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HID - SAFETY REPORT ASSESSMENT GUIDE: CHLORINE

Safety Report Assessment Guide: Chlorine

Introduction

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.

The predictive criteria are designed to help the Assessor 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. 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.

The purpose of this document is to describe how Assessors should test whether the criteria that applies to the predictive aspects of COMAH safety reports have been met. It provides an interpretation of the criteria based on useful examples. The information supplements rather than supplants that in the safety report assessment manual.

The initial sections provide important background information, particularly on ALARP decisions and the application of the proportionality principle to the assessment of safety reports.

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Criteria

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. 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.
- COMAH Remodelling Policy and when this applies.
- The COMAH Training 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.

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. The report fails to meet criterion 3.3; the Operator has to provide more information.	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, 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 has 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 `s view is 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 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[1].

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

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.

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 . The following RA definitions are relevant:-

(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 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 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 amount 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 2×10^{-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 3.5×10^{-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 CI4 and CI5 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 the Enforcement Policy Statement (HSE 1995), 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) 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.

(d) All safety reports need to demonstrate that the risks to occupied buildings have been assessed, for example, in line with the CIA guidelines.

When the assessment has been completed the HID form should be filled in and the conclusions summarised for the Assessment Manager

Assessment against Criterion 3.1

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). 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, commissioning (HAZOP) and cost benefit analysis. 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 are 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.

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, 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?

This question is related to the previous one, but in this case a basis for judging if the safeguards systems are adequate can be suggested:

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 may fail 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. Assessors should not

expect to see detailed cost benefit analysis arguments in a safety report, but they should expect the Operator to provide a list of possible mitigation measures together with their costs and reasons why the additional expense that would be involved in implementing them is not considered worthwhile. 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 excessively expensive 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 not focus exclusively on random failures of hardware, but should also consider all types of operator error that can result in a major accident 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 necessarily mean simply accounting for process plant Operators opening the "wrong" valve or failing to control the process properly. Events such as corner cutting, unauthorised absence, and even sabotage may warrant consideration. Examples of other types of event which may warrant consideration are:-

- Failure to successfully carry out an operation that is part of normal duties.
- Bulk tank filling and discharging errors made by the tanker driver.
- 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 of 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.

v 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 all possible accident scenarios, but it is essential that the risk dominating accidents are dealt with comprehensively. Very improbable accident initiators such as a meteor strike, simultaneous multiple failures of reliable systems and terrorist activity can usually be neglected, but cold catastrophic failure of vessels and guillotine rupture of pipe work should not be discounted.

Assessors should recognise that the COMAH regulations do not call for 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.

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 decision. 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 grouped the consequences of several accidents together?

It is reasonable for Operators to describe in detail the consequences of only a relatively small number of representative accident sequences, provided all significant accidents are identified and ranked according to the risk they pose. Thus, for example, if six different accidents resulted in a similar rate of release of chlorine, with smaller duration and dispersion characteristics, the consequences of only one of them need be described in the safety report. The relative likelihood

of the others should be evaluated in order to demonstrate that the risks are ALARP. Operators have discretion on the way this is done and Assessors should not insist on a particular approach, but the arguments presented must be robust.

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

All accidents that the company has taken measures to prevent occurring should be described. 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?

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 chlorine inventory and how and under what conditions is it stored?

The site description must describe the location and type of each storage system and provide information on the maximum inventories of chlorine and the conditions (temperature and pressure) under which it is stored.

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 having severe consequences can be identified. The detail provided needs to be sufficient to enable Assessors to determine if the accident analysis is thorough and complete. In addition to a full description of the bulk storage vessels, the safety report should describe all other plant with significant chlorine inventory. Plant operations must be described in sufficient detail that failures and errors having severe consequences can be identified.

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 large chlorine inventories, populated areas and features of the built and natural environment i.e. the presence of a SSSI or SBI, at risk from the installation. Lists of important features of the local environment are given in the safety report assessment manual.

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?' Assessors should take the view that any containment system or item of plant can fail and release its contents, therefore the safety report should provide:

- The volume of large vessels and other plant containing more than 0.5 tonnes of chlorine (2% threshold), together with their operating pressures and temperatures.
- The diameter and length of pipe to an isolation valve that can be closed (pipeline failures).
- A list of equipment such as pumps, regulators and compressors together with the operating pressures and temperatures.
- A list of ancillary plant and equipment that either contains or is connected to a significant inventory of chlorine (> 0.5 tonnes).

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. For example, if the Operator assumes that an alarm will be

seen immediately, or that a hardware failure will be detected immediately, the control room must be permanently manned and the instruments that would detect the failure in question should have a status indicator. Even then, the possibility of a delay before remedial or emergency action is taken should be considered. Of particular concern are failures that would allow a large release of gas into the atmosphere to go unnoticed.

Any reliability assumptions about the following should be justified:

- ROSOVs to terminate a release.
- Operators to perform tasks correctly.
- Instruments to detect a dangerous situation.
- Shut down systems that respond on demand.

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 requirement 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. If it presents the consequences of releases under worst conditions identified by wind rose data, an absence of detailed probability data required for a full risk assessment is not a reason for rejecting the report.

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^{o}C and that D5 and F2 do not necessarily encompass the full range of consequences of an accident. Releases under low wind speed conditions tend to have the worst consequences.

Chlorine releases under ambient conditions are denser than air and treating them as passive will result in the width of the hazard being underestimated, but the down wind hazard range being over estimated.

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

Operators should not reduce 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 or 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 chlorine, this would be primarily chemical reactivity and acute toxicity in addition to more common data such as molecular weight and density.

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

Initiator	Method of Model
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	Site environs information plus relevant data

pipeline rupture	
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?

The report should explain how major accidents have been identified and demonstrate that no important scenarios have been overlooked. When the method of identifying accidents is not systematic or transparent it will be much more difficult to convince the assessor of its completeness. Simple lists of accidents without evidence to show they are comprehensive may be appropriate in some cases, depending of the scale of the risk to off-site populations, but generally Operators will need to demonstrate that no major accident has 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). On-site accident initiators such as over pressurisation or equipment failure may require a more detailed frequency assessment in order to demonstrate the adequacy of installed safeguard systems.

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

The accident identification process should not be limited to the major hazards from chlorine releases. It should also recognise the presence of any other hazardous material with the potential for a major hazard and in particular the potential for accidents on the chlorine facility to initiate other major hazard scenarios.

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

There is no requirement to repeatedly describe the consequences of accidents that have a similar impact on employees, local populations and the environment. The safety report does not have to describe the consequences of all the major accident hazards, but just to identify them. Instead it may define a representative set of accidents that includes the most severe plant failures and consider all possible type of consequence (eg toxic cloud, chlorine/iron fire, chlorine/hydrogen explosion). In other words, the consequence analysis can be based on a reduced set of accidents that are representative of the hazards from the site.

Q: Does the 'representative sample' of major accidents include the risk dominating accidents?

The Assessor must be satisfied that the accidents considered dominate the risk and encompass the complete spectrum of severity. Table 2 identifies plant items that contain, or are connected to, a large inventory of chlorine and lists the most obvious potential accidents or failure modes. While it may not be completely exhaustive for all installations, it can be used as a checklist to assess the completeness of the accident analysis. If there are any unexplained omissions that would significantly change the predicted risks posed by the site, it may be deemed to fail to comply with the assessment criteria.

Q: Are the descriptions of accidents in the safety report sufficiently comprehensive to allow the adequacy of the methods for preventing major accidents and for limiting their consequences to people and the environment to be assessed?

The safety report should determine the consequences of essentially identical accidents in very similar plant if the consequences are likely to be different. For example, if a transfer pipe failure can release chlorine at say 50 kg/s and failure of a pipeline in an enclosed storage area can also give rise to a 50 kg/s release, the safety report should consider both failures because they may have different consequences. The safety report should also consider failures occurring at the 'worse locations' which may be on pipelines through points upstream of emergency isolation systems. A safety report that fails to address the 'worst case' consequences of representative accidents does not meet the assessment criteria.

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

It is possible for chlorine containment failures to give rise to thermal radiation/explosion hazards, all of which must be addressed in the safety report. For example, if a safety report identifies high

temperature distillation column failure as one of the accidents requiring consideration, the consequences that should be addressed are chlorine gas emissions, of varying scale, and chlorine/iron fire. In such a case, explosion is unlikely in the absence of high levels of hydrogen or nitrogen trichloride, but accidents considered to contribute little to the total risk should not be completely ignored.

Q: Has the potential for escalation been properly addressed?

Some accidents at an installation can cause other failures in that they may have as severe or even more severe consequences. The safety report must recognise this possibility and address it by postulating accidents in 'worst case' locations. Of particular concern are:

- Incapacitation of operators in adjacent plant preventing effective shutdown procedures in plant enveloped by the toxic plume.
- Explosions (nitrogen trichloride, hydrogen/chlorine, or pressure burst) that can cause a variety of mechanical failures.
- Radiation from chlorine/metal fires that can impinge on vital elements of adjacent plant and equipment.

The site description should be detailed enough to enable the Assessor to identify the most hazardous locations for component failures and hence determine if the accidents considered are 'worst case'.

Types of Accident suffered by Chlorine sites

Although Operators need to demonstrate the use of a systematic approach to accident identification, Assessors are likely to find that few safety reports present the results of formalised methods such as cause-consequence diagrams or failure modes and effects analysis. An alternative approach that some Operators may adopt involves listing each item of plant and identifying all its failure modes that would give rise to a major accident hazard.

The primary accident that chlorine facilities can suffer is the loss of containment leading to a major toxic release of a dense gas, which disperses over a wide area. Additional accident scenarios include:

- Fire - from the exothermic reaction of chlorine with metals and certain organic materials.
- Explosion - from accumulated nitrogen trichloride or chlorine/hydrogen mixtures.

The loss of containment accidents that chlorine facilities can suffer fall into two main categories:

- Vessel, process equipment or transport equipment failure leading to a release of chlorine.
- Overloading of scrubber equipment leading to a release of chlorine.

The consequences of a loss of containment accident will be influenced by the process conditions immediately prior to the release as well as the actual release location. Releases that take place inside buildings will result in a different source term to that which take place in the open environment. Within chlorine manufacturing facilities, explosions can occur if flammable mixtures of hydrogen/chlorine meet an ignition source. Such a situation can occur if hydrogen concentrations are allowed to rise to high levels within liquifier and absorption facilities. UV Light, electrical equipment or hot surfaces can initiate ignition. Explosions can occur if the system has the potential to accumulate quantities of nitrogen trichloride, which is a shock sensitive material.

Overloading of abatement equipment such as absorption facilities can lead to a chlorine release at elevated temperatures and elevated release points. Failure of an Operator to consider any of these events should be justified in the safety report.

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

In order to judge compliance with this requirement of the regulations, Assessors can ask the following questions:

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

Identification of all major accident scenarios is a very important requirement of the regulations and a safety report that fails in this respect may be considered deficient. Systematic approaches to accident identification include HAZOP, event tree analysis and failure modes and effects analysis. However, the regulations do not specifically require their application. An Operator may be able to demonstrate that all major accidents have been identified without resort to formalised methods by providing a detailed description of the plant and by systematically addressing the hazards from each part in turn.

Q: Have all of the hazard phenomenon associated with each major release been identified?

A major release of chlorine can behave in different ways depending upon the nature of the source. For example, its original temperature and pressure significantly influenced the impact of a release of liquid chlorine. Catastrophic failure of a pressure vessel containing liquid chlorine at ambient temperature results in flashing, which dominates the source term. The contribution from evaporation of a pool that may be formed may be negligible. However, when chlorine is stored at sub-ambient temperatures and low pressure, source terms are dominated by pool evaporation. In both instances the plume exhibits dense gas characteristics. Chlorine utilised within a process at elevated temperatures may, however, initially exhibit a buoyant phase before cooling down to then act as a dense gas. In the absence of such considerations, the Assessor would be justified in requesting further information.

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: Is the depth and detail of the accident analysis commensurate with the scale of the hazard?

The safety report should consider the potential domino effects, but Assessors should recognise that many accidents do not give rise to a hazard range that extends off-site. In the main, the consequences of accidental releases of chlorine are limited to toxic gas clouds with a hazard range that can extend well beyond the site boundary. Risks to the public should be addressed in as much detail as the situation warrants.

Where chlorine inventories are limited and the site is situated well away from local populations the risk to the public may be relatively low. In such circumstances the risk assessment need not be as detailed as that for an identical situation close to a busy shopping centre. However, all major accident sequences should be identified and the consequences of "worst case" releases quantified.

If an instantaneous release of the whole contents of a chlorine vessel is predicted to gives rise to a toxic cloud that does not produce any off-site fatalities, then the safety report need not evaluate the off-site consequences of smaller toxic clouds, although on-site consequences would still need to be considered.

Table 2: Chlorine Facility Major Accident Scenarios.

Plant Item Failure	Accident Scenarios			
Storage or Transport Vessel	**Catastrophic failure** **Toxic gas cloud**	**Hole in vessel wall** **Toxic gas cloud**		
Filling line	**Rupture** **Toxic gas cloud**	**Puncture** **Toxic gas cloud**	**Small hole** **Toxic gas cloud**	**Flange leak**
Export line	**Rupture** **Toxic gas cloud**	**Puncture** **Toxic gas cloud**	**Small hole** **Toxic gas cloud**	**Flange leak**
Process Equipment, Compressors, liquifiers, vaporisers **pumps**	**Disintegration** **Toxic gas cloud**	**Leak** **Toxic gas cloud**	**Loss of control** **Toxic gas cloud** **Hydrogen/** **chlorine fire.** **Nitrogen trichloride explosion**	
Abatement Equipment	**Disintegration** **Toxic gas cloud**	**Leak** **Toxic gas cloud**	**Loss of control** **Toxic gas cloud** **Hydrogen/** **chlorine fire**	**Overload** **Toxic gas cloud**

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 component failure 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 other standard making organisations.
- Chlorine industry e.g. Eurochlor, guidance documents.
- Historical data.

It is acceptable for the safety report to refer to world-wide failure data on chlorine vessels built and operated to equivalent standards and deduce, on the basis that the company's standard of construction and operation is at least as good if not better, that the failure frequency of site chlorine

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 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. The origin of all probabilities quoted in a safety report should be given so that, where necessary, Assessors can make a judgement on their appropriateness.

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

All events/initiators identified in Table 3 should be considered even if some of them are not applicable to the plant in question.

Some events such as aircraft impact, earthquake, dropped load, etc are capable of damaging any item of plant, but a safety report need only consider the event once unless a different hazardous substance can be released, or the severity of the release varies significantly.

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 and at worst can impact a small number of plant operators. In the case of chlorine, this implies that the frequency determination for severe accidents that include loss of an appreciable quantity of liquid chlorine to an unbunded area should be more reliable than for small gaseous chlorine leaks such as minor weeps from valve stems.

If the safety report has not adopted a QRA approach, but has ranked accidents in terms of their severity and likelihood, the level of detail in the consequence analysis for accidents at the top of the list should be greater than that for accidents at the bottom of the severity list.

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 overfilling a stock tank leading to a significant chlorine breakthrough from the emergency

absorption facility is ‘f’ on the basis of historical data should be judged as containing insufficient detail. However, it is acceptable for the frequency of single events such as the failure of a particular type of liquid chlorine compressor to be based solely on historical data.

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 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.

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.”

Here reference should be made to Criterion 3.3 and how it was met by the safety report. Essential for the identification of major accident hazards is a detailed description of the site and all its components, with particular emphasis on those containing or connected to large volumes or high-pressure sources of chlorine. The safety report should consider each of these in turn, identifying release scenarios and potential consequences (fireball, jet fire, explosion). It should also provide an estimate of the frequency of each event. It is not necessary for the safety report to quantify the consequences of all of these, but a sufficient and representative set must be identified. Assessors may find the following questions useful when judging the completeness of the accident scenarios considered.

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 release, then it can be considered systematic. However, if by reference to Table 3, the Assessor can identify scenarios that have been overlooked, the report may be 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.

If, for example, a safety report failed to examine the consequences of a credible chlorine compressor failure that could produce high energy missiles capable of puncturing a storage vessel, then the safety report might be considered as failing to meet the criteria.

Q: Does the safety report consider the effect of failure of automatic or manually operated safety systems in the sequence of events leading to a major accident?

The accident sequence identification and analysis in a safety report should consider the failure of all automatic and manually operated safety systems and evaluate the consequences in each case. For example it should consider sequences consisting of:-

a) A hidden fault (eg a failed ROSOV).

b) An initiating event (eg pipe rupture).

c) Failure of an operator to respond correctly.

It may use QRA to demonstrate that the probability of such accidents is very low, but their consequences must be determined.

Table 3: Accident Initiators Requiring Consideration in a Safety Report

Off-site Events	Operator Error	Abnormal Load	Arson or Sabotage	Inadequate Management	Loss of Service
Aircraft impact	system opened	impact by vehicle	fire	corrosion	Loss of electricity.
Seismic event	filled when not closed	impact by missile	explosion	erosion	loss of cooling water.
Subsidence	system overfilled	impact by dropped load	valve opened	vibration failure of process controls.	loss of nitrogen
Extreme environmental conditions abnormal rain fall abnormal snow fall very low temperature high temperature flooding gale force winds lightening strike	containment degraded.	internal temperature or pressure outside design limit.	safety system degraded.	cyclic load .	loss of compressed air
Vehicle/train impact	excess load	external temp/ pressure outside design limit.	contamination	inadequate materials or specification.	loss of steam
Land slip	failure to respond correctly to an alarm.	pressurisation.	control system degraded.	chemical attack	
Explosion	incorrect valve action.	under pressure	containment system degraded.	hidden defect in containment system.	
Fire	Contamination			failure to detect dangerous situation.	
Missile	Loss of control Nitrogen trichloride, hydrogen/ chlorine, overload of abatement equipment			failure of process controls.	
Pipeline rupture					

Criterion 3.4.2 "All safety critical events and associated initiators should be identified."

Safety critical events are those that dominate the risk at different distances from the plant. The accident at a chlorine installation that has the greatest hazard range is an instantaneous release to atmosphere of the whole contents of a stock tank or tanks. The safety critical events for shorter distances are those occurring the most frequently occurring and rise to that particular hazard range. The questions below will help Assessors determine if safety critical events are dealt with appropriately.

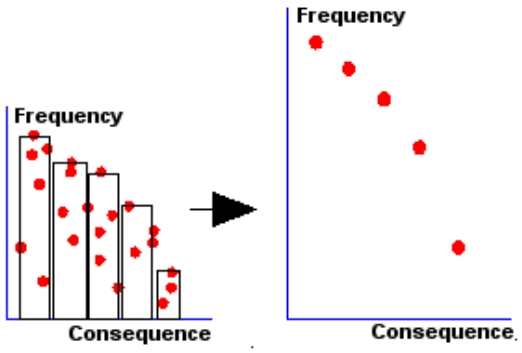
Q: Does the safety report define a safety critical event and describe an approach to their identification?

Some safety reports may not make use of the term 'safety critical event', but all safety reports will calculate the consequences of only a small fraction of the total accidents a site can suffer. These must be chosen carefully in order to ensure they dominate the risk at increasing distance from the site.

The first step in the identification of these risk-dominating events is the quantification of frequency and approximate consequences of all major accidents. These may be grouped into consequence bands as indicated below. The accident at the top of each band is the safety critical event for consequences of that particular level of severity. However, this method should be used with caution since the consequence categories may be quite broad. For example, if a consequence category is defined as one or more off-site fatalities, the most frequent may cause 2 fatalities and would be classed as the SCE, whereas a less frequent event that could cause 200 fatalities would not be identified as a SCE but may be unacceptable and require further risk reduction. It is suggested that the events should also be reviewed qualitatively (i.e. By visual inspection) to identify unusual or high consequence events which should be added to the list of SCEs. In addition, events which in themselves might be low risk, but could escalate to give a more serious event, should be included. The non-QRA approach would group accident according to likelihood and consequences.

The frequency of all accidents in a band can be added together to provide an estimate of the overall frequency of a particular level of consequences. The safety report should then identify a set of representative accidents and frequencies for more detailed consequence analysis.

A safety report that fails to analyse accidents in this way may not be complying with the assessment criteria. However, approaches that are not based on quantification, but never the less rank accidents appropriately should not be rejected out of hand.



representive accident set for detailed consequence analysis

Q: Does the safety report list the safety critical events that have been identified?

The safety report should list the safety critical events for each group of accidents that have similar consequences. In general these will form the reduced set that are analysed in depth in the report as indicated above where 5 safety critical accidents are used to represent the risk from the site.

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."

Operators should not base their accident analysis on the assumption that all protective systems will perform perfectly and Operators are 100% reliable. For example, if a liquid chlorine line is fitted with a slam shut safety valve, ROSOV, the safety report should consider the consequences of it failing to isolate a break on that line. Similarly, if a pipe is fitted with a manually operated shut-off valve, the safety report needs to consider what would happen if it was not closed in the event of a failure down stream. The following questions are designed to provide guidance on this criterion:

Q: Are appropriate failure probabilities used in the accident analysis?

Operators should not use failure probabilities taken from standard references in their accident analysis without showing that they are applicable to the plant and conditions in question. The Assessor should be particularly concerned about the data used in the determination of the frequency of safety critical accidents. For example, if the hoses failure rate is *f*, an Operator can only claim a similar failure rate if hoses on his site are inspected and maintained to the same standard as the population to which the failure data applies.

If the Operator determines accident likelihood on the basis of historical data or some other method that does not involve a calculation of accident frequency, the Assessor should be convinced that the probabilities are applicable to the plant in question. This implies that good evidence should be presented to show that the plant is designed, operated and maintained to appropriate standards and that the operators controlling it are adequately trained.

Q: Does the accident analysis make use of optimistically short response times for control/ safety equipment?

A safety report that does not examine the consequences of prolonged releases (20 minutes or more), on the basis that a valve will be closed and the release terminated within a shorter period should be deemed to contain an optimistic accident consequence analysis.

Q: Are the assumptions made about operator response reasonable?

The safety report may claim that control room Operators will notice an illuminated alarm indicator immediately or will respond to an emergency perfectly and close valves in a matter of seconds. Such assumptions may be optimistic, but their presence does not necessarily signify that the safety report is deficient if the consequences of much longer response times are determined.

Q: Does the Operator claim that some potentially serious failures will not result in a major accident because a single safety/control system will recover the situation?

Since all safety/control systems can fail, Operators and Assessors should take the view that chlorine can escape from its containment system and that releases of 100% of the inventory of chlorine vessels must be considered in a safety report irrespective of the complexity of the safeguards.

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 conventional methods of determining the frequencies of accidents involving multiple failures are fault tree and event tree analysis or a combination of the two. They are labour intensive and require reliable failure probabilities and experience in their application. Many safety reports adopt a much simpler approach. For example, accident sequences may be broken down into three components - an initiating event, a control system failure and an Operator failure. The frequency of the accident is then determined by assigning probabilities to the components and multiplying them together. While this approach may be acceptable, Assessors should be aware that it can hide a large number of events/failures that are not being quantified. There may be a dozen ways the control system can fail and several ways in which the Operator can respond incorrectly. Since the probabilities of these alternatives are usually additive, the Assessor needs to be convinced that the analysis is not optimistic. The following questions may help the Assessor to reach a conclusion on this issue:

Q: Does the frequency analysis recognise that failures of complex systems and Operators have many components?

An explosive hydrogen-chlorine mixture inside a chlorine process vessel will only occur following a series of Operator and control equipment failures, the Operator will need to identify each of these in order to satisfy the Assessor that his calculated event probability is reasonable. If a break down of the individual events and probabilities is not provided, the Assessor is justified in requesting further information from the Operator.

Q: Does the safety report consider the full range of conditions for each accident?

Accident consequences should not be reduced on the grounds that the probability of the wind blowing in a particular direction is low if very similar consequences arise when the wind is blowing in any direction. Nor should risk be based on the probability of a failure in a particular location when failures over a whole range of other locations may have similar consequences. The Assessor must decide the weight attached to such omissions.

Q: Does the analysis take into account uncertainties in the estimation process?

The fact that most failure probabilities are not single values, but distributed about a mean should be accounted for in risk analysis. If there is no information on the probability distribution of the probability, it must be concluded that the upper figure is just as likely as the lower figure.

Q: Does the safety report show that site specific factors have been taken into account in the methods used to generate event sequences and estimates of the probabilities of potential major accidents?

Assessors should be careful not to accept accident analysis from an Operator's 'core safety report' if the safety report in question does not take account of site specific information on accident initiators and initiator probability. For example, a core safety report may give a frequency for aircraft impact based on a background crash rate for the whole of the UK. This would not be applicable to a site located close to a busy airport. Likewise the presence of a railway line running along a site boundary increases the probability of an accident caused by a derailment.

In general, off-site accident initiators tend to be site specific, but differences in site management, operation and competence (training) of the staff can also significantly affect accident frequency.

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."

Many risk assessments in safety reports make use of industry standard probabilities for events such as pipe rupture, cold catastrophic failure of vessels, Operator response time etc. The Assessor should compare these data against those given in the table below and request the Operator to explain the reasons for any significant difference.

Table 4: Typical Failure Frequencies

Event	Probability/Frequency
Rupture of pipe on a pressurised storage system	1×10^{-5}/yr
Lightning strike	1×10^{-7}/yr
Severe earthquake capable of rupturing pipework	1×10^{-6}/yr - 1×10^{-7}/yr
Sudden catastrophic failure of vessels	3×10^{-6}/yr
Failure of a ROSOV on demand	3×10^{-2}
Failure of an excess flow control valve on demand	1.3×10^{-2}/yr
Failure of an automatic shutoff valve to close	1×10^{-2}/demand
Failure of a level sensor (sticking)	50 per 10^{-6} hrs
Failure of a flow sensor	40 per 10^{-6} hrs

Generic or industry standard failure probabilities for valves, pumps, etc are based on appropriate operation under an industry standard maintenance regime, which may be different from that prevailing at a site. Use of such data in risk calculations in a safety report should therefore be justified. Assessment of the justification can be via the following questions: -

Q: Are the failure data derived from long experience of operation in the same industry and under the same conditions?

Failure rate data from the Operator's own and long established database can usually be accepted, but if data are based on experience in another industry (eg nuclear), the Operator must justify their use in accident analysis by reference to operating conditions, maintenance regimes, etc. If this justification is not present, the Assessor may reach the conclusion that the risk assessment is optimistic.

Q: Is the probability of failure of a particular item of plant based on generic data for an identical component or one that closely resembles it in design, manufacture and operation?

The mean failure frequency of plant components should be increased when they are used under conditions that are different from their design operating conditions. Similarly, the mean failure rate of a component should be increased if it is assumed to apply to another similar, but not identical,

component. The increase depends on whether the new conditions make more or less demands on failure to recognise such reliability. Changes can result in an optimistic risk assessment, particularly if the data is used to quantify the frequency of a safety critical sequence.

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 a chlorine handling facility are the release of a cloud of toxic gas, chlorine/metal fires and to a lesser degree explosion due to a build up of hydrogen or nitrogen trichloride within the stock tanks themselves or ancillary equipment such as pumps and pipelines. The scenarios that should be covered in a safety report include:

- Leaks to atmosphere from loss of containment from storage plant, process equipment, transport equipment and pipe work.

- Releases resultant from the overloading of abatement equipment such as scrubbers.

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?

A safety report should discuss external events and site incidents that may give rise to a release that ranges in severity from catastrophic failure of a chlorine storage tank to a small leak. It should also identify the measures and precautions taken to reduce their probability, duration and impact. Catastrophic failure can be caused by aircraft impact, subsidence, earthquake, a freak storm, a nearby explosion, undetected faults and possibly by abnormal operation. Less severe leaks may be the result of mechanical failure, corrosion, erosion, impact damage, lightning, flame impingement or electrical failure.

The accident consequence analysis should be a systematic process comprising the following steps:

- List the assumptions that will be made about containment failures (size, location).

- Describe the essential features of the model that will be used to calculate the rate of outflow of chlorine and the duration of the release.

- List the assumptions used to run the model.

- Present the results of running the model to characterise the chlorine release.

- Identify the model that will be used to determine the dispersion characteristics of the toxic plume.

- Describe the essential features of the model used to calculate the dispersion of release chlorine.

- List the assumptions used in the dispersion analysis (stability, wind speed, ground roughness).
- List the assumptions about the dose received by individuals indoors and outdoors.
- Present the results of individual dose calculations.
- Describe the effect of accidents on local populations and the environment.

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 a chlorine handling site would be: -

- Catastrophic failure of a pressurised stock vessel leading to an instantaneous release of 100% of the contents.
- Catastrophic failure of a refrigerated storage vessel leading to an instantaneous release of around 25 % of the contents (depending on storage temperature), the remainder forming an evaporating pool.
- Catastrophic failure of a chlorine transport container during loading/unloading operations leading to an instantaneous release.
- The fire engulfment of a transport container during loading/unloading operations.
- Continuous releases from vessel/equipment/pipe work walls.
- Overloading of abatement equipment.

Q: Has the full range of consequences been addressed?

The safety report should not discount any scenario unless it can provide good reasons for doing so. Chlorine/metal fires, hydrogen/chlorine fires and explosions as well as nitrogen trichloride explosions in kettle vaporisers should be addressed, or an adequate justification for discounting them should be provided.

The number of fatalities and individuals with severe injuries should be determined. The footprint of a toxic plume should be superimposed on a map so that the effect of wind direction on the number of casualties can be assessed. The accident analysis should address the effect of other variables such as time of year, time of day and day of the week if they have a significant effect on the off-site consequences. A limited analysis that neglects variability in accident consequences may 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 that has been well validated, 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. If a chlorine gas plume is predicted to fall just short of a densely populated area, the Operator should consider uncertainties in the analysis and any circumstances, which could lead to extension of the hazard into the populated area.

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'. For example, a chlorine release from a pipe or vessel is characterised by the release rate, the duration of the release and its form (eg liquid or gas and whether as a vertical jet, horizontal jet or obstructed jet). Assessors can use the following questions to test the adequacy of the description of accidents given in a safety report:

Q: Do the source terms for each accident encompass an adequate range of release rate and include the 'worst case'?

Since release rate is effectively determined by hole size, the accident consequences described in a safety report should encompass a range of hole size and include the largest possible failure. This means guillotine rupture of a pipe and catastrophic failure leading to an instantaneous release of the whole contents of a vessel.

The 'worst event' should be assumed to occur under 'worst conditions', for example when the pressure in a pipe is a maximum, when the vessel is filled to its maximum level and when the filling pressure is a maximum

Q: Are pessimistic assumptions used to quantify source terms?

The flow rate of chlorine through a hole or from a pipe depends on the assumptions made about the discharge coefficient, the pipe roughness, the friction factor, etc. The values assigned to these parameters should ensure that the calculated consequences of accidents are not optimistically small. For example, use of a discharge coefficient less than 0.9 should be justified, the appropriate value for a low pressure system is 0.65. A liquid chlorine leak can, depending on the leak path, release pure liquid or a mixture of gas and liquid. Assumptions about the physical form of the release should be justified. If in doubt, the assessor should consult the relevant MSDU topic specialist.

Q: Does the safety report show that site specific factors have been taken into account in the use of source term models?

The source terms for accidents should account for site-specific features. These relate to:

- The frequency of releases.
- The magnitude of releases.
- The duration of release.

and could include parameters such as:

- The size and type of chlorine vessels.
- he number and capacity of road tanker deliveries per year.
- Whether the site is manned 24 hours/day.
- Tank padding pressure and the maximum value this could rise to in the event of a failure. The maintenance schedule for key safety features such as ROSOVs.

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

The transport models used to determine the consequences of accidents at chlorine sites are likely to be dense gas or passive dispersion models. Both are used to determine the maximum toxic envelope of chlorine releases.

Nearly all models used to characterise chlorine dispersion are complex and make use of several assumptions and input parameters. Therefore, it is often difficult for an Assessor to reach conclusions about the adequacy of the consequence analysis. Answers to the following questions may provide the basis for an assessment.

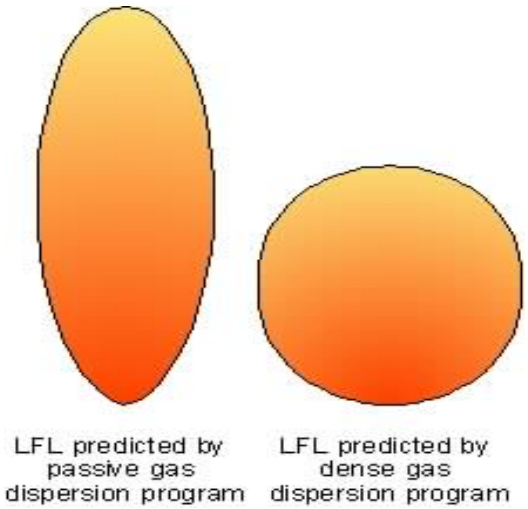
Q: What sort of dispersion model is used to calculate the dimensions of a toxic cloud of chlorine?

Since the molecular weight of chlorine is greater than that of air, ambient temperature releases are denser than air. This means that the gas falls to the ground and its rate of dispersion is greater than that of a passive release. In addition to being affected by the wind, the gas spreads out sideways, therefore centreline concentrations are lower than for a similar low level passive release, but off-axis ground level concentrations are higher - see the diagram below.

Consequence analysis based on the assumption that a chlorine release disperses passively may be optimistic or pessimistic depending on local conditions. Once a large amount of air has been mixed into a chlorine cloud, it disperses passively.

Q: Does the dispersion model take account of obstacles such as buildings and changes in topography?

Chlorine released accidentally at ground level has to disperse around buildings at or near to the chlorine facilities. In general the presence of buildings results in enhanced mixing with air and ground level concentrations predicted by models that do not explicitly include equations and correlation's for flow around buildings are likely to be pessimistic in the far field. The width of the cloud is increased, but generally neglecting buildings is acceptable provided it does not lead to an over estimate of the hazard range to such an extent that off-site emergency procedures would be compromised.



Q: What wind speeds are considered for dispersion calculations?

In general, for continuous releases, the higher the wind speeds the more rapid is the dispersion and shorter is the hazard range. D5 weather conditions occur frequently in the UK and should be used to calculate the hazard range for daytime releases. Dispersion is reduced under stable atmospheric conditions, hence F2 weather, which characterises night time conditions, generally produces the greatest hazard range. Under any stability, increases in wind speed tend to decrease the predicted hazard range unless building wake effects are modelled. A safety report should calculate the consequences of accidents under a range of weather conditions including those that maximise the hazard range.

For instantaneous releases, these general observations may not be applicable.

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

The rougher the ground over which a toxic gas is dispersing the more rapid is the rate of air entrainment and the shorter, but wider is the toxic 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.

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 respectively. 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.

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 chlorine transport models, the consequence analysis may need to consider other types of accident such as explosions in a vaporiser. 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. The following questions may help Assessors judge if the consequence analysis is based on appropriate assumptions:

Q: Does the safety report consider explosions?

Even if the safety report does not calculate the consequences of explosion resulting from a build-up of nitrogen trichloride or ignition of a chlorine hydrogen mixture, it should describe the measures in place to prevent a hazardous situation arising and present credible arguments as to why an explosion will not occur.

Q: Have appropriate models been used to calculate the consequences of explosions?

The TNO multi-energy approach is applicable to chlorine-hydrogen explosions and the TNT equivalence method can be used to calculate the consequences of nitrogen trichloride explosions.

Q: Are the consequences of missiles from exploding pressure vessels considered?

The safety report should examine the potential consequences of missiles from exploding pressure vessels such as a chlorine cylinder using the methods outline in part II. In the main the consequences will generally be less severe that those of a release of toxic gas, but the report should examine the potential for accident escalation. For example, an exploding cylinder causing rupture of a much larger chlorine storage vessel.

Table 5: Effect of Input Parameters on Predicted Accident Consequences

Parameter	Accident type/phenomena	Acceptable value	Direction to reduce severity of consequences
Wind speed	**Dense and passive gas dispersion**	**2m/s F stability** **5m/s D stability**	**+** **+**
Ground roughness	**Dense & passive gas dispersion**	**0.1m- 0.3m (suburban environment)**	**+**
Averaging period	**Dense and passive gas dispersion**	**600s plume** **10s puff**	**+** **+**

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 the toxic hazard ranges and casualties for several severity levels, which may include:

- Immediate fatality (1000 ppm for a few seconds).
- Dangerous effects (50 ppm for around 5 -10 minutes).
- Serious irritation (15 ppm).

The dangerous toxic load based on the HSE published criterion:

Toxic Load = (Concentration, ppm)^2 x time, minutes = 108,000 ppm^2 min

Which would result in:

- Severe distress to almost everyone exposed.
- A substantial fraction requiring medical treatment.
- Some of those injured requiring prolonged hospital medical treatment

v Susceptible people possibly being killed.

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 the criteria, such as a dose that relates to a value considered immediately dangerous to life and health (IDLH). Assessors should 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 toxic plumes have been calculated?

Although HSE has published its dangerous toxic load criteria, some safety reports may calculate hazard ranges to different dose levels. Any dose implies a exposure duration and Assessors need to understand the assumptions being made before making judgements about acceptability. In particular outdoor personnel are unlikely to be able to escape indoors at concentrations above 300 ppm.

Q: What account has been taken of the influence of indoor versus outdoor exposure?

People can reduce their exposure to toxic gas by escaping indoors but, once the building is surrounded by gas, the concentration inside increases at a rate that is dependent on the ventilation rate. When the release terminates, the outside concentration reduces sharply, but the indoor concentration fall much more slowly and people inside are subjected to a prolonged exposure. Sheltering provides the greatest benefit if people are indoors when the release occurs and move outside as soon as the gas has drifted away. Off-site emergency plans usually assume that members of the public will be advised to go inside and close all windows at the start of the release and that they will be further advised to vacate their houses as soon as the gas cloud has passed. Since this may not happen, the operator needs to justify any reduction in hazard range, which is based on people escaping indoors.

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 large release of gas and the probability that a ROSOV will close on demand.

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'?

An chlorine facility safety report should consider an instantaneous release of the whole contents of storage vessels and various other scenarios that result in a continuous release of several 10s of kg/s and give rise to a variety of toxic clouds. In addition, it should address failure of associate plant such as the vaporiser giving rise to a variety of hazards.

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.

Accidents can occur any time although their probability is not usually constant. It is important that a safety report describes the consequences of the worst conceivable accidents at a site, which occur when the vessel is full of chlorine and high pressure pipes and vessels are at their maximum operating pressure. If the accident analysis in a safety report is based on average inventories, it may be judged as incorporating too much optimism.

Failures on plant can occur almost anywhere, but with variable probability. The safety report should consider failures in the "worst" locations, which include failures up stream of an isolation system, which will maximise the release period before remedial action can be effective. A safety report that does not calculate the consequences of worst case accidents may fail to comply with the assessment criteria.

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 Operators 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: What are the criteria used to judge the hazard range?

Use of widely different values for toxic load to that generally accepted should be justified, otherwise the accident consequences may be deemed unrealistic.

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 6. Assessors should compare these values with those used by the Operator and make judgements about the realism of the consequence predictions.

Criterion 3.6 “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 3.6. 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 chlorine 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 Uncertainties
Source Term	**100% of release**	**0-50%**
Density	**Dense**	**0-50 %**
Dispersion	**Passive & Dense model**	**+-50% on length and width**
	persons outside receive a	

Hazard	Typical Parameter Value	Approximate Level of Uncertainties
Hazard range	**dangerous dose**	**+-50%**

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 frequencies 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:

- Expected number of casualties with mild toxic effects.
- Expected number of people requiring hospitalisation.
- Expected number of deaths.
- The householders that need to be warned to stay in doors.

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

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 the 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 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 (i.e. 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 extent of a toxic cloud of chlorine depends on the weather conditions assumed for the dispersion process. 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 wind speeds for the site. Low wind speed conditions occur regularly at most sites and should be considered in the risk assessment. Assessors should check that values used in the accident consequence analysis are close to those shown in Table 6.

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 shut off valves and excess flow devices 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 (mild burns or superficial injuries, 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 weekend, 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.

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 should be mainly down wind (toxic cloud) or isotropically distributed around the site (explosion). In each case the maximum distance out to which people are likely to be injured is of vital importance.