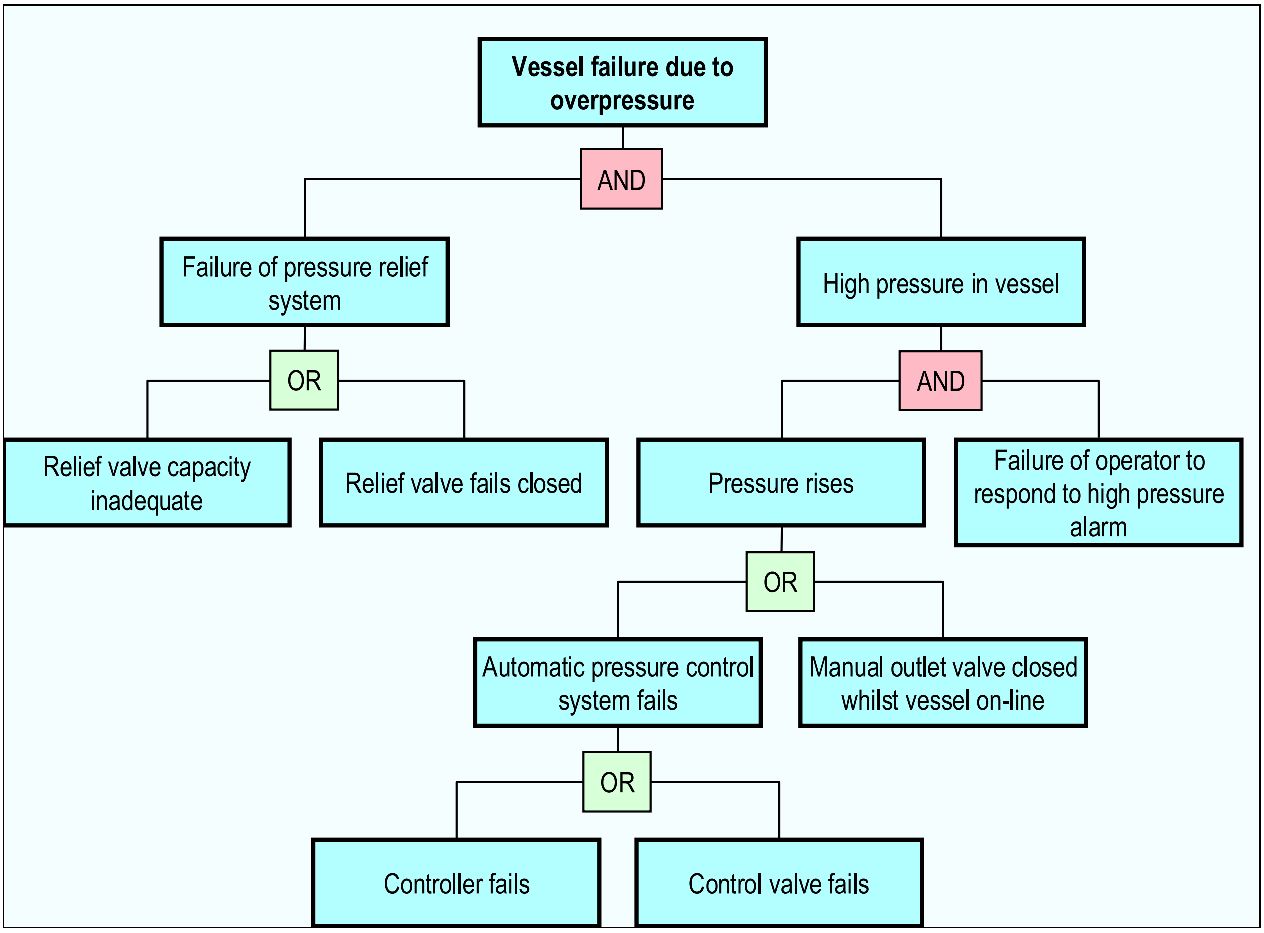
Fault Trees

One of the most commonly used logic models for the estimation of the likelihood of hazardous incident scenarios is fault tree analysis.

Fault trees use logic similar to that of event tree analysis. However, the starting point is the final event of interest and the analyst works backwards in order to identify the sequences of events required to produce that final event. The technique is useful both for the quantification of likelihood and as a method for identifying the event sequences and causal factors which could lead to a hazardous incident.

Fault trees are typically used when the failure likelihood of a particular system is required and no specific failure data are available directly. The failure modes can be broken down into combinations of failures of smaller components for which failure data are available. Hence, the system failure likelihood can be estimated using a fault tree approach as shown in Figure A1.7.

Figure A1.7: Example Fault Tree



Other Data Requirements

Other data which may be required for the development of risk results are as follows:

- meteorological data, such as the probabilities of the occurrence of particular wind and weather conditions
- natural event data, such as the likelihood of flooding, earthquakes and cyclones
- external events data, such as the likelihood of aircraft impact or events on neighbouring sites

- susceptibility data, for example, if a probit approach is used to estimate fatality probability given a particular dose
- population presence data, if societal risk calculations are to be undertaken.

Much of these data are specific to the location of the facility and can be obtained from local sources.

A1.3.3 Risk Estimation

Risk may be defined as the likelihood of any defined adverse outcome. It may be expressed in terms of death or injury to people or damage to property or the environment.

In some cases, such as human fatality risk from fire and explosion, the risk from each event can be identified at any point in the affected area. For each point in the area affected, the risk from each final like outcome (e.g. fatality, injury, irritation) can be calculated and, by summation, the total risk at each point can be determined. Hence, the distribution of risk around the facility can be calculated.

Similarly, the total risk at a particular location due to a number of facilities can be estimated by a summation of the risks from each individual facility. If the population in the affected areas is combined with the likelihood and consequence information for particular points, estimations of societal risk can also be made.

For other cases, the defined adverse outcome could be a toxic concentration, a system failure or an impact on an ecosystem or species. Where a number of events contribute to the same outcome, summation is possible. For any facility or activity, however, there may be a number of risks which need to be analysed, understood and managed.

Throughout the hazard analysis process, it is necessary for the analyst to be aware of the uncertainties involved in each of the calculation steps. At the risk estimation stage it should be possible to estimate the uncertainty in the final results and to understand the sensitivity of the results to various critical assumptions.

In discussing the tolerability of a particular risk, the analysis should consider:

- qualitative and quantitative risk criteria
- the likely future development of surrounding land uses
- cumulative effects from existing, developments
- the vulnerability of people and the surrounding environment
- local conditions
- benefits of the activity or development being studied.

The presentation and evaluation of risk results is as described in section 0 and section 4 in the body of the guidelines.

Appendix 2

Worked Example

A2.1 Introduction

This example demonstrates the use of the multilevel risk assessment method as set out in the body of the guidelines. It should be emphasised that the example is a hypothetical one, designed to illustrate the techniques, and should not be considered to be representative of a particular situation. There has been no verification of the storage conditions or distances against relevant standards or regulations, and none of the following sketches is shown to scale.

While the example is contrived, in that the storage and handling operations described may not occur in practice precisely as described, it demonstrates the benefits of the multi-level approach as well as some of the strengths and weaknesses of the various techniques.

A2.2 Facility Description

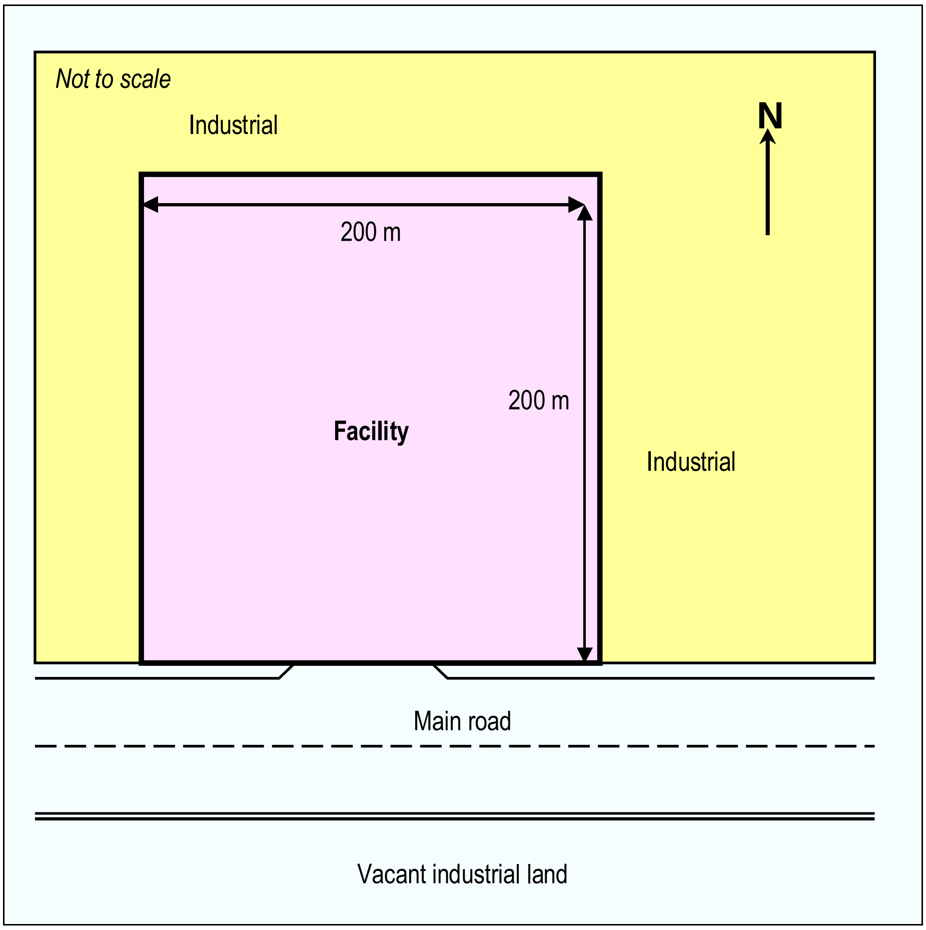
An existing motor vehicle fleet depot is being assessed. The vehicles are both petrol- and LPG-fuelled and there are fuel storage and dispensing facilities on site. Maximum quantities of fuel held on site are as shown in Table A2.1.

Table A2.1: Site Inventory

Material	Quantity on Site	Storage Mode
LPG	2 x 16 kL (16 te)	two above ground liquefied under pressure bullets
Petrol	1 x 50 kL tank (45 te)	above ground bunded tank

The site is located in an industrial area as indicated in Figure A2.1.

Figure A2.1: Site Location

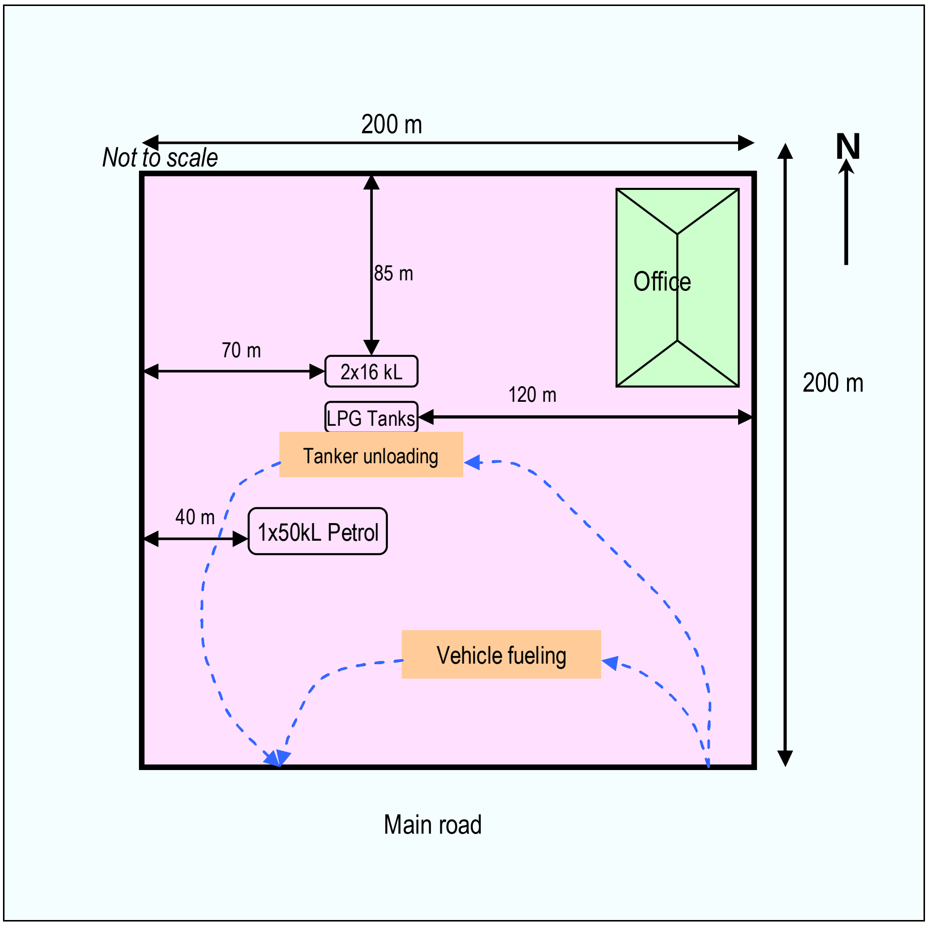


The site is surrounded on three sides by an industrial area. Land to the south is currently vacant but zoned industrial. The industrial population averages 15 people per hectare.

The site stores LPG in two interconnected 16 kL above ground bullets and petrol in one 50 kL above ground bunded tank. These are used for fuel dispensing. The LPG is transported to the site in 16 kL road tankers which unload at the road tanker loading bay into the bullets. The petrol is delivered in 20 kL tankers. Dispensing of fuel is carried out remotely from the tanks. There are 100 fuel deliveries to the site each year (50:50 LPG:Petrol) and 10,000 fuel dispensing operations (60:40 LPG:Petrol). Dispensers have automatic shut-off in the event of a line break and there are also emergency remote shut-off buttons around the site that will isolate the filling lines at the tanks. There are firewalls between the storage tanks and the dispenser area. Bulk tanker unloading is carried out away from the dispensing area

The site layout is shown in Figure A2.2.

Figure A2.2: Site Layout



A2.3 Preliminary Screening

The first step of the assessment is a screening step to determine whether or not there could be significant off-site consequences. The method used is described in section A1.1.

Information is gathered about the location of dangerous goods stored or handled on site. The information about the site is collated and grouped by dangerous goods class, activity and location as shown in Table A2.2.

Table A2.2: Summary of Materials Held on Site

Material	Quantity on site	Method of storage	Dangerous goods classification	Min distance to plant boundary
LPG	2 x 16 kL (16 te)	Bulk tank, above ground	2.1	65
Petrol	1 x 50 kL (45 te)	Bulk tank, above ground	3PGI	40

The next step is to select the screening method for the materials as shown in Table A2.3.

Table A2.3: Screening Method to be Used

Material	Quantity	Classification	SEPP 33 Table 1 refers to
LPG (bulk)	32 m^3	2.1	SEPP 33 Table 3
Petrol {bulk)	50 m^3	3PG1	SEPP 33 Figure 8

It is now necessary to compare the quantity stored with the screening threshold to determine the need for further analysis. For the quantity of LPG stored on site, SEPP 33 Table 2 is to be used for screening. The threshold screening quantity for LPG above ground storage is 16m^3. The site's 32 m^3 exceeds the screening threshold so that further analysis is required. From SEPP 33 Figure 8, 50 m^3 of petrol would require a separation distance from the boundary of approximately 20 metres in order to be considered not potentially hazardous. The actual distance to the boundary is 40 metres, so that the product in isolation would not be expected to pose a significant off-site risk. Since, however, the quantity of LPG is above the screening threshold and the LPG and petrol storages are within 20 metres of each other, both products are carried forward to the classification and prioritisation stage.

A2.4 Risk Classification and Prioritisation

The initial part of the procedure is aimed at identifying the external consequences $C_{a,s}$ using the following equation:

$$C_{a,s} = A \, . \, d \, . \, f_A \bullet f_m$$

Where A = affected area

d = population density in populated areas within the affected zone = 15 people/ hectare

f_A = area correction factor for the distribution of population in the affected zone

f = correction factor for mitigation effects.

The site contains 2 x 16 kL (16 te) LPG bullets. It is necessary to consider the inventory of hazardous substances and the layout of the facility and conservatively estimate the maximum amount that could realistically be involved in an accident. For this example, it is assumed that both bullets could be involved since they are interconnected.

Each substance is allocated a reference number and a corresponding Effect Category using IAEA Table IV(a).

The bulk LPG is above ground storage liquefied under pressure corresponding to Reference Number 7. Reference Number 6 (bulk above ground bunded storage) applies to the petrol.

The next step is to use IAEA Table V to obtain the maximum effect distance and area of effect. All distances and areas are expressed in terms of fatal effects.

Table A2.4: Incident Inventory Classification

Material	Site inventory (tonnes)	Reference no. From IAEA Table IV(a)	Effect category from IAEA Table V
LPG (bulk)	16 tonne	7	CI
Petrol (bulk)	45 tonne	6	BII

IAEA Table IAEA Table V is now used to obtain the maximum effect distance and area of effect, using the effect category determined above. This estimates the area that will be affected by an accident. Results are shown in Table A2.3.

Table A2.5: Effect Distance and Area of Effect

Material	Effect category from IAEA, Table IV(a)	Effect area (ha) from IAEA Table V	Maximum distance from IAEA Table V
LPG (bulk)	CI	3	50-100
Petrol (bulk)	BII	0.4	25-50

The effect area and maximum diameter for accidents involving each substance are determined. This step calculates the populated areas that will be affected by an accident. The effect area for each of the substances is determined, as is the maximum distance. The plant layout indicates that the plant is surrounded on three sides by an industrial estate, a minimum of 40 m from the petrol storage tank and 65 m from the LPG tanks. Table A2.5 indicates that both substances could have off-site effects, conservatively assuming that the maximum effect distances apply.

The next step is to estimate the population distribution around the site. For this example, the population density is taken from recent census and council data. The surrounding industrial estate has a population density of 15 people per hectare. The area factor for each of the exposed areas, f_A, is then calculated to estimate the fraction of the exposed area that actually lies off-site.

Using geometry the following values are obtained for f_A:

for the bulk LPG storage, $f_A = 0.21$
for the bulk petrol storage, $f_A = 0.1$.

After calculating the affected population, the next step is to estimate the effects of mitigation, using IAEA Table VIII. For bulk LPG and petrol the mitigation correction factor f_m applied is 1.

The external consequences of the accident can now be calculated, using the equation given above. Results are summarised in Table A2.6.

Table A2.6: External Consequences

Material	Consequences (fatalities/ accident)
Bulk LPG storage	$C_{a,s} = 3 \times 15 \times 0.21 \times 1 = 9.5$
Bulk petrol storage	$C_{a,s} = 0.4 \times 15 \times 0.1 \times 1 = 0.6$

The frequency of occurrence of an accident is now estimated, using an average probability number for the installation and substance, and then correcting this for safety systems, organisational and management safety and wind direction towards the populated area. The following equations are used to calculate the frequency:

$$N_{i,s} = N^*_{i,s} \bullet n_l \bullet n_f \bullet n_o \bullet n_p$$

$$N = | \log_{10} P |$$

Using IAEA Table IX the average probability number is determined for each of the materials on-site. The general nature of the site is a storage establishment so all numbers are taken from the storage column. The bulk LPG is assigned a value of 6 for $N^*_{i,s}$, and the petrol is assigned a value of 7.

A correction factor for loading and unloading operation frequencies is then assigned. As previously indicated, there are 50 bulk LPG and 50 petrol tanker unloading operations per year. Therefore a parameter of -1 is applied for n_l. Because dispensing is carried out in small quantities, with good emergency shutdown mechanisms and segregation by means of firewalls, no probability correction number has been applied to allow for the dispensing operations.

The data collected on the site layout and design indicates that the bulk LPG storage will have a sprinkler system. The calculation of the probability correction factor for flammables for the bulk LPG storage is therefore 0.5.

The organisational safety correction factor is typically the hardest to assign to a proposed facility. For this example, the company is known to be generally well established and managed but there is insufficient information to justify applying other than the industry average factor of 0.

The populated area surrounding the plant is industrial. While the published IAEA risk classification and prioritisation method concentrates on residential populations, in assessing the risk in this case, we are concerned with all population external to the site. The probability correction factor for wind direction towards people in the affected zone is taken from IAEA Table XIII. For the bulk LPG storage, the factor is 0, as the effect category is I. For the petrol storage, effect category II, the percentage of off-site people affected is conservatively assumed to be greater that 50 percent and therefore a value of 0 is also used.

Combining the base probability numbers and correction factors, overall probability numbers are shown in Table A2.7.

Table A2.7: Probability Number

Material	Probability Number
Bulk LPG storage	$N_{i,s}$ = 6 -1 + 0.5 + 0 + 0 = 5.5
Bulk petrol storage	$N_{i,s}$ = 7 -1 + 0 + 0 + 0 = 6.0

The conversion of probability number to frequency is carried out, using IAEA Table XIV.

Table A2.8: Frequency (Event/Year)

Material	Frequency (events/year)
Bulk LPG storage	$N_{i,s}$ = 5.5 = 3 x 10^{-6}
Bulk petrol storage	$N_{i,s}$ = 6.0 = 1 x 10^{-6}

From this ranking, the following results are obtained:

LPG (bulk storage): C_{LPG} = 9.5 fatalities/accident

C_{LPG} = 3 x 10^{-6} accidents/year

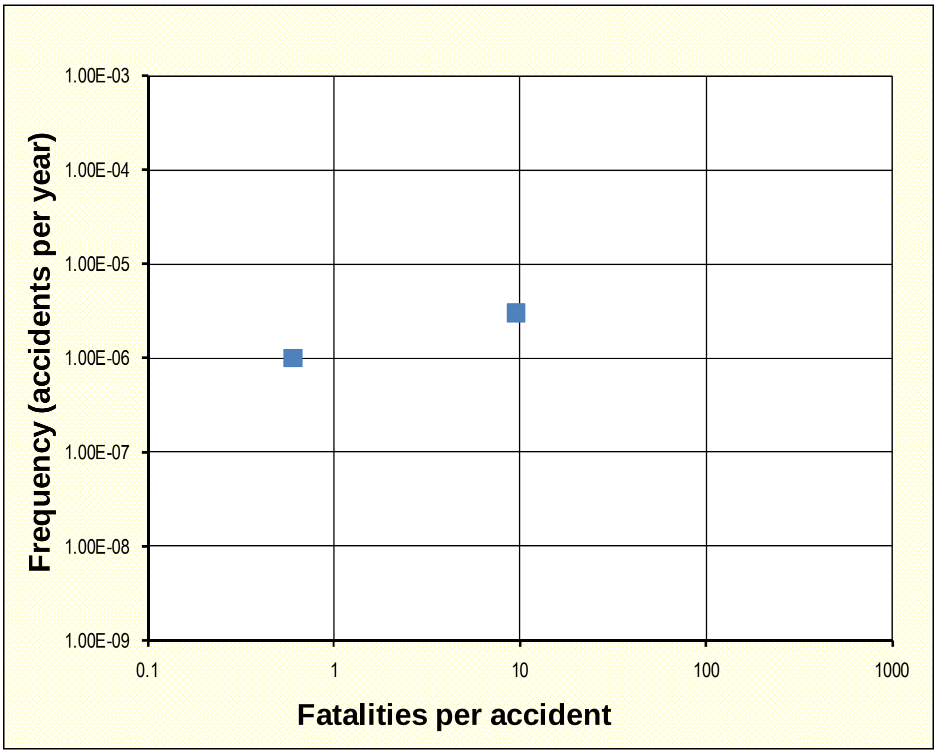
Petrol (bulk storage): C_{PETROL} = 0.6 fatalities/accident

C_{PETROL} = 1 x 10^{-6} accidents/year

The final step of the calculations at this level is the plotting of the results and the estimation of societal risk. As seen above, a pair of numbers has been calculated for each of the activities on the site with off-site impacts comprising the number of fatalities per accident and the expected frequency of the accident.

The frequency/consequence pairs are plotted in Figure A2.3.

Figure A2.3: Frequency/Consequence Pairs



Individual risk estimates can also be generated, as shown in Figure A2.4. This demonstrates how the risk classification and prioritisation method can be extended to indicative individual fatality risk, as described in the body of the guidelines.

Societal risk results are shown in Figure A2.5 in the form of an F-N curve, together with the indicative criteria shown in the body of the guidelines, for comparison.

Figure A2.4: Indicative Individual Risk Contours (Risk Classification and Prioritisation)

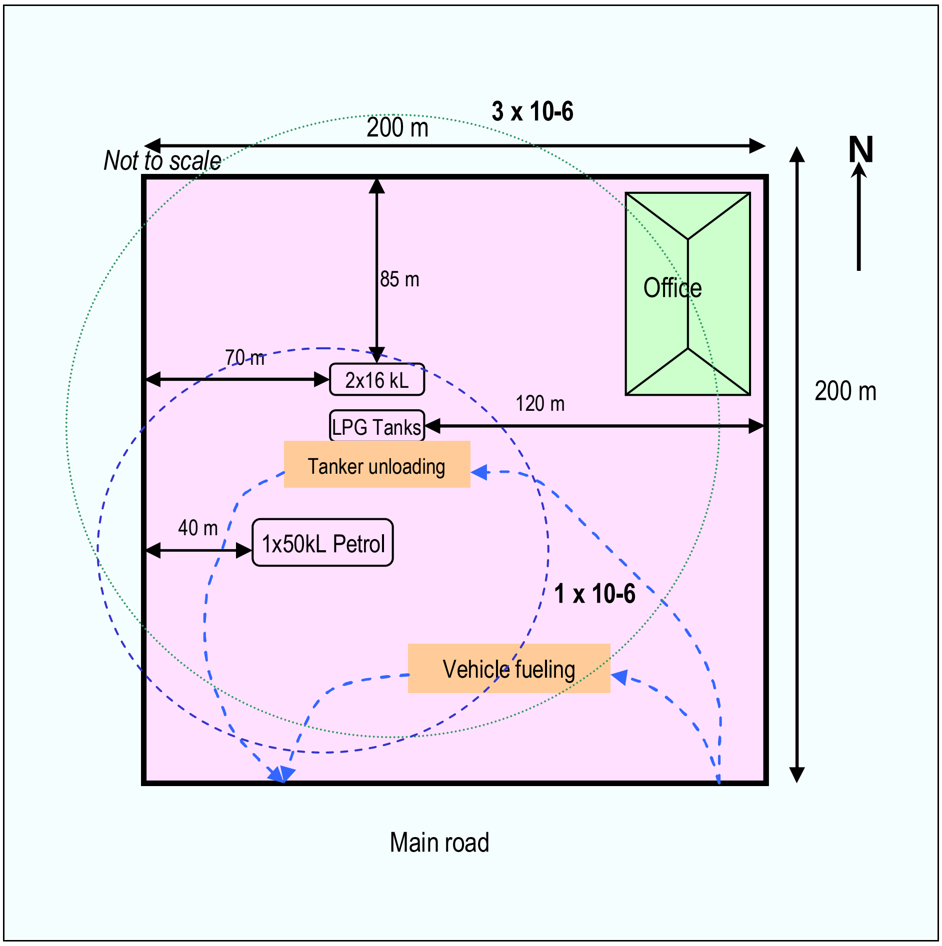
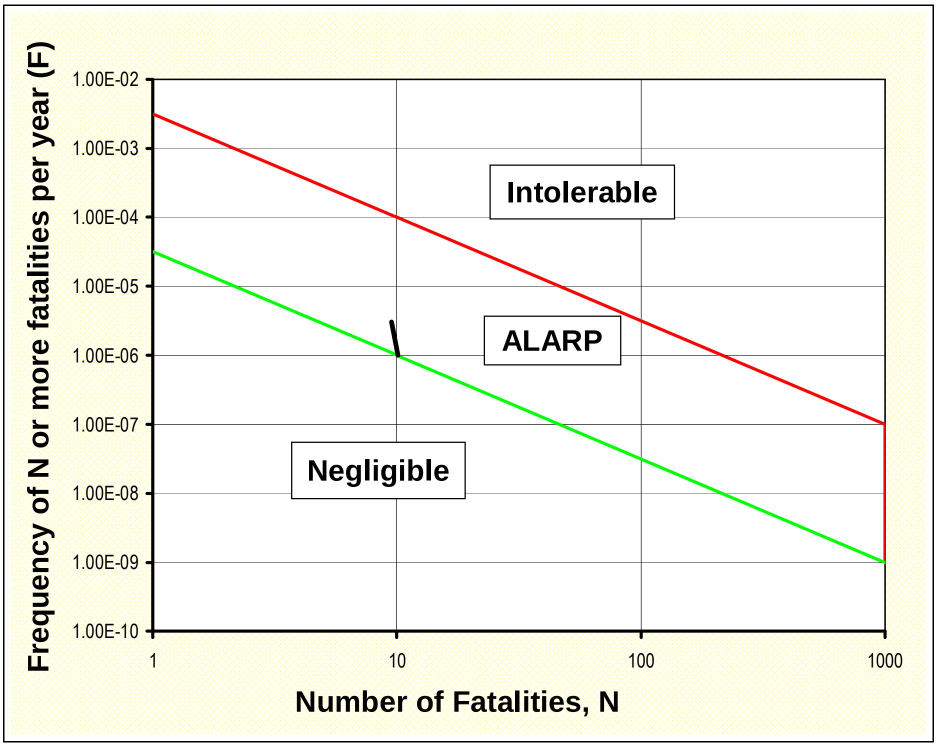


Figure A2.5: Societal Risk (Risk Classification and Prioritisation)



A2.5 Level Of Assessment

Having completed the classification and prioritisation stage, it is now necessary to consider the appropriate level of assessment, using the criteria set out in section 2.4 in the body of the guidelines.

In order for a level 1 (qualitative) analysis to be sufficient, all points on the indicative societal risk curve produced from the risk classification and prioritisation should be below the negligible line. Additionally, there should be no events with off-site consequences with a frequency of greater than 1 x 10^{-7}. Neither condition is satisfied, making it necessary to carry out a further level of analysis.

A level 2 analysis (partial quantification) is appropriate where screening, hazard identification or risk classification and prioritisation has identified one or more significant risk contributors, but where the likelihood of an event with significant off-site consequences is relatively low. This appears to be the case with this facility, given the comparatively low societal risk. As a minimum, quantification should be carried out on any component of the risk classification and prioritisation which has off-site consequences at a frequency of greater than 1 x 10^{-7} per year, as well as any credible scenarios with off-site consequences found during hazard identification (see Table A1.4). This involves

- modelling the consequences of all events for which hazard identification, screening or classification and prioritisation indicate could have credible effects beyond the site boundary
- estimating the likelihood of each event which detailed modelling confirms would have significant off-site consequences
- analysing the results of the preceding estimation steps, which confirm that the overall effect of all events considered would not cause risk criteria to be exceeded.

It should be noted that these steps do not require formal calculation of risk contours. The analysis only needs to be taken far enough to conservatively demonstrate that there are no combinations of likelihood or consequences which could lead to risk criteria being exceeded.

A2.6 Risk Analysis

The analysis is carried out in accordance with the principles set out in section A1.3.1 In the interests of brevity, this example outlines the analysis of the main scenarios only. Further, it does not include any of the detailed information concerning the location, process or hazardous materials on site.

The technique is illustrated by including a section of the hazard identification word diagram and the results of the consequence and frequency analysis for the major scenarios.

A2.6.1 Hazard Identification

The identified hazards are summarised in Table A2.9. It should be emphasised that the table is by no means comprehensive and includes only sufficient information to demonstrate the use of the multi-level risk assessment method. A fuller analysis would examine the dispensing area also, to confirm that this would not have an off-site impact.

Table A2.9: Hazard Identification Word Diagram

Event	Cause	Consequence	Mitigating factors
LPG			
Catastrophic failure or leak from vessel	• Corrosion • Mechanical damage • External fire	• May disperse if no ignition source • Possible BLEVE, vapour cloud explosion, flash fire or ground fire	• Design of vessel to AS1596 • Control of ignition sources • Crash barriers to protect vessel • Water sprays
Failure or leak from piping	• Corrosion • Mechanical damage • Weak connections	• May disperse with no ignition • Possible vapour cloud explosion or flash fire • Jet fire at leak source if ignited	• Design of piping to AS1596 • Excess flow valve, non-return valve and remote shutdown to be installed • Control of ignition sources
Rupture or hole in tanker	• Mechanical damage • Fire impingement may cause BLEVE • Pressure relief valve fails	• Possible release of contents of tanker • May disperse without ignition • Jet fire if immediate ignition • Vapour cloud explosion or flash fire if delayed ignition • Possible escalation to BLEVE	• Design to AS1596 • Regular maintenance and inspection of tankers • Driver training • Deluge system on unloading bay • Restrict access to loading bay
Tanker hose rupture or leak	• Mechanical damage • Wear and misuse	• May disperse without ignition • Jet fire if immediate ignition • Vapour cloud explosion or flash fire if delayed ignition • Possible escalation to BLEVE	• Regular maintenance and inspection of hose and fittings • Tanker brakes interlocked to prevent drive away while connected • Flow limited by excess flow valve, nor return valve and remote shutdown where appropriate • Deluge system on unloading bay

Event	Cause	Consequence	Mitigating factors
PETROL			
Petrol tank rupture	• Mechanical damage • Corrosion	• Spill of contents to bund • Possible bund fire or tank fire if ignited	• Design to AS1940 • Regular maintenance and inspection • Fire fighting equipment to be installed • Bund sized for adequate containment • Cathodic protection • Control ignition sources
Tank hole - liquid leak	• Mechanical damage • Pressure relief valve failure • Corrosion	• Release of large quantity to bund • Likely bund fire if ignition source • Possible tank fire	• Design to AS1940 • Regular maintenance and inspection • Fire fighting equipment to be installed • Cathodic protection • Control ignition sources
Pipe rupture or leak	• Mechanical damage • Corrosion	• Release of significant quantity to bund • Likely bund fire if ignition source • Possible tank fire	• Regular maintenance and inspection • Fire fighting equipment to be installed .Cathodic protection • Control ignition sources
Tanker rupture or leak	• Mechanical damage • Traffic accident	• Release of significant quantity from tanker • Fire may result if ignition source present • May disperse without ignition	• Design to AS1940 • Regular testing and maintenance of tanker • Fire fighting equipment to be provided
Tanker hose rupture or leak	• Mechanical damage • Wear and misuse	• Release of significant quantity to environment • Fire may result if ignition source present • May disperse without ignition	• Regular inspection and testing of hose and fittings • Tanker brakes interlocked to prevent drive away while connected • Unloading operations should be in bonded area • Fire fighting equipment to be provided

A2.6.2 Major Consequences

The events of greatest consequence are those which have the potential to release sufficient quantities of LPG or petrol to have off-site consequences. These include:

- catastrophic LPG vessel failure
- catastrophic LPG tanker failure
- LPG pipe 50 mm leak
- petrol tank failure or large leak into the bund, leading to fire

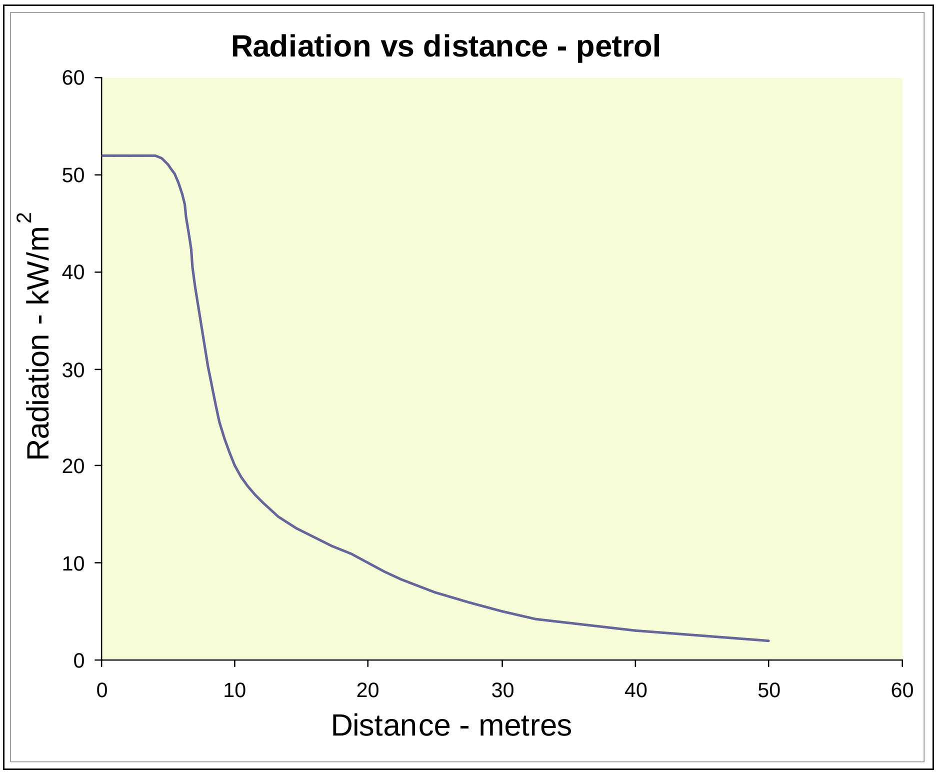
- catastrophic petrol tanker failure.

Selected consequence modelling results for these events, using typical modelling software, are shown and discussed in the following sections.

A2.6.3 Consequence Analysis - Petrol

The petrol is stored in a 50 kL tank as identified in Figure A2.2. The bund around the petrol tank is 600 mm high and approx 11 min diameter. The worst case scenario for the petrol tank would be a full bund fire, the results of which are shown in Figure A2.6.

Figure A2.6: Bund Fire - Petrol Storage



From the figure it can be seen that should there be a fire in the bund of the petrol storage area, 20 m from the LPG tanks, the LPG storage tanks would be subjected to a heat radiation of some 10 kW/m2, not enough to cause damage, particularly given the water spray protection on the LPG tanks. The radiation versus distance graph also shows that a bund fire would also have limited off-site impact as the heat radiation at the site boundary is below 5 kW/m^2.

Therefore a petrol storage accident would not have significant off-site consequences and can be discounted from further analysis.

A2.6.4 Consequence Analysis - LPG Storage

The worst case events from the standpoint of off-site effects are BLEVE and vapour cloud explosion or flash fire.

BLEVE

Although the LPG storage consists of 2 x 16 kL bullets, it is highly unlikely that both tanks would BLEVE simultaneously, so that the inventory of only one tank has been considered. A BLEVE could be caused be flame impingement from the other tank or associated pipeworks. Preliminary calculations of the jet size from a jet fire involving one of the tanks or above ground pipes/valves, indicates that the separation distance between the two vessels is such that there is a possibility of flame impingement from one tank to another.

BLEVE of one tank due to flame impingement from the other is therefore modelled. Assuming the tanks are three quarters full at the time of the incident (a conservative assumption, as the tank is filled once a week), the available inventory would be 6000 kg in each tank. The existence of relief valves on the tank would decrease the inventory of the product further since, while the flame is impinging on the tank, prior to reaching BLEVE conditions, the relief valve will release some of the tank's contents as pressure increases due to the heat. Assuming that one third of the tank's contents is lost through the relief valve and, for the source tank, one third of the contents is also lost in initiating the BLEVE, the quantity available for the BLEVE is 2/3 x 6000 kg = 4000 kg per tank.

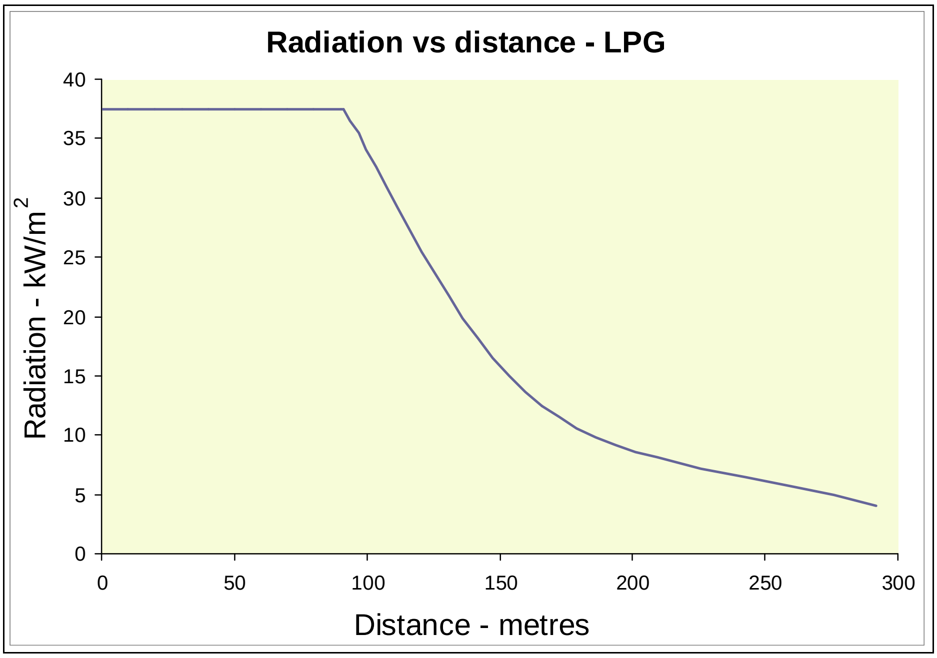
Assuming one tank is involved in the BLEVE, containing 4000 kg, and the following results are obtained. Table A2.10 shows that; should a vessel be involved in a BLEVE, the resulting heat radiation level could be sufficient to cause off-site fatalities.

Table A2.10: BLEVE Effect Distances

Radiation level kW/m2	Effect distance m	Area m2
4	292	267,500
12.5	166	86,600
37.5	91	26,700

Figure A2.7 shows the radiation versus distance for the BLEVE of the LPG tanks. While a BLEVE is a very short-lived occurrence of no more than a few seconds duration, fatality is possible if the heat radiation is high enough. For example, at a heat radiation level of 35 kW/m^2 there is a ‘significant chance of fatality for people exposed instantaneously’ (*HIPAP No 4 - Risk Criteria for Land Use Safety Planning*). HIPAP No 4 also indicates that at levels of 23 kW/m^2, there is a chance of fatality for instantaneous exposure. Both these levels of heat radiation are reached off-site so that there is a need to consider the frequency of the event.

Figure A2.7: Heat Radiation vs Distance - LPG BLEVE



Vapour Cloud Explosion/Flash Fire

Another possible off-site impact would be the release of LPG from one of the vessels and the formation of a vapour cloud. This cloud could ignite soon after forming (early) or drift and ignite after some time (late).

The modelling of these events shows that dispersion effects depend on weather conditions. Distances to the lower flammable limit (LFL) and 1/2 LFL were calculated for various conditions. Table A2.11 indicates the distance from the release these levels were reached.

Table A2.11: Dispersion Distances – LPG Vapour Clouds

Meteorological conditions	Distance to LFL	Distance to 1/1/2 LFL
D1.5 m/s	73m	115 m
D5 m/s	112m	190m
F1.5 m/s	84m	115 m

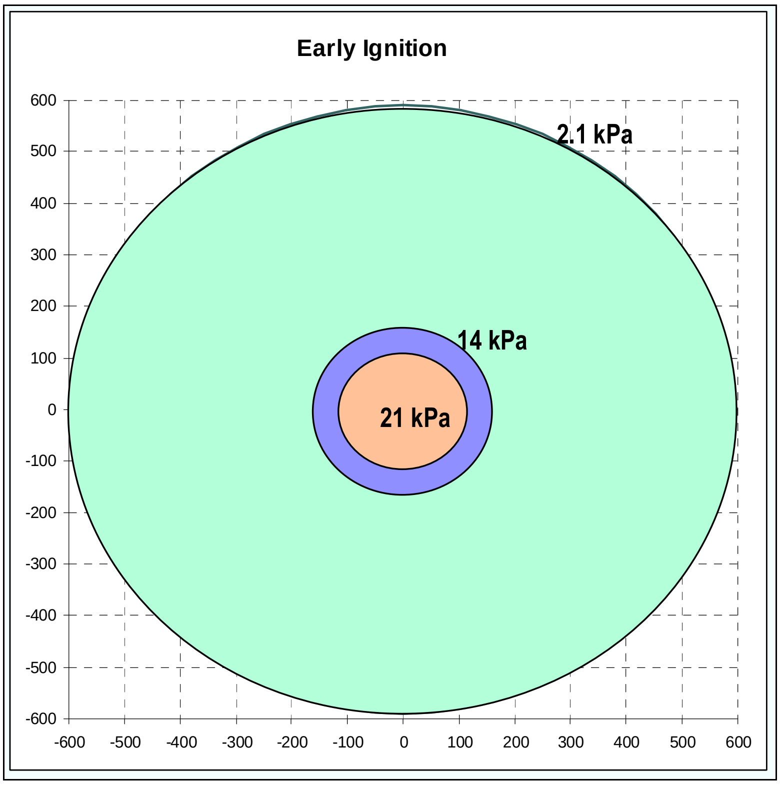
For early ignition of the vapour cloud the cloud was assumed to be ignited at the source of release; for the late ignition clouds, the ignition was conservatively assumed to occur at the distance to 1/2 LFL.

The resulting consequence results for the explosion model are shown in Figure A2.8. Both early and late ignition results were calculated but only the early ignition results are shown. The figure shows the explosion overpressure at various distances (in metres) from the release point.

An explosion overpressure of 14 kPa equates to a house becoming uninhabitable and badly cracked, while 21 kPa can lead to storage tank failure. This would affect the petrol tank. At this level of overpressure, there is also a significant possibility of fatality.

Since potentially fatal or damaging consequences can extend off-site, as with the BLEVE case, it is necessary to consider the frequency of occurrence.

Figure A2.8: Vapour Cloud Explosion Effects



A2.6.5 Other Consequences

For the sake of simplicity, the above modelling results cover only those major storage incidents which could lead to off-site fatality or significant property damage. In practice, LPG tanker unloading incidents as well as injury consequences would also have been considered.

A2.6.6 Event Frequencies

Event frequencies have been generated from a combination of specific failure data and the use of fault and event trees. Full details are not shown in the interests of brevity. The resultant frequencies for the key scenarios for which the consequences were modelled are discussed in this section.

The estimation requires two types of information. The first is the basic equipment failure rates which can lead to an accident and the second is a consideration of the ways in which these basic failures can result in hazardous consequences, taking into account design characteristics, technical and management safeguards and other mitigation measures,

Basic Failure Rates

Some of the key base failure frequencies are shown in Table A2.12. Conservative figures have been used to ensure event frequencies are not underestimated during the partial quantification step

Table A2.12: Base Failure Frequencies

Event	Frequency – per year
LPG vessel cold catastrophic failure	1.2×10^{-7}
25 mm process pipe leaks	1.7×10^{-6} (per m year)
25 mm flange leaks	4.0×10^{-5}

This table is illustrative and does not attempt to be complete. For example, failure rates for equipment such as excess flow valves, transfer hoses and couplings have not been included. Similarly, the actual values are specific to the example and should not be taken to be necessarily representative of figures for an actual installation.

In this case, a cold catastrophic tank failure is sufficiently unlikely to rule it out from detailed consideration. However, leaks from pipes, flanges, fittings and equipment are sufficiently frequent as to require further study, since they could result in events with off-site consequences.

The next step of the assessment is to establish the frequency of those incidents which could have off-site consequences. In this example the logic is shown for the case of BLEVE only.

Event Frequencies

Two success trees[2] were constructed to calculate the reliability of the emergency shutdown (ESD) and deluge systems on the LPG storage facility. These were then used in an event tree to estimate the likelihood of a BLEVE, as discussed below. The success and event trees are shown in Figure A2.9 to Figure A2.11.

The actual numbers, which were conservatively set, have not been included in the examples, which are primarily given to illustrate the techniques used.

These calculated values for the likelihood of successful ESD or deluge operation are used as input to the overall event tree for the release of LPG from the storage tanks. The event tree demonstrates and quantifies the possible outcomes following an initiating event.

---

[2] Success trees are fault trees with reversed logic.

In particular, the tree shows which of the events from one tank can result in a BLEVE of the other tank. By inputting the base frequencies for LPG leaks from the storage tank and associated equipment, the frequencies for each of the release scenarios can be calculated and the frequency of a BLEVE of the neighbouring tank can also be calculated.

In this case, the result of these calculations indicated that the probability of one tank and associated pipeworks causing a BLEVE on the neighbouring tank was about 6 x 10^{-7} p.a. (i.e. 1.2 x 10^{-6} after taking into account the fact that there are two tanks).

The overall results of the likelihood of events leading to fatal off-site consequences are summarised in Table A2.13.

Figure A2.9: Success Tree - ESD Actuation

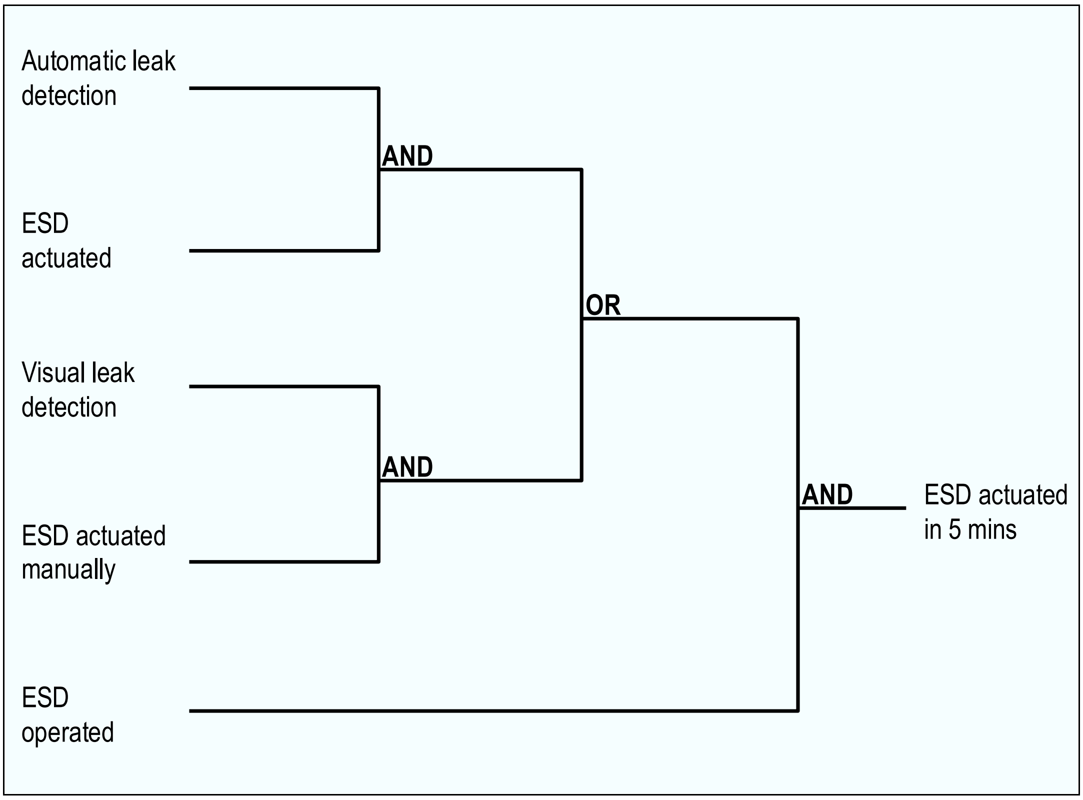


Figure A2.10: Success Tree - Deluge System

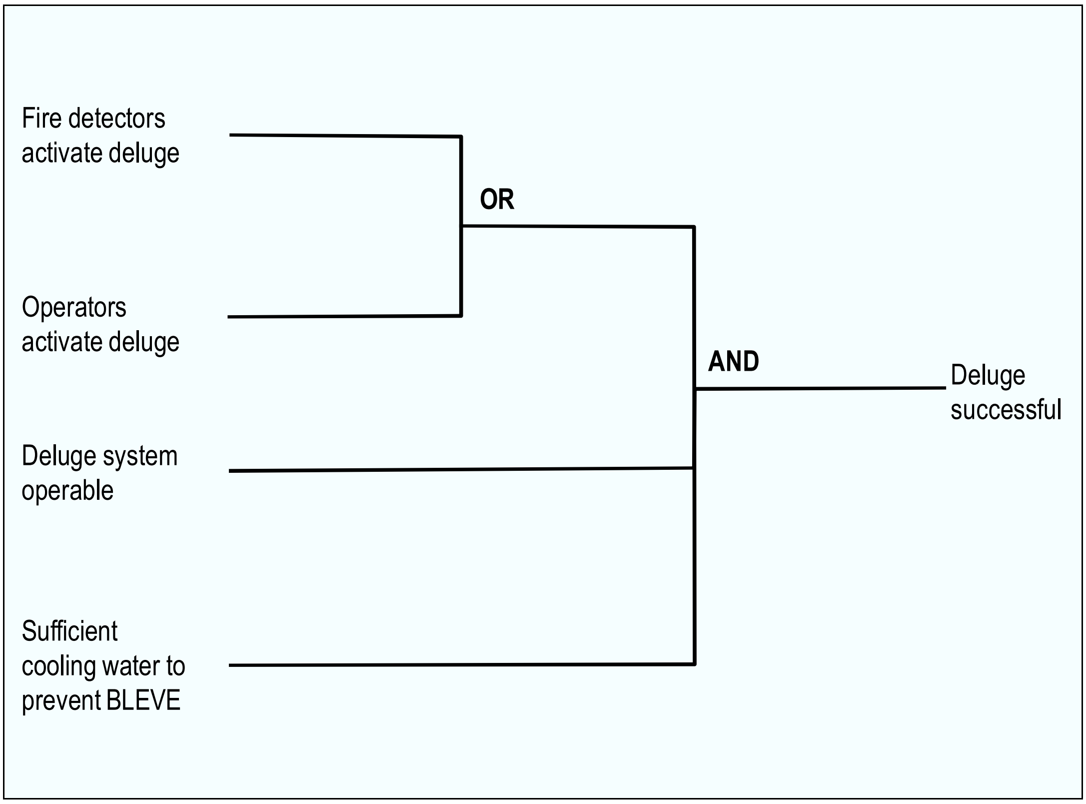


Figure A2.11: Event Tree - LPG Tank Fires

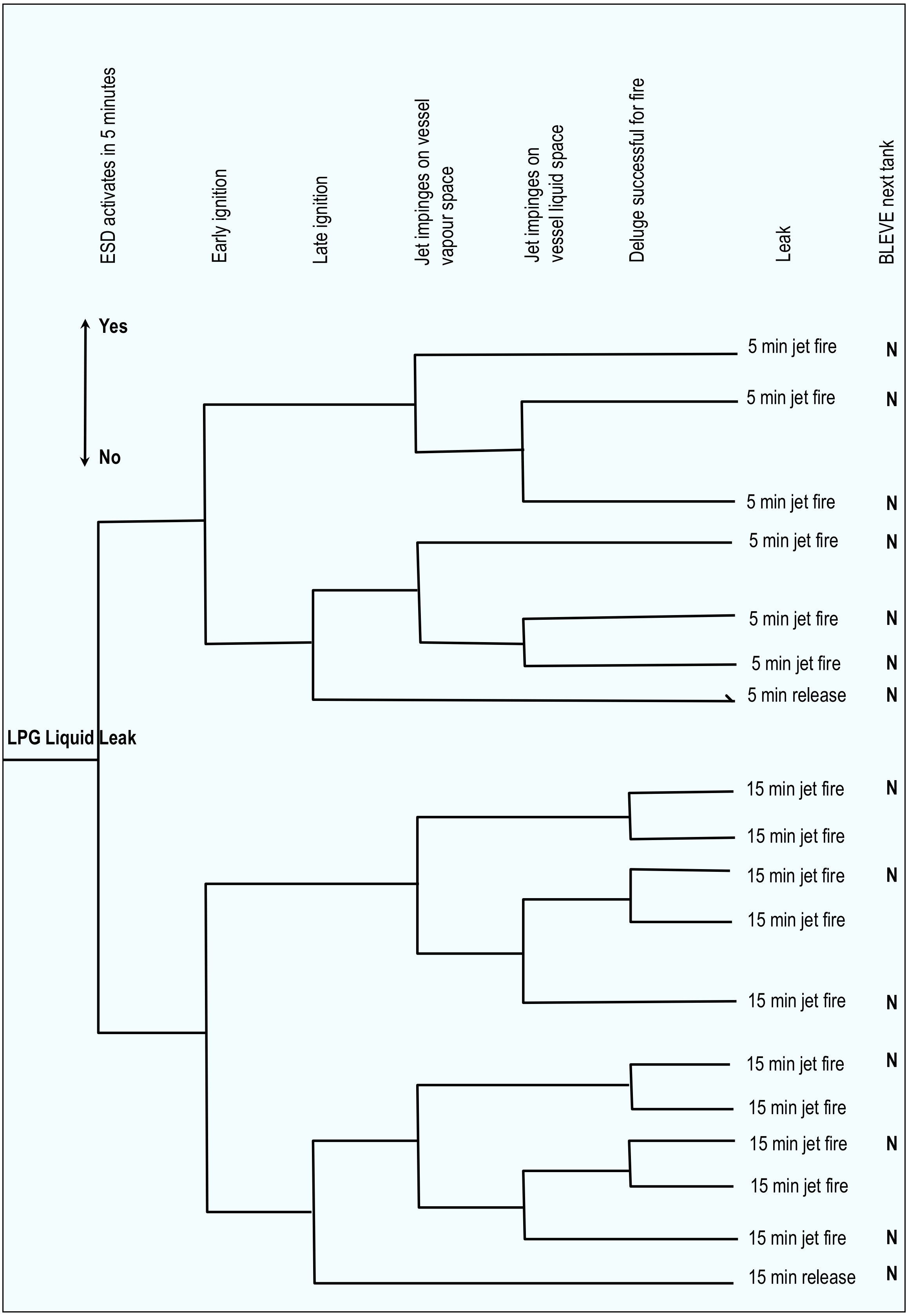


Table A2.13: Likelihood of Off-Site Effects

Event	Frequency per year
LPG vessel catastrophic failure	1.2×10^{-7}
BLEVE of storage tank	1.2×10^{-6}
BLEVE of road tanker at loading bay	9.0×10^{-7}
Flash fire/vapour cloud explosion	3.4×10^{-6}
TOTAL	$\mathbf{5.6 \times 10^{-6}}$

A2.6.7 Assessment of Results

The results of the conservative partial quantification have shown that the aggregate frequency of all events which could have significant off-site consequences is approximately 6×10^{-6}.

If the surrounding land uses had been residential there would have been a clear need to carry out a more refined quantitative assessment. In this case, however, all surrounding land uses are industrial and the partial quantification is sufficient to demonstrate that the fatality criterion of 50×10^{-6} will not be exceeded.

Consequently, a full QRA will not be required.

A2.6.8 Risk Reduction and Management

In terms of risk reduction and management, the results show that risk reduction and management efforts are best concentrated on minimising the likelihood of a major leak leading to possible fire and explosion and on ensuring that safety systems are well maintained and managed. Possible improvement measures include:

- automatic leak detection and isolation
- a formal inspection and maintenance program, incorporating rigorous and frequent inspection of pipes, fittings, vessels and technical safety systems
- a strong safety management system.

A full study would take account of the full range of risk reduction and management measures outlined in section 3.4 in the body of the guidelines.

Additional Information

Relevant Departmental Publications

Hazardous Industry Planning Advisory Papers (HIPAPs):

No. 1 - Emergency Planning
No. 2 - Fire Safety Study Guidelines
No. 3 - Risk Assessment Guidelines
No. 4 - Risk Criteria for Land Use Planning
No. 5 - Hazard Audit Guidelines
No. 6 - Hazard Analysis
No. 7 - Construction Safety Studies
No. 8 - HAZOP Guidelines
No. 9 - Safety Management
No. 10 - Land Use Safety Planning
No. 11 - Route Selection
No. 12 - Hazards-Related Conditions of Consent

Other Publications:

Applying SEPP 33: Hazardous and Offensive Development Application Guidelines

Multi-level Risk Assessment

Locational Guideline: Liquefied Petroleum Gas Automotive Retail Outlets

Locational Guideline: Development in the Vicinity of Operating Coal Seam Methane Wells

Risk Prioritisation

International Atomic Energy Agency, 1996, *Manual for the classification and prioritisation of risks due to major accidents in process and related industries,* IAEA-TECDOC-727 (Rev. 1), Vienna

Electronic copies of some of these publications are available at: **www.planning.nsw.gov.au**