

# **HID - SAFETY REPORT ASSESSMENT GUIDE:**

## **Chemical Warehouses - Criteria**

**1 July 2002**

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# 1. Introduction

The purpose of this document is to describe how the Competent Authority's Assessors test whether COMAH safety reports meet the criteria that apply to the predictive aspects of COMAH. It provides background information on hazards from chemical warehouses, and an interpretation of the criteria based on useful examples. The information supplements rather than supplants that in the safety report assessment manual.

It is assumed that the Assessor is fully familiar with:-

- HSC/E's enforcement policy, the application of the ALARP principle and associated publications (eg HSE, 1999; HSE 1992; Treasury, 1998).
- The COMAH Manual.
- The contents of the HID Safety Report Assessment Manual (SRAM), particularly the guiding principles, and the procedures for handling and assessing safety reports.

The sections below provide important background information, particularly on ALARP decisions and the application of the proportionality principle to the assessment of safety reports. Section 1.2 provides guidance to supplement the explanatory text for the predictive criteria in Part 2, Chapter 3 of the SRAM and should be applied for each safety report assessment.

## 1.1 Fundamental Considerations

Before assessing a safety report an Assessor needs to be clear about:-

- His/her role in the assessment process and what the safety report Assessment Manager (AM) is expecting from the assessment.
- The degree of proportionality that applies, this determines what can justifiably be expected from the Operator's risk assessment (RA) - ie the depth of the arguments supporting the various demonstrations.
- HSE's approach to the application of the ALARP principle to **on-site** (ie HSW Act Section 2), and **off-site** (ie Section 3) risks for new and existing establishments.
- How the assessment criteria should be applied and factors which influence the depth of the assessment process; an important consideration is the type of report being assessed eg first submission, or an update report.

These issues are outlined in the remainder of this Introduction and are revisited as appropriate in later sections of the guidance.

## 1.2 Role of the Assessor

The predictive assessment is pivotal to the demonstrations required under Section 4, Part 1, paragraph 2 of the COMAH Regulations; particularly the need to demonstrate that:-

- all major accident hazards (MAHs) have been identified;

- that all necessary measures to prevent and limit the consequences of these MAHs are identified and implemented.

The Assessor's role relates solely to the risks to people both on-site and off-site. Risks to the environment are for the Environment Agencies and are not addressed here.

**When the assessment of the predictive aspects of a safety report is complete, the Assessor should return the completed assessment form to the Assessment Manager giving conclusions about whether:-**

- the process of the hazard identification and risk analysis is fit for purpose;
- all MAHs have been identified; any gaps must be recorded on the AF;
- the consequence assessment is adequate for the purposes of COMAH ie the extent **and** severity of representative MAs must be quantified (Schedule 4, Part 2, Paragraph 4).

The assessment form allows Assessors to comment against each criterion and subcriterion. This guidance is designed to help provide consistent comments and conclusions and is structured in terms of questions which relate to the criteria and help to identify any weaknesses in the safety report. These should help Assessors to write succinct 'deficiency' statements and make clear what is required eg further information or analysis or both.

When filling in the assessment form the paragraph number and page number in the report should be shown for cross referencing purposes. For example:-

Criterion	Safety Report Refs	Comments	Issue* Category
3.3 The safety report should identify all potential major accidents and define a representative and sufficient set for risk analysis	pxx para yy	The safety report does not identify catastrophic vessel failure leading to total loss of contents as a potential MA. <b>The report fails to meet criterion 3.3; the Operator has to provide more information.</b>	Decided by team at final meeting

\* The Issue Category relates to the inspection plan only.

The assessor must also provide input to the assessment team conclusions on whether the prevention and mitigation measures make risks ALARP.

### 1.3 Consistency and Proportionality

The assessment approach needs to be proportionate and consistent (HSC 1995; HSE 1999), therefore Assessors should come to a view on proportionality before starting to assess a report against the predictive criteria.

**Consistency** does not mean uniformity. It means taking a similar approach in similar circumstances to achieve similar ends. For some, professional judgement may need to be exercised in order to come to a decision on whether the demonstrations in the report are fit for purpose when assessed against the predictive criteria. The criteria and the associated

guidance are designed to help Assessors exercise this judgement in a consistent way. Occasionally they may need to discuss some issues with HID colleagues who are familiar with the site, the land use planning situation, or the Operator's approach to discharging his Section 3 responsibilities, before reaching a decision.

The assessment team have a key role to play in achieving consistency in the overall assessment of safety reports and in the drawing of the Competent Authorities (CAs) conclusions. Other ways of achieving consistency include;

- exemplar reports
- Lead unit system
- Sharing experiences through knowledge management systems.

**Proportionality** is a fundamental consideration when exercising judgement on whether assessment criteria are met or not. HSE guidance (HSE 1999b) on the COMAH Regulations (paragraph 74) states that 'there must be some proportionality between the risk and the measures taken to control the risk. The phrase "all measures necessary" will be interpreted to include this principle'.

Proportionality is essentially determined by the severity of the worst possible consequences, ie those resulting from the worst case scenario, and the levels of risk (individual and societal), that remain after taking account of the prevention and mitigation measures the Operator has put in place. The following factors (see also paragraph 292 of HSG 190), are therefore important:-

- (a) the scale (inventory, vessel sizes, etc) and nature (hazardous properties, toxicity, flammability, etc) of the hazards;
- (b) the location of the site in relation to off-site populations;
- (c) the density and types of off-site population (eg dwellings, hospitals, schools, etc);
- (d) the number of people on site;

- (e) the variation of residual individual risks with distance<sup>1</sup>.

Proportionality should influence the aspects on which Assessors focus the most attention ie the issues where the occupier is expected to provide convincing arguments to support the demonstrations. Information in the safety report should enable Assessors to fully understand site specific circumstances (on-site and off-site), so that a view on proportionality can be reached. The report should therefore describe the processes, the hazardous substances involved and their effects on people, the distribution of people off-site, and the numbers of people on-site and their distribution in relation to the various installations.

To reach a view on proportionality the Assessor needs to know the potential maximum injury toll. Schedule 4, Part 2, Paragraph 4(b) requires the Operator to determine the extent and severity of the consequences of identified major accidents. Schedule 7 defines injury severity that constitutes a major accident. The threshold is a single death, six persons on the establishment hospitalised for at least 24 hours; or 1 person off-site hospitalised for at least 24 hrs. Severity therefore includes fatal and serious injury (ie hospitalisations) as a minimum. Operators must include the severity of the consequences for the worst case event in terms of expected numbers of fatalities and serious injuries in their accident consequence analysis. Less severe injuries should also be considered eg minor injuries.

#### 1.4 Proportionality and Depth of Risk Assessment

Proportionality will influence the type and level of analysis detail that Assessors might expect to underpin the various demonstrations in the safety report (see paragraph 292 of HSG 190). HSG 190 gives the following RA definitions:-

- (a) **Qualitative risk assessment** is the comprehensive identification and description of hazards from a specified activity, to people or the environment. The assessment is informed by a representative selection of specific examples for comparison with standards and relevant good practice.
- (b) **Semi-quantitative risk assessment** is the systematic identification and analysis of hazards from a specified activity, and their representation by means of qualitative and quantitative descriptions of the frequency and extent of the consequences, to people or the environment. The range of possible events may be represented by broad categories, with classification of the likelihood and consequences for comparison and the identification of priorities.
- (c) **Quantitative risk assessment** is the application of methodology to produce a numerical representation of the frequency and extent of a specified level of exposure or harm, to specified people or the environment, from a specified activity . There is also a comparison of the results with specified risk criteria.

It is implicit in para 292 of HSG 190 that as proportionality increases from a low level to the highest level, the form of risk assessment is likely to change from qualitative, through semi-quantitative to quantitative risk assessment. It is important for Assessors to realise that QRA does not mean that a detailed and full numerical analysis resulting in iso-risk contours and F/N societal risk curves is needed. Rather the extent of the quantification and

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1. Societal risks considerations are implicit in b) and d) above. Although the risks may be ALARP , they could be towards the top end of the band. Such a site would require more evidence and arguments to support the various demonstrations and deserve more inspection/assessment resource than a similar plant where the risks to people were towards the bottom end of the ALARP band.

the form it takes will depend on the site specific circumstances determining the level of proportionality that applies.

## 1.5 Input to the decision on whether the risks ALARP?

Criterion 3.6 addresses the “all necessary measures” demonstration, which is essentially an ALARP demonstration. In general, decisions on whether risks are ALARP for major hazard installations are based on the generalised Tolerability of Risk (TOR) Framework (HSE 1992, HSE 1999 - the latter being referred to as R2P2 below). For nuclear hazards there is considerable experience in making such ALARP decisions, but the mechanisms for other hazards are still evolving (see HSE 1999). Nevertheless some companies have adapted the TOR framework to devise their own major hazard risk criteria. Whatever approach is used, professional judgement is usually needed; the team approach to assessment should help achieve consistency in such decisions for top-tier COMAH sites.

The Operator’s ALARP demonstration should be founded on the degree to which good practice, engineering standards, recognised codes, guidance and standards, etc have been adopted. The control measures introduced by this process will be usually satisfactory for low hazard sites. In terms of the TOR framework this amounts to using **technology-based** criteria for making ALARP decisions, ie qualitative risk assessment. Such criteria will usually be sufficient when inherently safe design principles have been adopted because then the scale of the hazard should have been drastically reduced. As the level of proportionality increases, a decision has to be made as to whether further risk reduction measures are reasonably practicable as required by the HSW Act. Basically, two questions have to be answered:-

- what additional risk reduction measures are possible?
- which of these are reasonably practicable to implement, ie to make the risks to people (on-site and off-site), ALARP?

If no further measures can be identified, the Operator must have all necessary controls in place; it is then a matter to verify by inspection that this is the case and that the measures are sufficiently reliable. To answer the second question some quantification and CBA is usually required. The degree and rigour of this quantification will depend on the level of proportionality and the site specific circumstances. Such ALARP decisions usually involve the application of the generalised TOR framework as outlined in R2P2. The ALARP band is defined by levels of individual fatality risk. For members of the public the corresponding fatality risk levels are  $10^{-4}$  (upper limit of tolerability) to  $10^{-6}$  (broadly acceptable level) per year.

Societal risks should meet the criterion in R2P2 ie the likelihood of a single major industrial activity producing 50 or more fatalities should be less than 1 in 5000 per year ie less than  $2 \times 10^{-4}$  per year. This is essentially an **equity-based** criterion for societal risk. If the criterion is met for a single plant it is still necessary to judge whether the risks are ALARP for the site, which may have several plants.

To assess whether the societal risks are ALARP **utility-based** criteria are usually applied. These are based on the individual risk levels and a cost benefit analysis to estimate what further risk reduction is costing for each life saved by the introduction of an additional measure. By comparing this ‘value of preventing a fatality’ to the value society puts on each life (eg £1M) an indication of the level of disproportion is obtained. Judgement on whether this is gross will depend on the site specific circumstances, in particular the nature of the hazard and the likely value of the number of fatalities from the worst case scenario (WCF).

In the case of societal risks, deciding whether the risks are ALARP can be quite onerous, particularly for complex sites. One of the earliest examples, which underlines the complexity of making ALARP decisions, is the Canvey Island Studies, which are documented in two Reports (HSE 1978; HSE 1981). The Canvey studies considered the risks to members of the public from a number of major hazard sites operated by different companies and a proposed new refinery.

Individual risk (aggregated for all sites), was predicted at a number of locations together with the Societal risk arising from all operations. The first assessment showed that the risks were unacceptable and Industry accepted that risk reduction measures were needed, despite the fact that no agreement had been reached on risk criteria that were appropriate for major hazards. A second study (about two years later), which took account of the proposed measures and advances in risk assessment methods showed that the risks were lower by about a factor of 20. The highest individual risk of fatality was about  $3.5 \times 10^{-5}$  ie close to the limit of tolerability. However, HSE decided that no further risk reduction was necessary. HSE's decision attracted criticism, which is encapsulated in this extract from the report:- **“We have been criticised for seeming to adopt too high a level of acceptable risk in our conclusions. We concede that others may legitimately question our view of acceptable risk, but we would emphasise that in our opinion decisions about acceptable risks have to be made in the light of the facts of risk, consequences and costs in each individual case. We are not tied to a particular numerical level of acceptable risk, and inferences about what we have judged to be an acceptable risk in particular cases in the Canvey area should not automatically be applied elsewhere.”**

This extract from the second Canvey report underlines the site specific nature of ALARP decisions - a vital consistency consideration. An important point stemming from the Canvey studies and the 1992 TOR document is that when several sites contribute to the risk born by an off-site individual, the aggregated fatality risk must be ALARP and less than  $10^{-4}$  per year. This has implications for multi-installation sites and multi-occupier sites, and for the assessment of safety reports at such sites. This issue is not addressed in R2P2. **Should this type of situation arise in the assessment of COMAH safety reports the team should consult HID OPU on the way forward.**

In the case of new plant, precedents have been set to apply more stringent ALARP criteria (HSE 1992). This precedent recognises that most risk reduction opportunities exist at the design stage, eg through the application of inherent safety principles and the application of new technology.

## **1.6 How the Predictive Criteria Should be Used**

The purpose of HSE's assessment of a safety report against the criteria in the SRAM, is to come to a conclusion on whether the requirements and demonstrations in Schedule 4, Part 1 have been met. The extent of the information required for each demonstration to be made will depend on the level of proportionality considerations and the type of safety report required by COMAH Regs 7 or 8. The different report types include: the initial report for existing establishments, pre-construction (PCSR), pre-operation (POSR), modification and updated reports.

Operators will write the safety report in a structure that suits them. Whatever structure is adopted, the Operator should ensure that the information is linked to the required demonstrations in a transparent way. The Assessor should bear in mind that the same control measures and arguments may apply to more than one demonstration. This means

that information to support a demonstration is likely to be found in different parts of a safety report.

The predictive criteria are designed to help you make consistent professional judgements about whether the demonstrations in a safety report are adequate. Such demonstrations need to be based on a suitable and sufficient risk assessment (EU 1998). The criteria are necessarily quite general, but sufficiently broad in nature to cover the various types of installation, the range of hazards to be encountered, and the types of risk assessment that might be employed. Therefore, not all the predictive criteria may need to be considered in the same detail by the Assessor, but **all the top level criteria need to be applied**. The issues identified in the assessment plan for close examination should help identify the predictive criteria that are key for a particular assessment. The extent to which the sub-criteria are applied should be proportionate. At the lowest level of proportionality a qualitative risk assessment based on recognised codes or guidance will suffice; no quantification of event probabilities may be needed so that the associated criteria need not be tested rigorously.

The criteria are provided as a guiding framework with in which professional judgements are made: *they are not provided as a tick list*. The assessment form should make clear that the Assessor has tested all the predictive criteria. **The effort put into the assessment should be proportionate and sufficient to enable valid conclusions to be drawn; the reasons behind these conclusions need to be transparent ie recorded for auditing purposes.**

Assessors should bear in mind that Operators may rely on published guidance or standards in seeking to demonstrate compliance. However, Operators who demonstrate compliance using company, or other non-published standards will have to show that they are fit for purpose, ie they need to be based on a risk assessment. They must also show that they have properly identified all foreseeable hazards and that they have implemented all necessary measures to prevent major accidents. **This means that the Operator has to demonstrate that HSW Act Section 2 (on-site) and Section 3 (off-site) risks are ALARP.** The report will therefore have to address any risks that remain after compliance with standards or guidance in order to demonstrate that all the necessary measures have been taken. For example, standards may only address risks to workers, in which case the Operator may (depending on the level of proportionality), need to justify their relevance to making off-site risks ALARP. It is then a matter of judgement whether the risks to people on and off site are ALARP. {Note that HSC's Enforcement Policy Statement (2002), emphasises that neither codes or guidance material are in terms which necessarily fit every case}.

The SRAM provides guidance on how to assess the various types of safety report. As a general guide, the Assessor should take a quick overview to gain insight into the sites activities, environs, the scale and nature of the hazards, the range of MAs, the controls in place, and the maximum casualty potential (WCF). This will enable a view to be taken on proportionality and the most important issues. Then the assessment criteria can be used in detail to draw conclusions on the report.

The following points are central to the assessment process:-

- (a) Above all, an Assessor should ensure that he/she is clear about how the proportionality principle applies. The type of report will be an influence eg if it is an update report, or a modification report, the primary focus should be on the new material and how this affects the risk assessment.

- (b) The Assessor needs to take a view about whether the Operator's approach to risk assessment is proportional to the risks presented by the site. This should be done at an early stage in the whole assessment process because it is key to deciding whether a report contains grossly insufficient information eg when some quantification (eg of event likelihood), is needed and only qualitative arguments are used.
- (c) For existing CIMAH sites there may be outstanding risk assessment issues already raised with the occupier that are fundamental to the COMAH requirements. Assessors are advised to check whether there are outstanding issues and whether they have been addressed.
- (d) All the criteria must be applied in a proportionate and consistent way. For qualitative risk assessments the main focus is on the top level criteria.
- (e) All safety reports need to demonstrate that the risks to occupied buildings have been assessed, for example, in line with the CIA guidelines.
- (f) When the assessment has been completed the HID form should be filled in and the conclusions summarised for the Assessment Manager.

**Criterion 3.1 "The safety report should clearly describe how the Operator uses risk assessment to help make decisions about the measures necessary to prevent major accidents and to mitigate their consequences."**

The purpose of this criterion is to help the Assessor determine if the Operator's approach to risk assessment is suitable and sufficient ie.(proportionate and systematic). Since this can only be properly assessed after the safety report has been read, it is probable that Assessors will need to return to this criterion at the end of the assessment process. To this end the following questions and answers may prove useful:-

**Q: Has the Operator a policy on risk assessment?**

This is an important point because the Operator must demonstrate a risk-based approach to his activities and to the production of the safety report. Failure to provide adequate evidence on this point may be viewed as a failure to comply with both the Management and the COMAH Regulations. The section of the safety report dealing with the major accident prevention policy (MAPP) will inform the Assessor on this issue.

Companies that manage their business with the aid of risk assessment might refer to the use of risk assessment in areas of safety management such as COSHH, the identification of procedures for dealing with spills, the permit to work system, fork-lift truck operations and segregation of hazardous substances. In these cases there may be reference to one or more formalised methods of determining risks such as event tree, fault tree and FMEA, and the use of risk assessment will probably not be confined to major accident analysis, but be detectable throughout the report. Assessors should not forget that risk does not necessarily involve quantification and that qualitative risk assessment has its place in the demonstration of safe operation.

Examples of non-quantified approaches that are acceptable include:-

- Hazard studies.
- Job safety analysis.

- Reference to industry standards.
- Safety reviews.
- Human error identification.

**Q: Does the safety report summarise the methods of risk assessment or quantified risk assessment that are used in the report?**

The Operator should describe the extent, to which the Company relies on recognised standards and good practices and demonstrate that the standards appropriate. He should describe the methods used to determine risks and give details of the competence and expertise of the people carrying out the risk assessment. In addition he should describe how the significance of the results of risk assessment are determined and the basis on which they are implemented.

Since the regulations call for a risk assessment, the safety report should describe the approach adopted. If a QRA has been undertaken, the information that should be presented includes:-

- The extent of the analysis (plants/processes addressed).
- The method of identifying major accident event sequences (HAZOP).
- The analytical approach (event tree, fault tree, FMEA).
- The source of the base failure rate.

If a non-quantified approach is adopted because the risks are low, the basis for demonstrating that the residual risks are both tolerable and ALARP should be given. One or more of the following is acceptable if supported by well reasoned argument:-

- Industry standard good practise.
- Regulatory guidance.
- Industry association guidance.
- Historical data.

**Q: Does the safety report summarise the criteria for use with the risk assessments or quantified risk assessments that are used in the report?**

Operators should summarise the criteria used to judge when risks are tolerable. Ideally this should appear near the beginning of the report so that the Assessor can make the following judgements:-

- Are the criteria appropriate?
- Does the safety report demonstrate compliance with its own criteria?

**Q: Does the safety report state the basis for judging whether all necessary measures have been taken to prevent major accidents and to limit their consequences?**

The way Operators demonstrate that all necessary measures have been implemented is likely to depend on their approach to risk assessment. Most will not base their report on QRA and will be able to satisfy the requirements of the regulations by demonstrating compliance with good practice and adherence to standards and regulatory guidance. If a significant number of off-site casualties are predicted as a consequence of the worst accidents, other more quantitative approaches may be required.

For example:-

(a) Demonstrating that the risks are negligible (risk of death of an individual  $< 10^{-6}$ /year).

or

(b) Demonstrating that risks are tolerable (risk of death of an individual  $< 10^{-4}$ /year).

or

(c) Societal risks are shown to be tolerable or broadly acceptable.

Assessors should not expect to see detailed cost benefit calculations in a COMAH safety report, but Operators should list possible practical improvements and justify why they are not implemented.

*Q: Is the Operator aware of the ALARP principle and is he using it in conjunction with cost benefit analysis to ensure that all necessary measures are taken to reduce the probability of a major accident.*

Fundamental to the demonstration that "all necessary measures" have been taken to reduce the risk from the site, is evidence to show that risks are ALARP. An Operator, who fails to provide this evidence, fails to comply with the regulations.

Demonstrating that risks are ALARP is easier if operational risks are quantified in some way, but risk quantification is not an essential requirement of the COMAH regulations. Operators should describe how they decide when risks are ALARP and show that that additional safety measures are not justified on cost grounds, but Assessors should not expect to see detailed cost benefit analysis arguments in a safety report. They should use their knowledge and expertise to make professional judgements about the adequacy of existing safety measures and the acceptability of the absence of additional safety systems that might be grossly disproportionate to implement.

*Q: Has the Operator demonstrated a routine and general application of risk assessment in different aspects of operations, or has a limited amount of quantified analysis been carried out for the sole purpose of the safety report.*

The safety report should convince the Assessor that the Operator understands risk assessment and routinely uses it to reduce risks at all levels and in all aspects of site operations. The complexity of such uses and level of detail given in the safety report should be proportionate to the risks involved.

The tone of the safety report and the way it is written will be a reliable indicator of the Operator's use and understanding of risk assessment. Assessors should look to the MAPP

for evidence of a risk assessment culture rather than the accident analysis that may have been carried out by a consultant.

### **Criterion 3.1.1 “It should be clear that human factors have been taken into account in the risk analysis.”**

When making a judgement about compliance of the safety report with this criterion, Assessors should pose the following questions:-

**Q: Has the Operator demonstrated that the risk assessment he has carried out to aid decision-making on the measures necessary to prevent major accidents and to mitigate their consequences includes allowance for human factors?**

Risk assessment should consider all types of operator error that can result in a major accident (fire) or a dangerous situation. The Operator should describe the role operatives play in controlling hazard and show that their potential errors are identified. He should also describe measures that have been taken to reduce their probability and how they are accounted for in the major accident analysis. The safety report should demonstrate that his systems and procedures are fit for purpose and incorporate adequate attention to human factors. This may be described in the management section dealing with staff training, competence assessment, and the way incidents and near misses are dealt with.

Accounting for human error in risk assessment is not straightforward because some human reliability literature data are not universally applicable. Assessors should primarily be concerned with checking that human reliability is included in the analysis rather than with the accuracy of the data used.

**Q: Does the safety report consider an adequate range of human failings?**

Inclusion of human factors in risk assessment does not only mean identifying poor fork lift truck driving or poorly controlled hot work as potential fire initiators. Events such as, corner cutting, unauthorised absence, and even sabotage may warrant consideration. Errors at the design and construction stage of storage vessels should not be overlooked.

Examples of the types of event which may warrant consideration are:-

- Failure to successfully carry out an operation that is part of normal duties.
- Erroneously carrying out an operation that is not part of normal duties.
- Failure to respond correctly to an alarm situation (failure to control or making a situation worse).
- Deliberate or inadvertent degradation of the safety of a plant (eg switch an alarm off, or bypass a safety system),
- Deliberate rule flouting (eg smoking in a non-smoking area).
- Failure to detect failed components during testing.
- Introduction of failures by damaging equipment or leaving equipment mis-aligned during testing or maintenance.

In practice many safety reports will not address human factors as thoroughly or with as much rigour as engineering issues. This can be understood in the light of traditional approaches to safety and safety reports, but cannot be justified where human reliability plays a critical role.

The following are examples of common omissions in safety reports:-

**The potential for an operator to override designed safety features has not been covered.**

There should be some mention of 'violations' or 'breaking the rules' as well as 'human error'.

**The hazard analysis process failed to identify anything more than errors of omission (the operator failing to act).**

Most safety reports need to consider errors of commission (an operator making an action but the wrong one), or decision making errors.

**The role of people other than as front-line operators (eg maintainers, supervisors) is not considered.**

Many human failures are the result of actions, omissions and decisions taken by other people including designers and managers. For example, the potential for a maintenance error on a safety related system may not be addressed in the RA process.

**There was no consideration of the possibility of a hardware failure with a simultaneous human error.**

Some appreciation that when the hardware of a protective system fails the operator may also not respond in the intended manner.

**The operator is being asked to do a critical task that would probably be more reliably done automatically.**

**There appears to be undue reliance on an operator to identify and respond rapidly to an alarm condition.**

If so, we would need some justification of the human error probability included. This should be justified in relation to the specific design of the system interface they have on site rather than a generic value taken from a table.

**There is reliance on 'heroic' acts by operatives to recover situations eg going back to the control room when suffering from effects of toxic gas.**

[Q: Does the safety report show how human factors are included in the risk assessment?](#)

Data tells us that human failures contribute up to 80% of industrial accidents. Even in oil refineries, which are highly capitalised and automated, the figure is 50%. The implications of this run throughout the safety report and through many of the assessment criteria, so they will need to be considered by several members or all of the assessment team.

The safety report should consider in a rigorous and proportionate way how operators may contribute to the initiation of a major accident (see Criterion 3.4.4). It should also describe the part operators play in controlling hazards and risks. If an operative is required to take

certain actions following an alarm, the risk analysis will need to make assumptions about the likelihood that the correct action is taken. For example, if the economic consequences of emergency shutdown are great, the operator may very well hesitate or fail completely to press the button.

If a task is critical to the prevention of a major hazard and an unrealistically high level of human reliability has to be assumed to make the risks ALARP, this may not be acceptable as it places an undue burden on the operator. Instead automatic control and protection systems can be used to reduce the reliance on the operator to intervene correctly. To achieve the required reliability it may be necessary to build redundancy and diversity into the control systems.

Not all safety reports will need to quantify human reliability. The focus should be on demonstrating the quality of the training and supervision. If a human reliability figure is used in a fault tree, the Assessor should check that the top event is not sensitive to the value adopted.

**Q: Does the safety report describe how the probability of operator error is reduced?**

In the context of operator error and how the company ensures that it is minimised, the safety report should:-

- Describe how operator errors are identified.
- What measures have been taken to reduce their probability.
- How they are accounted for in the major accident analysis.
- Demonstrate that the systems and procedures for selection, training and supervision of operators are fit for purpose.

**Criterion 3.1.2 “Any criteria for eliminating possible hazardous events from further consideration should be clearly justified.”**

This criterion deals with the Operator’s limitation of accident analysis in the safety report and can be judged by reference to the following:-

**Q: Have any major accidents been discounted on probability grounds?**

Operators are obliged to demonstrate that low frequency events with severe consequences are adequately controlled - that all necessary measures have been taken to prevent their occurrence. However, most safety reports are unlikely to determine the consequences and frequency of very improbable accident initiators such as a meteor strike, simultaneous multiple failures of reliable systems, and terrorist activity. It is essential that the risk dominating accidents be dealt with comprehensively and that accidents such as lightning strike or aircraft impact should not be discounted.

In general an Operator will present consequence analysis for some but not all warehouses on his site. Provided the risks do not vary greatly, such an approach is acceptable, but the reasons for not considering fires in a particular warehouse should be given.

**Q: Does the safety report unjustifiably eliminate ‘small scale’ releases?**

It is reasonable for the Operator to reduce the number of release cases by defining a scale of event that will not lead to a MA. For example, the consequence assessment may show that any failure resulting in a release smaller than that equivalent to a 10 mm diameter hole does not produce a hazard to on-site or off-site populations. This provides a basis for defining major accident hazards. However, Operators may need to take account of smaller flammable releases into confined spaces, which might ignite and explode and trigger a more severe accident. The Operator should also consider any known or foreseeable changes to the sensitivity of the surrounding environment, eg future dwellings which may be built nearer to the site boundary as these can affect the appropriate degree of proportionality. Such changes should be also considered whenever the risk assessment is reviewed.

In situations where this 'protection' based approach is not sufficiently limiting, ie the hazard ranges from very small releases extend into population, a risk based approach may be needed. This requires the contribution to the residual risk of releases of different sizes to be considered so that a justifiable 'cut-off' can be decided. All contributions to release likelihood need to be taken into account otherwise, the 'cut-off' may be overly optimistic.

**Q: Has the Operator determined the consequences of accidents in different warehouses at different times of year?**

It is reasonable for Operators to describe in detail the consequences of only a relatively small number of warehouse fires/explosions, provided all significant accident initiators are identified and ranked according to the risk they pose. The consequences of fires in different warehouses and at different times of the year should be determined, particularly where inventories change significantly. The Operator should demonstrate that the risks are ALARP, but he has discretion on the way this is done subject only to the requirement that the results are convincing.

**Q: Is adequate justification provided for dismissing major accidents on the grounds of low probability?**

A safety report may describe the consequences of a representative set of accidents, provided account is taken of all major accidents. In particular it should describe the risk from all accidents that the Company has taken measures to prevent occurring. The frequency determinations do not necessarily have to involve the application of formalised methods such as fault tree analysis. Reference to appropriate source material/documents, industry standards etc. is likely to be the norm.

The safety report should also demonstrate that risks from accidents, for which no preventative measures are taken are tolerable. In general these will be low probability events initiated by an off-site event such as aircraft impact or an earthquake.

Incredible accidents are not clearly defined in this context, and Assessors are expected to use common sense and professional judgement about events that can be neglected. Examples include meteor strike, terrorist activity and simultaneous failure of several diverse and redundant safety systems.

**Q: Has the Operator determined or ranked the frequency of all major accidents?**

Most warehouse safety reports are unlikely to present a detailed quantification of the probability of fire or explosion. It is acceptable for the accident analysis to quote historical data and the results of surveys of the causes and probability of fire in warehouses. Assessors should expect Operators to demonstrate that the risks at his site are tolerable on account of adequate management systems and installed safeguards

Assessors should recognise that the COMAH regulations do not call for a full QRA. Frequency evaluation for highly improbable accidents does not need to be as detailed as that for risk dominating sequences and can be based on historical data, industry standards and regulatory guidance, etc. However, the statement - 'the probability of this accident is judged to be less than  $10^{-6}$ ' is not acceptable if they are not backed with supporting evidence. A poorly documented or sparsely detailed frequency analysis that appears somewhat optimistic may be judged as failing to comply with the assessment criteria.

Operators are obliged to demonstrate that low frequency events with severe consequences are adequately controlled, ie that all measures necessary have been taken to prevent their occurrence. If precautions have been taken to reduce the probability of an accident, then the consequences of the event must be assessed so that they can be balanced against the precautions.

If the Operator has not attempted to quantify accident frequencies, but builds a case based on terms such as high, medium and low probability, he should rank the accidents according to their perceived severity. Without any quantification it is difficult to determine if an accident that kills a few people with "medium likelihood" is worse than one that kills many people with "very low likelihood". In such cases, the Operator should determine that both risks are tolerable.

### **Criterion 3.2 "The safety report should demonstrate that the Operator has used information and data that are suitable and sufficient for risk analysis".**

A key requirement of the regulations is that information provided about the site and its hazardous substances is **suitable** and **sufficient** for a risk assessment. Table 1 provides some examples of where such information may be found. When considering this part of the safety report the assessor should ask if it provides answers to the following questions:-

**Q: What is the maximum hazardous inventory and how and under what conditions is it stored?**

The site description must describe the location and type of each warehouse and provide information on the maximum inventories of all hazardous substances and the conditions (temperature and pressure) under which they are stored. This probably means accounting for seasonal variations in stock levels and the toxicity of different products. It is important that the report adequately addresses the requirements of Schedule 1 of COMAH and considers all substances qualifying under the aggregation rules. The hazard from each qualifying substance must be assessed.

**Q: Does the safety report give a description and explanation of site operations sufficient to enable all potential major accident scenarios to be identified?**

The safety report should describe plant and plant operations so that failures and errors that result in a fire can be identified. The detail provided needs to be sufficient to enable Assessors to determine if the accident analysis is thorough and complete. Of particular concern are spills, the separation of incompatible substances and hot work such as shrink wrapping.

**Q: Are there sufficient maps and plans to allow the location of hazard sources and vulnerable populations/habitats to be identified?**

The standard of maps and plans is likely to vary from one report to another, but all the information needed to determine risk should be present. Maps and plans should clearly

show the location of all warehouses and populated areas at risk from the installation. Particular attention should be given to elevated structures such as railway viaducts and high rise buildings that may be at risk from buoyant releases such as the smoke plume from a fire, or even the flames themselves when tilted by a strong wind.

Some accidents at the chemical warehouses have the potential to affect the natural environment, and in particular aquatic systems, SSSI's or SBI's that may lie some considerable distance from the site but are connected to it by a water course.

Therefore, in addition to assessing the consequences of fire, the safety report should describe the potential effects of contaminated fire fighting water run-off. In this context the location of warehouses with respect to watercourses is particularly important.

**Q: Can the source terms for all accidents be determined from the information provided?**

The information in a safety report must be sufficient to enable the Assessor to deduce the approximate source term for each major accident. In other words, sufficient information should be given to allow the Assessor to determine 'how much, for how long and from where?' This includes the rate of plume seeding in the event of a fire, and the quantity of chemicals that could, under worst circumstances, leave the site in fire fighting water.

A safety report that fails to supply all of this information, is unlikely to comply with the assessment criteria.

**Q: Are the assumptions used in the accident analysis adequately justified and clearly stated?**

The assumptions referred to here do not relate to mathematical modelling of an accident, but are connected with the operation of a site. They include assumptions such as the local fire brigade will reach the site within 10 minutes, that the sprinklers will extinguish most fires and/or that the site isolation system will function perfectly.

Of particular concern are:-

- The reliability of shut-off valves on site drains.
- The probability that an Operator will be directed to isolate the site in an emergency.
- The reliability of the bund to hold up fire fighting water and not allow any to leave the site.

**Q: If a QRA approach has been adopted, are accessible sources provided for base failure frequencies/probabilities?**

Key documents that the safety report relies on should be available to the Assessor, ideally by being included as an annex to the main report. Fault tree analysis, for example, should not be based on failure probabilities given in a confidential report unless the company is prepared to provide HSE with a copy.

The minimum requirements in this respect is references to published work. An Operator's failure to provide any supporting evidence should be considered a failure to comply with the criteria.

Source documents are targets for the follow-up inspection to validate the report, but Assessors should bear in mind their right to request further information from an Operator to help them assess his safety report.

**Q: Does the safety report provide, or reference accessible sources for, the predictive models adopted, including the underlying science?**

The safety report should provide information on the methods and models used to predict the consequences of major accidents. If a well known computer program such as PHAST has been used, then only details of the input data and the version number are required. If an in-house computer program is used to calculate the consequences of accidents, then the physics on which the predictions are based should be described or reference made to a published article.

**Q: Does the safety report describe meteorological conditions, which are appropriate for the site, and in sufficient detail?**

A safety report should present wind rose data (wind speed, wind direction and atmospheric stability) for the site in order to establish the frequency and direction of adverse atmospheric conditions. This is particularly important for pool fire hazard.

Operators should demonstrate awareness of the changes in accident consequences with weather conditions by presenting results for different atmospheric stability and wind speed. They should recognise that the wind direction can vary over 360° and that D5 and F2 do not necessarily encompass the full range of consequences of an accident.

An intense fire generates a buoyant smoke plume which, under certain weather conditions, will rise high into the air. Ground level concentrations of dangerous substances are then very low and the hazard range for the fire may not extend off-site. A high-speed wind (15m/s) tends to prevent a buoyant plume rising, therefore a safety report should evaluate the consequences of fires for a range of weather conditions.

If a passive dispersion model is used to predict down wind concentrations of dangerous substances, weather conditions used to calculate the hazard range should include D5.

**Q: Are the features/systems that may limit the consequences of accidents identified?**

Operators should not reduce the frequency of an event or the severity of the consequences of an accident on the grounds of the presence of a safety system. For example, the Operator should not claim that a release will be terminated early by a shutdown system that may fail on demand. Nor should he discount an initiating event on the grounds that a permit-to-work system precludes the necessary conditions.

Ideally, the safety report should quantify the consequences of events with and without safety features operating so that their 'value' can be assessed and balanced against their reliability.

**Q: Does the safety report contain all the chemical and physical properties needed to assess the risks from the site?**

A safety report should present the entire chemical, physical, toxicological and eco-toxicological information that is needed to calculate risk to people and the environment. In the case of agrochemicals this means: -

- Mammalian oral toxicity data.
- LC50 for rainbow trout or some other sensitive species.
- Concentraions that will kill flora.
- Concentrations that will kill bees.
- LC50 for crusteau.

Toxicity data should also be provided for any toxic substances produced by combustion together with their production ratio in (kg of combustion product)/(kg of compound burnt).

**Table 1 : Sources of Data for Off-site Accident Initiators**

<b>Initiator</b>	<b>Method of Model</b>
Aircraft impact	AEA methodology
Seismic event	British geological survey data
Lightning strike	Electricity council data and methodology, BS 6651: 1999
Severe environmental conditions:- Abnormal rainfall Abnormal snow fall Very low temperature High temperature Gale force winds	Historical data plus reasoned argument
Flooding	Site and met office data plus reasoned argument
Subsidence	Historical data plus reasoned argument
Land slip	Historical data plus reasoned argument
Fire or explosion at adjoining plant	Site environs information plus relevant data where relevant
Missile from off-site	Site environs information plus relevant data
Hazardous substance pipeline rupture	Site environs information plus relevant data
Collapse of high voltage cable	Site environs information plus relevant data
Impact by out of control road or rail vehicle	Site environs information plus relevant data
Other	

**J.P. Byrne, “The calculation of aircraft risk in the UK”, prepared by AEA Technology plc for the Health and Safety Executive 1997. Contact Research Report 150/1997**

The method of measuring the frequency of accidents caused by off-site events should be fit for purpose. In other words it should be proportionate to the level of risk. Thus, if a site is located far away from any airport or flight path (military or civil), then it is acceptable for the safety report to refer to the background crash rate for the UK. On the other hand, if the site is located close to a busy airport then a much more detailed assessment of aircraft impact should be carried out.

**Criterion 3.3 “The safety report should identify all potential major accidents and define a representative and sufficient set for the purpose of risk assessment.”**

This criterion reminds Assessors that they need to check that:-

- The safety report meets Schedule 4, Part 2, paragraph 4 of the regulations, which requires identification of all possible major accident scenarios.
- If the major accidents are put into groups, the representative accident sequences are suitable and sufficient for risk assessment purposes.

Ideally, the Operator should summarise, in a proportionate way, the results of hazard studies, the methods used and the expertise of the team involved. The scope of the studies and the HAZID process used should also be described. To provide a convincing demonstration that the list of MAs is complete, the process needs to be systematic, ie each

plant and its operational sequences should be considered in turn, including the possibility of interactions. Assessors should judge the completeness and adequacy of the way these issues are dealt with by asking the following questions:-

**Q: Is the approach the Operator has adopted to identify all major accidents suitable and fit for purpose?**

Operators are likely to refer to a list of fire initiators because these are common to all warehouse sites. In the case of explosions, fire is probably the main initiator, but the report should demonstrate that no other accident initiators have been overlooked. Assessors should take into account the scale of the hazards when making a decision on this issue (proportionality).

**Q: The accidents considered should include those initiated by off-site events.**

The accident analysis should identify all potential off-site initiators of major accidents and an indication of their likelihood (see Table 1). Other environmental initiators such as a freak storm and subsidence do not necessarily cause a fire. Assessors should not expect to see a detailed derivation of fire probability for on and off-site initiators; in most cases, the Operators will assign frequencies on the basis of engineering judgement or historical records

**Q: Have all possible sources of major accident hazard been identified?**

Many chemical warehouse sites store LPG for fork lift trucks and diesel for HGVs outside the warehouse. Others have small segregated stores containing peroxides or highly toxic or highly flammable substances. The accident identification process should not be restricted to the main warehouse, but should describe the consequences of accidents involving these additional hazardous substances.

**Q: Are the accidents addressed in the safety report representative of the full spectrum of major hazards presented by the installation?**

The safety report should describe the consequences of an explosion if the warehouse contains explosive substances and a large spill if it stores toxic or eco-toxic liquids in bulk. Fires present three hazards, - thermal radiation from the flame pillar, a smoke plume that contains substances hazardous to health, and run-off of contaminated water. All of these should be addressed in detail. The hazards from LPG and diesel storage should be addressed if they extend off-site, but the detail should be proportional to the off-site risk.

At some sites a fire in one warehouse can spread to another. A safety report does not need to determine the consequences of two warehouses on fire simultaneously, but it should independently consider fires in different warehouses if these contain different substances, or, by virtue of their location or construction, present a different off site risk to local populations or the environment.

**Q: Have all the potential consequences of each of the reduced accident set been considered?**

Fire in chemical warehouses can give rise to:-

- thermal radiation hazards.
- explosion hazards.

- a smoke plume containing dangerous substances.
- deposition of eco-toxic substances onto surrounding areas.
- contamination of local water courses.

All of these should be addressed in the safety report. Some are more probable than others, but those contributing little to the total risk should not be ignored. Operators of warehouses that do not store explosive substances should not ignore explosions completely, but state that explosions are very unlikely because of the absence of explosive material.

**Criterion 3.3.1 “The safety report should demonstrate that a systematic process has been used to identify all foreseeable major accidents.”**

A systematic accident identification process is more important for chemical processing plant than for warehouse sites, but to judge compliance with this criterion Assessors can ask the following questions:-

Q: Is it obvious that all major accident scenarios have been identified?

Systematic approaches such as HAZOP, event tree analysis and failure modes and effects analysis are probably not appropriate for warehouse sites, but all accident (fire) initiators should be discussed. Since the majority of these are common to all sites, it is permissible for Operators to simply list them and deal with each one in turn. Compliance with the regulation is then a matter of checking if the Operators list is complete when compared to that given in Table 1.

Q: Does the Operator provide evidence that all major accident hazards have been addressed.?

Explosions can damage houses, listed buildings, nearby office blocks and chemical plant. Assessors should expect to see all of these potential consequences addressed. Safety reports that neglect of any one of them should be considered deficient, unless it is obvious that the hazard cannot be realised (e.g. explosive material not stored).

**Criterion 3.3.2 “The hazard identification methods used should be appropriate for the scale and nature of the hazards.”**

Hazard studies employing HAZID techniques are widely used in the chemical industry and can be carried out at various stages during the lifecycle of a plant. They are systematic way of managing hazard over time, from the business requirement stage through to demolition and disposal. HAZID techniques seek to identify hazards in an absolute or relative way. Relative methods use checklists or hazard indices based on experience and lessons from incidents. Absolute methods are based on deviations from design intent eg HAZOP. Details can be found in Lees (1996), Kletz (1999) and CCPS (1989).

Methods (listed in increasing proportionality) that might be used include:-

- Industry standard or bespoke checklists for hazard identification.
- Safety reviews and studies of the causes of past major accidents and incidents.
- FMEA (Failure Mode and Effect Analysis).

- HAZOP (Hazard and Operability Studies).
- Job safety analysis (eg Task Analysis).
- Human error identification methods.

Whatever approach is used, it must be documented as part of the safety report, or separately - in which case the main findings should be summarised in the report. As proportionality increases, and particularly in the case of new novel plant, some use of absolute methods is normally required. Both type of method need to consider 'common cause/mode' failures such as loss of power, or other services.

In order to test compliance with this criterion the Assessor can ask the following questions:-

**Q: Does the safety report describe a hazard identification process that instils confidence in its completeness?**

The safety report should describe and justify the method used to identify major accident hazards. Assessors who are not convinced that all accident scenarios have been identified may deem the report 'non compliant'. However, use of a formalised accident identification process is not essential and an approach that is not completely systematic, but is seen as 'fit for purpose' is acceptable.

**Q: Does the warehouse only store packaged goods that are incapable of exploding?**

When explosions are not major accident hazards, the safety report only needs to consider the consequences of spills and fires initiated by off-site or on-site events. These are listed in Table 1 and each one should be addressed. A safety report that fails to discuss systems and procedures to minimise the risk from accidents may fail to meet the assessment criteria. Discussions of off-site accident initiators for warehouses in isolated locations, where very few if any people are at risk, do not need to be very detailed.

**Q: Does the warehouse store explosive (e.g. sodium chlorate) or potentially explosive substances (e.g. organic peroxides)?**

Safety reports for warehouse sites that store explosive materials must consider all the different ways an explosion can be triggered and describe the safeguards that are in place to prevent such events occurring. The consequences that should be addressed are blast over pressure, missiles and knock-on effects. Organic peroxides can give rise to an explosion, an intense fire and a fireball. The consequences of all of these should be determined in the safety report.

The principal initiators of explosions are fire, spills that result in fire, or any other event that produces localised and prolonged high temperatures such as an overloaded electrical cable, a steam pipe, an exothermic chemical reaction or an overheated fork-lift truck. The safety report should address each of these in turn and show that the risk is controlled and tolerable.

**Q: Does the site store toxic or eco-toxic liquids in bulk**

The safety report should consider ways, in which the contents of large drums and IBCs containing toxic or eco-toxic liquids can be spilt. In particular, leaks, punctures and sabotage should be addressed and the safety report should demonstrate that all necessary measures have been implemented to reduce the risk of spilt material leaving the site.

**Criterion 3.4 “The safety report should contain estimates of the probability (qualitative or quantitative), of each major accident scenario or the conditions under which they occur, including a summary of the initiating events and event sequences (internal and external), which may play a role in triggering each scenario.”**

Criterion 3.4 is about the completeness of the accident analysis and the quantification of probabilities. It focuses on initiators - have all of them been identified and whether the methods used to determine accident sequence probabilities are appropriate.

The depth of the analysis of the event sequences, which determine the likelihood of realising each major accident scenario needs to be proportionate. At the lowest level of proportionality - provided it is demonstrated that a plant is designed, built and operated to current standards - it will usually suffice for qualitative descriptors of likelihood to be assigned to each MA. For example, the CIA's guidance on emergency planning for chlorine installations gives the following frequency categories:-

Extremely	<	$10^{-6}$ /year
Very unlikely		$10^{-6}$ to $10^{-5}$
Unlikely		$10^{-5}$ to $10^{-4}$
Quite unlikely		$10^{-4}$ to $10^{-3}$
Somewhat unlikely		$10^{-3}$ to $10^{-2}$
Fairly probable		$10^{-2}$ to $10^{-1}$
Probable	>	$10^{-1}$

In more complex situations a satisfactory demonstration under Schedule 4 may require the consideration of the conditions under which events occur, their likelihood, and how the events interact so that the likelihood of certain major accidents can be estimated. This will require consideration of the whole causation/outcome sequence.

In order for Assessors to form a judgement on these issues, they should ask the following questions:-

**Q: Does the report quantify, albeit with limited accuracy or in qualitative terms, the frequency of each major accident scenario?**

Assessors should expect to see all events producing a major accident hazard identified and the frequency of each event sequence determined. There is a requirement to demonstrate that the risk from risk dominating sequences is ALARP. The greater the risk to people off-site, the more reliable must be the quantification.

For single event initiators such as aircraft impact and earthquake, probabilities based on historical data are acceptable. But it may not be sufficient for the Operator to use data from published sources for event sequences involving say hot work and operator error, without justifying their suitability. The safety report should justify the absence of further redundancy and diversity and show that all necessary measures have been taken to minimise operator error.

Fault tree analysis is not essential to determine accident probability and companies are much more likely to use argument based on the following:-

- Prescriptive legislation.
- Regulatory guidance.

- Standards produced by Industry Associations and other standard making organisations.
- Operating company or market leader documents.
- Historical data.

Approaches based on well founded argument are acceptable, but a safety report that:-

- discounts some accident sequences;
- fails to consider worst case locations for breaks;
- assumes procedures and/or safety systems function perfectly;

may be judged as failing to meet the assessment criteria.

Base event failure rate data are essential components of quantitative risk assessments, but they must be relevant and applicable to site circumstances. Simply taking a number from the literature without consideration of whether it applies to the site in question is unlikely to be acceptable. On the other hand, use of a failure rate that is not consistent with historical or relevant generic industry data must be justified.

**Q: Have all the sequences leading up to each major event been identified?**

All events/initiators identified in Table 1 should be considered, even if some of them are not applicable to the site. If the warehouse does not store explosive materials or peroxides, some accident scenarios listed in Table 3 may not be relevant. In such cases the safety report should state that there is no intention to store these particular materials, therefore their associated hazards do not need to be considered.

Assessors should not expect quantitative analysis in respect of the probability of some on-site fire initiators such as employees smoking, arson, spillage of incompatible chemicals etc. because they are almost impossible to quantify.

**Q: Is the complexity and level of detail of the analysis appropriate to the scale of the hazard?**

The frequency of accidents that have severe consequences for local populations need to be determined more precisely than accidents that have only on-site effects. For most sites this implies that fires should be analysed in depth while thermal radiation hazards from the flame pillar can be treated simply. The radiation falling on targets more than about 30m from the warehouse can be calculated using a point source model approximation assuming 33% of the heat generated by combustion is radiated.

**Q: Does the accident analysis identify and quantify all event sequences.**

Accidents that are the result of multiple failures should not be assigned a frequency unless details of the analysis of the mode and probability of each of the failures that comprise the accident sequence are provided. For example, a safety report that simply states that the frequency of an event is 'f' on the basis of historical data should be judged as containing insufficient detail.

Q: Where the likelihood of a major accident scenario is not predicted, does the safety report describe the measures to prevent all conditions and events leading to it?

If a safety report does not predict the frequency of one or more major accidents, it must describe the conditions under which the accidents can occur. It must then show that the installed safeguards (see Table 2 for some examples) ensure that those conditions are very unlikely ever to arise. This demonstration is only possible for certain systems which have been designed to be intrinsically safe. A system that depends on operators and a mixture of active and passive control systems is always at risk from human and equipment failures.

**Table 2: Measures to Reduce Risk and Mitigate Accident Consequences**

<b>Initiators and MAH control</b>	<b>Measure to reduce risk</b>
Fire initiators	
Smoking	Clear no smoking signs, staff instructions/training and threat of loss of employment.
Vehicle fire	Vehicles not unloaded in warehouse, strictly enforced speed limit on site, fire extinguishers at main entrance.
Fork-lift truck fire	Scheduled maintenance programme, well trained drivers, use of electric vehicles, fire extinguisher on each vehicle.
Spill of flammable liquid	Staff training, spill cleanup kits available, use of non sparking tools in warehouse, oversized drums and trays available, regular inspections of warehouse stock.
Incompatible chemicals	Incompatible chemicals not kept in same warehouse, stock inspection before storing, operator training.
Overloaded electrical circuit	Absence of electrical circuits in warehouse.
Arson	Security fence, intruder alarms, CCTV, forecourt lighting.
Hot work	Permit to work system, work fully supervised, risk assessment prior to work starting.
Fire during fork lift truck charging	Fork lift trucks not charged in warehouse.
Diesel tank fire	Diesel tank sited well away from warehouse, ignition sources well controlled.
Other on-site fire	LPG tank sited well away from warehouse.
Fire Control	
Sprinkler system	in rack foam+water system, testing of diesel engines, back up , regular testing.
Fire fighting arrangements	Staff training, fire fighting facilities in warehouses, specially trained staff, good supply of fire fighting water, fire fighting plans drawn up in consultation in fire service.
Fire walls	Between warehouses and dividing warehouses, structural elements clad in fire resisting material, vents to reduce smoke logging.
Accident consequence mitigation	
Fire fighting strategy	Agree let-burn policy with fire service.
Site isolation	Single valve prevents water leaving site, instruction to isolate in emergency plan, hold up for several hundred cubic metres of water.
Clean up	Plans for dealing with large volume of contaminated water.

**Criterion 3.4.1 “The report should demonstrate that a systematic process has been used to identify events and event combinations, which could cause MAHs to be realised.”**

Most fire initiators are common to all warehouse sites and the severity of spills, for which accident scenarios are easily identified, depends on location. Highly reactive substances such as peroxides can be responsible for major accidents and several scenarios need to be identified, but again the number of scenarios leading to a dangerous situation are limited and tend not to be site specific. In order to test compliance with this criterion Assessors may find the following questions useful.

**Q: Has a systematic process been used to identify events that cause the realisation of a major accident.**

It is more important for the Assessor to be satisfied with the completeness of the accidents considered than for the report to use a formalised methodology to identify accident scenarios. If the accident analysis deals with each item of plant in turn and identifies all initiators and all types of fire/explosion, then it can be considered systematic. However, if by reference to Table 3, the Assessor can identify scenarios that have been overlooked, the report is deficient. The seriousness of the omission depends on whether the consequences to the public are worse than those from other accidents that are dealt with and whether the risk from the event in question is ALARP.

**Q: Are the hazards from all warehouses on site identical?**

The risk to local populations and the environment from different warehouses on a large site is likely to vary depending on the inventory and location. A safety report should evaluate the consequences of fire/explosions in all warehouses that store significantly different substances, and/or are located such the fire is more probable, or fire fighting water run-off is more likely. The location factors that may be significant include:-

- Presence of an overhead high voltage line.
- Close to the site boundary where fire fighting water could run-off site.
- Close to storage of a flammable substance e.g. diesel tank, LPG tank.
- Close to a high pressure gas pipeline.
- Close to an adjoining site storing flammable or explosive substances.
- Close to an area that is regularly used for open air functions attended by many people e.g. a Sunday market or a football ground.

With respect to warehouse inventory, the differences that may be significant include:-

- A large quantity of highly toxic substances.
- A large quantity of highly eco toxic substances.
- A large quantity of substances with particularly toxic combustion products (e.g. sodium cyanide).
- A large quantity of aqueous toxic substance (e.g. Paraquat).

**Table 3: Check List of Accident Initiators**

Accident	Comment
<b>OFF-SITE ACCIDENT INITIATION PROBABILITY</b>	
Aircraft impact	
Seismic event	
Subsidence	
Extreme environmental conditions abnormal rain fall abnormal snow fall very low temperature high temperature flooding gale force winds lightening strike	
Vehicle impact	
Land slip	
Explosion	
Fire	
Missile	
Pipeline rupture	
<b>ON SITE ACCIDENT INITIATOR PROBABILITY</b>	
Overloaded electrical cable	
Malfunctioning fork lift truck	
Uncontrolled hot work	
Arson	
Spillage of incompatible chemicals	
Employee smoking	
Ignition of spill of HFL	
Diesel tank fire	
Lorry fire	
Fire during battery charging	
Other on-site fire	

**Criterion 3.4.2 “All safety critical events and associated initiators should be identified.”**

Since the majority of hazards presented by chemical warehouses stem from fires and explosions (following a fire), the concept of safety critical events may not be strictly applicable.

**Criterion 3.4.3 “Estimates of, or assumptions made about, the reliability of protective systems and the time for operators to respond and isolate loss-of-containment accidents, etc need to be realistic and adequately justified.”**

Dangerous materials tend to be stored in warehouses in small quantities ranging from 1kg to 1m<sup>3</sup> IBC. In general the loss of containment in an accident results in a small spill that has little off-site safety implications for people but could have an impact on the local environment.

However, failures (or inappropriate use or omission) of protective systems such as sprinklers, fire doors, spill kits, respiratory protective equipment and protective clothing in

general should be considered, together with issues covered by Criterion 3.1.1. This is particularly important when failure of such systems can lead to escalation of an event.

**Criterion 3.4.4 “The methods used to generate event sequences and estimates of the probabilities of potential major accidents should be appropriate and have been used correctly.”**

The only event sequences that were related to warehouses are those that result in a major fire/explosion. In general, these consist of an initiating event and a failure to prevent the fire from spreading. Therefore, criteria 3.4.4 is not strictly relevant to warehouse safety reports.

**Criterion 3.4.5 “The safety report should provide adequate justification for event probabilities that are not consistent with historical or relevant generic industry data.”**

It is acceptable for Operators to make use of historical data on the frequency of off-site and some on-site accident initiators. However, Assessors should be convinced that the measures and procedures to reduce the probability of fires/explosions are adequate. In order to test “adequacy” Assessors may find the following questions and answers useful.

**Q: Has the Operator used site specific data to determine aircraft impact frequency?**

Warehouses located several tens of miles from an airfield are unlikely to suffer aircraft impacts at a higher rate than the background rate for the area. This has one of three values depending on location: -

$9.7 \times 10^{-5} \text{ km}^{-2} \text{ yr}^{-1}$  if warehouse lies within one of three high crash concentration zones.

$5 \times 10^{-6} \text{ km}^{-2} \text{ yr}^{-1}$  if it lies more than 40km from one of these zones.

A value between these two figures, based on linear interpolation, if it lies within 40km of a high crash rate zone.

If the site is located with 15km of an airfields, regardless of size, then a methodology similar to that proposed by AEA should be used to determine impact frequency.

**Q: How has the Operator determine the probability of a seismic effect initiating a major accident?**

Although seismic activity varies slightly across the UK, Operators are justified in making use of average background data produced by the British Geological Survey. It is probable that modern warehouses will not suffer serious damage at seismic intensities of less than MSK VIII and these events occur at a frequency of  $2 \times 10^{-5} \text{ yr}^{-1}$ . The probability of an earthquake causing a major fire is not likely to be more than 0.1, hence  $2 \times 10^{-6} \text{ yr}^{-1}$  is about the figure Assessors should expect to see in a COMAH safety report for a major fire initiated by a seismic.

**Q: How has the Operator determined the probability of lightning strike on his warehouse?**

The frequency of lightning strikes in the UK is between 0.1 and 0.6 flashes to the ground per  $\text{km}^2$  per year. Most modern warehouse, with the exception of high-bay warehouses, are not more than 15m to the ridge and the frequency of a lightning strike on the building can be

determined by multiplying the appropriate location figure by the area of the warehouse in km<sup>2</sup>.

**Q: How has the Operator determined or ranked the probabilities of accident initiators**

Essentially all scenarios resulting in a major fire can be split into an initiating event and a conditional probability of a fire in the warehouse. Operators should rank scenarios and show that none have an intolerable frequency, and that the risk from those with a frequency between about 10<sup>-6</sup>yr<sup>-1</sup> and 10<sup>-4</sup>yr<sup>-1</sup> is ALARP.

Most Operators will not calculate frequencies and probabilities, but may simply place points on a diagrammatic representation of the event risks. Assessors should expect to see some form of justification for the location of the points even if it is entirely qualitative. Operators who do not address fire or explosion probability fail to comply with the criteria.

In order to be satisfied about the level of safeguards, Assessors should ask themselves - could this Operator have done more to reduce the probability of fire at a cost that is in proportion to the decrease in risk that would be achieved, and using a system or procedure that would not unreasonably hinder normal day-to-day operations. The sort of measures falling into this category include:-

- Partial site bunding to a height of 0.5m.
- Prohibit smoking on site except in one designated area.
- Remove electrical circuits from warehouses with the exception of lighting.
- Prohibit loading/unloading of vehicles in warehouses.
- Comply with HSE recommendations on segregation of chemicals.
- Stop charging fork-lift trucks inside warehouses.
- Install intruder alarms in warehouses.
- Remove naked flames from warehouses.
- Replace shrink wrapping with stretch wrapping.
- Introduce a high quality permit to work system.
- Stop storing pallets inside warehouses.
- The installation of smoke alarms in all warehouses.
- Introduce daily inspections and monthly audits.

**Criterion 3.5 “The safety report should provide details to demonstrate that suitable and sufficient consequence assessment for each major accident scenario has been carried out with respect to people and the environment.”**

The principal hazards from warehouses are fires and explosions. There is little point in a safety report for an agrochemical or general warehouse discussing small fires that do not envelope the whole warehouse.

Assessors can test compliance with Criterion 3.5 by asking the following questions:-

Q: Is the Operator's accident consequence assessment thorough and adequately documented?

The impact of warehouse fires on local populations depends greatly on:-

- Substances burning.
- The physical form (powder, aqueous solution, dissolved in hydrocarbon).
- Where the fire starts.
- The wind speed.
- Wind direction.
- Warehouse construction.
- Assumptions about survival fractions.
- Assumptions about combustion products.
- Assumptions about the buoyancy of the smoke plume.

The consequence analysis should address all of these parameters and show how they affect the severity or hazard range. Justification should be provided for use of survival fractions less than 10%.

The steps in the consequence analysis that an Assessor should expect to see are:-

- List the assumptions that will be made about the location of the seat of the fire.
- Describe the essential features of the model that will be used to calculate fire growth, buoyancy of the plume and plume seeding.
- Describe the plume dispersion model.
- List the assumptions used to run the dispersion model (stability, wind speed and ground roughness).
- List the toxicity assumptions.
- Describe how a toxic load will be calculated.
- Present the results of running the model in terms of concentrations and dose down wind.

Present the results of thermal radiation calculations to demonstrate that the fire will not have knock-on effects.

All of the above steps should be clearly documented in the report. However, omission of one or more of them is not a significant failing if overall the consequence analysis is satisfactory.

Q: Has the Operator selected a set of accident scenarios for the safety report that encompass the hazards and risks from the site and that are sufficient to demonstrate that all necessary measures have been taken to minimise risk?

A minimum accident set for an agrochemical warehouse site would be:-

- w Fire in the flammable substance warehouse.
- w Fire in general chemical warehouse fire in small dedicated store (nitro-cellulose, sodium cyanide).
- w Explosions in materials such as sodium chlorate.

Organic peroxides hazards including explosion, fireball and intense fire.

It is likely that the hazard analysis will need to address fires occurring at different times of the year when inventories are very different.

The safety report should also consider the environmental impact of run-off of contaminated fire-fighting water.

**Q: Has the full range of consequences been addressed?**

If the warehouse contains very eco-toxic substances in powder form, the consequences analysis should consider dispersion and deposition of particulate and its impact on environmentally sensitive locations such as SSSIs, SBIs and shallow lakes etc.

The number of fatalities from inhalation of toxic substances and individuals with severe burns from fires and explosions should be determined. The effect of blast should also be quantified in terms of the number of buildings in each of several damage categories. The effect of wind direction on the number of casualties should be addressed, and the accident analysis should take into account the effect of other variables such as time of year, time of day, day of the week and rain if they have a significant effect on the off-site consequences. A limited analysis that neglects variability in accident consequences does not meet the assessment criteria.

**Q: Does the safety report outline the principal features of the mathematical models used in the consequence analysis?**

A safety report should include a brief description of the essential features and assumptions of the mathematical models used by the Operator to determine the consequences of major accidents. If the models are part of a well-known software package, then only the name of the software is required, but full details of the input should be provided. In-house models and any validation studies that have been carried out to support them should be described in detail. The main equations of a model should be given in an appendix if they have not been published elsewhere.

The fact that an Operator has used a well-validated model to determine the consequences of an accident does not guarantee that the results are reliable. Assessors should recognise that the predictions of consequence analysis are more important than the means by which they were obtained. Assessors may feel that a safety report that fails to provide input data details for predictions, which appear optimistic, fails to meet the criteria.

**Q: Does the severity of the predicted consequences influence the amount of information the Operator should supply on how they were determined?**

The level of detail that should be provided on the calculation of the consequences of an accident that do not extend off-site is less than if the hazard range encompassed a large number of people. It is not possible to be prescriptive on this issue and Assessors are expected to use professional judgement when deciding if the Operator has provided sufficient information on his consequence analysis. However, the following examples may help Assessors make a judgement on this issue.

If the level of thermal radiation at the site boundary from the flame pillar of a burning warehouse, as calculated assuming a point source radiator, is not hazardous to people, the safety report does not need to describe the thermal radiation modelling in great detail.

If the warehouse is in a rural location and no one beyond the site boundary is predicted to be significantly affected by the smoke plume, assuming passive, non-buoyant dispersion, then sparse details of the fire and dispersion modelling are adequate.

**Q: Does the accident consequence analysis extend to all dangerous substances on site?**

The safety report should determine the consequences of fires starting in different locations in different warehouses at different times of the year. In order to do this typical inventory

variations over the year for each warehouse must be provided, and the assumptions about the inventory used in the analysis clearly listed.

If a warehouse stores paraquat, the safety report should examine the off-site risk caused by a fire adjacent to the paraquat drums on the basis that toppling of the drums around the edge of the fire could release droplets into the smoke plume.

Some agrochemicals that are not very toxic contain large amounts of chlorine or sulphur. The safety report should consider combustion of these substances assuming 100% conversion of the chlorine to HCl and 100% conversion of the sulphur to SO<sub>2</sub> at a rate that depends on the rate of combustion of the parent substances by the fire.

### **Criterion 3.5.1 “Source terms used should be appropriate and need to have been used correctly for each relevant major accident.”**

The source term for an accident sequence expresses ‘how much’, ‘for how long’ and in ‘what form’. The source term for a warehouse fire defines two parameters - the rate of release of dangerous substances into the smoke plume as a function of time and the buoyancy of the plume. These in turn depend on the rate of combustion, the rate of seeding of parent compounds and the rate of heat released to the atmosphere. All are difficult to calculate and should be based on conservative assumptions. Assessors can use the following questions to test the adequacy of the source terms used in the consequence analysis.

#### **Q: Does the accident analysis include “worst case” fires?**

Worse case fires occur under "worst conditions", which are when the amount of toxic material in a warehouse is at its maximum level, when the fire starts in the in the most toxic substances and when the heat lost from the smoke plume is a maximum. An analysis based on an average inventory taking no account of the location of the seat of the fire may be overly optimistic, unless the smoke is assumed to disperse passively.

#### **Q: Are pessimistic assumptions used to quantify source terms?**

Plume seeding rates and the rate of production of toxic combustion products is almost impossible to calculate reliably. The accident analysis should be based on the assumption that 10% of the toxic inventory is seeded into the smoke plume and that the conversion of chlorine and sulphur to HCl and SO<sub>2</sub> is quantitative. Conversion of nitrogen to HCN and NO<sub>2</sub> should be set at about 5% and the conversion of carbon to CO should be 5%. A safety report should justify use of more optimistic assumptions.

The other factor greatly affecting ground level concentrations of toxic substances down wind of a burning warehouse is the heat content of the smoke plume. Fire analysis for a COMAH safety report should assume that no more than 0.4 of the heat of combustion is retained. Accident consequences based on a buoyant plume dispersion model in which more than 40% of the heat of combustion remains in the smoke released to the atmosphere may be considered optimistic.

### **Criterion 3.5.2 “The material transport models used should be appropriate and need to have been used correctly for each relevant MAH.”**

Dispersion and deposition are the transport mechanisms that determine the consequences of major fires. Assessors are likely to see a wide variety of different approaches used in

safety reports and it is impossible to provide prescriptive guidance on each of them. However, three general approaches can be identified: -

- (i) Passive dispersion model with the smoke plume passing through a virtual window not more than a few metres wide or high located at the end of the warehouse.
- (ii) Passive dispersion model using a virtual point source at a height above the ground calculated from an assumed plume buoyancy and a maximum plume rise formula similar to those proposed by Briggs.
- (iii) A buoyant plume dispersion model based on the work of Ooms or use of a computer program such as ADMS.

The first approach is the most pessimistic and will usually predict hazard ranges that are too large. The second approach is acceptable if the assumed height of the virtual source does not exceed about 50m. Computer programs that can reliably predict plume rise from an area source are usually unable to deal with the fire growth and plume seeding part of the calculation. Assessors are likely to see all three models used in safety reports.

An important part of the consequence assessment is the calculation of ground deposition from the smoke plume. Ground contamination is the product of ground level concentration of particulate, the deposition velocity and the duration. Assessors are likely to encounter a range of deposition velocities in safety reports, but a value less than the settling velocity is likely to yield an optimistic estimate of ground deposition.

Assessor can test compliance with this criterion with the aid of the following questions: -

**Q: Does the safety report present a graph or details of the rise of the smoke plume as it travels away from the warehouse.**

Its buoyancy number, the windspeed, the atmospheric stability class and the height of any inversion layer govern the rise of a smoke plume. Plume buoyancy increases as the fire spreads through the warehouse while the other parameters are constants. Some Operators may use a model that incorporates time dependency, while other may adopt a more simpler approach and assume the smoke plume quickly rises to a certain height and then disperses passively. In either case there is scope for optimism in the assumptions and the safety report should provide full details of the model and its assumptions. Failure to do so is may be regarded as a failure to comply with the criteria.

A safety report that bases the consequence assessment on an average burning rate and a constant plume buoyancy and predicts that dangerous substances are carried high into the air, fails to meet the assessment criteria because its predictions are likely to be overly optimistic.

**Q: Does the safety report address particulate hazards?**

A safety report should identify any dangerous substances in powder form that can be seeded into the smoke plume during a fire and determine the consequence of its uplift and dispersion in the smoke plume. When the particle size range is not known, or extends over a wide range, two calculations may be required. The first based on the assumption that toxic particles have an aerodynamic diameter of 1-2 $\mu$ m and disperse as a gas, and the second assuming that the aerodynamic.

The dispersion model should be able to account for the settling and deposition, but again several models have been developed. The “tilted plume” approach, which assumes uniform depletion of the plume, is as good as any other.

A safety report that does not discuss hazards from particulates is likely to underestimate the potential impact of a warehouse fire on local populations and the environment and consequently may be deemed to fail to meet the assessment criteria.

**Q: Does the safety report consider an appropriate range of weather conditions for the dispersion and deposition analysis.**

The wind speed, the atmospheric stability and the height of an inversion layer affect the rise of a buoyant plume. The safety report should identify the conditions that maximise the hazard range. These could be D15 or D5 with a low inversion height. Under F2 weather conditions, the positive vertical temperature gradient inhibits the rise of marginally buoyant plumes, but the smoke plume from a warehouse fire, even in the early stages rises to a height of several tens of metres. Hence hazard ranges for warehouse fires under F2 conditions rarely extend off-site.

A very buoyant plume will fail to rise under D15 conditions. Instead it will disperse rapidly at low level and produce high concentrations in the near field. Under D5 conditions a buoyant plume rises quickly, but if there is an impenetrable inversion layer at a height of 200m, ground concentrations of dangerous substances could be relatively high at large distance.

A safety report that fails to consider a wide range of weather conditions may fail to meet the criteria.

**Q: Does the consequence analysis consider different wind directions and hence the effect of the warehouse on the dispersion process.**

The behaviour of a buoyant plume released from a burning warehouse is affected by wind direction with respect to the axis of the warehouse (see Figure 1). Plumes that are released into a wind blowing along the ridge of a warehouse produce smaller ground level concentrations than those produced by a wind blowing at right angles to the ridge. A safety report that only calculates hazard ranges for a wind blowing along the ridge is likely to under estimate the consequences of fires.

**Q: What ground roughness values are used for the dispersion calculation?**

The rougher the ground over which a flammable gas is dispersing the more rapid is the rate of air entrainment and the shorter is the flammable hazard range. A ground roughness value of 0.1 corresponding to elements on the ground about 0.5-1 metre high is recommended for dispersion over agricultural land. A roughness value of 0.3 should be used for dispersion over a suburban area. Although higher roughness values may be assigned to some industrial sites, their use results in a reduced hazard range that could, under certain circumstances, be optimistic. An Operator should make a special case for use of a ground roughness value of more than 0.3. A value of less than 0.1 may be considered appropriate for dispersion over water i.e. at estuary or coastal sites.

**Q: What averaging time is used for dispersion calculations?**

Due to the variability of atmospheric conditions a dispersing gas plume meanders and the concentration at a fixed point down wind of a release fluctuates. Most dispersion models account for this phenomena by introducing an averaging period. The longer this is, the

more allowance is made for the variations in wind direction and the smaller is the predicted concentration.

There is not a consensus on the most appropriate averaging period for dispersion calculations, but widespread support exists for use of 600 seconds and 10 seconds for continuous and instantaneous releases. In some passive dispersion models the standard deviations are linked to specific averaging times.

Since criteria 3.5.2 is concerned with the appropriateness of transport modelling assumptions, and averaging time can have a significant affect on the predicted hazard range, it is important that the Operators state the values used in the dispersion analysis. This requirement is not restricted to averaging time; Operators are obliged under criterion 3.5 to provide details of all important modelling assumptions and input.

**Q: Is a time dependent fire/dispersion model used to calculate hazard range?**

Fires that are not controlled spread through a chemical warehouse in about in about 20 minutes. During this period both the burning rate and hence the rate of release of heat increase, but so does the rate of plume seeding with vaporised substances and combustion products. Down wind concentrations of dangerous substances that individuals are exposed to reach a peak after about 10 minutes.

A time independent model is likely to underestimate the dose received by individuals down wind of the fire, unless it is based on several pessimistic assumptions. If these are not described in detail in the safety report, Assessors must conclude that the predictions are optimistic.

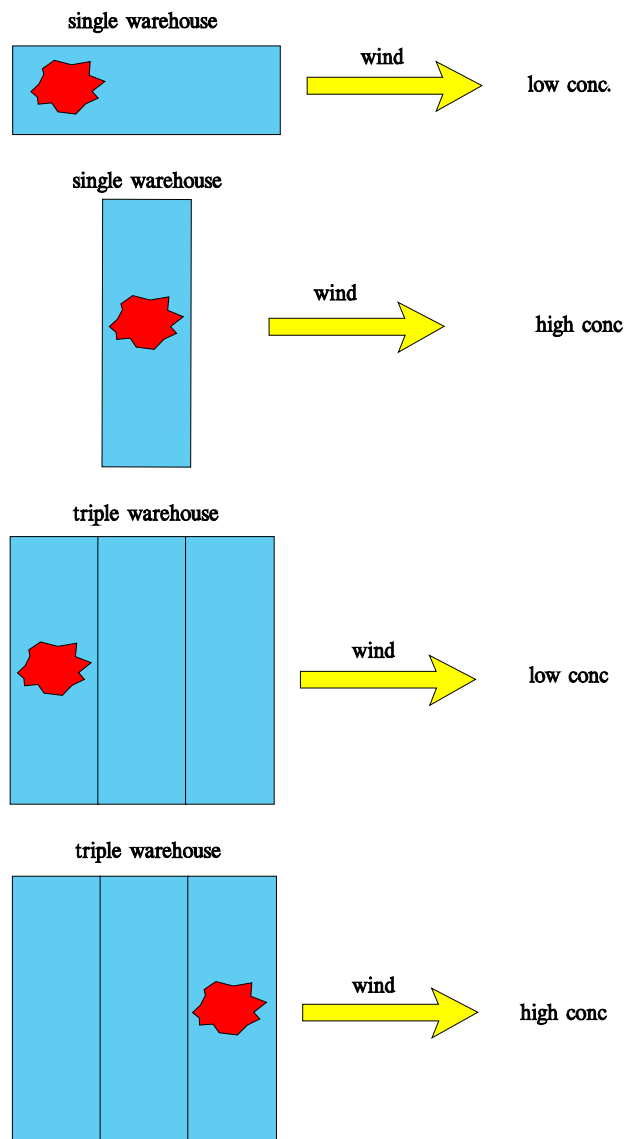


Figure 1: Effect of fire location on down wind concentration

**Criterion 3.5.3 “Other consequence models (eg BLEVE, warehouse fire, etc), used should be appropriate and need to have been used correctly for each relevant major accident.”**

Aside from vapour transport models, the consequence analysis for a chemicals warehouse needs to include models for thermal radiation from different types of fire and for the over pressure produced by explosions. It is important that these models do not under estimate the hazard range, but it is difficult for an Assessor to make judgements about the level of pessimism in a calculation if full details of the model are not supplied. Toxic effects and toxic combustion products should also be included in the report, but their assessment presents problems. The following questions may help Assessors judge if the consequence analysis is based on appropriate assumptions:-

**Q: What wind speeds are considered for the consequences of thermal radiation from the flame pillar?**

The flame pillar from a burning warehouse becomes tilted in a high wind and the thermal radiation flux falling on downwind objects increases. Under these conditions the risk of the fire spreading to an adjacent warehouse or igniting a nearby diesel or LPG tank increases. A safety report should therefore determine the consequences of a warehouse fire in a high wind, otherwise the accident analysis may be deemed optimistic - see Table 5.

**Q: What atmospheric humidity is assumed for thermal radiation calculations?**

The thermal radiation emitted by a fire is attenuated by water vapour in the atmosphere, therefore the flux at a target is inversely proportional to the humidity. In the UK, humidity varies considerably, but an average value of 60% is often assumed for hazard calculations. This figure is probably overly pessimistic for F2 weather conditions, but an Operator should justify the use of significantly higher values that could result in optimistic predictions.

**Q: What surface emissive power is assumed for warehouse fires?**

Chemical warehouses generally hold a large range of compounds hence it is difficult to specify the most appropriate emissive power for the flame pillar. Hydrocarbon pool fires have a peak emissive power in the range 90-200kW/m<sup>2</sup> therefore a safety report should justify any figure that is less than this upper figure - see Table 5.

**Q: What stored energy figure is used in explosion calculations?**

There are several methods of calculating blast over pressure from flammable gas explosions.

The consequences of explosions in warehouses containing sodium chlorate and organic peroxides can be determined on the basis of an equivalent mass of TNT. Data on equivalent explosive power and efficiency is sparse, but the following data are recommended:-

**Table 4: TNT Equivalence for Some Explosive Substances**

<b>Substance</b>	<b>TNT Equivalence</b>
Sodium chlorate	0.04
Ammonium nitrate	0.14
High strength hydrogen peroxide	
Dibenzoyl peroxide	0.09
t-butyl-peroxyacetate	0.17
t-butyl-peroxypivalate	0.14
t-butyl-peroxy maleate	0.14
Methyl-ethyl-keytone 60%	0.26
Peroxyacetic acid (40%)	0.05
Teriary butyl peroxybenzoate	0.4
Dibezoyl-peroxy benzoate	0.25
Di-tert-butyl peroxide	0.38

It is reasonable to set the mass of TNT to twice the mass of gas in the confined or congested volume. The TNT equivalent of most hydrocarbons is 0.42 M, where M is the mass of vapour in the cloud and major deviations from this require a good explanation.

Assessors should be aware that the TNT model is considered over simplistic because gas explosions have different characteristics to TNT explosions. The multi-energy method based on lines 2 and 7 is preferred.

**Table 5 : Effect of Input Parameters on Predicted Accident Consequences**

Parameter	Accident Type/Phenomena	Acceptable Value	Direction to Reduce Severity of Consequences
Wind speed.	Passive dispersion Buoyant plume	2m/s F stability 5m/s D stability 10 - 15m/s D stability 2m/s F stability	+ + -
Ground roughness.	Passive dispersion.	0.3m (suburban environment). 0.1m (open countryside)	+ +
Averaging period.	Passive dispersion.	600s plume 10s puff	+ +
Humidity.	Fires and fireballs	60% or less	+
Surface emissive power.	Fireball. Warehouse fire flame pillar	200kW/m <sup>2</sup> 200 kW/m <sup>2</sup>	- -
Inversion height	Buoyant plume	400m	+

**Criterion 3.5.4 “The harm criteria or vulnerability models used to assess the impact of each MAH on people and the environment should be appropriate and have been used correctly for each relevant major accident.”**

A safety report should calculate hazard ranges for exposure to toxic smoke, thermal radiation and explosion over pressure. The hazard range for the smoke plume should be based on the concept of Dangerous Dose assuming that the dangerous dose fractions from a variety of toxic substances are additive. These include:-

Vaporised parent compounds and particulates:-

- Pesticides.
- Herbicides.
- Fungicides.
- General organic and inorganic chemicals.

Combustion products:-

- hydrogen chloride.
- sulphur dioxide.
- hydrogen cyanide.
- nitrogen dioxide.
- carbon monoxide.

Toxic gas exposure estimates for indoor and out of doors should be based on the dangerous toxic load  $C^n t = A$  (ppm<sup>n</sup> min) relationship where concentration is raised to a power “n” depending on the hazardous substance. A “dangerous toxic load” typically represents, a dose that would result in:-

- 1-5% fatality.
- 50% hospitalisation.

- Severe distress for the remainder.

However the “A” value can be modified to account for populations of different sensitivity. A lower value of “A” may be appropriate for predicting the effects of a release into an old persons home. Toxicity relationships for the above light gases can be found in the hazards section of this SRAG.

Hazard range and casualties from thermal radiation should be based on:-

- dangerous dose of thermal radiation for vulnerable people (500 tdu);equivalent to 4.9kw/m<sup>2</sup> exposure for 1 minute.
- dangerous dose of thermal radiation for average members of society (1000 tdu);equivalent to 8.2kw/m<sup>2</sup> exposure for 1 minute.
- significant likelihood of death (1800 tdu);equivalent to 12.8kw/m<sup>2</sup> exposure for 1 minute.

For over pressure the appropriate hazard ranges correspond to:-

- window breakage (40 mbar);
- houses uninhabitable but repairable (100 mbar);
- severely damaged houses (200 mbar);
- houses completely demolished (500 mbar).

For secondary fires:-

- Spontaneous ignition (25.6 kW/m<sup>2</sup>).
- Piloted ignition (14.7 kW/m<sup>2</sup>).

It is very important that the full spectrum of casualties is calculated, not only for risk evaluation, but also for emergency planning purposes. Some safety reports may contain casualty estimates based upon other criteria such as a dose that relates to a value considered immediately dangerous to life and health (IDLH). Assessors should be check that such predictions are not overly optimistic.

The following questions may assist the Assessor to judge the adequacy of the accident consequence analysis:-

**Q: What hazard ranges for thermal radiation has been calculated?**

Although HSE has published its thermal radiation criteria, some safety reports calculate hazard ranges to different dose and flux levels. One of these is 300 tdu, which is the dose to cause blistering of the skin. It extends beyond the 500 tdu range and may be regarded as pessimistic, but any dose implies an exposure duration and Assessors need to understand the assumptions being made before making judgements about acceptability. In particular significant departures from the following assumptions that lead to shorter hazard ranges should be justified:-

- The exposure period for fireballs is the fireball duration (no escape).

- Average members of the public escape from long duration fires at 2.5 m/s.
- The escape speed for the old and very young is closer to 1 m/s.
- The distance to shelter in suburban areas is typically 50 metres.
- The distance in rural areas is more likely to be at least 75 metres.

Individuals escaping from a source of thermal radiation reduce the dose they receive on two counts. Firstly they increase the distance between them and the fire, (and thereby reduce the level of received thermal flux) and secondly, they can reduce the exposure period by going indoors.

HSE has two criteria for thermal radiation flux to buildings based on the ignition of American Whitewood (see Consequence Assessment in part 2), and while these are useful for assessing risk to occupants of houses, they provide little information on the hazard flux for a chemical warehouse storage facility. In this context the actions of the local fire service are important because they may be able to keep adjacent items of plant cool with water sprays. However, a safety report should assume that plant in the vicinity of a major fire do not receive water spray protection for 20 minutes. Predictions based on a much shorter response time for the fire brigade are likely to be optimistic. Operators must consider the consequences of late arrival of fire fighting services, but it is permissible for them to make judgements about the probability of such an occurrence.

**Q: What hazard ranges for blast overpressure is calculated?**

The effects of blast over pressure on buildings and on people cannot be predicted precisely, but HSE has published tables of the consequences of a range of side-on over pressure. Different over pressures can be used in consequence calculations provided they convey a realistic picture of the scale and extent of the damage from an explosion. To this end, the following data are useful: -

- 2.5 mbar or 250 Pa - lower limit of window damage.
- 50 mbar or 5000 Pa - lower limit of damage to doors, cladding and people.
- 150 mbar or 15000 Pa - lower limit of severe structural damage to buildings.
- 250 mbar or 25000 Pa - lower limit of significant likelihood of severe injury.

A safety report that presents hazard ranges corresponding to higher over pressures than those above is not providing the full picture of the potential damage caused by explosions.

**Q: What dangerous substances are assumed to be in the smoke plume?**

A safety report that only considers vaporisation of toxic substances in the warehouse may underestimate the real hazard range. Neglecting of combustion products and particulate is a serious shortcoming, but some safety reports will neglect combustion products from substances not classified as dangerous under the COMAH regulations. This is not an acceptable omission as LIII (page 9 of Guide to the Control of Major Accident Hazard Regulations 1999), makes clear that all dangerous substances produced by a fire must be considered.

**Q: Do the consequence calculations account for every toxic substance in the warehouse?**

Many warehouses store agrochemicals that contain low concentrations of toxic substances and are not classified as toxic. However, they can contribute significantly to the total toxic inventory and increase the toxicity of the smoke plume if the warehouse is on fire - see Figure 1. Under COMAH the impact of all substances released by a fire in a warehouse containing dangerous substances must be determined. Therefore, the consequence analysis must take account of toxic combustion products from all substances in the fire, and toxic substances vaporised by the fire from preparations that are not classified as toxic.

It is not acceptable for a safety report to focus only on substances classified as dangerous under COMAH and neglect all others and combustion products that can contribute to the toxicity of the smoke plume.

**Q: Since many substances are likely to generate carbon monoxide when burnt, is it justifiable to only consider CO from the combustion of toxic substances?**

Virtually all organic substances produce carbon monoxide when burnt and a case can be made for taking account of the production of CO from combustion of all substances/materials in the warehouse. In fact it is acceptable for a safety report to ignore carbon monoxide production from wood, building materials etc. provided the overall approach embodies sufficient pessimism to compensate for this omission.

By comparison with toxic substances stored by a top tier COMAH site, the toxicity of CO is small, therefore its production as a fire spreads throughout a warehouse can be neglected, if the assumptions made about the release of other dangerous substances in the first 30 minutes of the fire are pessimistic.

### **Criterion 3.5.5 “Are the assumptions in the accident analysis justified and not unduly optimistic.”**

The assumptions being referred to here are those made about the response/effectiveness of accident consequence mitigation systems and include such things as the time to detect a fire in a warehouse or an operator will act in a predetermined way. The safety report should determine the consequences of worst accident scenarios on the assumption that all control and mitigation systems fail on demand and operational conditions correspond to worst case. Such a scenario should have a very low probability. The analysis should also consider the effect of various combinations of partial success of the control and mitigation systems in order to determine the risk dominating accidents.

A safety report that minimises accident consequences on the assumption that installed mitigation systems work perfectly is underestimating risk. Assessors can judge this aspect of safety reports by reference to the following questions:-

**Q: Are the accident source terms 'worst case'?**

The safety report for a chemicals warehouse facility should consider an instantaneous release of the whole contents of a storage vessel to an uncontained evaporating pool with and without early ignition and with subsequent dispersion of the vapour and fire.

Various other scenarios that result in a continuous release of several 10s of kg/s and give rise to a variety of fires which may engulf other substances and escalate the accident should also be considered. The conditions that could give rise to a VCE or BLEVE should be identified and the consequences of these events determined. Environmental hazards must also be adequately addressed.

**Q: Does the accident analysis examine the effect of different conditions and assumptions on the predicted consequences?**

The consequences of many severe accidents depend on the environmental conditions, the state of the plant at the moment of failure and the location and type of failure. Since there are many combinations with roughly equal probability, the safety report must determine the consequences of each accident under a range of conditions that encompass the full severity range.

Both day time and night time conditions should be considered for accidents affected by stability (ie those involving dispersion) and different wind speeds. It is important that a safety report describes the consequences of the worst conceivable accidents at a site, which occur when warehouses are full and toxic inventories are at a maximum number. If the accident analysis in a safety report is based on average inventories, it should be judged as incorporating too much optimism.

**Q: Does the safety report fully describe the models used to predict accident consequences?**

A safety report should describe the mathematical models used to predict the consequences of accidents. If the Operator or his consultant used well known software to calculate the consequences of accidents, information on the input data files should be provided so that Assessors can check its appropriateness and degree of conservatism both of which provide an insight into the Operator's approach to accident consequence analysis. If doubts remain, entering the Operator's input data into an HSE model can check the predictions in the safety report.

A difference in opinion about the severity of accident consequences may occur from time to time. It does not imply a major failing of the safety report but one which the Assessor should try to resolve by communication with the MSDU topic specialist, and, if necessary, with the Operator.

**Criterion 3.5.6 “Estimates of the severity and extent of each major accident consequences are realistic.”**

COMAH Regulations Schedule 4, Part 2, Section 4(b) requires operators to provide an “assessment of the extent and severity of the consequences of identified major accidents”. This is extended by SRAM Criterion 3.5.6 which requires that this assessment is realistic.

Duty holders should provide explicit information (perhaps in tabular form) which links each scenario with the number of people who may be affected (as a minimum) and preferably estimates of the number of fatalities and hospitalisations and those receiving minor injuries for each wind direction (where appropriate). This will provide the assessor with the information needed to determine the significance of each scenario.

We believe it is necessary if we are to be able to make a judgement on “all necessary measures” and the suitability of the information provided for offsite emergency plans (Schedule 4, Part 1, Section 4 and SRAM Part 2, Chapter 1).

Safety reports should determine the consequences of the worst accidents, but the analysis should not be overly conservative. If unrealistic hazard ranges are predicted, the off site emergency plan devised by the Local Authority may be ill conceived and under some circumstances, lives could be put at risk by spreading emergency services too thinly. The

Assessor can gauge the degree of conservatism in the calculations by asking the following questions:-

**Q: Are the input data for mathematical models reasonable?**

Reasonable values for some of the more important input data for accident consequence modelling are shown in Table 5. Assessors should compare these values with those used by the Operator and make judgements about the realism of the consequence predictions.

**Q: Are the predictions reasonable by comparison with published assessments?**

The Assessor should check that the results of the predictive analysis are neither optimistically small nor conservatively large. The majority of chemical warehouses will have a hazard range between 100m and 1000m, and values outside this range require careful scrutiny.

**Predictive input to Criterion 1.7 “Do the findings and conclusions in the safety report demonstrate that the measures adopted to prevent and mitigate major accidents make the risks ALARP?”**

The findings and conclusions from the predictive risk analysis should summarise the relationship between hazards and risks and demonstrate that the measures adopted to prevent and mitigate major accidents make the risks ALARP.

The assessment team must come to an agreed view on whether the report meets the requirements of criterion 1.7. Guidance is provided in SRAM Part 2 Chapter 1 for this purpose. The predictive assessor needs to form their own view on how the report meets this criterion so as to contribute into the team’s overall conclusions. The assessment guidance is repeated here and expanded upon where relevant for LPG installations.

Most safety reports will not present particularly reliable accident probabilities and in many cases the degree of uncertainty attached to consequence predictions will be unknown. This is relatively unimportant if the scenario is not risk dominant, but when it is, or could be, uncertainties should be offset by extra conservatism. Risk calculations based on optimistic assumptions and highly uncertain data should be treated with great caution, but Assessors should bear in mind the following typical levels of uncertainty:-

**Table 6 : Typical Uncertainties in Consequence Modelling**

Hazard	Typical Parameter Value	Approximate level of Uncertainty
Burning rate	0.15xArea on fire	+ - 0.1A
Parent seeding rate	10%	+ - 5%
Combustion product production rate	elemental conversion rate x burning rate	+ -20%
Plume buoyancy no.	assume 30% radiated + loss in building	+ -50%
Plume height	Briggs or Hall predictions	+ -50%
Ground level concentration	Hall or Gaussian plume model accounting for plume height	+ -50%
Toxicity of parents	Derive from LD50	+ -20%
Toxicity of combustion products	Use HSE published data	+ -20%
TNT equivalent	See Table 4	+ -25%
Particle diameter (inhalation)	1µm	-50% + 100%
Particle diameter (deposition)	100µm	+ -50%
Settling velocity	Classical value with Cunningham correction	+ -100%
Deposition velocity	Sehmel	+ -100%

Irrespective of the mix of argument, semi-quantitative evidence and quantitative analysis used to determine risk, an Assessor should have confidence in the results and concur with the conclusions presented in the safety report.

While the probabilities of worst case scenarios that are not risk dominating do not need to be quantified precisely, the calculation of their consequences should be reasonably reliable so that the emergency services can plan an appropriate response. In this context overly pessimistic predictions are almost as bad as grossly optimistic predictions. The information that emergency planners may require for each accident scenario and for twelve different wind directions is:-

- Probable number of casualties with mild burns or superficial injuries.
- Probable number of people requiring hospitalisation.
- Possible number of deaths.
- The need to evacuate the area around the site.
- Amount of property destruction.

This information should be supplemented with additional guidance on differences caused by time of year, time of day (night), day of the week and the presence of rain.

Assessors are required to judge if the risk quantification, risk reduction measures and residual risk meet all the assessment criteria. In effect, they need to take a view on the reliability/accuracy of the predicted hazard ranges and risks and hence upon the acceptability of the predictive analysis. The following set of questions may aid this process:

**Q: Does the safety report combine the magnitude of the various consequences assessed with event frequencies, or the likelihood of initiating conditions, to estimate the risk to the most exposed person or groups of persons, on-site and off-site?**

There are several ways, in which the results of a risk assessment can be presented including:-

- Contour plots of individual risk of death based on certain assumptions about the individual (ie he is out of doors and he remains out of doors for 30 minutes).
- Risk of death of the individual who is most at risk by being in a certain location for long periods.
- Dose versus distance for accidents with different probability.
- An F/N plot where N is casualties or individuals receiving a dangerous dose.
- A cumulative frequency/N plot.

In order to judge the acceptability of a safety report that presents the results of a QRA, the Assessor may have to make reference to HSE guidance on the tolerability of risk. Since this is expressed in terms of individual risk of death, risk of death is the most useful end point for a risk calculation. However, this does not imply that other representations of risk are unacceptable, merely that they are more difficult to interpret.

A safety report that presents only a table of hazard range and relative likelihood does not comply with the assessment criteria.

**Q: Does the safety report show that these risks are negligible or, where not negligible, are ALARP?**

It is a requirement of the regulations that Operators demonstrate that all necessary measures have been taken to make residual risks ALARP. The process of "demonstration" is not clearly defined in the regulations, but is interpreted to mean, "justify by well founded arguments or reference to reliable data". In this context Assessors should expect to see risk dominant sequences broken down into a series of events and failures with the probability of each one estimated (either qualitatively or quantitatively as appropriate) by reference to historical data, a respected authority, or by formalised methods such as fault tree analysis. The Operator should be able to show that there is redundancy and diversity in control systems, that operator error is fully accounted for and that the more common initiating events will not progress to a major accident. All of this should be supported by sound arguments about the absence of further measures that could be introduced to reduce the risks still further.

If the Operator presents a risk assessment based on good practice, industry standards and compliance with HSE recommendations, then it is still possible to show that the residual risks are ALARP by use of cost benefit analysis. In this case, the Operator should list additional safety features that could be incorporated and show that their cost far outweighs the reduction in risk.

**Q: Are the risks broadly consistent with HSE guidance on the tolerability of risk?**

The Assessor should check that the accumulated probability of death of the off-site individual most at risk from all accident sequence is less than  $10^{-4}$ . If it is not, it is probable that either the safety systems on the plant are deficient (ie risks are not ALARP), or that the accident analysis is overly conservative. In either case the Assessor should reflect his concerns in his assessment report.

Situations may occasionally arise when the safety report fulfils the requirements of the regulations, but the Assessor feels that the societal risk from the installation is uncomfortably high. In such cases, the safety report should not be deemed deficient, but the Assessor should convey his/her feelings to the Assessment Manager for the safety report.

**Q: Has the Operator demonstrated that additional safety measures cannot be justified on cost benefit grounds?**

The Operator should systematically examine the risk dominant accident sequences and identify additional measure that would reduce the residual risk. He should also justify why none of them have been implemented. Such arguments remove the grounds for rejecting the safety report and open up the possibility of a dialogue about which improvements would be cost effective.

**Q: Does the safety report use quantitative arguments for the ALARP demonstration - if so, are the risk criteria stated and justified?**

The level of quantification expected for the various types of risk assessment are dealt with by other criteria. The number of failure cases and the depth of analysis increases with proportionality. For a QRA of a complex site a few hundred different MAs may need to be analysed. The presentation of the quantitative arguments may need to be coupled with cost benefit analysis in order to provide the justification that all measures necessary have been taken.

If quantitative arguments are used the methods, assumptions and the criteria adopted for decision making should be explained. For example in the case of fatality risks to people off-site it is common practice [HSE, 1992] for the maximum tolerable level of individual fatality risk to be set at  $10^{-4}$  per year and for the broadly acceptable level to be set at  $10^{-6}$  per year. The corresponding figures for workers are  $10^{-3}$  and  $10^{-6}$ . There are no commonly agreed criteria for lower severity levels, however, HSE have published harm criteria for LUP purposes for a variety of substances, ie the 'dangerous dose' level, which is equivalent to a 1% chance of fatality when a healthy person receives the dose.

## **Risk Reduction Measures**

The safety report should demonstrate that a systematic and sufficiently comprehensive approach to the identification of risk reduction measures has taken place.

Where proportionality indicates that a site could rely on qualitative ALARP demonstration, operators may refer to relevant standards or guidance on good practice to support their demonstration that adequate safety and reliability have been incorporated and that by the measures provided have reduced the risks to as low as is reasonably practicable (ALARP). In making this demonstration operators need to consider the particular circumstances of their site and the consequences of identified major accidents **both on and off site** and decide whether there is anything further which is reasonably practicable before they can complete their demonstration of ALARP. Focus should be placed on **preventing** major accidents but the risks off-site in particular can be reduced by mitigation measures to reduce their consequences.

Where proportionality indicates that something more than a qualitative demonstration is required, the safety report should show that a systematic assessment of additional risk reduction measures has been carried out. In some circumstances there may be risk reduction measures that are reasonably practicable in addition to existing published industry good practice.

Determination of whether risks have been reduced ALARP involves an assessment of the benefits arising from the reduction in risk achieved by particular measures, an assessment of the cost in time, money or trouble of implementing those measures and a comparison of the two. Where there is deemed to be a 'gross disproportion' between the two i.e. The risk reduction being insignificant in relation to the cost then such measures can be ruled out as not reasonably practicable.

**Q: Are the standards employed in the risk assessment relevant and up-to-date?**

Operators often refer to standards in their risk assessment. These may be a failure frequency, an HSE guidance document or a plant design and operating standard. In each case, the Assessor should consider if the standard is applicable to the Operator's plant and if it is appropriate, given that HSE guidance and standards are updated from time to time. British Standards are revised at regular intervals and while not all the data in the standard may change, a major accident somewhere in the world can lead to a revision of failure frequencies of certain plant items.

At five-year updates HSE expects Operators to carry out a reappraisal of the risks from their operations and to examine if recent technological advances offer opportunities for risk reduction.

### **Assumptions and Uncertainties**

The main conclusions on the measures necessary to control risks should adequately take account of the sensitivity of the results of the analysis to the critical assumptions and data uncertainties.

One of the purposes of the risk assessment in a COMAH safety report is to demonstrate that sufficient control measures are in place to reduce the risks from the installation to a tolerable level. This is possible if the Operator has accounted for uncertainty in both the frequency and consequences of accidents. Considerable uncertainty is tolerable in the frequency and consequences of accidents that are, beyond a shadow of doubt, not risk dominating, but Operators should present sensitivity studies that show their predictions for safety critical events are not seriously in error. Assessors can ask the following questions to test compliance with this criterion:-

**Q: Has the uncertainty in consequences arising from different mathematical model input data been addressed?**

The severity of the off-site hazards from a warehouse fire may depend critically on the location of the seat of the fire, the effectiveness of the sprinkler system, the rate and mode of degradation of the building. Since the magnitude of the hazard is inversely proportional to wind speed under both D and F stability, it is important that the consequences are evaluated at typical low wind speeds (F2 and D5). Depending on the type of dispersion model used in the hazard analysis, off-site consequences should also be determined under a 15m/s wind. Input data for most other accident scenarios are fairly well defined, with the exception of emissive power. Assessors should check that values used in the accident consequence analysis are close to those shown in Table 5 and applicable to the local weather conditions experienced at the site location.

**Q: Has the uncertainty in accident frequency been properly accounted for in the reliability of installed protective measures?**

Particular areas of concern include ventilation rates of chemical warehouses, electrical circuits in warehouses, bulk storage facilities and the ability of bunds to contain spillages. The safety report should quantify uncertainties in the predicted failure frequency and factor these into the final risk assessment.

**Q: Have the uncertainties attached to the risk calculations been addressed and justified?**

A safety report that fails to mention uncertainties in the risk estimates should be considered deficient. Individual uncertainties attached to calculated hazard ranges should to be estimated by discussion of both model inadequacies and imprecise input data. The safety report should justify the results, if necessary by reference to confidence levels. Assessors can find uncertainty information in Table 6.

With regard to uncertainty in the reliability of containment and control systems, it is reasonable to assume that standards that have been developed over many years provide adequate protection. However, if a site makes use of new technology, for which an historical database is not available, then the safety report should discuss uncertainty attached to failure probabilities.

Operators who base their safety report on QRA, should take account of the potential for protective devices not to function e.g. remotely operated sprinkler systems may fail to operate effectively when called upon. The Operator should recognise that other protective systems may also fail and should describe the measures in place to show that his ranking of risk is not seriously flawed.

Most risk assessments, even those not based on quantification, make use of a variety of input data which have uncertainties attached to them. Operators should describe the effect uncertainties can have on their predictions and demonstrate, by reasoned arguments, or quantitatively, that even under worst case assumptions the risks are ALARP.

## **Links to Emergency Planning**

The conclusions drawn from the risk analysis with respect to emergency planning should be soundly based.

A safety report does not need to describe the off-site emergency plan, but it should provide guidance for the Local Authority on the severity of the risk dominant accidents. This information should be presented in an easy to assimilate form such as a table that summarises accident probability and likely numbers of casualties in three severity groups (breathing difficulty or superficial burns, hospitalisation and fatalities) for at least two weather conditions. It should also indicate the number of people likely to be made homeless by the effects of explosions. The information should be tabulated for a representative range of weather conditions and for all wind directions.

The safety report should also indicate any significant differences in the numbers of casualties due to seasonal changes, the accident occurring at week end, at night or on function days. In addition to the consequence information, it should present probability data in order that emergency planners can tailor their resources around the accidents presenting the greatest risk.

Of particular concern is whether the Operator will detect the occurrence of a fire in a chemical warehouse or bulk storage area, and be able to take appropriate steps remotely to minimise its consequences. Assessors should be convinced that remote monitoring of all

safety-related parameters is adequate and protected by redundant and diverse equipment appropriate to the level of hazard and risk.

**Q: Does the safety report give the distances to a range of consequence levels of relevance to emergency planners?**

In the event of a major accident the emergency services will want to know where to deploy their staff in order to bring relief to the maximum number of people in the shortest time. Depending on the accident, the consequences could be mainly down wind (warehouse fire) or isotropically distributed around the site (VCE if possible). In each case the maximum distance out to which people are likely to be injured is of vital importance.