HSE

Health & Safety Executive

Safety Report Assessment Guide: Explosives

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INTRODUCTION

This document describes how the Competent Authority's Assessors evaluate safety reports for compliance with the predictive criteria of COMAH. This Safety Report Assessment guide should be read in conjunction with the SRAM and it should be noted that the current document supplements rather than supplants the SRAM.

Assessors must be fully familiar with the following:

- HSE's enforcement policy
- 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.

This document only covers evaluation of explosives hazards; it does not cover evaluation of other types of hazard that may be present at explosives site, e.g. non-explosives thermal hazards (solvent fires) or toxic hazards. Other types of hazards are covered in other Safety Report Assessment Guides.

1.1 Fundamental considerations

Before assessing a safety report, Assessors need to be clear about:

Their role in the assessment process and what the Safety Report Assessment Manager is expecting from the assessment.

The proportionality principle: this determines the depth of the Risk Assessment required from the Operator.

HSE's approach to the application of the ALARP principle to both on-site and off-site risks for new and existing establishments

How the assessment criteria apply to the type of report submitted, i.e. first submission, or an update report.

This introduction briefly reviews the above issues, while further sections of this report discuss the issues in more depth.

1.2 Role of the Predictive 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 potential major accidents have been identified
- All necessary measures to prevent and limit the consequences of major accidents are implemented

The Assessor's role relates to the risks both to people on-site and off-site. The Environment Agencies will assess risks to the environment separately.

On completing the assessment, the Assessor should fill in the assessment form (AF) and return it to the Assessment Manager giving conclusions about whether:

- The process of the hazard identification and risk analysis is fit for purpose;
- All major accidents have been identified – any gaps must be recorded on the AF;
- The major accident likelihood assessment is adequate for the purposes of COMAH
- The major accident consequence assessment is adequate for the purposes of COMAH i.e. the extent and severity of representative major accidents must be adequately quantified (Schedule 4, Part 2, Paragraph 4).
- The prevention and mitigation measures make risks as low as reasonably practicable (ALARP).

The AF allows Assessors to comment against each criterion and sub-criterion specified in the SRAM. Where appropriate, Assessors should write succinct "deficiency" statements against the criteria, and make clear what is required, e.g. further information, analysis or both.

The guidance contained in this document aims both to help Assessors identify any weaknesses in the safety report and to write consistent comments and conclusions. It outlines a number of questions that Assessors should ask to judge compliance with the predictive criteria specified in the SRAM.

When filling in the AF, Assessors should specify the page and paragraph number in the Operator's safety report for cross-referencing purposes. For example:

Criterion	Safety Report Refs	Comments	Issue Category*
10.3 The safety report should identify all potential major accidents and define a representative and sufficient set for risk analysis	Page xx Para yy	The safety report does not consider how a fire on site might cause a major accident. The report fails to meet criterion 10.3; the Operator has to provide more information.	Decided by team at final meeting

* The Issue Category relates to the inspection plan only.

1.3 Making judgments about proportionality

Information in the safety report should enable Assessors fully to understand site operations and any circumstances on-site and off-site that could affect the severity of potential accidents. To this end, the report should describe the processes carried out on site, the types and quantities of the hazardous substances involved and their potential effects on people in accident conditions. The report should also specify the numbers of people involved in the various hazardous activities and the distribution of people on site within the range of any hazardous effects expected in accident conditions. Application of proportionality will highlight the hazardous activities for which the Operator must provide the most detailed arguments to support the ALARP demonstrations.

Proportionality is a fundamental consideration when considering compliance against assessment criteria. HSE's view is that there must be some proportionality between the magnitude of the risk and the measures taken to control the risk. The phrase "all measures necessary" is to be interpreted with this principle in mind. Both the likelihood of accidents occurring on site and the severity of the worst possible accident determine proportionality. The following factors are important concerning the latter:

1. The nature of the hazards (i.e. whether the explosives are of Hazard Type 1, 2, 3 or 4) and the scale of the hazards (inventories of explosives);

2. The number of people involved in the operations undertaken on site;

3. Whether the operations are manual or remote;

4. Compliance with the standard quantity-distances

5. The number of people in adjacent buildings or populated areas

6. The density and types of nearby off-site population (e.g. dwellings, hospitals, schools, etc);

7. The variation of residual individual risks with distance[1]

Proportionality should influence the aspects on which Assessors focus the most attention, i.e. the issues where the occupier must provide convincing arguments to support the demonstrations.

[1] Multiple fatality risks and societal concerns are implicit in 2, 3, 4, 5 and 6 above. The nearer these risks are to the top end of the ALARP band, the more evidence and analysis are required to support the ALARP demonstration.

1.4 Proportionality and depth of risk assessment

It is important that Assessors should come to a view on proportionality before starting to assess a report against the predictive criteria.

Consideration of proportionality will help Assessors decide the type and level of analysis required to underpin the various demonstrations in the safety report. Depending on the level of risk, one of three levels of assessment will be appropriate: qualitative, semi-quantitative or quantitative.

1. Qualitative risk assessment is the comprehensive identification and description of hazards from a specified activity, to people or the environment, and high level qualitative assessment of likelihood and consequences of a representative set of scenarios with relevant good practice.

2. 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 and selection of a representative set of specific scenarios for more detailed assessment and ALARP analysis.

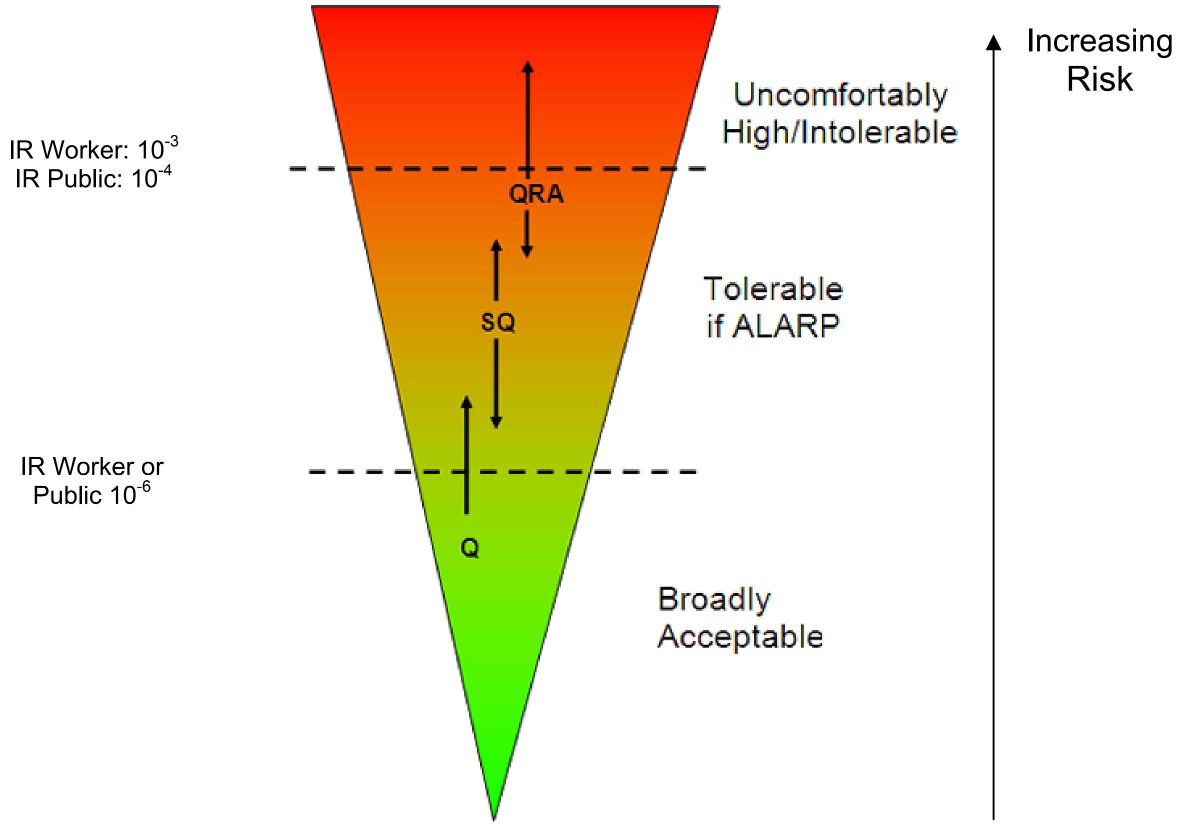
3. Quantitative risk assessment is the application of methodology to produce a numerical representation of the frequency and extent of a specified level of exposure or harm, to specified people or the environment, from a specified activity. There is also a comparison of the results with specified risk criteria.

Proportionality requires that as risk increases from a low level to the highest level, the form of risk assessment should change from qualitative, through semi-quantitative to quantitative. The diagram below depicts this principle and shows the Tolerability of Risk (TOR) Framework (see HSE, 2001) for ALARP decision-making. This emphasizes the need to take account of Individual Risk (IR) to both workers and members of the public when making ALARP judgments. When risks are in the tolerable region, they must also be ALARP; the nearer IR is to the uncomfortably-high boundary, the greater the degree of proportionality that applies and hence the greater the amount of detail required to support the risk analysis.

Compliance with the standard quantity-distance prescriptions specified in MSER or JSP 482 should ensure off-site risks are proportionately low. Although HSE has the discretion to vary the separation distances, it would normally only do so if alternative risk, hazard-reduction and mitigation measures ensure an equivalent level of safety. These measures would be included as conditions in any licence. Thus any operators who chose not to use standard quantity-distances must present a detailed technical justification to HSE in order to obtain a licence. The Safety Report should build the technical justification into the Safety Report as appropriate. The justification may inform the operator's assessments of the consequences of an accidental ignition.

The technical justification is unlikely to provide information on the likelihood of scenarios, so Operators will need to focus more on these aspects in the risk analysis. Cost benefit analysis (CBA) may be used to demonstrate that all measures necessary are in place and further risk reduction is not reasonably practicable. However, CBA alone cannot rule out a measure that is *prima facie* reasonable for the site-specific circumstances.

Tolerability of risk framework (adapted from SPC/Permissioning/37 - www.hse.gov.uk/foi/internalops/hid/spc/spcperm37/index.htm)



In the case of explosives installations that are compliant with QD prescriptions, individual risks to workers on site will drive proportionality considerations[2], because QD license limits will normally ensure that risks to the public are very low[3].

When considering proportionality, Assessors should exercise judgment against the expectation shown below, paying particular attention to IR to workers.

IR Worker	IR Public	Type of Risk Assessment
$>10^{-3}$	$>10^{-4}$	QRA & full options analysis – risk reduction required
$10^{-3} – 10^{-4}$	$10^{-4} – 10^{-5}$	SQ+
$10^{-4} – 10^{-5}$	$10^{-5} – 10^{-6}$	SQ
$10^{-5} – 10^{-6}$	$< 10^{-6}$	Q+
$< 10^{-6}$	$< 10^{-6}$	Q

Where: Q = qualitative; SQ= semi quantitative; and QRA= quantitative RA. The '+' sign reflects increasing depth of analysis or quantification, e.g. Q+ is somewhere between the expectation for Q and SQ levels.

The suggested divisions between the boundaries in each row are fuzzy to allow Assessors to exercise discretion on the type and depth of analysis that is fit for purpose in a particular circumstance, i.e. the

[2] Advice on historical ignition rates for different types of processes can be found at the following link: http://www.hse.gov.uk/comah/assessexplosives/step2.htm.

[3] The historical accident record for licensed explosives sites lends support to this argument: there have been no accidents at licensed sites resulting in off-site fatalities since at least 1946, and possibly much longer. However, in this time there have been over 90 fatal explosives accidents within licensed sites, resulting in over 100 fatalities amongst workers.

suggested ‘boundary’ values of IR are approximate. However, it would be exceptional to judge that a SQ+ risk assessment was needed when proportionality considerations indicate a Q+ analysis should suffice and vice versa. As the level of proportionality increases the level of detail in the demonstrations and the analysis of risk reduction measures should also increase, the increasing depth of risk analysis supporting the demonstrations being represented above by the variation Q, Q+, SQ, SQ+, QRA.

Where QRA is appropriate, it is important for Assessors to realise that measurement of multiple-fatality risk does not necessarily require production of iso-risk contours and F/N risk curves.

1.5 Input to the decision on whether the risks are ALARP

The Operator’s ALARP demonstration should always show compliance with good practice, engineering standards, recognized codes and guidance, etc. A consideration and evaluation of further risk-reduction measures is also required. Two important questions are:

- What additional risk-reduction measures are possible? A list of such measures is required in support of the demonstration that the risks from the operation are ALARP

- Which of these are reasonably practicable to implement? If the Operator demonstrates that further risk-reduction measures would not be reasonably practicable, then the existing controls are critical for the continued safe operation of the establishment. These controls become an important focus for verification by inspection to ensure that they are sufficiently reliable.

Multiple-fatality risks should as a minimum meet the criterion in R2P2, i.e. the likelihood of a single major industrial activity producing 50 or more fatalities should be less than 1 in 5000 per year, i.e. less than 2×10^{-4} per year.

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 the cost of preventing fatalities by the introduction of additional safety measures. By comparing the cost of preventing a statistical fatality to the value society puts on each life (e.g. £1.6M) an indication of the level of disproportion is obtained. Judgment 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 maximum credible accident. As the level of risk increases, the gross disproportion factor increases approaching ten towards the threshold of intolerability.

1.6 How the predictive criteria should be used

Operators will write their safety reports in a structure that suits them. Whatever the structure adopted, Operators should ensure that there is a clear link between the information presented in the report and the required demonstrations. The Assessors should bear in mind that the same control measures and arguments may apply to more than one demonstration, and that this information may appear in different parts of the report.

As a general guide, Assessors should take a quick overview to gain insight into the site's activities, environs, the scale and nature of the hazards, the range of potential major accidents, the controls in place, the maximum credible accident for the site and the levels of risk that remain after controls have been implemented. This will enable Assessors to take a view on proportionality and identify the assessment criteria requiring greatest consideration.

The predictive criteria aim to help Assessors make consistent professional judgments about whether the demonstrations in a safety report are adequate. The AF should make clear that the Assessors have tested all the top-level 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, i.e. recorded for auditing purposes.

Operators must also show that they have properly identified all foreseeable major accidents and that they have implemented all necessary measures to prevent such accidents. This means that the Operator has to demonstrate that on-site and off-site risks are ALARP, and that all necessary measures are in place to address any risks that remain after compliance with standards or guidance. Assessors should bear in mind that Operators who demonstrate compliance using company or other non-published standards should show that they are fit for purpose, i.e. based on risk assessment.

The following points are central to the assessment process:

1. Assessors should ensure that they are clear about how the proportionality principle applies.

2. The type of report will influence where attention should be focused, e.g. if it is an update, five-year revised report or a modification report, the primary focus should be on the new material and how this affects the risk assessment.

3. 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, e.g. when some quantification (e.g. of event likelihood), is needed and only qualitative arguments are used.

4. All the criteria must be applied in a proportionate and consistent way. For qualitative risk assessments, the focus is on the top-level criteria.

5. All safety reports need to demonstrate adequate assessment of the risks to occupied buildings.

It is always necessary for Assessors to exercise professional judgment in order to reach a decision on whether the demonstrations in a report are fit for purpose when assessed against the predictive criteria. The criteria and the associated guidance aim to help Assessors exercise this judgment in a consistent way. Occasionally, Assessors may need to take advice on some issues with HID colleagues 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 drawing the Competent Authority's (CA) conclusions. Ways of achieving consistency include:

- assessment against exemplar reports

- Lead unit system
- Sharing experiences through knowledge management systems

Once the assessment is complete, the AF should be filled in and the conclusions summarised for the Assessment Manager.

Criterion 10.1 "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."

For many years, the hazards associated with explosives installations have been limited by formal licensing procedures based on quantity-distance (QD) principles. These principles limit the quantities of explosives that can be present in workshops, magazines, etc. according to the proximity of nearby buildings and certain other facilities both on and off site.

The aim of QD licensing is (1) to provide an acceptable degree of protection for the workforce elsewhere on site should an explosion occur in a danger building or area and (2) to provide a high level of protection for the public from such events. However, it should be noted that the QD prescriptions have never at any stage guaranteed workers and members of the public complete immunity against the effects of explosives events – for which aim impracticably large separation distances would be required. Rather the prescriptions offer adequate protection on the understanding that the likelihood of a major accident is low and that a limited amount of damage can be tolerated in the unlikely event that an accident occurs. **The conditions of the licence thus provide important measures for mitigating the effects of a major accident but have limited impact on preventing major accidents arising or for dealing with the safety of any people immediately affected by an accident. These issues should be addressed elsewhere in the safety report.**

Explosives limits for cells/workstations within processing buildings might be further constrained to protect occupants. Remote working, type-tested guarding of machinery and minimal quantities for highly sensitive explosives are further measures used to safeguard personnel from the harmful effects of accidental ignitions.

A site Operator not compliant with the QD prescriptions or normally accepted control measures (i.e. non-compliance with industry standards, HSE guidance and approved codes of practice) would be required to present a quantified analysis and rigorous ALARP demonstration. In some cases this may require full QRA.

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

Whether or not an Operator is compliant with QD prescriptions, the HSE should expect to see a policy statement in the Operator's safety report confirming a commitment to risk minimization on the ALARP principle. Failure to provide adequate evidence of a risk minimization policy may be viewed as a failure to comply with the COMAH Regulations. The section of the safety report dealing with the Major Accident Prevention Policy (MAPP) may inform the Assessor on this issue.

For the purpose of establishing the risk profile of the site, an Operator may undertake an initial assessment in which broad-brush estimates of the likelihood and consequences of all identified potential major accidents are entered onto a risk matrix of the type shown in Figure 1. The Operator is not required to undertake detailed analysis in this initial assessment, but the personnel involved in the exercise should be suitably qualified with appropriate experience. To this end, the Assessor should expect to see a list 10.5.4 involved, their position within the company, their qualifications and brief details of their experience (further advice on this issue is given in http://www.hse.gov.uk/comah/assessexplosives/step2.htm).

A more detailed assessment of a representative set of scenarios should follow the initial assessment. The type of information that appears in this more detailed assessment will depend on proportionality, which in turn will dictate the level of quantification required, from semi-quantitative through to fully quantified assessment as appropriate. The table below summarizes in broad outline the information requirement for semi-quantitative and fully quantified assessment:

Table 1: Comparison of Information Requirements for detailed Risk Assessment

Semi-quantitative risk assessment	Fully Quantified risk assessment
(1) Systematic identification of potential causes of explosives events.	(1) Systematic identification of potential causes of explosives events.
(2) List of safeguards to protect against the occurrence of explosives events (these safeguards may be engineered or procedural).	(2) List of safeguards to protect against the occurrence of explosives events (these safeguards may be engineered or procedural).
(3) Semi-quantitative estimates for the likelihood of each indentified potential fault. These can range from estimates based on past experience to more rigorous quantified estimates, including logic tree analyses of potential faults and reliability analysis of controls, depending on proportionality	(3) Quantified estimates for the likelihood of explosion of each identified fault.
(4) List of mitigating measures to ameliorate the consequences of explosives events (these mitigating measures may also be engineered or procedural).	(4) List of mitigating measures to ameliorate the consequences of explosives events (these mitigating measures might also be engineered or procedural).
(5) Semi-quantitative estimates for the consequences of explosives event (in terms of injury/fatality – see Figure 2). Again, these can range from point estimates based on obvious outcome to more rigorous quantified estimates for particular scenarios. All such estimates should be backed up with sound technical arguments	(5) Quantified estimates for the consequences of explosives events (in terms of numbers of fatalities, injuries and detailed assessment of property damage).
(6) Justification for the safeguarding and mitigating measures employed (e.g. complies with industry standards, codes of practice, best available technology, etc.).	(6) Quantified estimates of individual and group risk for both workers on site and members of the public off site
(7) List of further safeguarding and mitigating measures that may be adopted or rejected on the ALARP principle. The use qualitative arguments will often suffice in such cases	(7) Use of cost-benefit analysis to justify safeguarding and mitigating measures and demonstrate that risks have been reduced ALARP.

It is important to realize that the term "semi-quantitative estimates" does not imply that there is never any need to undertake rigorous estimation of the likelihood and consequence of specific events. In some cases, the outcome of an event may be obvious – for example, an ignition of a 1kg-charge in a cell specifically designed to recognized standards to contain the effects of the explosion; in this case the assumption that fatal injury would be limited to the cell occupants is reasonable and detailed modeling of the effects is not required. However, events involving quantities of explosives that could potentially harm persons remote or adjacent to an operation may require detailed assessment. In such cases, recognized explosion effects and harm models can provide estimates for the number of fatalities and injuries expected in surrounding buildings and populated areas – see discussion under the heading of Criterion 10.5.4 for advice on modeling. Detailed assessment is also required in cases where an ignition could potentially propagate within a building. Where prevention of propagation is dependent on control measures working on demand, e.g. drencher systems, an estimate should be made for the numbers of casualties that would result should these controls fail and the associated likelihood.

For all events, the Operator must demonstrate a systematic approach to risk minimization. Failure to address the issues summarised in the above table constitutes a major shortcoming.

Q: Does the safety report summarize the tolerability criteria for use with the risk assessments?

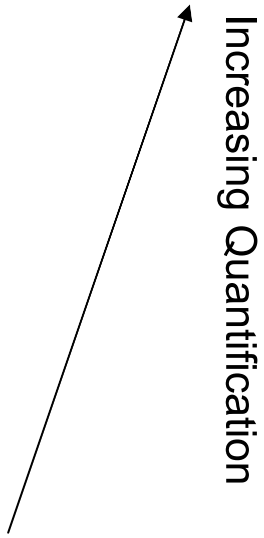
Operators should summarize the criteria used to judge when risks are tolerable. Ideally, this should appear near the beginning of the report so that the Assessor can make the following judgments:

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

For the purpose of making an initial assessment, risk matrices provide a convenient way of summarizing risk estimates and tolerability criteria. A matrix, as illustrated below, typically comprises a rectangle divided into a number of boxes, with each box representing a different underlying risk level. Probability and fatality bands represent accident likelihood and severity respectively. Each band has a semi-quantitative description together with indicative values.

Figure 1 Blank Risk Matrix

F ($year^{-1}$)	Consequences (No of fatalities)			
	1	**2 – 5**	**6 – 10**	**11 – 50**
$>10^{-3}$ Somewhat unlikely				
$10^{-3} – 10^{-4}$ Quite unlikely				
$10^{-4} – 10^{-5}$ unlikely				
$10^{-5} – 10^{-6}$ Very unlikely				
$<10^{-6}$ Extremely unlikely				



Uncomfortably high
Tolerable if ALARP
Broadly acceptable

The matrix is partitioned into three areas to denote whether the risk of an accident is intolerable (red-shaded area), tolerable if ALARP (yellow shaded area) or broadly acceptable (green shaded area). In the case of QD compliant sites, fatalities are only likely to occur amongst workers in danger areas or amongst people on-site exposed to transient risk, i.e. workers in offices located near to routes used by on-site explosives transport.

Risk matrices also provide a convenient way for summarizing the results of detailed semi-quantitative analyses of representative scenarios or exemplar processes. Such a matrix is illustrated over page. It is important that an appropriate level of risk analysis – which would include systematic methods for identification of potential accident initiators and failures modes for protective systems, together with systematic methods for estimation of accident likelihood and consequences – underpin the use of such matrices. These methods are considered further under Criteria 10.3, 10.4 and 10.5.

Figure 2: Example matrix for use with detailed semi-quantitative analysis

Consequences	**CRITICAL** **Multiple fatalities**	**5**	0	5	10	15	20	25
	VERY HIGH **Single Fatality**	**4**	0	4	8	12	16	20
	HIGH **Severe incapacity or major injury**	**3**	0	3	6	9	12	15
	MODERATE **3-day RIDDOR reportable injury**	**2**	0	2	4	6	8	10
	SLIGHT **Minor injuries requiring first aid treatment**	**1**	0	1	2	3	4	5
	NIL **No injury or disease**	**0**	0	0	0	0	0	0
			0	**1**	**2**	**3**	**4**	**5**
			Very Unlikely **Theoretically possible, but extremely remote chance of occurrence** $F < 10^{-7}$ **pa**	**Unlikely** **Foreseeable event, but requires multiple failure. Very remote chance of occurring during lifetime of plant** $10^{-5} > F > 10^{-7}$ **pa**	**Possible** **Incidents known in industry. Requires at least two failures. Event not expected during lifetime of plant** $10^{-3} > F > 10^{-5}$ **pa**	**Quite possible** **Could occur in plant lifetime. root causes likely to have occurred on plant** $10^{-1} > F > 10^{-3}$ **pa**	**Likely** **Event or near miss that has occurred during plant lifetime** $1 > F > 10^{-1}$ **pa**	**Very Likely** **Event occurs regularly on the plant** $F > 1$ **pa**
			Likelihood					

Q: Is the Operator aware of the ALARP principle and is he using it to ensure that all necessary measures are taken to reduce the likelihood and consequences of a major accident?

Fundamental to the demonstration that "all necessary measures" are in place, is evidence to show that risks arising from the activities on site are ALARP. An Operator who fails to provide this evidence may fail to comply with the regulations.

Assessors generally would not expect to see detailed CBA arguments in a safety report for a site that is compliant with QD prescriptions, industry standards, HSE guidance and approved codes of practice. However, they should expect the Operator to provide a list of possible further mitigation measures together with qualitative arguments for whether these measures are or are not reasonable practicable

Criterion 10.1.1

"It should be clear that human factors have been taken into account in the risk analysis."

When making a judgment about compliance with this criterion, Assessors should ask the following questions:

Q: Does the safety report demonstrate that adequate allowance has been made for human error?

A failure to address the potential for human error constitutes a serious omission. The safety report should describe the procedure used to identify all potential human errors that might result in dangerous occurrences and ultimately major accidents. The report also should clearly state what measures are in place to reduce the likelihood of these errors.

Most particularly, Assessors should look for evidence of clearly written process instructions and that operatives are properly trained and adequately supervised.

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

The safety report should consider how the following types of human error might initiate a major accident together with the safeguards in place:

- Failure of personnel to carry out operations that are part of normal duties
- Latent errors by designers, management personnel, maintenance crew (i.e. non-front-line operatives). For example, the risk assessment should address the potential for incorrect re-assembly of equipment following a maintenance operation.
- Personnel carrying out erroneous actions that are not part of normal duties
- Misuse of machinery by personnel and use of incorrect work tools, etc.
- Unauthorized absence of personnel from machinery/processes
- Failure of personnel to respond correctly to alarm signals
- Deliberate or inadvertent degradation of the safety of a plant (e.g. by switching off alarms, bypassing safety systems, etc.)
- Deliberate rule flouting (e.g. smoking in danger areas)
- Failure of personnel to detect faulty components during checking/testing operations
- Failure of personnel to carry out maintenance operations correctly
- "Violations" or "breaking the rules"
- Vandalism, attempted burglary and even sabotage may warrant consideration.

Q: Does the safety report show how human factors are included in the risk assessment?

The assessment criteria reflect the fact that historical data suggest human failure is the root cause of most industrial accidents. All members of the assessment team should consider the potential for human error.

The safety report should describe the part personnel play in controlling hazards and risks. If an operative is required to take certain actions following an alarm, the report will need to consider the likelihood of success.

If a task is critical to the prevention of a major hazard and the ALARP demonstration relies on an unrealistically high level of human reliability, this may not be acceptable if the installation of automatic control and protection systems can remove the potential for operative error. To achieve the required reliability, control systems need an appropriate level of redundancy and diversity.

Not all safety reports will need to quantify human reliability: for qualitative analysis, the focus should be on demonstrating the quality of the training and supervision. Where quantitative assessment is appropriate, Assessors should check that use of human reliability figures in fault trees does not result in top event frequencies that are highly sensitive to the values used.

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

In summary, the safety report should:

- Describe how human errors are identified
- What measures have been taken to reduce their probability
- Demonstrate that the systems and procedures for selection, training and supervision of operatives are fit for purpose.

Criterion 10.1.2

"Any criteria for eliminating possible hazardous events from further consideration should be clearly justified."

This criterion deals with the scope of the Operator's accident analysis. The following questions help assess the adequacy of the scope:

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

Operators are obliged to demonstrate that the risks of low frequency events with severe consequences are adequately controlled. However, the process of assessing the likelihood of highly improbable accidents not need be as rigorous as that employed for assessing the likelihood of risk dominating sequences, and very improbable accident initiators, such as meteorite strikes and earthquakes, need not be considered.

Likelihood analysis for highly improbable accidents need not be as detailed as that for risk dominating sequences. In this case, estimates based on historical data, industry standards and regulatory guidance, etc. are acceptable.

Q: Does the safety report unjustifiably eliminate "small scale" events?

The Operator should address all potential major accidents, bearing in mind that even small quantities of explosives can cause significant injury and death.

The term "major accident" is fundamental to the provisions in the regulations and the duties placed upon operators. All incidents involving the unintentional ignition of explosives or pyrotechnic material, unless covered by a certificate of exemption under RIDDOR, constitute an uncontrolled development outside normal operating conditions. All processes involving explosives or pyrotechnic materials should be included in the analysis.

A Process operated remotely or designed so that only the minimum of explosive is present still constitutes a major accident hazard if there is a potential for injury to occur. The arrangements for remote operation or minimizing the quantity of explosives form part of the control measures for the prevention of injury to people and damage to the environment and should be included in the demonstration that all measures necessary are being taken.

Q: Has the Operator grouped the consequences of several accidents together?

While the Operator must identify all significant potential accidents, it is permissible to describe in detail the consequences of only a representative set of events. For example, if six different sequences of event are identified with the potential to initiate the same type and quantity of explosives, then the consequences of only one of them need be described, provided the likelihood of the others is addressed. However, the Operator must demonstrate that the risk from every accident scenario is ALARP.

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

As noted previously, an Operator who is fully compliant with normally accepted control measures (i.e. industry standards, HSE guidance and approved codes of practice) need not undertake a full QRA. In such cases, semi-quantitative estimates of accident likelihood will usually suffice. The following table illustrates one such scheme, but the Operator must be able to support any such estimates with sound technical arguments.

Table 2: Definition of accident likelihood

Likelihood	Definition	Indicative Frequency Band (per year)
Frequent	Event occurs regularly on the plant	F > 10
Likely	Likely to occur a few times in plant lifetime	10 > F 10-1
Occasional	Could occur in plant lifetime; root causes likely to have occurred on plant	10-1 > F > 10-3
Unlikely	Unlikely; incidents known to have occurred in industry but would require at least two failures	10-3 > F > 10-5
Remote	High unlikely, but may exceptionally occur; would require multiple fatalities	10-5 > F > 10-7
Incredible	Extremely unlikely that the event will ever occur	F < 10-7

The Operator is not obliged to use the scheme outlined in this table, but it is important that the Operator clearly define any qualitative terms used.

Quantification of accident likelihood does not necessarily require use of formalized methods, such as fault and event tree analyses. Historical data, industry standards, regulatory guidance, etc. can all be used to determine overall accident likelihood. However, statements of the kind "the probability of this accident occurring is judged to be less than 10-6 per year" are not acceptable if not backed by supporting evidence. A poorly documented or sparsely detailed likelihood analysis that appears somewhat optimistic may fail to comply with the assessment criteria.

Criterion 10.2 "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 the Operator provides information about the installation and its hazardous substances that is suitable and sufficient for risk assessment purposes. When considering this part of the safety report, the Assessors should ask whether it provides answers to the following questions:

Q: Has the Operator specified the maximum inventory of dangerous substances on the installation?

The site Operator should specify the types and quantities of explosives that could be present at each location at the installation. This information will determine whether the installation falls within the remit of COMAH and, if so, whether it is a lower-tier or top tier site. Appendix 1 provides further guidance on this matter.

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 contain sufficient information about the site and its operations to allow identification of potential major accidents. The detail provided needs to be sufficient to enable Assessors to determine whether the accident analysis is thorough and complete.

The Operator should identify all the buildings and other facilities on site where explosives might be present – these building and facilities are conveniently referred to as potential explosion sites (PES). The Operator should list the types of processes undertaken at the various PES along with the types and quantities of explosives present, and additionally specify the associated licence limits for each type of explosives. It is not necessary to provide copies of the licences with the safety report but the report should ideally reference the licence numbers, e.g. Licence Number 0999 or X1/4111/999/9, noting if they have been subsequently amended.

Failure to identify all PES and provide clear descriptions of the activities undertaken, or failure to list the types and quantities of explosives present at PES would preclude independent evaluation of the likelihood and consequences of potential accidents and as such should be viewed as a major shortcoming.

Where danger buildings and areas are compliant with QD prescriptions, little further information on prevention of communication of explosion from one building to another is required. However, where the licence incorporates arrangements for unit risking of buildings, e.g. by segregation into compartments, the report should stipulate how this is achieved and the basis for the design used. Similarly, where a licence allows reduced separation distances, a description of the mitigating circumstances and how they are maintained should be included in the safety report.

Q: Has the Operator adequately described the operations undertaken on site?

As well as containing brief descriptions of the operations undertaken at the PES, the safety report should also describe arrangements for bringing explosives onto the site, taking explosives off the site, and moving explosives between buildings.

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

A suitable and sufficient risk analysis can only be achieved if all relevant information specified at Schedule 4, part 2, paragraph 3 [http://www.legislation.gov.uk/uksi/1999/743/schedule/4/made] is supplied and the quality of that information is consistent with the need for proportionate risk analysis. The relevant part of the SRAM is headed 'Descriptive Aspects'; the information requirement outlined below is that necessary to enable Assessors to check the background data for the risk analysis.

The safety report should contain a map of the installation to a scale large enough to show any features that may be significant to the assessment of the hazard or risk from the operations undertaken (an Ordnance Survey map of scale 1 to 10,000 should provide the necessary detail). The map should show the location of the installation and its relationship to local features such as:

- Residential areas
- Premises where evacuation would prove difficult, e.g. schools, hospitals, prisons, old peoples homes and sheltered accommodation etc.
- Industrial premises
- Other hazardous installations
- Transport features, e.g. major roads and railways
- Recreational areas
- Buildings of vulnerable construction

The report should contain the most up-to-date map available and any recent changes of significance should be marked. If there are many features around the installation for which information is required, the use of a tabular form referring to points marked on the map may be appropriate.

The report should contain a plan of the installation to a scale of 1 to 2,500 or better. The plan should be large enough to cover the entire area of the installation and show:

- The location of all PES. The PES should be individually and unambiguous identified (e.g. by use of a numbering system) and a key provided - see Table 3 [http://www.hse.gov.uk/comah/sragexp/images/tables.pdf] as an example. Any mitigating features, such as earth mounds (also known as traverses) or blast walls, should be shown.

- The location of all populated buildings and any other facilities on site where people may be present, e.g. office buildings, canteens, footpaths. All such facilities (conveniently referred to as Exposed Sites, or ES) should be individually and unambiguously identified and a key provided- see Table 4 [http://www.hse.gov.uk/comah/sragexp/images/tables.pdf] as an example.

- The location of emergency and access points

A full description of each ES should include:

- Brief constructional details (e.g. steel-framed, concrete-framed, traditional brick-built construction, etc.)

- Number of storeys and height of the ES

- Whether the ES is protected by earth mounds, or some other form of barricade

- The number of people typically present in the building at different times of the day.

Again, this type of information could be summarised in tabular form, as shown in Table 4 [http://www.hse.gov.uk/comah/sragexp/images/tables.pdf].

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

The safety report should clearly describe any measures in place to contain the effects of explosions and fires and limit propagation to adjacent stores. The design of drencher systems, detonation breaks, flame/smoke venting arrangements, shields, etc should be justified by reference to established standards, trials, etc. For remote operations, the means of protecting personnel in control rooms and other areas should be clearly set out and justified by reference to standards, trials, etc.

Q: Does the safety report specify 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 ecotoxicological information needed to establish risks to people and the environment from the hazardous substances on site. Toxicity data should also be provided for any toxic compounds produced by combustion of these substances.

Tables 3 & 4 - Summary details for PES & ES
[http://www.hse.gov.uk/comah/sragexp/images/tables.pdf]

Appendix 1 to Criterion 10.2: Threshold limits for Lower Tier and Top Tier Installations

The site Operator should specify the types and quantities of explosives that could be present at each location at the installation. This information will determine whether the installation falls within the remit of COMAH and, if so, whether the installation is to be classed as a lower-tier or top tier site. For this purpose, the explosives on site need to be partitioned into two groups:

1. Substances, preparations or articles that are explosives within UN/ADR Division 1.4

2. Substances, preparations or articles that are explosives within UN/ADR Division 1.1,1.2,1.3,1.5 or 1.6 or risk phrase R2 or R3

R2 explosives comprise: -

- Substances or preparations which create the risk of an explosion by shock, friction, fire or other sources of ignition;
- Substances or preparations designed to produce heat, light, sound, gas or smoke or a combination of such effects through non-detonative self-sustained exothermic chemical reaction (these types of explosives are commonly known as pyrotechnic compositions);
- Explosives or pyrotechnic substances or preparations contained in objects.

R3 explosives comprise:

- Substances or preparations, which create extreme risks of explosion by shock, friction, fire or other sources of ignition (these types of explosives are more commonly known as primary explosives).

R3 substances are those that are either as sensitive or more sensitive to impact and friction than RDX. An indicative list of explosives falling into this category is shown in Table A1.1.

Table A1.1: Indicative List of Risk Phrases for Explosives

Explosive Type	Substance/Preparation	Risk Phrase
Ammonium Picrate	Substance	R21
Ammonium Perchlorate	Substance	R2
ANFO, emulsion, slurry, water gel, explosives	Preparation	R2
Barium Azide	Substance	R3
Black Powder	Preparation	R2
Cast Explosives	Preparations	R2
Casting liquids	Preparations	R3
Casting Powders	Preparations	R3
Ethylene Glycol Dinitrate	Substance	R3

Explosive Type	Substance/Preparation	Risk Phrase
Hexanitrostilbene	Substance	R3
Hexolite (Hexotol)	Substance	R2
HMX Dry	Substance	R32
HMX (Desensitized by addition of water or Phlegmatizer	Preparation	R22
Lead Azide	Substance	R3
Lead Styphnate	Substance	R3
Mercury Fulminate	Substance	R3
NG Gelatines	Preparation	R3
NG Powders	Preparation	R2
Nitrocellulose	Substance	R3
Nitroglycerine	Substance	R3
PETN	Substance	R3
PETN/WAX	Preparation	R3
Plastic explosive	Preparation	R2
Primary explosives	Preparation	R2
Pyrodex	Preparation	R3
RDX (Dry Pure)	Substance	R32
RDX (Desensitized by addition of water or Phlegmatizer	Preparation	R22
Single/double/triple base propellant	Preparation	R3
Tetrazene	Preparation	R3
Trinitrobenzene	Substance	R23
Trinitrophenol (Picric Acid)	Substance	R23
Trinitoresorcinol (styphnic acid)	Substance	R23
Trinitrotoluene	Substance	R2
Trinitrotriazalone	Substance	R2

Notes: Pyrotechnic compositions (mixture of substances) and articles containing explosive or pyrotechnic substances/preparations are included as explosives of Category 4 in schedule 1 part 3 of the COMAH regulations (Note 2(a)) and are subject to the same threshold quantities as R2 substances and preparations.
Note 1 Risk phrase contrary to that in Approved Supply List.
Note 2 Based on R3 substances being those which are equally sensitive or more sensitive to impact and friction than RDX.
Note 3 Entry as given in Approved Supply List.

In addition to explosives, the Operator should identify any other dangerous substances on site. The dangerous substances to which the regulations apply and the threshold limits to be applied are listed in Schedule 1 of the regulations. For the majority of explosives establishments the dangerous substances likely to be involved are shown in Table A1.2.

Table A1.2: Category of Dangerous Substances

Category of Dangerous Substances	Lower Tier Limit (tonnes)	Top Tier Limit (tonnes)
Ammonium Nitrate[1]	10	50
Ammonium Nitrate[2]	350	2,500
Ammonium Nitrate[3]	1,250	5,000
Ammonium Nitrate[4]	5,000	10,000
1. Very Toxic	5	20
2. Toxic	50	200
3. Oxidising	50	200
4. EXPLOSIVE where the substance, preparation or article is an explosive within UN/ADR Division 1.4	50	200
5. EXPLOSIVE where the substance, preparation or article is an explosive within UN/ADR Division 1.1,1.2, 1.3, 1.5 or 1.6 or risk phrase R2 or R3	10	50
6. Flammable	5,000	50,000
7a. Highly Flammable Liquids[5]	50	200
7b. Highly Flammable Liquids[6]	5,000	50,000
8. Extremely Flammable Liquids	10	50
9. Dangerous for the environment (a) R50: "very toxic to aquatic organisms" (including R50/53) (b) R51/53: "Toxic to aquatic organisms: may cause long term adverse effects in the aquatic environment"	100 200	200 500
Any classification not covered by those given above in combination with risk phrases (a) R14: "Reacts violently with water" (including R14/15) (b) R29: "in contact with water, liberates toxic gas"	100 50	500 200

Notes:

Note 1: **Ammonium nitrate (10/50):** "off-specs" material and fertilisers not satisfying the detonation resistance test.
This applies to –

(a) material rejected during the manufacturing process and to ammonium nitrate and preparations of ammonium nitrate, straight ammonium nitrate-based fertilisers and ammonium nitrate-based compound/composite fertilisers referred to in Notes 2 and 3, that are being or have
been returned from the final user to a manufacturer, temporary storage or reprocessing plant for reworking, recycling or treatment for safe use, because they no longer comply with the specifications of Notes 2 and 3; or
(b) fertilisers which do not fall within Notes 1(a) and 2 because they do not satisfy the detonation resistance test, other than fertilisers which –
(i) at the time of delivery to a final user satisfied the detonation resistance test; but
(ii) later became degraded or contaminated; and
(iii) are temporarily present at the establishment of the final user
prior to their return for reworking, recycling or treatment for

(b) safe use or to their being applied as fertiliser.
(i) at the time of delivery to a final user satisfied the detonation resistance test; but
(ii) later became degraded or contaminated; and
(iii) are temporarily present at the establishment of the final user

prior to their return for reworking, recycling or treatment for
(c) *safe use or to their being applied as fertiliser.*

Note 2: **Ammonium nitrate (350/2,500):** technical grade.
This applies to –

(a) ammonium nitrate and preparations of ammonium nitrate in which the nitrogen content as a result of the ammonium nitrate is –

(i) between 24.5% and 28% by weight, and which contain not more than 0.4% combustible substances; or

(ii) more than 28% by weight, and which contain not more than 0.2% combustible substances; and

(b) aqueous ammonium nitrate solutions in which the concentration of ammonium nitrate is more than 80% by weight.

Note 3: **Ammonium nitrate (1,250/5,000):** fertiliser grade.
This applies to straight ammonium nitrate-based fertilisers and to ammonium nitrate-based compound/composite fertilisers in which the nitrogen content as a result of ammonium nitrate is —

(a) more than 24.5% by weight, except for mixtures of ammonium nitrate with dolomite, limestone and/or calcium carbonate with a purity of at least 90%;

(b) more than 15.75% by weight for mixtures of ammonium nitrate and ammonium sulphate; or

(c) more than 28% by weight for mixtures of ammonium nitrate with dolomite, limestone and/or calcium carbonate with a purity of at least 90%,

and which satisfy the detonation resistance test.

Note 4: **Ammonium nitrate (5,000/10,000):** fertilisers capable of self-sustaining decomposition
This applies to ammonium nitrate-based compound/composite fertilisers (compound or composite fertilisers containing ammonium nitrate with phosphate and/or potash) in which the nitrogen content as a result of ammonium nitrate is —

(a) between 15.75% and 24.5% by weight and either with not more than 0.4% total combustible or organic materials or which satisfy the detonation resistance test described in Schedule 2 to the Ammonium Nitrate Materials (High Nitrogen Content) Safety Regulations 2003*(a)* "the detonation resistance test"; or

(b) 15.75% or less by weight and unrestricted combustible materials,

and which are capable of self-sustaining decomposition according to the UN Trough Test specified in United Nations Recommendations on the Transport of Dangerous Goods: Manual of Tests and Criteria (3rd revised Edition), Part III, subsection 38.2.

Note 5: Substances and preparations that may become hot and finally catch fire in contact with air at ambient temperature without any input of energy (risk phrase R17). Substances and preparations that have a flash point lower than 55ºC and that remain liquid under pressure, where particular processing conditions, such as high pressure or high temperature, may create major-accident hazards

Note 6: substances and preparations having a flash point lower than 21ºC and which are not extremely flammable (risk phrase R11, second indent).

An aggregation rule applies where combinations of dangerous substances are present below their threshold limits. The dangerous substance categories listed in the above table, with the exception of substances in the VERY TOXIC category, are aggregated in accordance with the rule described in Schedule 1 of the Regulations in order to determine the total quantity of qualifying substances present.

Dangerous substances at an establishment in quantities of not more than 2% of the relevant qualifying quantity should be ignored for the purposes of calculating the total quantity present, provided their location is such that it cannot act as an initiator of a major accident elsewhere on site. This 2% rule will only apply where the total quantity present at one location within the establishment is equal to or less than 2% of the relevant qualifying quantity.

Example: In calculating the total quantity of dangerous substances present at a potential Top Tier site, a magazine containing 4 tonnes of blasting explosives (2% of the Top Tier limit for explosives in Category 4) may be excluded for the calculation aggregating the total quantity, provided its location is such that it cannot initiate a major accident elsewhere on site.

Whether the explosives in a magazine or process building could initiate another major accident depends upon the nature and construction of the receptor (i.e. other magazines, tanks containing flammable or toxic liquids, stocks of oxidizers, etc.) and the characteristics of the donor building itself (e.g. the type and quantity of explosives present, the construction of the magazine or process building and mounds).

The requirement to prevent the initiation of another major accident elsewhere on site is not restricted to instantaneous communication but includes delayed events, e.g. secondary fires caused by an explosion leading to a second explosion. It should be noted that the internal separation distances required by the explosive licence are intended to prevent instantaneous communication but these distances will not ensure delayed secondary events are prevented. For these reasons it is not possible to lay down general rules regarding what will and what will not initiate a major accident elsewhere on site and the Operator will need to make an individual assessment of the specific circumstances for each case where the 2% rule is to be applied.

The rule is only relevant for the purposes of calculating the extent to which the regulations apply; all dangerous substances present must be considered when preparing the major accident prevention plan or safety report.

Examples:

An establishment holding 40 tonnes of explosives and 200 tonnes of technical grade AN will be aggregated as follows:

40/50 + 200/350 = 1.37 i.e. Lower Tier

but

40/200 + 200/2500 = 0.28 not Top Tier.

A factory holding 500 tonnes of technical grade AN, 150 tonnes of explosives, 1.5 tonnes of primary explosive (Category 5, Risk Phrase R3) and 10 tonnes of sodium and calcium nitrate will be at least Lower Tier and on aggregation becomes Top Tier as follows:

500/2500 + 150/200 + 1.5/50 + 10/200 = 1.03

(If the stock of R3 explosives is reduced to 1 tonne and located so that it could not initiate a major accident elsewhere on site, then the calculation becomes:

$$500/2500 + 1500/200 + 10/200 = 1.00$$

Since the quantity of R3 explosives present equals 2% of the qualifying quantity, it can be ignored for the purposes of this calculation. The factory is then a Lower Tier site).

It is important to note that the quantity to be used in any calculation of this type is the quantity the Operator envisages being on site at any one time, NOT THE TOTAL QUANTITY ALLOWED BY THE EXPLOSIVES LICENCE, e.g. if it is envisaged that a magazine will never hold in excess of either lower threshold limits for explosives then the regulations will not apply, even if the quantity allowed by the licence is in excess of these limits. However, should the Operator subsequently wish to make use of the excess capacity and hence exceed a qualifying limit (either into Lower Tier or from Lower to Top Tier), the site will be regarded as a new establishment and the requirements for the relevant notification, major accident prevention plan and/or safety reports will need to be complied with, before the increase is made.

Explosives containing more than 7% of nitroglycerine (NG) and/or ethylene glycol dinitrate (EGDN) are assigned to the very toxic category as well as being explosives. Where substances and preparations fall into two categories they are regarded as being in the category that has the lowest threshold. Therefore, explosives containing more then 7% of NG/EGDN are treated as “Very Toxic”, but only for the purposes of determining the application of the regulations. Thus COMAH will not apply to a magazine holding 49.9 tonnes of water based blasting explosives and 4.9 tonnes of NG based explosives because Explosives and Very Toxic substances are not aggregated together.

Criterion 10.3 "The safety report should identify all potential major accidents and define a representative and sufficient set for the purpose of risk assessment."

Explosives pose an obvious hazard, but the potential for accidental ignition varies considerably across the broad range of substances and articles classed as "explosives". The most sensitive, i.e. primary explosives and certain pyrotechnic compositions, will detonate when exposed to low levels of stimuli generated in many common place activities – for example, crystals of lead styphnate will detonate if trampled underfoot. At the other end of the spectrum are certain insensitive secondary explosives that can withstand considerable "insults" and may even require a booster charge to effect detonation. It follows that the risk of accidental ignition during processing or handling of explosives is a function of both the "sensitiveness" of the material and the types and amounts of energy to which it might be exposed, particularly during fault conditions. These considerations should inform the measures taken by Operators to guard against accidental ignition. In general, one could expect to see increasingly more stringent measures applied the greater the sensitiveness of the explosives and the more energetic the activities undertaken.

The Operator should specify the methods used to identify the potential causes of accidental ignition together with the expertise of the people involved in these studies. The identification exercise needs to comprehensive; it should cover every danger building/area on the installation and all processes undertaken therein, including the possibility of interactions between different processes and items of plant. Assessors may ask the following questions to help judge the completeness and adequacy with which these issues are covered:

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

The report should explain the methods used to identify the potential causes of major accidents and demonstrate that no important scenarios have been overlooked. The Operator should summarize, in a proportionate way, the results of studies undertaken to identify the potential causes of major accidents. The use of simple accident checklists may be appropriate in those cases where the risks to on-site and off-site population are broadly acceptable; however, Operators generally will need to undertake a systematic method of hazard identification, e.g. Past Accident Review, HAZOP or FMEA where appropriate.

Appendix 2 lists some potential causes of explosives accidents. While the examples given may not embrace the entire range of possible sources of ignition, they do form a checklist to help Assessors judge the completeness of the Operator's hazard identification analysis.

Q: Do the accidents considered include those initiated by off-site events?

The safety report should identify all potential causes of major accidents originating outside the installation, such as spread of fire from adjoining installations and lightning strikes. However, very improbable causes of such accidents, such as aircraft crashes (for installations not under major flight paths or within the vicinity of any type of airport), meteorite strikes and earthquakes may be discounted.

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

The Operator should take account of any other types of hazardous materials, other than explosives, that might be on site. The report should recognize the presence of any such materials (e.g. pressurized gases) on the installation, and state whether the quantities of these materials are sufficient to constitute a major hazard in their own right. The report should state whether an explosives event could trigger a major accident involving these types of materials.

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

There is no requirement for the Operator to provide a detailed consequence assessment for every potential major accident. The safety report need only define a representative set of accidents for this purpose. However, the consequence analysis must embrace the most severe accident that could potentially occur on the installation, the risk dominating events and a representative range of accident scenarios covering the spectrum of hazards posed by the installation.

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

The Assessors must be satisfied that the accident scenarios considered encompass the complete spectrum of severity and include the risk dominating events. The safety report must consider explosions and fires at the "worst locations", for example, the danger buildings nearest to office blocks or other populated buildings on and off site. The report should also consider the effects of an event involving the maximum quantity of explosives allowed to be present at the "worst locations". The safety report should also recognize that the number of people at risk from an event could vary with time. There may be occasions when personnel pass close to the danger building or when routine work is undertaken in the vicinity of the danger building – grass cutting, for example. It should be clear that the maximum possible exposure has been considered.

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

An accidental initiation of explosives (hereafter called an explosives event) may give rise to a number of harmful and damaging effects. The particular effects would depend on the types of explosives initiated while the magnitude of these effects would largely depend on the quantities of explosives initiated. The table below lists the different types of effects that could be expected from the four Hazard Types of explosives defined by the HSE.

Table 5: The hazards posed by different types of explosives

Hazard Type	Explosion Effect
1 (subs.)	Blast, cratering, ground shock and secondary fragments.
1 (articles)	Blast, cratering, ground shock and primary & secondary fragments.
2	Small blast effect plus primary fragments.
3	Fire and thermal radiation effects.
4	No significant effect.

In general, the magnitude of the effects produced by an explosives event will increase with the quantities of explosives initiated. Explosives articles of Hazard Type 2 are an exception in that these articles, when exposed to fire, tend to explode in ones and twos over a period. This means that the effects from an event involving a large number of such articles would be no more severe than those involving a small number; rather the effects would continue over a longer period.

Q: Has the potential for escalation been properly addressed?

An explosives event may escalate in one of two ways: by a process of instantaneous communication, where a detonation of explosives in one location causes a virtually simultaneous detonation of explosives in another; and by delayed communication, where a fire started by the initial event spreads and eventually involves other explosives. The internal QD prescriptions should prevent instantaneous communication between PES on site, but consideration should be given to the possibility of delayed communication through spread of fire, etc. However, the Operator should list measures to prevent delayed communication, such as fire-fighting procedures, as well as measures to ameliorate the effects of any delayed communication, such as evacuation. A failure to list these measures would be indicative of a lack of thoroughness in the performance of the hazard identification exercise and would hinder the Assessors in reaching judgements concerning accident severity.

The safety report should also address any measures designed to unitise risk within a danger building, such as construction design and detonation traps. Additional measures might include engineered systems and/or procedures to limit the quantities of explosives present at any particular workbench, apparatus or item of equipment. Whilst such measures might protect against instantaneous communication, any potential for escalation by subsequent spread of fire, etc. should also be addressed.

Appendix 1 to Criterion 10.3: Learning from Experience

Important lessons can be learnt from past accidents and incidents, including those which may be categorised as “near misses”. An analysis of accident causes can indicate what problems might again arise in the future and measures to prevent any recurrence. The HSE analyzes the causes of explosives accidents on three levels.

1. The energetic stimulus that initiates the explosives material

2. The immediate or proximate cause of the accident, i.e. the sequence of events resulting in exposure of explosives to the stimulus

3. The underlying cause, i.e. any organizational deficiencies, oversights, etc. allowing the sequence of events to occur in the first place.

To take the previously cited example of a crane toppling onto explosives material, where this mishap is caused by human error, the causes might be stated thus:

Stimulus:	impact/friction
Proximate:	fall of crane
Underlying:	operative error

However, underlying causes may be judged differently by various parties and it may often prove difficult to establish a unanimous opinion in the course of an accident investigation. For example, an incident that is ostensibly caused by operative error may have a deeper cause in such shortcomings as poor training, lack of supervision, failure of management to provide reasonable safeguards against human error, etc. Underlying causes thus normally need to be resolved in a court of law.

It is beyond the scope of this document to provide a comprehensive list of potential accident scenarios for each of the many types of processes and activities undertaken with explosives.

In the remainder of this appendix, a number of explosives accidents are discussed with respect to initiating stimuli and proximate cause. These examples illustrate the types of problems, which can arise and provide pointers to the type of information that should be included in a safety report with respect to both accident causes and safeguarding/mitigating measures.

Impact accidents involving falling objects

The following two accidents were caused by objects falling onto explosives materials. No direct human action was involved in the first of these accidents; a badly fixed notice board simply fell off the wall onto some detonators that had been placed on a bench below. The second accident was caused by an operative inadvertently dropping a tool onto a sensitive explosives composition.

Stimulus: Impact/friction
Proximate cause: falling object

Date:	16/02/44
Location:	Explosives factory
Type of explosives:	Detonators
Type of activity:	Passive storage
Number of fatalities:	0

Two wooden carrying boxes containing detonators exploded in an unoccupied varnishing shop. It is believed that the plywood SSO board fell off the wall and hit the carrying box.

Stimulus: Impact/friction
Proximate cause: falling object

Date:	07/05/86
Location:	Explosives factory
Type of explosives:	Tantallium pressed powder
Type of activity:	Passive storage
Number of fatalities:	0

An Operative suffered burns to his hand after inadvertently dropping a tool into a can containing phials of tantallium pressed powder.

Pointers to look for in safety report
Has the Operator considered the potential for objects to fall onto explosives? Are there any engineered safeguards against such incidents (e.g. crash nets)? Are there any procedural safeguards against such incidents (e.g. regular inspection and maintenance of danger buildings and fixtures and fittings therein)?

Impact accidents involving dropped explosives

Stimulus: **Impact/friction**
Proximate cause: **Dropped explosives**

Date:	26/02/59
Location:	Explosives factory
Type of explosives:	HMX
Type of activity:	Handling
Number of fatalities:	2

A charge of almost pure HMX exploded on being dropped. The accident occurred as the charge was being offloaded from a vehicle. The results of laboratory tests carried out on this type of explosive had suggested that it was not particularly sensitive to impact or friction.

This accident exemplifies the need for all explosives to be treated with caution. Although the results of the standard laboratory tests routinely carried out at the time prior to this accident had suggested that HMX was not particularly vulnerable to accidental initiation, further tests carried out after the accident showed that pressed charges of the explosives are sensitive to a combination of impact and friction. The moral of this story might be stated as “always expect the unexpected”.

Pointers to look for in safety report
Has the Operator considered the possibility of explosives being dropped? Are there any engineered safeguards against such incidents (e.g. crash mats)? Are there any procedural safeguards against such incidents (e.g. training of staff in safe handling techniques)?

Impact accidents involving vehicles

The following two accidents illustrate the potential danger from site transport. The first of these accidents exemplifies the need for explosives materials to be properly packaged for transport while the second simply exemplifies the need for explosives to be segregated from moving vehicles.

Stimulus: Impact/friction
Proximate cause: Impact by vehicle

Date:	06/06/51
Location:	Explosives factory
Type of explosives:	Waste sludge contaminated with nitroglycerine (NG)
Type of activity:	Transport
Number of fatalities:	2

An explosion occurred on a bogie loaded with bagged waste sludge, which had been dredged from a settling pond used for collecting NG water washings from the nitration house. NG dripped from the waste onto the bogie wheels and detonated when the bogie was moved. The net explosives quantity (NEQ) was approximately 230kg. The explosion caused considerable damage to two explosives buildings 45 & 75 yds away and formed a crater 22 ft in diameter and 4 ft deep.

Stimulus: Impact/friction
Proximate cause: Impact by vehicle

Date:	04/03/80
Location:	Explosives factory
Type of explosives:	Propellant
Type of activity:	Transport
Number of fatalities:	2

A truck carrying wet waste propellant toppled onto a tray causing an explosion that killed two workers.

Pointers to look for in safety report
Has the Operator considered the possibility of vehicles running into explosives? Are there any engineered safeguards against such incidents (e.g. crash barriers)? Are there any procedural safeguards against such incidents (e.g. vehicles inspection and maintenance, training of drivers)?

Friction-induced accidents caused by foreign objects

The following two accidents illustrate the need for high standards of housekeeping and maintenance of machinery within PES.

Stimulus: Impact/friction
Proximate cause: Foreign object

Date:	28/08/57
Location:	Explosives factory
Type of explosives:	Nitroglycerine-based blasting explosive
Type of activity:	Cartridging
Number of fatalities:	4

An explosion occurred in a cartridging house whilst cartridges were being made on Miller-Dann semi-automatic extruders. The explosive contained 27% nitroglycerine. The explosion was initiated by frictional forces caused by the presence of a foreign body in the extruder.

Stimulus: Impact/friction
Proximate cause: Foreign object

Date:	05/06/91
Location:	Explosives factory
Type of explosives:	Casting powder - propellant
Type of activity:	Mixing
Number of fatalities:	0

A detonation occurred during the process of incorporating casting powder. The accident happened during the final mixing phase shortly after ammonium perchlorate had been added to the mix. It was thought that the ignition may have been caused by the presence of a steel nut.

Pointers to look for in safety report
Has the Operator considered the possibility of foreign objects contacting explosives? Are there any engineered safeguards against such incidents (e.g. guards over equipment)? Are there any procedural safeguards against such incidents (e.g. regular inspection and maintenance of equipment)?

Friction-induced accidents caused by use of unauthorised tools or failure of Operatives to wear correct clothing

The details of the following accident illustrate the danger posed by the use of unauthorised tools.

Stimulus: **Impact/friction**
Proximate cause: **assumed to be use of unauthorised tool**

Date:	11/01/74
Location:	Fireworks factory
Type of explosives:	Pyrotechnic composition
Type of activity:	Cutting?
Number of fatalities:	1

An explosion occurred in a building where one man had just commenced manufacture of shop goods fireworks. The building, of brick with a light roof, was completely destroyed and the man later died of burn injuries. The cause of ignition could not be ascertained with certainty but a steel penknife belonging to the man was later found near the building, and it is considered that the accident may have been due to use of this unauthorised tool.

The details of the following accident illustrate the importance for Operatives to wear special clothing when working with sensitive types of explosives.

Stimulus: **Impact/friction**
Proximate cause: **Failure to wear correct clothing**

Date:	04/10/74
Location:	Explosives factory
Type of explosives:	Propellant
Type of activity:	Drying
Number of fatalities:	0

An Operative entered the drying building without putting on overshoes. As he left, he heard a crack underfoot. This was followed by an explosion which hurled him down the escape tunnel. The building was destroyed. The Operative's shoe had a protruding nail.

There are many possible underlying procedural causes leading to such accidents, ranging from unforeseen danger to inadequate assessments of risk to poor training, poor supervision or straight forward Operator error.

Pointers to look for in safety report
Has the Operator considered the possibility of use of unauthorised tools or failure to wear correct clothing? What procedural safeguards have been implemented (e.g. training of staff, supervision of staff, safety awareness and culture)?

Fire/heat-induced accidents - spread of fire from external source.

Stimulus: **Fire/heat**
Proximate cause: **Grass fire**

Date:	12/03/62
Location:	Explosives factory
Type of explosives:	Black powder
Type of activity:	Storage
Number of fatalities:	0

Four buildings in a gunpowder plant were destroyed by fire and explosion. It is thought that glowing gorse embers from a railway embankment initiated the incident. The building nearest the embankment exploded and flying debris set fire to other buildings.

The following accident illustrates both the fire hazard posed by leaking equipment and how a fire starting externally to a building may spread and initiate explosives material.

Stimulus: **Fire/heat**
Proximate cause: **Leak of acid from pipeline**

Date:	09/12/67
Location:	Explosives factory
Type of explosives:	NG-based blasting explosives
Type of activity:	Storage
Number of fatalities:	0

A leak of mixed nitric and sulphuric acid from a pipeline onto the grass below stated a fire which eventually consumed 4300 lbs of explosives. Initial first-aid fire fighting with a partially frozen 1” washing hose proved ineffective and may even have aggravated the fire. The fire spread to a hoist and thence along a wooden corridor to a mixing building containing 1000 lbs of blasting explosives. The fire brigade were by now controlling the fire when a partial detonation of the residue explosives fractured a water main. The fire was then spread by a strong wind to an adjacent mixing building containing approximately 3300 lbs of explosives. Fortunately, these explosives did not detonate but merely burned.

Pointers to look for in safety report
Has the Operator considered the possibility of fire spreading for external sources? Are there any engineered safeguards against such incidents (e.g. low fire loading)? Are there any procedural safeguards against such incidents (e.g. regular grass cutting, inspection of services, etc.)?

Fire/heat-induced accidents - hot surface

The following two accidents illustrate the danger posed by hot surfaces. The first accident occurred during a routine drying operation and brought to light some faults in the design of drying compartments which were subsequently corrected in a rebuilding programme. The second accident resulted from explosives material inadvertently coming into contact with a steam pipe.

Stimulus: **Fire/heat**
Proximate cause: **Assumed to be hot surface - poorly designed oven**

Date:	1967
Location:	Fireworks factory
Type of explosives:	Igniter composition
Type of activity:	Drying
Number of fatalities:	0

An explosion occurred in the drying shed of a fireworks factory shortly before work was due to commence. The two buildings adjacent to the drying shed were wrecked by blast and flying debris. A person who was about to enter one of these buildings sustained both a fractured skull and shoulder. Though the precise cause of the accident could not be established, it was found that a small quantity of igniter composition had been kept for some time in an electrically heated air oven the design of which was such that it was possible for the material to be blown by the circulating fan onto the heater.

Stimulus: **Fire/heat**
Proximate cause: **Assumed to be hot surface - uncovered steam pipe**

Date:	11/12/67
Location:	Explosives factory
Type of explosives:	Propellant
Type of activity:	Water steeping
Number of fatalities:	0

A fire and explosion occurred in a building used for the water steeping of propellant powders. The most likely cause of ignition was contact of propellant powder with a hot surface, possibly as a result of powder settling on steam pipes. The building was completely destroyed and there was considerable blast damage and some missile damage to other buildings within the factory.

Pointers to look for in safety report
Has the Operator considered the possibility of explosives contacting hot surfaces? Are there any engineered safeguards against such incidents (e.g. lagging of pipes, guards in front of heaters, etc.)? Are there any procedural safeguards against such incidents (e.g. high standards of housekeeping, etc.)?

Fire/heat-induced accidents - overheating during process operations

The details of the following two accidents exemplifies the need for careful monitoring of process operations.

Stimulus: **Fire/heat**
Proximate cause: **Overheating**

Date:	05/12/85
Location:	Explosives factory
Type of explosives:	Nitrocellulose
Type of activity:	Mixing/drying
Number of fatalities:	0

Nitrocellulose and dibutylphthalate were being mixed to make plastic core composition. The mixture was left unattended during the process of steam heating and mixing and this led to a runaway thermal decomposition. The vapour from the decomposing material caught fire ad this in turn triggered an explosion.

Stimulus: **Fire/heat**
Proximate cause: **Overheating of explosives and possible admixture with contaminants**

Date:	02/02/71
Location:	Explosives factory
Type of explosives:	Pentolite
Type of activity:	Melting
Number of fatalities:	0

A fire followed by an explosion demolished a building used for melting and casting pentolite. A steam line had been left on during a break to melt a small quantity of pentolite. It is thought that a small amount of contaminant such as sulphur was also present.

As well as emphasising the need for careful monitoring of process operations, the details of this accident exemplify the importance of preventing explosives coming into contact with contaminants.

Pointers to look for in safety report
Has the Operator considered the possibility of explosives being heated to higher temperatures and for longer periods than intended? Are there any engineered safeguards against such incidents (e.g. thermostats, high temperature cut-out devices, etc.)? Are there any procedural safeguards against such incidents (e.g. regular monitoring of processes and equipment, etc.)?

Fire/heat-induced accidents - malicious action

There are numerous examples of explosives incidents caused by vandalism, sabotage and attempted robbery. Details of two such incidents are reproduced below: -

Stimulus: Fire/heat
Proximate cause: Vandalism

Date:	14/09/70
Location:	Fireworks factory
Type of explosives:	Black powder
Type of activity:	Storage
Number of fatalities:	0

A magazine containing 2000 lbs of gunpowder located outside the fence of a fireworks factory was destroyed in a series of explosions after work had ceased for the day. It was later established that some children had ignited some gunpowder on the step of the magazine, and this in turn set fire to waste cardboard cartons lying nearby. The magazine exploded as the children were running away.

Stimulus: Fire/heat
Proximate cause: Attempted robbery

Date:	05/10/95
Location:	Storage area
Type of explosives:	Fireworks
Type of activity:	Storage
Number of fatalities:	0

A gang of burglars triggered a large explosion when they used welding equipment to break into a concrete bunker containing up to 700 fireworks, the total net explosives quantity being about 60 kg. The bunker was reduced to rubble.

Pointers to look for in safety report
Has the Operator considered the possibility of malicious action? Buildings containing security-attractive items should be alarmed to an effective response force.

Accidents caused by electrical effects - static discharge

There are numerous examples of explosives accidents caused by static discharge. Details of one recent such accident are given below: -

Stimulus: **Static discharge**
Proximate cause: **Use of electrically insulating material**

Date:	07/06/96
Location:	Explosives factory
Type of explosives:	Pyrotechnic composition
Type of activity:	Storage Hand sieving
Number of fatalities:	0

An Operative sustained temporary hearing loss as a result of an explosion of a small quantity of pyrotechnic composition he was hand sieving. Use of electrically insulating beakers and watch glasses in the process was the most probable cause of ignition.

Pointers to look for in safety report
Has the Operator considered the possibility of static discharge? Are there any engineered safeguards against such incidents (e.g. earthing of machinery, anti-static floors, etc.)? Are there any procedural safeguards against such incidents (e.g. regular checking of earthed equipment, use of anti-static clothing, etc.)?

Accidents caused by electrical effects - lightning

There are also numerous examples of explosives accidents caused by lightning. The last such major accident recorded in the UK occurred in 1947 (brief details are given below). More recently (1987), lightning initiated a massive explosion at a dynamite plan in South Africa: eight tonnes of dynamite exploded producing a crater the size of a football field.

Stimulus: Static discharge
Proximate cause: Use of electrically insulating material

Date:	04/06/47
Location:	Explosives factory
Type of explosives:	Nitroglycerine
Type of activity:	Washing
Number of fatalities:	0

An explosion occurred in an NG wash house containing 3300 lbs of nitroglycerine, which was divided between two pans. An additional 800 lbs of nitroglycerine was held in another pan but did not explode. The explosion was caused by lightning. The wash house was erected before the war and the lightning protection provided was of the type normally adopted for explosive buildings, i.e. the conductors were attached to the building. The separate pole system was later adopted, i.e. supporting poles were placed in the earth mounds surrounding the NG buildings, with the poles projecting 18 feet above the level of the mound or embankment. The investigating committee considered NG wash houses to be particularly vulnerable to electrical storms due to the unavoidable film of NG which is present on the lead surfaces in these wash houses. As NG will detonate when heated to a temperature of the order of 200ºC it does not require very much energy, either from direct flash or an induced charge at a metal surface to cause an explosion.

Pointers to look for in safety report
Has the Operator considered the possibility of lightning strikes? Are there any engineered safeguards against such incidents (e.g. lightning protection system)? Are there any procedural safeguards against such incidents (e.g. evacuation of buildings during electrical storms, etc.)?

Accidents cased by runaway chemical reaction during process operations

There have been numerous cases of explosives events at manufacturing sites caused by runaway chemical reaction during process operations. The proximate causes for such events include: addition of incorrect proportions of reactants to process equipment, addition of reactants in incorrect sequence, addition of contaminants to process equipment, inadequate mixing of reactants, failure to control process temperature and failure to stabilise material prone to spontaneous decomposition. For each of these broad proximate causes it is normally possible to identify a number of sub-causes, such as failure of process equipment (which in turn may be due to such factors as inadequate inspection and maintenance) and human error.

Brief details of two incidents caused by runaway chemical reaction are reproduced below: -

Stimulus: **Runaway reaction**
Proximate cause: **Incorrect proportion of reactants**

Date:	29/08/56
Location:	Explosives factory
Type of explosives:	Dinitroresorcinol
Type of activity:	Nitrating
Number of fatalities:	1

There was an explosion in a dinitroresorcinol manufacturing plant. Due to insufficient nitric acid, a stick mass formed, partially blocking the discharge line. During the following nitration the material decomposed with fragments of a pipe killing a man.

Stimulus: **Runaway reaction**
Proximate cause: **Inadequate mixing**

Date: 03/03/92
Location: Explosives factory
Type of explosives: Propellant
Type of activity: Mixing
Number of fatalities: 0

A slow decomposition of NPP propellant occurred during the process of coating with TEGDM and AIBN. The decomposition was probably due to inefficient mixing, allowing hot spots to form as the exothermic polymerisation reaction progressed.

Pointers to look for in safety report
Has the Operator considered the possibility of runaway reaction? Are there any engineered safeguards against such incidents (e.g. dumping and drenching systems)? Are there any procedural safeguards against such incidents (e.g. training of staff, emergency procedures, etc.)?

Accidents caused by chemical reaction

Intermediate and finished explosives products may also be initiated by chemical reaction in the event that they are mixed with incompatible substances or become degraded. Some example incidents are given below:

Stimulus: **Chemical reaction**
Proximate cause: **Spontaneous combustion?**

Date: 29/05/58
Location: Explosives factory
Type of explosives: Nitrocotton
Type of activity: Storage
Number of fatalities: 0

An expense magazine containing 6500lbs of nitrocotton (most of it dry) exploded when nobody was in or near it. Extensive damage was caused to other buildings. The exact cause of the accident was not ascertained but was most probably due to spontaneous combustion.

Stimulus:	**Chemical reaction - reaction of copper with lead azide**
Proximate cause:	**Incompatible materials**

Date:	30/06/52
Location:	Explosives factory
Type of explosives:	Ammunition
Type of activity:	Storage
Number of fatalities:	0

An explosion occurred during passive storage of derelict ammunition awaiting disposal on an open site. The 20 mm ammunition concerned was known to be in an extremely bad condition and many of the shell were heavily rusted. The exact case of the explosion was not found but the most likely explanation was that sensitive copper azide had been produced in one shell and that the high temperatures on the day of the incident caused movement of some part of the detonator which ignited the sensitive copper azide and fired the detonator.

Stimulus:	**Chemical reaction - corrosion**
Proximate cause:	**Incompatible materials**

Date:	05/02/70
Location:	Quarry
Type of explosives:	Detonators
Type of activity:	Storage
Number of fatalities:	0

An explosion wrecked a magazine at a quarry. Corroded detonators were later recovered from the remains of the demolished building.

Pointers to look for in safety report
Has the Operator considered the possibility of contamination of explosives? Are there any engineered safeguards against such incidents (e.g. testing of materials for compatibility)? Are there any procedural safeguards against such incidents (e.g. high standards of house keeping, etc.)?

Criterion 10.3.1 "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?

In principle, explosives can be initiated by a number of different types of energetic stimuli, including:

impact/friction
fire/heat
fragment attack/overpressure
electrostatic discharge
electromagnetic radiation (in the case of electro-explosive devises)
Chemical attack
Runaway reaction (in the case of certain types of explosives manufacture)

The Operator should consider the ways in which explosives material might be exposed to these stimuli. There are a number of techniques, including Hazard and Operability Study (HAZOP), Failure Modes and Effects Analysis (FMEA) and Past Accident Review (PAR), which the Operator might use to help identify such incidents. The regulations do not require the application of any one particular technique; but any technique used should be proportionate to the severity of the potential outcome of the identified accidents (see Criterion 10.3.2 below).

An Operator need not necessarily undertake detailed hazard identification exercises for every danger building on site, providing one particular building is sufficiently representative of a group of buildings. For example, there may be a number of magazines on site, all built to the same design, all containing the same types of fixtures and fittings, and all containing the same types of explosives. Clearly, there is no need to carry out separate exercises for each magazine; one such exercise performed on a representative magazine would suffice.

What is important is that the Operator should identify the hazards arising from each type of process carried out on site. The Operator should consider all the types of initiating stimuli listed above or provide good reasons for discounting these stimuli as potential causes of accidents. As already mentioned, an Operator is not obliged to use any one particular hazard identification technique; the requirement is that the Operator should endeavour to identify all potential causes of major accidents and employ a systematic technique to this end.

Criterion 10.3.2 "The hazard identification methods used should be appropriate for the scale and nature of the hazards."

Q: Has the Operator used a systematic method to identify all potential causes of major accidents?

The technique employed by the Operator to identify potential causes of accidents should be proportionate to the severity of the potential outcome of those accidents. Where an explosives event has the potential to cause significant on-site or off-site effects, i.e. casualties or damage to several properties, use should be made of formalized techniques, such as PAR, HAZOP and FMEA. For lesser events, the Operator might use some other technique, such as safety reviews or bespoke checklists drawn up from the results of previous hazard identification exercises. The Operator should always clearly state the technique used as well as the expertise of the personnel involved in the exercise.

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

As mentioned, the level of analysis employed by the Operator should be proportionate to the perceived risk. The greatest risks to workers are likely to arise from manual operations involving sensitive explosives; the greatest risk to persons not directly involved these operations arise from activities involving comparatively large quantities of explosives, such that an ignition would result in harmful effects beyond the building immediately involved. For relatively high-risk activities, the Operator may choose to employ a structured technique, such as HAZOP, FMEA etc., to identify potential faults with the activities.

For proportionately low-risk activities, the Operator may employ simple checklists of the type shown in the table below. For proportionately high-risk activities, the Operator may choose to carry out pseudo HAZOP studies using the following parameters and guidewords.

Initiating stimulus/ Parameter	Immediate Cause / Guideword
Impact/friction	Falling object Projected object Impact by vehicle Drop Other
Fire/thermal effects	Fire inside building External fire Vehicle fire Hot surface Other
Electrical effects	Static discharge Lightning Faulty electrical equipment Other

Initiating stimulus/ Parameter	Immediate Cause / Guideword
Overpressure/fragment attack	Communication VCF Other
Chemical attack	Contamination Water ingress Compatibility Degradation Other
Electromagnetic radiation	RF radiation Other

Q: Has the Operator listed, for each of the identified accident scenarios, the engineered and procedural safeguards in place?

The Operator should list the measures in place to guard against the identified dangerous occurrences. These measures may be either engineered or procedural. For instance, to take the previous example of the falling crane, the engineered safeguards may consist of such measures as intrinsically safe design, fail-safe mechanisms, crash nets to catch falling objects. The procedural safeguards may comprise measures such as regular inspection and maintenance of equipment and training of staff in safe operating techniques, or procedures prohibiting the use of the crane while explosives are in the building.

Failure to list these safeguards would be indicative of a lack of thoroughness in the performance of the hazard identification exercise. A failure to list these safeguards would also hinder the Assessors in the further stages of the evaluation procedure when judgements concerning accident likelihood would need to be made.

Q: Has the Operator listed, for each of the identified accident scenarios, the engineered and procedural mitigation measures in place?

The Operator should also list all measures designed to mitigate the consequences of any accidents that may occur. Again, these measures may be either engineered or procedural. Examples of engineered measures include design features such as interlocks, frangible roofs and blast panels, protective earth mounds, etc.; while examples of procedural measures include quantity-distance prescriptions, man limits, minimal quantities for sensitive explosives, emergency plans and evacuation procedures, etc.

Criterion 10.4 "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 or external), which may play a role in triggering each scenario."

All sequences of events that may potentially initiate a major accident should be identified and the likelihood of those events quantified in an appropriate way.

Many factors influence the likelihood of major accidents on an explosives installations, including: the inherent sensitivity of the explosives present; the types of processes undertaken (which will determine the types and amounts of energy to which the explosives may be potentially exposed); and the engineered and procedural safeguards in place, of which safety culture and training and supervision of staff are important aspects.

The depth of analysis needs to be proportionate. Those Operators who are compliant with normally accepted control measures (i.e. industry standards, HSE guidance and approved codes of practice), need only give semi-quantitative descriptors for the likelihood of each identified major accident scenario (such a scheme was previously shown in Table 2). Non-compliant Operators should provide quantitative estimates of risk.

Assessments of accident likelihood are notoriously difficult. Analysts commonly find that insufficient data are available to allow objective quantification of accident probabilities and subjective judgement is often used. It is important that subjective judgement, if used, be well structured, technically informed, recorded and based on all available evidence.

In order to form a judgement on these issues, Assessors might ask the following questions:

Q: Does the report quantify, albeit with limited accuracy or in qualitative terms, the likelihood of each of the major accident scenarios identified?

Assessors should expect to see all potential causes of major accidents identified and an ALARP demonstration provided for the risk dominating scenarios.

Q: Has the Operator produced appropriate estimates for accident likelihood?

In general, the likelihood of accidental ignition can be analysed as the product of two probabilities:

- The probability of a "mishap", i.e. an incident in which explosives are “insulted”. This may be an energetic event, such as the fall of an object, an outbreak of fire, an unprotected hot surface, a static discharge, etc. or a "contamination" incident in which explosives are mixed with incompatible substances.

- The conditional probability that explosives initiate”, given exposure to the insult

An explosives event may also occur spontaneously. This type of incident would result from a failure to stabilise/desensitise sensitive types of explosives - for example, a failure to incorporate stabiliser into a nitrate-ester-based propellant or a failure to ensure that sensitive compounds such as nitrocellulose have been sufficiently wetted.

The chance of a mishap occurring is usually expressed as an annualized probability, i.e. the chance per year of the undesired event arising, whereas conditional probabilities are dimensionless and simply express the chance that a specified outcome would occur given the occurrence of a mishap.

The Operator should address both the likelihood of mishaps occurring and the associated conditional probability of initiation. However, only semi-quantitative estimates are required for sites that are compliant with QD prescriptions and accepted standards (see Table 2).

Judgements on whether a particular event is likely, unlikely, incredible, etc., must be based on a consideration of the physical properties of the explosives, the safeguarding measures in place to prevent the event from occurring and the mitigating measures in place to limit the effects of any ignition. The Operator may refer to historical accident data to support assessments of accident likelihood.

Criterion 10.4.1 "The safety report should demonstrate that a systematic process has been used to identify events and event combinations, which could cause major accident hazards to be realised."

Here reference should be made to Criterion 10.3 and how it was met by the safety report. As previously noted, the Operator should give due consideration to the likelihood of mishaps occurring and the associated conditional probability of ignition.

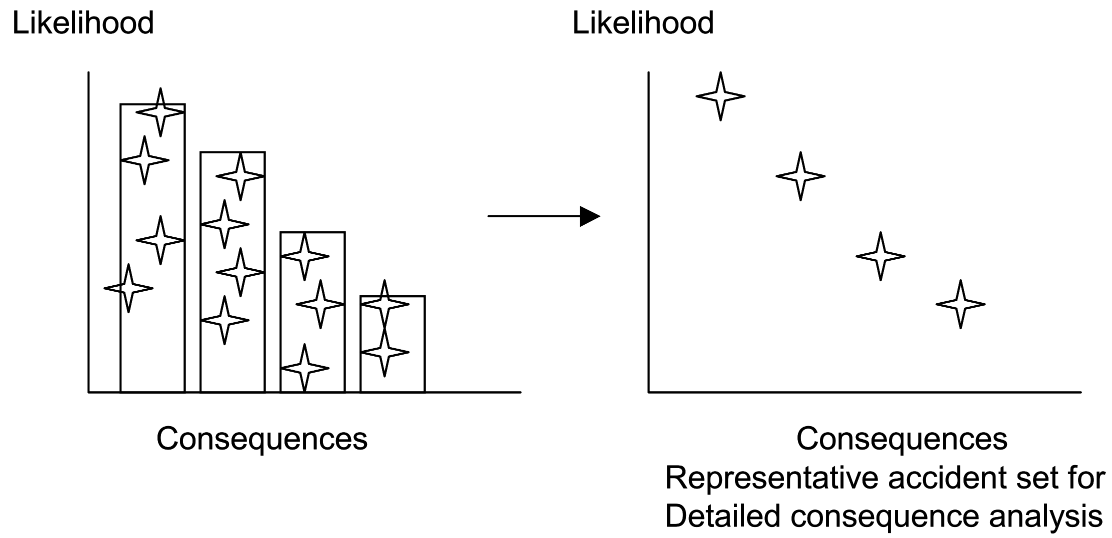
At this stage, the Operator should also consider the consequences of potential ignitions. The aim should be to show that low consequence events, involving no more than a few grams of explosives, and which may occur from time to time, are unlikely to cause injury due to *in situ* measures, such as remote working or use of shields and personal protective equipment.

The Operator should then identify any systems that are safety critical. A safety critical system comprises any item of equipment or procedure whose failure would immediately result in an ignition, posing a risk of serious injury, death or an unacceptable contamination of the environment.

Criterion 10.4.2 "All safety critical events and the associated initiators should be clearly identified."

Q: Does the report describe the risk-dominating events?

To identify the risk-dominating events, the Operator should first assess the likelihood and approximate consequences of all the potential major accidents identified. These may be grouped into consequence bands as indicated below.



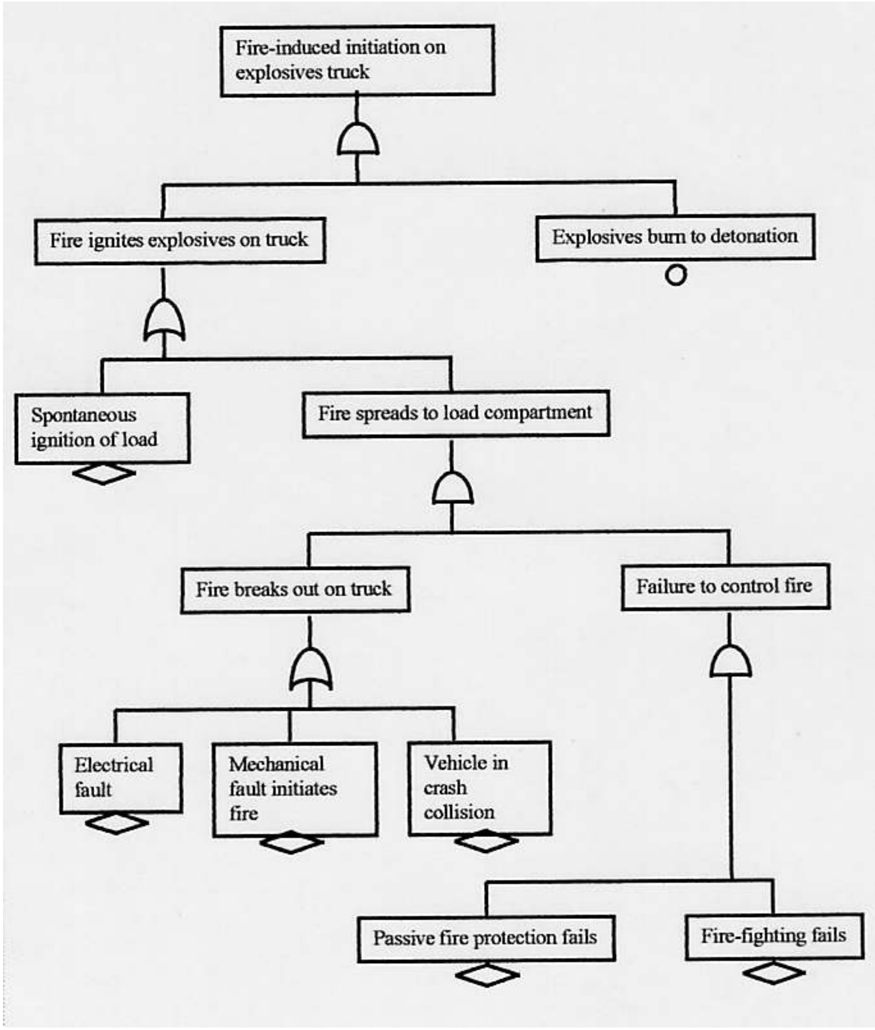
The accident at the top of each band is the safety critical event for the consequences of that particular level of severity. The report should identify a set of representative accidents for more detailed consequence analysis.

Criterion 10.4.3 "Estimates of, or assumptions made about, the reliability of protective systems and the times for operators to respond and isolate loss-of-containment accidents, etc., need to be realistic and adequately justified."

Operators should not assume that all protective systems will unfailingly perform perfectly or that operatives will always be 100% reliable. For example, an Operator needs to consider what would happen if an automatic drowning system failed on demand, or if an operative failed to activate a manually-operated drowning system.

Criterion 10.4.4 "The methods used to generate event sequences and estimates of the probabilities of potential major accidents should be appropriate and have been correctly used."

In general, major accident may arise in several different ways. In some cases, a number of faults may need to occur simultaneously or in a particular sequence. A site Operator might thus choose to use a technique such as fault tree or event tree analysis to set out the various sequences of events - including those necessary for a minor incident to escalate into a major accident – in a logical framework. Each of the basic events in the tree will have an associated probability. An example fault tree, which outlines some of the potential causes of fire-induced explosions on trucks transporting explosives on site, is shown below.



In the above example, it is postulated that a fire could break out on a truck following an electrical fault (e.g. an electrical short circuit), a mechanical fault (e.g. a binding brake) or the involvement of the truck in a road traffic accident. Fire might then spread to the explosives load if the passive fire protection on the vehicle were breached and fire-fighting action proved ineffective. Should the load ignite, then, depending on the types of explosives present, the load might detonate. In addition to these possibilities, there is also a chance that an explosion could occur following a "spontaneous" ignition should the load contain explosives badly designed, manufactured or unsafely packaged.

Logic tree analysis is labour intensive and requires reliable failure probability data and experience in its application. An Operator may adopt a much simpler approach. For example, accident sequences may be broken down into three components – a mishap, a control system failure and an operative failure, and the likelihood of the accident determined as the product of the probability of the three component failures. Whilst this approach may be acceptable, Assessors should be aware that it could potentially hide a number of failure events. A control system may fail in numerous ways or an operative may respond incorrectly to an abnormal situation. Since the probabilities of these failures are usually additive, Assessors need to be convinced that the analysis is complete and not unduly optimistic. The following questions may help the Assessors reach a conclusion on this issue.

Q: Does the likelihood analysis recognize that failures of complex systems and operatives have many components?

If a dangerous situation can occur from sequential failure of control systems or a series of errors by operatives, the Operator will need to identify each of these. Failure to provide a breakdown of the individual events may result in Assessors requesting further information from the Operator.

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

Where QRA or semi-quantitative analysis is required, there should be recognition that most failure probabilities are not single values but distributed about a mean. If there is no information on the probability distribution, 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?

It should be clear that the Operator has taken account of site-specific information when identifying accident initiators and their probability of occurrence.

Q: Has the Operator correctly combined the probabilities of events listed in logic trees?

Where the Operator employs fault tree, event tree or some other form of logic tree analysis, the Assessors should expect to see numerical or qualitative (as appropriate) estimates for the likelihood of the basic events appearing in the logic tree. The values assigned should be justified by reference to historical date wherever possible. Where values are subjective estimates, any assumptions made should be clearly explained.

Criterion 10.4.5 "The safety report should provide adequate justification for event probabilities that are not consistent with historical or relevant generic industry data."

Taking post-war historical experience in the UK explosives industry as a guide, the Assessors might expect to see values for major accident rates specified in the table below:

Table 6: Historical explosion frequency data

Manufacture or processing operations, except those involving modern blasting agents or insensitive explosives.	Typically 10-2 – 10-4 per process-building-year
Manufacture or processing of modern blasting agents	10-3– 10-5 per process-building-year
Storage in non-alarmed stores on civil sites	<10-3 per storage-building-year
Storage in alarmed stores on civil sites1	<10-4 per storage-building-year

[1]Of recent years all security-attractive explosives have been held in secure stores, which are alarmed and linked to an effective response force.

Q: Do the Operators' estimates for accident likelihood align with the generically derived rates?

Assessors should expect to see a detailed justification for any accident rates significantly better than those listed In Table 6. Failure rate data from the Operator's own and long-established database are normally acceptable.

Criterion 10.5 "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 Operator must assess the extent and severity of a representative set of major accident scenarios. The assessment should take account of potential damage to structures as well as hazards to people both on and off site. For each identified major accident scenario, the Operator should assess the chance of death or serious injury to persons at each exposed site on and off the installation.

Q: Has the Operator identified the persons at risk from major accidents?

The Assessors should expect to see evidence that the Operator has selected appropriate explosion effects/consequence models to identify the people and the structures at risk from a major accident.

The harmful effects produced by an ignition will depend on both type of explosives and type of structure of the PES. Table 5 previously reviewed the hazards associated with different types of explosives. Type of structure is particularly important in determining whether significant debris effects occur: an explosion inside a brick/concrete building might produce considerable amounts of flying debris, whereas an explosion of fibreboard-packed explosives in the open or inside a wooden building would not produce any significant debris effects.

Taking account of both Hazard Type and PES structure, an Operator will need the following models to assess the harmful effects of a major accident:

Table 7: Explosion model requirements

Hazard Type	Location	Models required
1 (articles)	Solid bldg.	Blast model Primary fragment (shrapnel) model Debris model
1 (articles)	Open/light bldg.	Blast model Primary fragment (shrapnel) model
I (substances)	Solid bldg.	Blast model Debris model
I (substances)	Open/light bldg.	Blast model
2	Solid bldg.	Blast model Primary fragment (shrapnel) model
2	Open/light bldg.	Blast model Primary fragment (shrapnel) model
3	Solid bldg.	Thermal radiation model
3	Open/light bldg.	Thermal radiation model

Rather than use separate blast, shrapnel, debris and thermal effects models, an Operator may choose to use a combined model to predict overall levels of lethality from explosives events. However, it should be clear that predictions obtained from such a model make appropriate allowance for each of the harmful effects produced in a major accident.

<u>Injuries caused by blast</u>

Three modes of blast injury can be distinguished:

- Primary Blast Injuries

Primary blast injuries are caused by the direct action of a blast wave on the body. The two most common such injuries are eardrum rupture and lung haemorrhage. Lung haemorrhage is in fact the most likely cause of death in cases where primary blast effects prove fatal. However, such injuries normally only occur at very high levels of overpressure and hence only amongst persons within a scaled distance of about three or so.

- Secondary Blast Injuries

Secondary blast injuries are defined as those, which occur as a direct consequence of blast damage to buildings and structures. These injuries include lacerations caused by flying glass, blunt trauma caused by crushing and impact of falling masonry, and suffocation caused by asphyxiating dust. Secondary blast injuries can occur at significantly greater distances from an explosion than either primary or tertiary blast injuries, and indeed experience shows that structural collapse is the dominant mode of death and injury from explosions in built-up areas. Thus secondary blast injuries are normally related to degree of building damage.

- Tertiary Blast Injuries

Tertiary blast injuries are defined as those resulting from body movement induced by the blast wave. Two modes may be distinguished: -

- injuries caused by differential displacement of internal body organs following high acceleration.

- injuries caused by impact when the body is either blown over or picked up by the blast wave and thrown against an object.

The second of these effects is sometimes called "whole body translation" or "whole body displacement". The extent of injuries caused by this effect is dependent on a number of factors, including: the velocity to which the body is accelerated, the part of the body which impacts the ground or object, the hardness of the ground or impacted object, and whether flailing of the limbs occurs as the body tumbles over the ground.

It follows from the above that the Operator should make separate assessments of blast-induced injuries for persons indoors and outdoors. For persons indoors, the Assessors should expect to see an assessment of secondary blast effects, while for persons outdoors, the Assessors should expect to see an assessment of primary and tertiary blast effects.

<u>Injuries caused by fragments</u>

Predicted casualty levels from fragment and debris effects will also be dependent on whether exposed persons are outdoors or indoors. Persons indoors will be afforded a certain degree of protection by the walls and roof of the building, while persons in the open, in the direct line of sight of the potential explosion site, will be completely unsheltered. However, other persons outdoors may be more or less protected by intermediate structures and other topographical features of the landscape. The Operator may legitimately choose to make some allowance for shelter and cover provided by any such features.

<u>Injuries caused by thermal radiation</u>

Whilst all explosives produce heat on ignition, this effect is most significant in the case of explosives of Hazard Type 3 - boxed propellant, for example. These types of explosives do not produce significant blast or fragment effects when initiated in unconfined conditions but burn fiercely and produce considerable radiant heat. It is this feature of intense and rapid release of radiant heat that has the potential to inflict serious burn injury over distance and in a very short time scale.

The heat emitted from Hazard Type 3 events may be capable of igniting secondary fires in nearby buildings. There are two mechanisms by which this may occur:

Unpiloted ignition (also known as spontaneous or auto ignition) occurs when the thermal radiation is sufficiently intense to decompose flammable material and raise the temperature of that material to its auto-ignition temperature.

Piloted ignition is similar to unpiloted ignition except that the flammable vapours given off by the decomposing material are set alight by a nearby source of ignition, such as a lighted cigarette or a gas fire. In general, thermal radiation doses necessary for piloted ignition are lower than those required for unpiloted ignition. In addition, secondary fires may be started by any firebrands thrown out from the explosives fire. The Operator needs to consider all these possibilities.

For persons indoors, glazing will afford a certain level of protection against thermal radiation. All radiation between the wavelengths of 2.8 μm and 5 μm (thermal - or infra red - radiation has wavelengths between 0.8 μm and 400 μm) is effectively screened out by all types of glass if it is at least 5 mm thick, although the usual thickness of window glass is only between 2 and 3 mm; furthermore glass need only be 1 mm thick to stop all thermal radiation above a wavelength of 5 μm. However, sudden heat pulses can easily break glass by thermal shock and for this reason some models conservatively ignore the possible attenuation of thermal radiation by glazing.

There are various factors that could significantly influence the thermal radiation dose recorded at targets in the vicinity of an explosives fire. These include wind speed, degree of confinement of the explosives and shielding afforded by structures or other features of the landscape. The Operator should consider all these possibilities.

Criterion 10.5.1 "Source term models should be appropriate and need to have been used correctly for each relevant major accident hazard."

Strictly speaking, this criterion applies to those processes that could potentially release hazardous materials into air, water or onto land with subsequent dispersion of these materials over some distance. However, for processes involving explosives, it may be interpreted as a requirement for the Operator to assess the effect of fire and explosion phenomena at various distances and locations from the incident.

Q: Has the Operator considered all appropriate explosion effects in determining those at risk from major accidents?

It should be clear that the Operator has considered the effects listed in Table 5. In considering the harm that may arise from blast, fragments, debris and thermal radiation, the Operator will need to take account of the type of location of any exposed population, i.e. whether these people are in the open, inside buildings of conventional construction or inside buildings of vulnerable construction. Buildings of vulnerable construction are those of curtain-wall construction, where the method of construction means that in the event of an explosion, there would be a hazard to anyone in the area from falling glass and masonry[4]. These buildings may be severely damaged by relatively low levels of blast loading - such that would cause only minor damage to buildings of conventional construction. It follows that at a given range from an explosion, persons located in buildings of vulnerable construction may be much more at risk from blast effects than those inside conventional buildings. Quantitative assessments of damage for vulnerable buildings and quantitative fatality assessments for persons inside may prove difficult, but failure of an Operator to identify any known vulnerable structures in the vicinity of the installation should be viewed as a deficiency.

Criterion 10.5.2 "The material transport models used should be appropriate and need to have been used correctly for each relevant MAH."

Again, this criterion is designed for those sites where there is a risk of the release of hazardous materials into air, water or onto land and with subsequent dispersion over some distance. Generally speaking, the criterion will not be applicable to explosives installations, unless these installations also contain significant quantities of flammable or toxic gases, or if there is a potential for a fire to result in the release of a cloud of toxic smoke. Further guidance on the assessment of this criterion is given in the SRAGS for LPG and chlorine.

Q: Has the Operator identified any buildings of vulnerable construction on or near to the installation?

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[4] More specifically, "vulnerable building" means a building of four storeys or more above ground with a curtain-wall construction, that is to say where the masonry, glass or other cladding is suspended from the structural framework of the building.

Criterion 10.5.3 "Other consequence assessment models (e.g. BLEVE, Warehouse fire, etc.) used should be appropriate and need to have been used correctly for each relevant major accident."

The modelling requirements for explosion effects were described in the discussion of the evaluation of Criteria 10.5 and 10.5.1. In addition to blast, fragment and thermal radiation models, the Operator may also need models to predict the dispersion of any toxic gases and acidic fumes generated in accident conditions that pose a threat to persons on or off site. The Operator should name and describe any models used to assess non-explosion effects. The Operator should also provide a justification for the use of these models.

In cases where an explosives installation contains significant quantities of dangerous substances other than explosives, the consequences of accidents involving these substances will also need to be modelled. Further guidance is given in the SRAGS for LPG and chlorine.

Criterion 10.5.4 "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."

The safety report should contain assessments of the damage and harm that would result from ignitions of explosives materials.

A few simple rules of thumb can be applied to obtain reasonable estimates for the casualties that would occur amongst personnel in explosives workrooms in the event of accidental ignition. The table below provides a guide to the likely outcome of accidents involving small quantities of explosives within small workrooms (of the order of 4 metres by 4 metres).

Table 8: Effects of small explosions

Quantity of Explosive Initiated (g)	Effect of Ignition
1	Any person holding the explosives could receive serious injury.
10	Any person close to this quantity of explosives at the time of the initiation would receive very serious injuries
100	Any persons standing approximately 1.5 metres away would be liable to a 1 per cent chance of eardrum rupture. 50% of windows in the room (size 6m x 6m) likely to be blown out. Approximately 1% chance of eardrum rupture at a distance of 3.5 metres. Approximately 50% chance of eardrum rupture at 1.5 metres. Persons in very close proximity to the explosion (e.g. holding the explosives) almost certainly killed.
500	Inside a 6m x 6m brick building, structural collapse is most likely; considerable damage to panels between steel or concrete frames in other structures. Persons very close to the blast almost certainly killed. Persons close to the blast sustain lung and hearing damage, and injuries from fragmentation effects and being thrown bodily. Almost all persons in the room will sustain perforated eardrums.

There are a number of models that might be used to assess lethality from explosions of larger quantities of explosives. Two such models which have been used in studies undertaken by the Health and Safety Commission's Advisory Committee on Dangerous Substances are the ESTC Outdoor and Indoor Blast Models, these provide estimates of lethality for persons in the open and indoors respectively at various ranges from a detonation of Hazard Type 1 explosives.

The ESTC Outdoor blast model

This is a theoretical model based on a review of the available literature on primary and tertiary blast effects. The model gives a single prediction of the probability of death (P) as a function of range and quantity of explosives. detonated, viz.:

$$p = e^{\frac{-5.785 \times \left(R/Q^{\frac{1}{3}}\right) + 19.047}{100}}$$

where R is measured in units of metres and Q in units of kilograms. The ratio R/Q1/3 is the scaled distance (S) from the detonation. This model is valid within the limits:

$$2.5 < S < 5.3 \text{ m kg}^{-1/3}$$

A 100% fatality probability can be assumed below a scaled distance of 2.5 m kg-1/3, while the fatality probability for persons located at a scaled distance greater than 5.3 m kg-1/3 can be taken as zero.

For example, persons located in the open at a range of 30m from a detonation of 1000 kg of explosives are predicted by the model to have about a 5% chance of fatal injury

ESTC Indoor blast model

This is an empirical model based on an analysis of casualty data collated from records of a number of major incidents of accidental explosion. The data on which the model is constructed do not distinguish between those people killed by blast and those killed by fragments. It is assumed that blast effects were the cause of most of the fatalities recorded in these incidents but the model implicitly makes some allowance for fragment effects. The model gives a single prediction of fatality probability (P) as a function of scaled distance (S) for persons located inside conventional buildings: -

$$\log P = 1.827 - 3.433.(\log S) - 0.853.(\log S)^2 + 0.356.(\log S)^3$$

within the limits 3 < S < 55 For example, the range at which indoor population would be exposed to a 0.01 fatality probability (i.e. a 1% chance of death) from the blast effects from a 1000 tonne detonation of explosives is estimated by the model to be about 950 m.

Q: Do the Operator's fatality estimates stack up with those predicted by the explosion effects/consequence models used by the HSE?

Further investigation will be required in the event that the results predicted by the Operator are significantly optimistic in comparison with the results given by models used by the HSE.

Criterion 10.5.5 "Are the assumptions in the accident analysis justified and not unduly optimistic."

The assumptions referred to here are those made about the response/effectiveness of any measures designed to mitigate the consequences of accidents. These measures might include fire-extinguishing systems, shields and guards within processing buildings, and unitization of danger buildings. The safety report should consider the consequences that might be expected should all control and mitigation systems fail in the event of an accident, though such a scenario should have a very low probability. However, a safety report that assesses accident consequences on the basis that mitigation systems work perfectly will underestimate risk. The Assessors might ask the following three questions in order to come to a judgement on this issue.

Q: Are the accident source terms "worst case"?

The accident analysis should not be based solely on average inventories for danger buildings. The analysis should include estimates for the outcomes of accidents involving the maximum quantities of explosives that could be present in danger buildings.

Q: Does the accident analysis examine the effect of accidents occurring under different circumstances?

The outcome of an accident may depend on the circumstances pertaining at the time. The analysis should consider the potential outcome of an accident occurring in the worst possible circumstances, for example, at the time of day when the population density in and around the installation is at a maximum. The Operator should clearly state any assumptions made regarding the relative likelihood of accidents occurring at different times. The Operator should also state any assumptions made with regard to the evacuation of personnel. Whereas some mishaps may result in an immediate ignition (an impact-type accident, for example), others may result in a gradual escalation to an explosives event (an outbreak of fire initially involving only non-explosives materials, for example). The Operator may legitimately make an allowance for evacuation for the latter type of incident, but any assumptions made should be clearly stated and justified. The Operator should carry out sensitivity tests to identify the effect that any such assumptions could have on the final results.

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

The safety report should specify the models used to predict the consequences of accidents. If these are well known and established (e.g. the ESTC Indoor and Outdoor Blast Models), then the Operator should list the input data so that the Assessors can independently check the results. The Assessors may wish to compare the consequence estimates reported by the Operator with those given by models currently used by the HSE. Should any discrepancies be found between the two sets of results, the reasons for the discrepancies should be explored.

Criterion 10.5.6 "Estimates of the severity and extent of all major accident consequences are realistic."

The Operator should provide realistic estimates for numbers of fatalities, serious injuries and hospitalisations for each major accident scenario in the representative set. It is recognized that any numbers quoted may be subject to uncertainty, given that consequence models will not give accurate estimates for casualties in all situations of practical interest. Where uncertainty exists, a cautious best estimate approach is preferred and Operators should examine whether changes in assumptions might make a difference to their conclusions on measures.

Where semi-quantitative analysis is appropriate, banding of events in terms of consequence to people, e.g. people at risk of fatality, 1, 2-5, 6-10, 11-20, >20 removes some of the problems associated with quoting exact numbers. A similar approach for serious injuries and light injuries is also appropriate.

The level of demonstration required is determined from the level of risk predicted, including any group risk (i.e. killing or harming large numbers of people in one event). The report should draw the information together to establish the risk dominating scenarios. The next step is for the operator to have a process by which it decides whether the measures they have in place are those that are necessary given the circumstances of their site. Where there is potential for large numbers of fatalities or injuries, the demonstration that the measures in place are all that are necessary needs to be clear and robust. Criteria 9.X covers the demonstration aspects.

As previously mentioned, the safety reports should specify consequences for the worst accidents. However, the analysis should not be overly conservative. If the analysis predicts unrealistic hazard ranges, 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.

Criterion 10.6 "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 summarize 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 10.6. Guidance is provided in SRAM Part 2 Chapter 1 for this purpose. Predictive assessors need to form their own view on how the report meets this criterion. The assessment guidance is repeated here and expanded upon where relevant for explosives installations.

Most safety reports will present uncertain estimates for both accident probabilities and consequence predictions. This uncertainty should be offset by conservatism in the analysis. The Operator should aim to identify all assumptions that could have a significant effect on the results of the assessment, and, if necessary, carry out sensitivity tests to determine the effects of changes in input data to the various models used. For example, if the fatality estimates are sensitive to assumptions regarding population density at a particular exposed site, then the effect of varying the population density at that site should be explored - the population density at a particular spot may vary with time of day and day of the week.

The Operator should provide numerical risk estimates, but recognizing that the degree of rigor required in quantification should reflect proportionality. In addition to providing estimates for the likelihood of events, the Operator should provide estimates for:

Probable number of casualties with superficial injuries
Probable number of people requiring hospitalization
Probable number of deaths
The need to evacuate the area around the site
Amount of property destruction

To this end, freely available explosion effects and consequence models are available to help the Operator (see assessment against Criterion 10.5.4).

Irrespective of the mix of argument, semi-quantitative evidence and quantitative analysis used to determine risk, Assessors should have confidence in the results and concur with the conclusions presented in the safety report. The Assessors should treat with great caution any risk calculations based on optimistic assumptions and highly uncertain data.

In addition to evaluating the sufficiency and suitability of the risk assessment presented in the safety report, Assessors needs to take a view on whether the Operator has taken all measures necessary to prevent and limit the consequences of major accidents. The following set of questions may aid this process.

Q: Does the safety report show that the residual risks posed by the installation are negligible or, where not negligible, are ALARP?

The Assessors should check that the accumulated probability of death of the off-site individual most at risk from all accident sequences is less than 10^{-4}. If it is not, it is probable that either the safety measures on the installation are deficient (i.e. risks are not ALARP), or that the accident analysis is overly conservative. In either case, the Assessors should reflect their concerns in their assessment report.

It is possible that a situation may arise where the risk to any one person is sufficiently low, but where nevertheless the risk of a multiple-fatality accident is uncomfortably high. In such cases, the safety report should not be deemed deficient, but the Assessors should convey their 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. For example, it may be possible to automate certain processes; or replace certain types of sensitive explosives with less sensitive explosives; or if there is a hospital or an environmentally sensitive area in the vicinity of the installation, then it may be reasonably practicable to take preventative or mitigation measures over and above recognized standards. The safety report should explain why any additional measures so identified have not been taken. 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 is dealt with by other criteria. Where a full quantification has been undertaken, 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 has published harm criteria for land use planning purposes for a variety of substances, i.e. 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 been adopted.

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 (for example, guidance given in MSER ACOP). However, in making this demonstration, Operators need to consider the particular circumstances of their installations and the consequences of identified major accidents both on and off site and decide whether there are any further reasonably practicable risk-reduction measures that could be taken. Attention should be focused both on measures to prevent major accidents and to mitigate the consequences of any accidents that might occur. Operators must take this step to demonstrate that risks are ALARP. In some circumstances, there may be risk-reduction measures that are reasonably practicable in addition to existing published industry good practice.

Where proportionality indicates that full quantification is required, the safety report should include a systematic assessment of additional risk-reduction measures.

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 and money 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 and published papers in their risk assessment. These may be HSE guidance documents, or plant design and operating standards, or papers containing information on historical accident rates, etc. In each case, the Assessors should consider whether 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 determine whether 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 Operator used explosion and effects models that are well established and known to err on the side of conservatism?

It is unlikely that any model can be relied upon to give exact predictions for the outcomes of explosives events at all the ranges of practical interest. These outcomes will be dependent on numerous factors, such as the stacking arrangements within the danger building, the type of construction and state of repair of the danger building, the topography surrounding the danger building, the type of construction and state of repair of the exposed buildings, climatic conditions and the state of health of the exposed population. Not all of these factors are amenable to modelling. Predictions for the numbers of fatalities/injuries to be expected in the event of an accident will thus inevitably subject to uncertainty. In view of this uncertainty, it is important that the underlying assumptions built into the models used by the Operator should err on the side of caution. The models should likely produce a slight overestimate of risk for the typical situation but not produce results which are patently exaggerated - in other words the models should give "conservative best estimates" for accident outcomes. The models discussed under Criterion 10.5.4 are considered to give such predictions. Further advice on suitable models is given in the HSE publication ‘Selection and use of explosion effects and consequence models for explosives’.

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

As well as uncertainties in the consequence analysis, it should be clear that the Operator has addressed possible uncertainty in the following areas: mishap frequencies; conditional probabilities of initiation; reliability of safeguarding measures, time-variable population data; efficacy of emergency plans and evacuation procedures. Where there is any doubt as to the exact value of any of these parameters, then the Operator should err on the side of caution and the Assessors should expect to see conservative values adopted. Any assumptions made by the Operator should be based on sound engineering judgement and backed up by strong qualitative arguments.

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 summarizes accident probability and likely numbers of casualties in three severity groups (superficial injuries, hospitalisation and fatalities). It should also indicate the number of people likely to be made homeless by the effects of explosions.

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. The Operator should consider the worst possible major accident scenarios when drawing up emergency plans. It should be clear that the Operator has considered the consequences of accidents involving the full licence limits for the potential explosives sites. It should be clear that the Operator has determined the areas where people may be seriously injured and require hospitalisation. The maximum distance out to which people are likely to be injured is of vital importance.

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