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**UKOOA/HSE**  
**PREPARATION OF UPDATED GUIDANCE FOR  
FIRE AND EXPLOSIONS HAZARDS –  
PART 1 – GUIDANCE ON DESIGN AND OPERATIONAL  
CONSIDERATIONS FOR THE AVOIDANCE  
AND MITIGATION OF EXPLOSIONS**

**MAIN GUIDANCE**

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## FOREWORD

This document has been prepared by MSL Engineering Limited for UKOOA/HSE and presents guidelines on the design and operational considerations for the avoidance and mitigation of explosions.

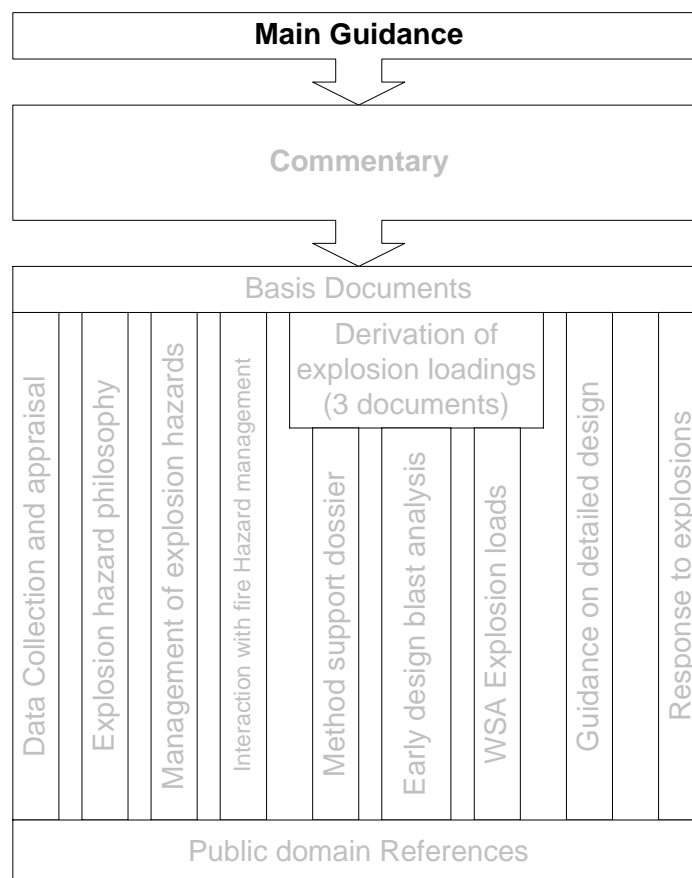
This document has been prepared by Steve Walker who assembled (and augmented as necessary) material from the 'Basis Documents' created by member organisations of the MSL Consortium <sup>(1,2,3,5,6,7,8,9,10)</sup>. The Project Manager for the Consortium was Minaz Lalani of MSL Engineering. The Consortium comprises the following:

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A full list of those involved in the preparation of this Guidance is given in Appendix A.

The guidance is presented in two parts, viz:

- Main Guidance (this document)
- Commentary to Main Guidance (Document Ref C268R007, Rev 2 December 2002).



### Part 1 Guidance Documentation

Foreword

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# 1. INTRODUCTION

## 1.1 General

The United Kingdom Offshore Operators Association (UKOOA) and the Health and Safety Executive (HSE) have co-sponsored the development of updated industry Guidance to assist in the design of new structures and the assessment of existing structures against fire and explosion hazards.

The Guidance is divided into three sections:

Part 1 Guidance on design and operational considerations for the avoidance and mitigation of explosions

Part 2 Guidance on design and operational considerations for the avoidance and mitigation of fires

Part 3 Guidance on design practices for fire and explosion engineering

This document (Main Guidance) and the Commentary form the first part of the Guidance. The second part will be at an equivalent level of detail but will relate to fire hazards. The third part will contain detailed engineering advice on the implementation of the principles and philosophy described in the first two parts.

The treatment described in this part of the guidance draws on the experience gained during the period since the Interim Guidance Notes <sup>(11)</sup> were prepared. This has allowed simplifications to be made and a more clearly defined approach to be adopted in some circumstances, without compromising safety.

This Guidance does not have the force of a Standard and contains information on good practice which may or may not be on a firm scientific basis and may require clear justification. Where this is the case the uncertainties are highlighted and the limitations of the methods are identified. There is a recognized need to provide such guidance to avoid decisions being made out of context during the explosion assessment process. The term 'assessment' is taken to include the assessment of a design in progress and the assessment of an existing installation.

This part of the Guidance identifies methodologies for explosion assessment, the circumstances in which the methods may be applied and their limitations. Part 3 of the Guidance will deal with the detailed implementation of these and other methodologies.

Alternative methods to those presented may be used so long as they are justified by a risk assessment and provided their use leads to reducing risks to as low as practicable (ALARP).

## 1.2 Explosion Philosophy Overview

In this Guidance, the goals which should be achieved in designing for and managing the explosion hazard are identified. The legislative basis is reviewed and some high level *performance standards* are given. (Terms in italics are defined in the Glossary given in Appendix B).

The features of an effective Safety Management System (SMS) are identified and the choice and management of detection, control and mitigation systems is discussed. The main characteristics of the explosion hazard are identified and the relevant issues relating to interaction with fire hazard management are discussed. The techniques of inherently safer design described in this Guidance are central to the approach to eliminate, prevent and mitigate the explosion hazard for new designs.

In order to focus effort where it is most needed, a risk screening method is described which classifies installations and compartments according to their risk level. The measures for frequency and consequence severity are based on process complexity and the exposure potential for people on board. These measures are combined in a risk matrix to give low, medium and high risk categories. The risk level is an indication of the level of sophistication to be used in the explosion assessment process.

A number of explosion scenarios on various installations have now been assessed using the techniques described in this Guidance. It is proposed that this data be used in the determination of *nominal overpressures* or for use in the early quantification of explosion hazards for new offshore facilities. These *nominal overpressure* values should be available for inclusion in Part 3 of this Guidance. Methods of deriving useable nominal explosion loads are discussed in section 5.7 of the Commentary.

In other situations a scenario based approach will generally be used where release scenarios are postulated and their consequences and probabilities of occurrence determined. For existing installations, reliable estimates of explosion loads may be available from previous assessments.

An essential part of the process of explosion assessment is the determination of the *design explosion loads*. The worst credible case of a *stoichiometric* cloud engulfing the whole installation or filling an entire compartment will frequently give rise to loads which cannot be designed against. *Design explosion loads* are selected on the basis of their frequency of occurrence and should be accommodated by the *safety critical elements* (SCEs) of the installation which will include parts of the structure.

Explosion loads will include both overpressure loads and *dynamic pressure* loads on piping and equipment which are due to the movement of gases around them. It is suggested that the number of SCEs which need to be considered in detail is reduced by classification into criticality categories with respect to the explosion process.

Reducing risks to ALARP must be demonstrated in all cases, both through the justification of the choice of design load and from a determination of the impairment frequency of the SCEs under these loads.

The supporting structure, panels and barriers must be shown to resist the design explosion loads without collapse and with minimal risk of impairment of the temporary refuge (TR), escape routes or means of escape. The structure therefore is required, globally, to be *robust* enough to resist the loads without excessive deformation and *ductile* enough to undergo local deformations, preferably without rupture.

The extreme design event explosion load cases are represented by the ductility level blast (DLB). This is determined using the associated frequencies of occurrence or exceedance and the *space averaged overpressures* derived for the relevant scenarios.

An acceptable level of risk should be identified within the ALARP framework, which identifies the acceptable frequency of exceedance of the severity of these scenarios. Typically this frequency of exceedance will be of the order of  $10^{-4}$  to  $10^{-5}$  per year depending on the risk to people on board, the impact on the SCEs and the overall individual risk from all sources.

There is at present a lack of consistency in the methods used for the generation of exceedance curves. The HSE has embarked on a study to clarify these, the results of which should be available for inclusion in Part 3 of this Guidance.

A lesser explosion event, the strength level blast (SLB), is also recommended which examined using elastic response techniques. This additional load case may detect additional weaknesses in a design and serves as a robustness check of the structure, other SCEs and their supports.

Guidance is given on the information required by the response disciplines from the explosion loading specialists. A common terminology has been developed to facilitate the transfer of complete and unambiguous information between these two disciplines.

The determination of the acceptability of the results of an assessment is also discussed. The aspects include comparison with high and low level or *element specific performance standards* and risk acceptability criteria. The guiding principle here is that risks should be reduced to ALARP.

Guidance on detailed design is included which brings together the approaches identified in the other sections and incorporates additional design and operations experience. Other industry initiatives which have generated detailed design and operating practice guidelines are presented and discussed.

### 1.3 Part 1 Guidance Overview

Chapter 3 gives an overview of the explosion assessment process each sub-section summarises the main conclusions of the basis documents <sup>(2,3,5,6,7,8,9,10)</sup>. Chapter 4 covers the same ground identifying some of the special features of the process for the assessment of existing installations.

The main Chapters of the Commentary each summarise the content of the basis documents.

The structure of the Commentary of Part 1 of the Guidance and the interfaces between them is shown in Figure 1.1 below. All the arrows on the diagram should be assumed to indicate an iterative process. The ability to repeat or refine activities and their inputs is dependent on the stage in the design or assessment project.

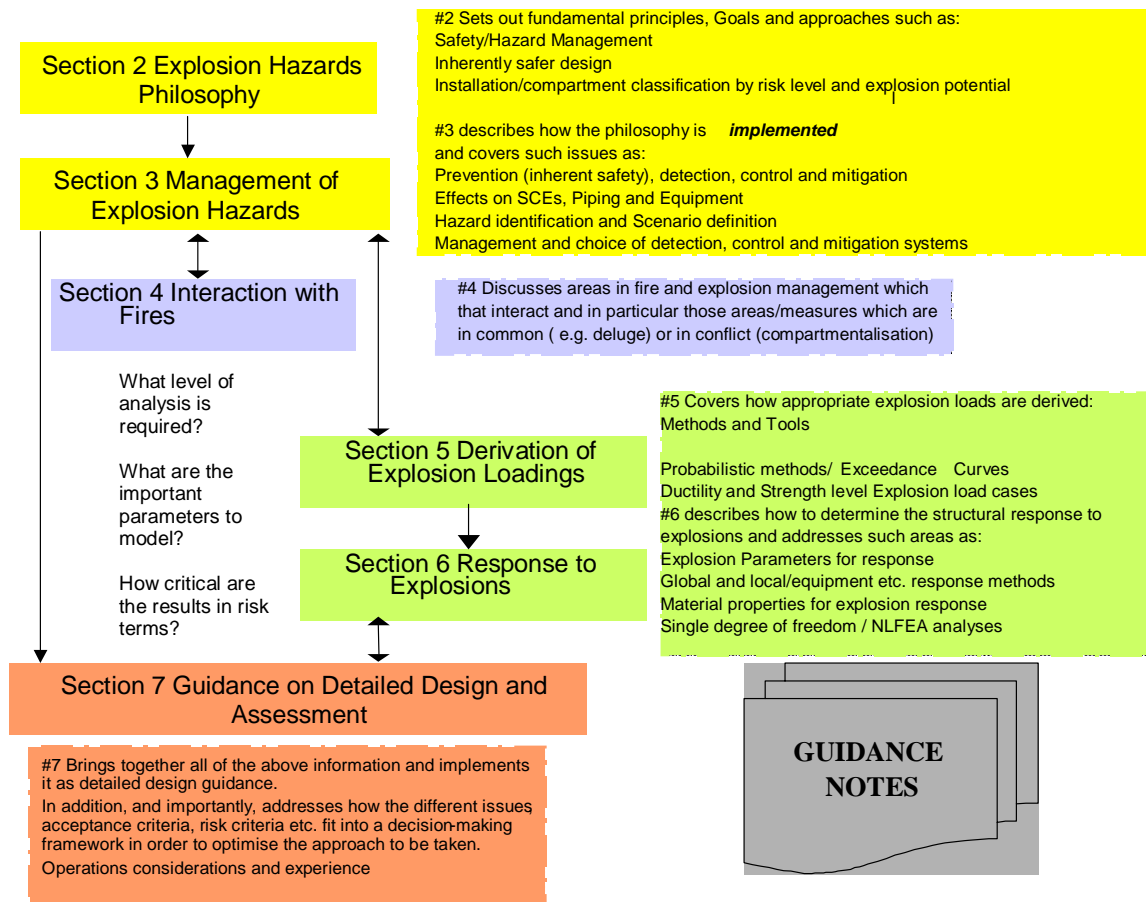


Figure 1.1 Overview of the Commentary

### 1.4 Objectives

The primary objective of this document is to offer guidance on practices and methodologies which can lead to a reduction in *risk* to life, the environment and the integrity of offshore facilities exposed to the explosion hazard.

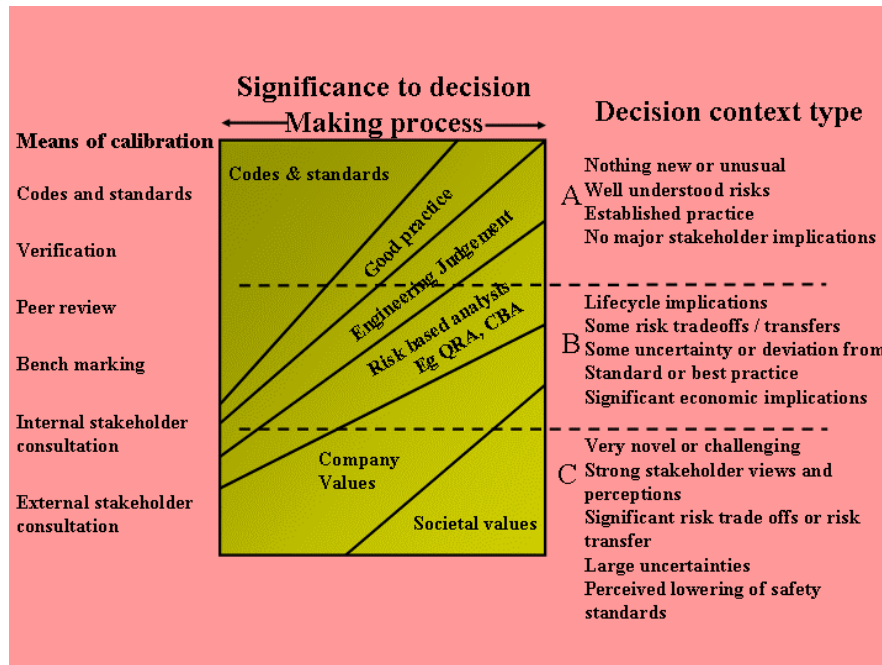
*Risk* is defined as the product of the probability of an event and its consequences. Alternative definitions are given in the Glossary, Appendix B.

Preventative measures are the most effective means of minimising the probability of an event and its associated risk. The concepts of Inherently Safer Design or ‘Inherent Safety’ are central to the approach described in this document both for modifications of existing structures and new designs.

This document consolidates the R&D effort from 1988 to the present day, integrates loading and response development and provides a rational design approach to be used as a basis for design of new facilities and the assessment of existing installations.

The initiative to develop the guidance is intended to assist designers and duty holders during the design of, and in making operational modifications to, offshore installations in order to optimise and prioritise expenditure where it has most safety benefit.

One intent of this Guidance is to move the decision-making processes within the fire and explosion design field as much as possible towards a 'Type A' process from 'Type B or C' as defined in UKOOA's document on decision-making illustrated in Figure 1.2 below<sup>(25)</sup>.



**Figure 1.2 The UKOOA decision making framework**

The framework in Figure 1.2 defines the weight given to various factors within the decision making process, ranging from those decisions that are dominated by purely engineering matters to those where company and societal values predominate.

A substantial number of installations will lie in Areas A or B of the chart resulting in an approach which involves codes and Guidance based on experience and 'best practice' as described in this document and supplemented by risk based arguments where required.

The philosophy of using past experience for the estimation of explosion loads has also been applied to the definition of explosion design load cases, the estimation of dynamic pressure loads, and to the assessment of explosion response.

### 1.5 Historical Overview

Following the Piper Alpha disaster a large Joint Industry Project called 'Blast and Fire Engineering for Topsides Structures (Phase 1)' was carried out between May 1990 and July 1991. Twenty-nine companies sponsored the project. The main deliverable from this project was the Interim Guidance Notes (IGNs)<sup>(11)</sup> and 26 background technical reports written by the participants and published by the Steel Construction Institute (SCI) in November 1991. These documents are available as free downloads over the Internet from the HSE web site.<sup>(12)</sup>

The development of the Interim Guidance Notes was a major step forward which consolidated the then existing knowledge of fire and explosion hazards. At about this time the Fire and Blast Information Group (FABIG) was set up and has subsequently issued a number of Technical notes on specific aspects of fire and explosion engineering <sup>(13 to 19)</sup>.

Three further phases of the Blast and fire engineering project JIP were conducted from 1994 to 2001, Phase 2<sup>(20)</sup>, Phase 3a and Phase 3b<sup>(21)</sup> consisting mostly of experiments to define and determine explosion overpressure load characteristics and to provide a basis against which load simulation software may be validated.

Other valuable work, mostly executed in Norway and following the probabilistic approach, has resulted in the new NORSOK guidance documents <sup>(22,23)</sup> which are amongst the source documents for this Guidance. The results of these and other major investigations are summarised in the new Engineering Handbook published by CorrOcean <sup>(24)</sup>.

During the same period, the HSE and others have funded approximately 300 individual projects and a number of Joint Industry Projects (JIPs) at a cost of £31million, which have contributed significantly to the understanding of the key issues. The relative maturity of the subject has enabled a more well defined approach to be adopted in this Guidance document relying more on 'good practice' which has been developed and implemented over the intervening years.

## 2. BACKGROUND AND PRINCIPLES

A release of hydrocarbon with immediate ignition will result in a fire; release of a flammable vapour or gaseous hydrocarbon followed by later ignition may result in an explosion. Explosion events, their elimination, prevention, detection, control, mitigation and consequences are the subject of this Guidance.

### 2.1 The explosion hazard

Gas explosions can be defined as the combustion of a premixed gas cloud containing fuel and an oxidiser that can result in a rapid rise in pressure. Gas explosions can occur in enclosed volumes such as industrial process equipment or pipes and in more open areas such as ventilated offshore modules or onshore process areas.

For an explosion to occur a gas cloud with a concentration between the *upper flammability limit* (UFL) and *lower flammability limit* (LFL) must be ignited. The overpressure caused by the explosion will depend, amongst other things, on:

1. The gas or gas mixture present
2. The cloud volume and concentration
3. Ignition source type and location
4. The confinement or venting surrounding the gas cloud
5. The congestion or obstacles within the cloud (size, shape, number, location)
6. Cloud density inhomogeneity
7. Ignition timing

*Confinement* is defined as a measure the proportion of the boundary of the explosion region which prevents the fuel/air mixture from *venting* which is the escape of gas through openings (vents) in the confining enclosure.

*Congestion* is a measure of the restriction of flow within the explosion region caused by the obstacles within the region.

*Gas explosions* in more open environments can also lead to significant overpressures depending on the rate of combustion and the mode of flame propagation in the cloud. All of the above points from 1 to 5 can affect the explosion overpressures in this type of environment. Two types of explosion can be identified depending on the flame propagation rate:

- A *deflagration* is propagated by the conduction and diffusion of heat. It develops by feedback with the expansion flow. The disturbance is subsonic relative to the un-burnt gas immediately ahead of the wave. Typical flame speeds range from 1-1000m/s and overpressures may reach values of several bars. The overpressures are not limited to the 8 bar maximum typical of completely confined explosions.
- A *detonation* is propagated by a shock that compresses the flammable mixture to a state where it is beyond its auto-ignition temperature. The combustion wave travels at supersonic velocity relative to the un-burnt gas immediately ahead of the flame. The shock wave and combustion wave are coupled and in a gas-air cloud the detonation wave will typically propagate at 1500-2000m/s and result in overpressures of 15-20bar.

Most vapour cloud explosions offshore would fall into the category of *deflagrations*.

A typical vapour cloud explosion on an offshore installation would start as a slow laminar flame ignited by a weak ignition source such as a spark. As the gas mixture burns, hot combustion products are created that expand to approximately the surrounding pressure. As the surrounding mixture flows past the obstacles within the gas cloud turbulence is created. This turbulence increases the flame surface area and the combustion rate. This further increases the velocity and turbulence in the flow field ahead of the flame leading to a strong positive feedback mechanism for flame acceleration and high explosion overpressures.

Large components of the structure such as solid decks or walls experience loads due to the pressure differences on opposite sides of the structure. Typically within an explosion there will be a strong variation of pressure in space and time. There will typically be localised high regions of overpressure with lower values of average pressure acting on large components. The overpressure at a location within a gas explosion will typically rise to a peak value and then fall to a sub atmospheric value before returning to zero overpressure.

The duration of the positive phase in an explosion can vary greatly with shorter durations often associated with higher overpressure explosions. Typical durations range from 50 to 200 milliseconds with longer durations common in large open areas such as the decks of FPSOs.

For smaller objects, such as piping, the overpressures applied to the front and reverse side of such items will be of approximately the same magnitude at any moment in time and in this case the overpressure difference will not be the only load component on the object. For this type of object the *dynamic pressure* associated with the gas flow in the explosion will dominate.

Small objects may be picked up during the explosion, creating secondary projectiles. The peak energy for typical projectiles may be calculated from the dynamic pressure load time history and their mass.

Secondary, *external explosions* may result as the unburnt fuel/air mixture comes into contact with the external (oxygen rich) atmosphere. These can affect the venting of the compartment and enhance the overpressure within.

A *blast wave* will be generated which will propagate away from the explosion region and may impinge on adjacent structures.

## 2.2 Lifecycle implications

The exploitation of offshore hydrocarbon reserves may be considered to consist of the following phases:

1. Concept Selection
2. Concept Definition
3. Front end engineering design (FEED)
4. Detailed Design
5. Fabrication/Construction
6. Installation/Start-Up
7. Operation
8. Decommissioning

It is particularly important to appreciate that the largest contribution to maximising safety benefits will be attained during the Concept Selection/Definition phases, ie.

- The cost effectiveness of safety effort expended during the Concept and FEED phases is significantly better than during the later phases.
- The impact on project schedule of safety effort expended during the Concept and FEED phases is significantly less than during the later phases.
- Unsuccessful safety performance during the Concept and FEED phases may result in failure to attain the maximum safety potential, or attainment at the expense of significant cost and schedule penalties.

Figure 2.1 illustrates the lifecycle/risk matrix, with the “traffic light” colours indicating the degree of difficulty/undesirability of the proposed option. Sections 2.6 and 2.7 of the Commentary contain a detailed discussion of life-cycle factors.

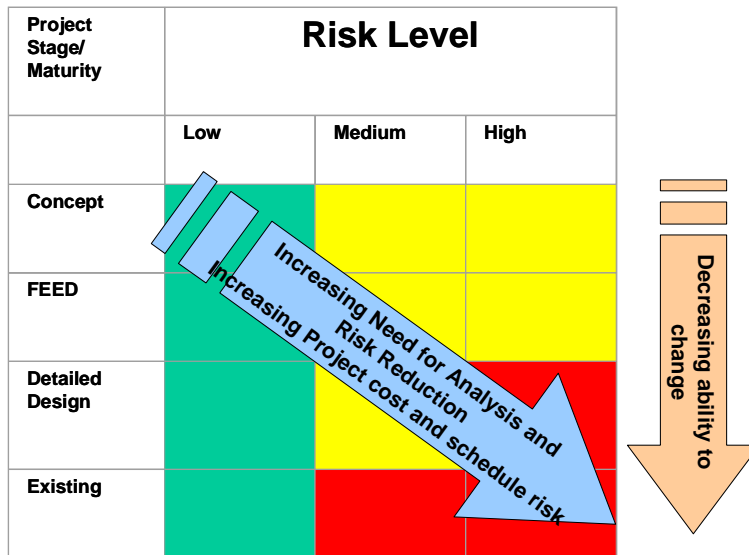


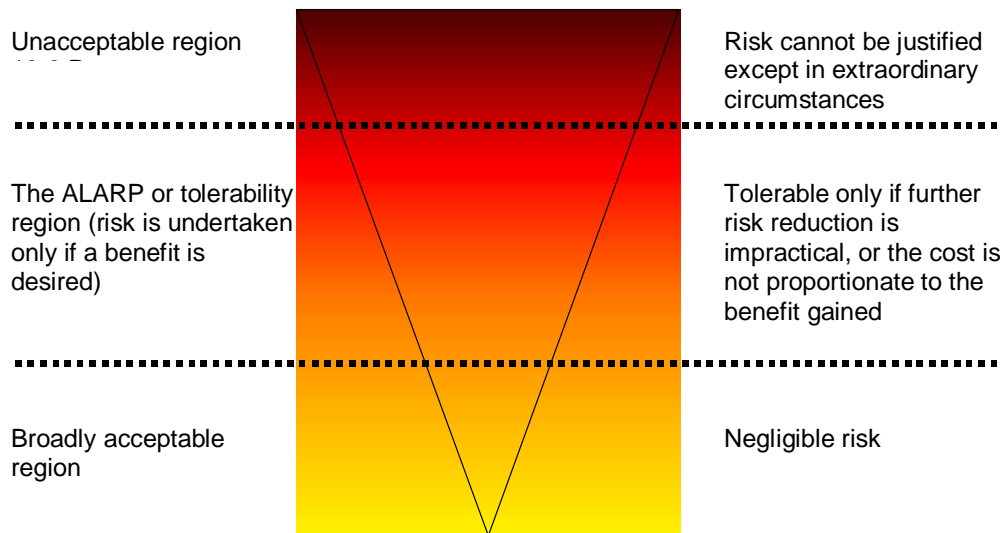
Figure 2.1 Risk vs. Lifecycle and Ability/Need to Change

### 2.3 ALARP

The ALARP principle states that “Risk must be kept As Low as Reasonably Practicable”.

ALARP can be described as the process of striving to reduce risks to a negligible level while taking due consideration of the economic and schedule implications of this goal, see Figure 2.2.

The cost of a measure (in terms of the time, cost and difficulties in implementing it) must be compared with the amount of risk reduction it brings. If the overall costs are ‘grossly disproportionate’ to the benefits, then implementation of the measure may be inappropriate.



Risks closer to the unacceptable region merit a closer examination of potential risk reduction measures

Figure 2.2 The ALARP Process

The risk measure used is individual *risk*, hence care needs to be exercised where risks appear to be low solely by virtue of low occupancy of the areas exposed to a hazard; for example, for a normally unattended installation (NUI); individuals may be exposed to a succession of NUI risks and it may be appropriate to consider risk exposure on an occupied year basis.

Societal risk will also need to be considered. If a large number of fatalities are predicted to result from a particular scenario then the acceptability of the risk should be considered to be reduced <sup>(26)</sup> (risk aversion).

Guidance on the demonstration of ALARP is available throughout the Commentary and from the following sources;

- Policy and Guidance on reducing risks to ALARP in Design <sup>(26)</sup> . <http://www.hse.gov.uk/dst/alarp1.htm>
- Principles and Guidelines to Assist HSE in its Judgement that Duty Holders Have Reduced Risk as Low as Reasonably Practicable <sup>(27)</sup> . <http://www.hse.gov.uk/hid/spc/perm12.htm>

HSE Books have published a guide which sets out an overall framework for decision taking by the HSE (R2P2), which is available in hard copy form <sup>(28)</sup> and as a free download from <http://www.hsr.gov.uk/dst/r2p2.pdf> .

In cases where safety issues have not been addressed at an early stage in a project, the incremental costs of dealing with the hazard later in the project life will increase significantly. In many cases a late design/construction change can be a magnitude greater in cost than had the feature been incorporated in the design basis of the project. This can result in a measure whose cost then becomes artificially 'grossly disproportionate' to the risk reduction achievable, and it will become more difficult to attain a true ALARP position.

An effective Safety Management System (SMS) must be implemented as early as possible during the design, construction, operation and decommissioning of an installation. This will enable safety input to be made at an early project stage. The properties of an effective SMS are discussed in Section 3.2 of the Commentary.

## 2.4 High level Performance Standards

The UK legislative basis which drives the definition of high level performance standards is discussed in Section 2.3 of the Commentary.

At the end of the assessment process described in Section 3 of this document, there is a need to evaluate the results of an assessment and their acceptability. A project needs well defined goals, plans for achieving these goals. *Performance standards* provide a means of defining these goals.

A *performance standard* is a statement which can be expressed in qualitative or quantitative terms of the performance required of a system, item of equipment, person or procedure and which is used as the basis for managing the hazard.

Typical high level scenario based *performance standards* are given below:

In an explosion event, at least one escape route must be available after the event for all survivors. For a manned platform a Temporary Refuge (TR) or Safe Mustering Area must be available to protect those not in the immediate vicinity of an explosion and to survive the event without injury.

For the ductility level blast (DLB), the primary structure should not collapse with escape possible from safe areas after the event. *Safety critical elements*. A Safety critical element (SCE) is defined as any structure, plant, equipment, system (including computer software) or component part whose failure could cause or contribute substantially to a major accident, as is any which is intended to prevent or limit the effect of a major accident. SCEs should have fulfilled their function or remain operational. Plastic deformation of the structure is acceptable provided collapse does not occur and barriers remain in-place and are able to adequately resist any subsequent fires. The ability of the structure to satisfy these requirements will depend on its ability to respond in a ductile manner and the ability of the barrier connection details to respond without rupture.

The frequency with which accidental events, from all causes, will result in loss of TR integrity within the *required endurance time* will not exceed  $10^{-3}$  per year <sup>(41)</sup>. The *required endurance time* is the estimated time for

people to travel from their work stations to the TR, then to the *primary and secondary means of escape*, allowing for the possibility of helping injured colleagues.

*Performance standards* may also be referred to as acceptance, screening or performance criteria.

## 2.5 Element specific performance standards

In addition to the high level performance standards above it is necessary to define measurable performance standards for specific key items or systems relating to the systems' *functionality, availability and survivability*. These are referred to in this document as *element specific performance standards* used in the evaluation stage of an explosion assessment. These are sometimes referred to as low level performance standards.

### Criticality categories for SCEs

It is helpful to consider a hierarchical approach to the identification of SCEs. It is suggested that the number of SCEs (systems, equipment or functions) requiring detailed assessment are classified into three levels of criticality with respect to the explosion hazard as below.

**Criticality 1** Items whose failure would lead direct impairment of the TR or emergency escape and rescue (EER) systems including the associated supporting structure.

Performance standard – These items must not fail during the DLB or SLB, ductile response of the support structure is allowed during the DLB.

**Criticality 2** Items whose failure could lead to major hydrocarbon release and escalation affecting more than one module or compartment. (Indirect impact on the TR is possible through subsequent fire).

Performance standard – These items must have no functional significance in an explosion event and these items and their supports must respond elastically under the strength level blast (SLB)

**Criticality 3** Items whose failure in an explosion may result in module wide escalation, with potential for inventories outside the module contributing to a fire due to blowdown and or pipework damage.

Performance standard – These items have no functional significance in an explosion event and must not become or generate projectiles.

Following this approach, those elements which have the highest criticality rating towards ensuring the achievement of the overall hazard management objectives, should be identified and should receive the most attention.

## 2.6 Available tools for explosion assessment

### Consequence assessment

There are a number explosion assessment tools available for the assessment of the severity of the explosion hazard, these are listed below in order of increasing sophistication:-

1. Installation risk screening – here the general level of vulnerability to explosion events is estimated using a risk matrix, as described in section 3.1. This is not scenario specific – it will only give a general view of the severity and likelihood of explosion events.
2. Comparison with recent design situations – the use of past experience and nominal overpressures if they can be justified. There are difficulties with the justification of the use of 'similar cases' resulting from the sensitivity of the explosion phenomenon to initial and environmental conditions. Advances in the science of explosion load determination may invalidate previous analyses.
3. Simple or empirical models – these are correlations with experimental data and relate to specific scenarios and geometries. Extrapolation to different situations will depend on the extent of the data on which the methods are based.

4. Phenomenological models – these model the underlying physical processes in a simplified manner and enable some extrapolation to situations not available from experiments. Generally they will give some measure of the general level of loading within the explosion zone, detailed information on local overpressure and dynamic pressure behaviour will not always be generated.
5. Computational fluid dynamics (CFD) models – these models have a more detailed representation of the underlying physics of the explosion process than phenomenological models, solving the equations of mass conservation, momentum and sub models for turbulence generation. Some of the simulation aspects are still simplified, however. The simulation will involve the discretisation of the explosion zone into a large number of cells. The equations are solved in each cell at each time step. Cells where large numbers of small obstacles are present will be represented by a porosity value representing the fine detail of the congestion. Dynamic pressures are generated at ‘gauge points’ chosen by the user. These models have the highest potential for modelling new situations including the dispersion of the gas cloud. The main limitation of their use is the relatively long execution time and the degree of detail required for the simulations.

The first three approaches may be useful at an early stage when geometry details are not available. They will not yield detailed overpressure or dynamic pressure information for use in component design or the assessment of SCE response.

A number of techniques are available for the calculation of the subsequent propagation of the blast wave emanating from the explosion zone. These relatively simple models have been developed by the military (TNT equivalence methods) and by the onshore process industry for modelling explosion effects at some distance from largely unconfined explosion combustion regions.

#### **Frequency assessment**

The frequency of a particular explosion scenario is an equally important aspect for the determination of risk defined as the product of probability and consequence or severity. This frequency of a particular outcome will depend on:-

1. The release frequency for a particular release site which should be available from published sources based on past experience <sup>(36,37,38,39)</sup>. The release direction, released material and rate of release.
2. The availability of detection, control and mitigation measures such as blow down, deluge and inventory isolation measures.
3. The dispersion characteristics determined by the detailed geometry, ventilation conditions including wind speed and direction. Environmental conditions and frequencies should be available for the location.
4. The probability of ignition determined by the ignition source location, timing and duration and its position relative to the flammable regions of the gas cloud.
5. The probability of failure of barriers such as blast walls and other pieces of safety critical equipment will depend on the response of these items to the dynamic or overpressure loads.

## Response calculation methods

Response to explosion loads is determined by the ratio of the natural period of the target to the duration of the load. Three regimes of response are possible:-

1. Impulsive – where the load duration is short compared with the target natural period. The shape of the time history of loading is not important, what is important is the total impulse represented by the pressure pulse. This regime may apply where the response of a distant object to a blast wave is required.
2. Dynamic – where the load duration is similar to the natural period of the target giving a response time similar to the load duration. This is the most common situation for a partially vented hydrocarbon explosion. The duration and peak of the load is important.
3. Quasi-static – where the duration of the load is much longer than the natural period of the target. The load magnitude may be considered to be constant during the time of response. An equivalent static load may be used and the stress energy absorbed by the target estimated. A dynamic amplification factor may be used for response in the elastic region where plastic deformation does not occur. This method is not useful when plastic deformations occur.

Most practical situations will require explosion response to be calculated in the dynamic regime using a single or multiple degree of freedom idealisation of the target. This is discussed in detail in Section 3.5 and Chapter 6 of the Commentary.

### 2.7 Uncertainty in explosion assessment

There are two types of uncertainty which need to be addressed <sup>(40)</sup> :-

Type A uncertainty – also known as aleatory, random, inherent uncertainty or variability. This is due to the intrinsic randomness in the input parameters and assumptions, for example variations of wind speed and ignition by intermittent ignition sources. Repeated measurement can reduce this type of uncertainty by better defining the statistical distribution of the parameters.

Type B uncertainty – also known as epistemic uncertainty. This is due to lack of knowledge and includes uncertainties in modelling methods and base data such as assumed leak frequencies. Most of the uncertainty in a risk analysis is of this type.

It is unlikely that the structure and SCEs will be able to withstand the worst credible event and hence a risk based approach is necessary.

Uncertainty analysis or sensitivity analysis is an attempt to quantify the uncertainties in the results of an analysis and identify the governing parameters by examination of the sensitivity of the results or by estimating the statistical distribution measures which define the variability of the input parameters.

The sources of uncertainty in a quantitative risk analysis (QRA) may include for example <sup>(40)</sup> :-

#### Type A

- Incomplete representation of time dependant ignition models – continuous and intermittent
- Ignition probabilities for inhomogeneous gas clouds
- Incomplete representation of environmental effects – wind speed and direction
- Explosion modelling of inhomogeneous gas clouds
- Incomplete physical understanding of the failure mechanisms and escalation chains.

## Type B

- Lack of precision in simulation tools
- Selection of study assumptions
- Selection of representative scenarios
- Treatment of randomness in the input variables Insufficient data. A small number of explosion incidents have actually occurred, where historic data is used, in leak frequency estimation for example, recent improvements in performance are not represented. Note: This is quoted as Type B above and is more consistent with a Type B uncertainty.
- Lack of competence in the assessment team
- Lack of understanding by the decision makers
- Inadequate representation of the functioning of detection, control and mitigation systems
- 'Soft' factors or human factors such as the role and response of the workforce to the scenario considered, leadership, ownership, inspection, safety management systems, accident investigation, escape and recovery.
- Inadequate care or precision in the estimation of the number of resulting fatalities.

This presence of uncertainty in any analysis is recognised, for example, in the process for evaluating ALARP, where a gross disproportion factor (typically of the order of 10) is normally applied. This accepts that there are likely to be uncertainties associated with an evaluation and that the cost therefore has to be considerably greater than the benefit, for the measure to be excluded.

Most of the effort to reduce the uncertainty in explosion assessment has been directed towards improvement in the modelling of physical mechanisms. This has resulted in CFD codes which are considered to predict overpressures to within  $\pm 30\%$  if the modelling assumptions are well defined<sup>(22,23)</sup>. This has resulted in reduction in the uncertainties in the assessment of the **consequences** of the selected scenarios. This concentration on consequences may, however, give a misleading perception of accuracy if a risk based approach is to be used. Frequency analysis is likely to be equally as important as the consequence analysis. It is important that this dependence on frequencies is recognised in any assessment, as the uncertainties may be significantly greater than in the consequence analysis.

The alternative approach to the reduction or understanding of uncertainties is to perform a large number of simulations involving variations in relevant parameters. A validated/calibrated phenomenological model is often used for the simulations as run times for such models are relatively small. This approach can use Monte Carlo simulation techniques in which the statistical distributions of the input variables are represented explicitly and output is provided by distributions which enable confidence limits to be attached to each variable and a much better understanding of the frequencies to be achieved. The computational effort is put into developing a broader understanding of the scenarios and their associated escalation likelihoods and consequences.

Ideally a combination of both approaches should be considered if the time and availability of input data permits.

The frequency depends on many factors in the chain of events which lead to an explosion, it is important to consider the sensitivity and uncertainties in all intermediate results which may feed into later stages in the assessment process. A holistic approach needs to be employed to identify the weak points in the chain of analyses for close scrutiny.

The above must be borne in mind in the decision making process. It is also desirable that the assessment process provides relevant information in time for decisions to be made as early in the project as possible and that the assessment process does not rely on firm detailed information which is not available at the appropriate stage.

### 3. OVERVIEW OF THE EXPLOSION ASSESSMENT PROCESS

The approach to explosion assessment hazard management recommended in this Guidance is illustrated in the 'top level' flow diagram given in Figure 3.1. A number of tasks to be performed by the various disciplines of the project and operations team are identified. These tasks are dealt with individually and in more detail in the Commentary. A number of representative flow charts illustrating each task in the process are given in this Chapter.

The level of detail appropriate for the tasks identified will depend on the risk level of the installation and the stage in a project during which these tasks are performed. Some of the tasks will need to be repeated during a project as the work progresses and as more information becomes available.

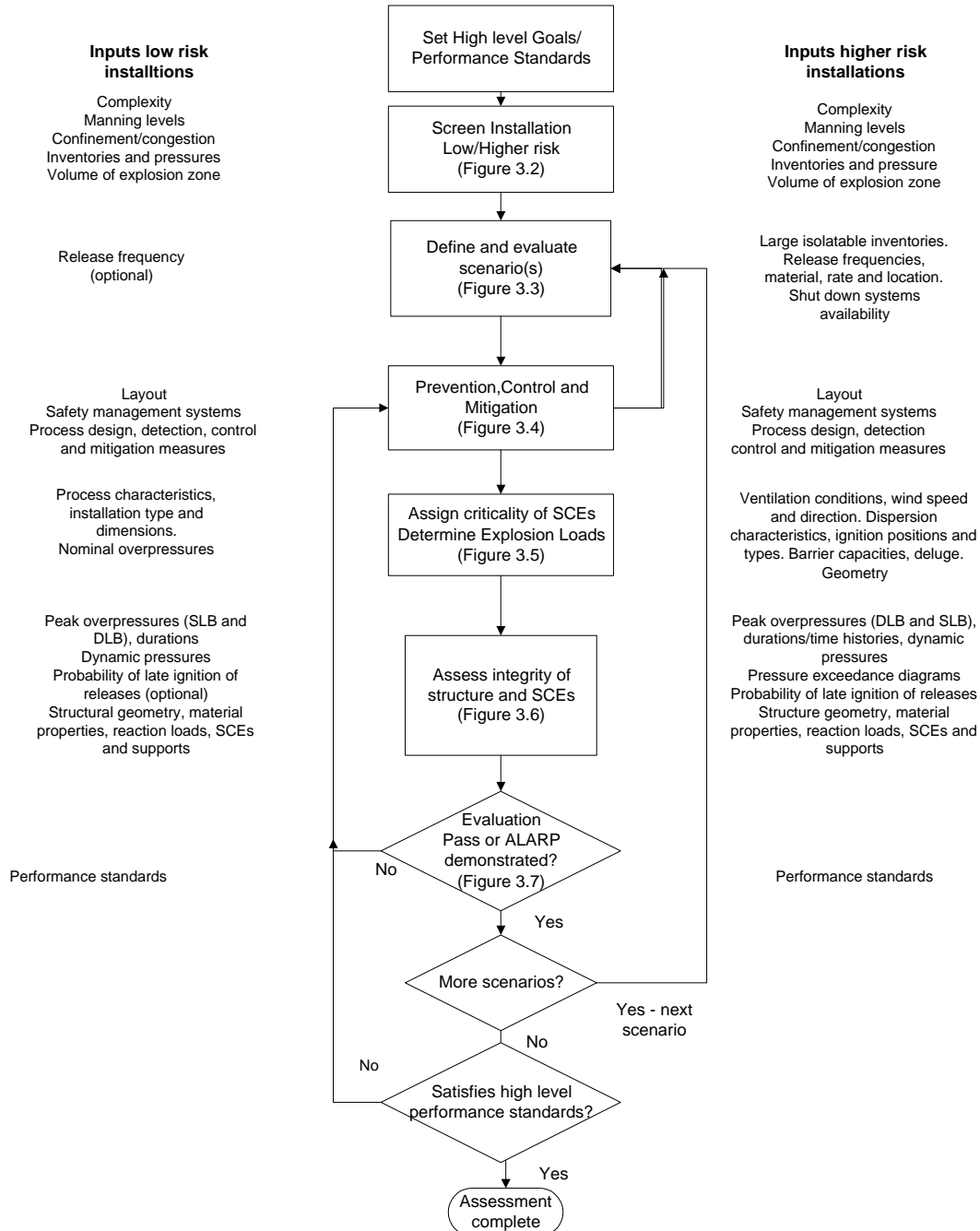


Figure 3.1 Overview of explosion hazard management and assessment

### 3.1 Installation Risk Screening

Installation screening is recommended to enable resources and time to be focussed where it is most appropriate when little detailed information is available for the specific hazards on the installation. It is also a useful exercise at the early stages of a project in order to focus attention on the safety issues at a time when the most benefit may be gained at the least cost. This process is illustrated in the flow diagram Figure 3.2. Further details are given in the Commentary Section 2.8.

This task consists of classifying the installation and its compartments into Low, Medium or High risk categories to determine the level of explosion assessment required. The complexity of the process in the compartment is taken as an important measure in the screening exercise.

In this context, risk is defined as a measure of the product of consequence and the probability of an ignited release giving rise to a *significant overpressure* greater than 50 millibar.

$$\text{Risk} = \text{Probability} \times \text{Consequence} \\ \text{(or likelihood} \times \text{severity)}$$

Likelihood is a more appropriate term in this context where a qualitative assessment is being performed, The terms probability and frequency imply that numerical values are available.

Installation screening is achieved by early consideration of the vulnerability of the installation and the likelihood of an explosion event.

#### Consequence severity

For the purposes of installation risk screening, the consequences of releases are always considered high if the installation is permanently manned and the living quarters are located on the same structure. The permanent presence of personnel on the installation indicates that frequent maintenance is required which in turn indicates high process complexity. Medium consequence installations will generally include manned installations where the living quarters are located on a separate structure.

Low consequence installations will be normally un-manned, with low confinement and congestion and with minimal process consisting of wellheads and manifolds.

#### Likelihood

The *likelihood* of a significant overpressure is considered high if the process on the installation or in a compartment is of high complexity. This is often reflected in the need for permanent manning of the installation. Low likelihood will be indicated for installations with a low equipment count or with an intervention frequency of more than 6 weeks.

#### The Risk Matrix

The Risk Matrix shown in the flow diagram is discussed in detail in the Commentary (Section 2.8). This enables the consequence and likelihood categories to be combined to place the installations in the low, medium or high risk categories.

#### Assessment methods

The recommended methods of assessment are based on the risk category of the installation. These are discussed throughout the Commentary and in particular in Section 2.9.

The low risk installations may be assessed using experience gained from similar installations or investigations if this can be justified. Alternatively appropriate *nominal overpressures* may be used for the assessment of installations in this category. This is referred to as the low risk methodology described in this Guidance.

Medium risk installations may also be assessed using *nominal overpressures* if they can be shown to apply. It should be borne in mind that some *nominal overpressures* will be high (for example greater than 1 bar peak space averaged overpressure). This indicates that risk levels may still be relatively high necessitating a more

sophisticated assessment level particularly for an existing installation and in the later stages in a design project. Medium risk methods are described in this Guidance which substitute for some of the tasks defined in the *high risk methodology*. The philosophy recommended in this Guidance is that for medium risk installations the choice of methodology for any particular task must be justified where it deviates from the *high risk methodology*.

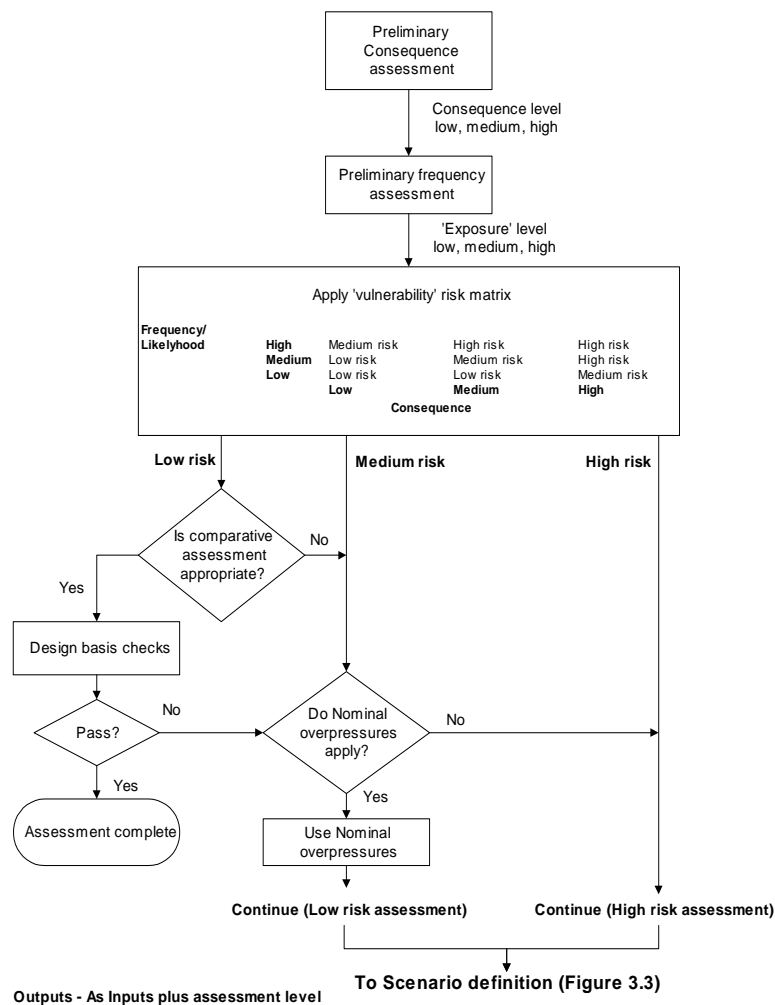
Where appropriate low *nominal overpressures* are indicated a low risk assessment approach may be used.

High risk installations will require the *higher risk methodology*. The ability of the installation and the compartment *safety critical elements* to withstand explosion loads needs to be accurately determined as any error could have a significant impact.

The category of an installation, or particular compartment, does not preclude the use of more sophisticated methods of assessment which may result in reductions in conservatism and hence cost, if they are considered more appropriate. In particular the methods described in the Norsok standard Z-013 <sup>(23)</sup> represent the most rigorously defined methods available at the time of writing and are the benchmark against which the methods used may be gauged. The Norsok approach is discussed in the Commentary in Section 5.13.

**Inputs**

Complexity, Manning levels, Confinement/congestion, Isolatable Inventories- vulnerability of Safety Critical Elements, TR location, layout, dimensions of potential explosive gas cloud, escalation potential, operating and control philosoph influencing manning levels and occupation frequency, extent of operator intervention and the potential for human error and inventory loss, hazardous inventory, complexity (number and type of flanges, valves, compressors), number of ignition sources, external inventories, ventilation, equipment reliability and maintenance regime.



**Figure 3.2 Installation risk screening**

## 3.2 Scenario Definition

In order to manage the explosion hazard, it is necessary to identify the initiating events which may lead to an explosion.

These *initiating events* should be eliminated if possible. Otherwise, prevention, control and mitigation will become necessary. An example methodology for the definition of scenarios is shown in the flow diagram of Figure 3.3. This topic is discussed in the Commentary Section 3.3. Fire and explosion interaction is discussed in Chapter 4 of the Commentary. Explosion scenarios must also be considered from the point of view of the fire hazard.

### Causes

Causes of a release may be dropped objects, ship impact, intervention, fatigue, vibration, extreme environmental conditions, imperfections, escalation from a fire, exceedance of design conditions and human error. These causes are often referred to as *initiating events*.

### Identification

The means by which hazards are identified may be by formal processes such as:

- Hazard identification studies (HAZIDS) and ENVIDS
- Hazard and operability studies (HAZOPS)
- Layout review
- Hazardous area review
- Identification of inventories, pressures and material properties

Hazards may be also identified by individuals, using an action tracking system such as a Safety, Health and Environment Action Management System (SHEAMS) which should ideally be in place to enable these hazards to be addressed. *Initiating events* for explosions may also give rise to fires either directly through early ignition or indirectly through escalation.

Hazards which cannot be eliminated are sometimes referred to as *residual events*. If the hazard cannot be eliminated then the frequency of the *initiating event* (and its immediate consequences) should be determined and minimised.

*Residual events* may give rise to an explosion. The sequence of events resulting in an explosion and possible escalation is referred to as an *explosion scenario*.

### Scenario definition

Scenarios are constructed by consideration of:-

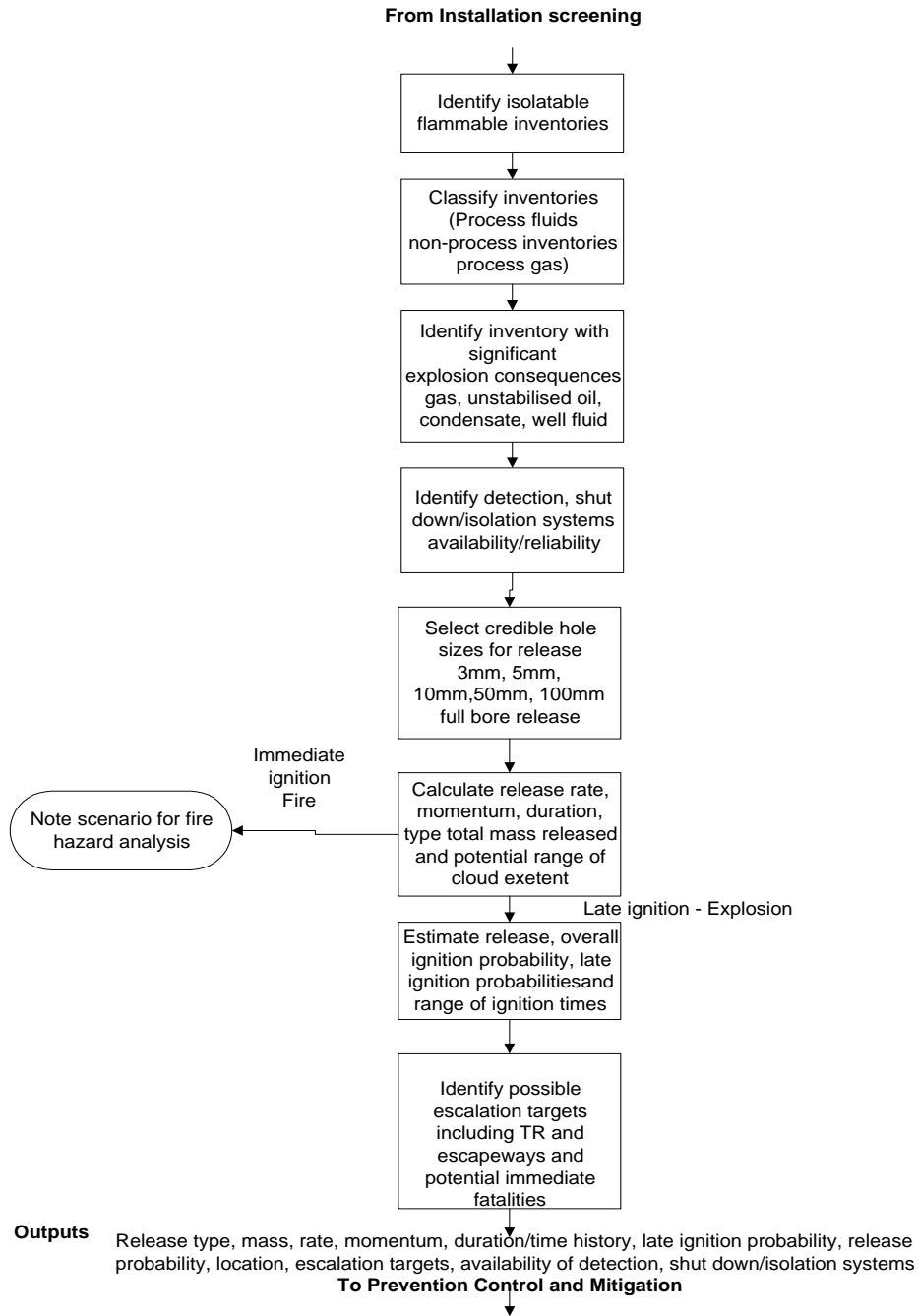
- Leak frequency from equipment item counts and generic release frequency data per item
- Leak location (in isolatable inventories with the possibility of causing escalation)
- Representative leak sizes
- Release rates based on release size, composition and pressure
- Duration of release and shutdown philosophy
- Cloud accumulation and composition in relation to release location/direction and ventilation conditions
- Ignition probability proportional to release rate or the incremental increase of cloud size in time
- The proportion of ignitions for which explosions occur

Other non-process related sources of flammable hydrocarbon may be located at storage or lay down areas, facilities within the accommodation area and local enclosures in power generation and utility areas. Oil mist releases may also give rise to an explosion.

The majority of explosions will give rise to low overpressures and are often referred to as *flash fires*. An on-going jet fire may result.

Scenarios generated in the context of fire studies may also give rise to explosion scenarios which should be considered. Most explosion scenarios will have an associated fire scenario in the case of early ignition which should be noted for the fire hazard analysis.

For low and medium risk installations where suitable nominal overpressures are not available, a small number of the more severe/less frequent representative scenarios may be sufficient for the explosion assessment.



**Figure 3.3 Scenario Definition**

### 3.3 Prevention, Control and Mitigation

Once the *initiating events* and scenarios have been identified, measures should be taken to investigate ways of reducing the risk bearing in mind that:

ELIMINATION or MINIMISATION is better than  
PREVENTION is better than  
CONTROL is better than  
MITIGATION is better than  
EMERGENCY RESPONSE.

As regards systems to reduce risk,

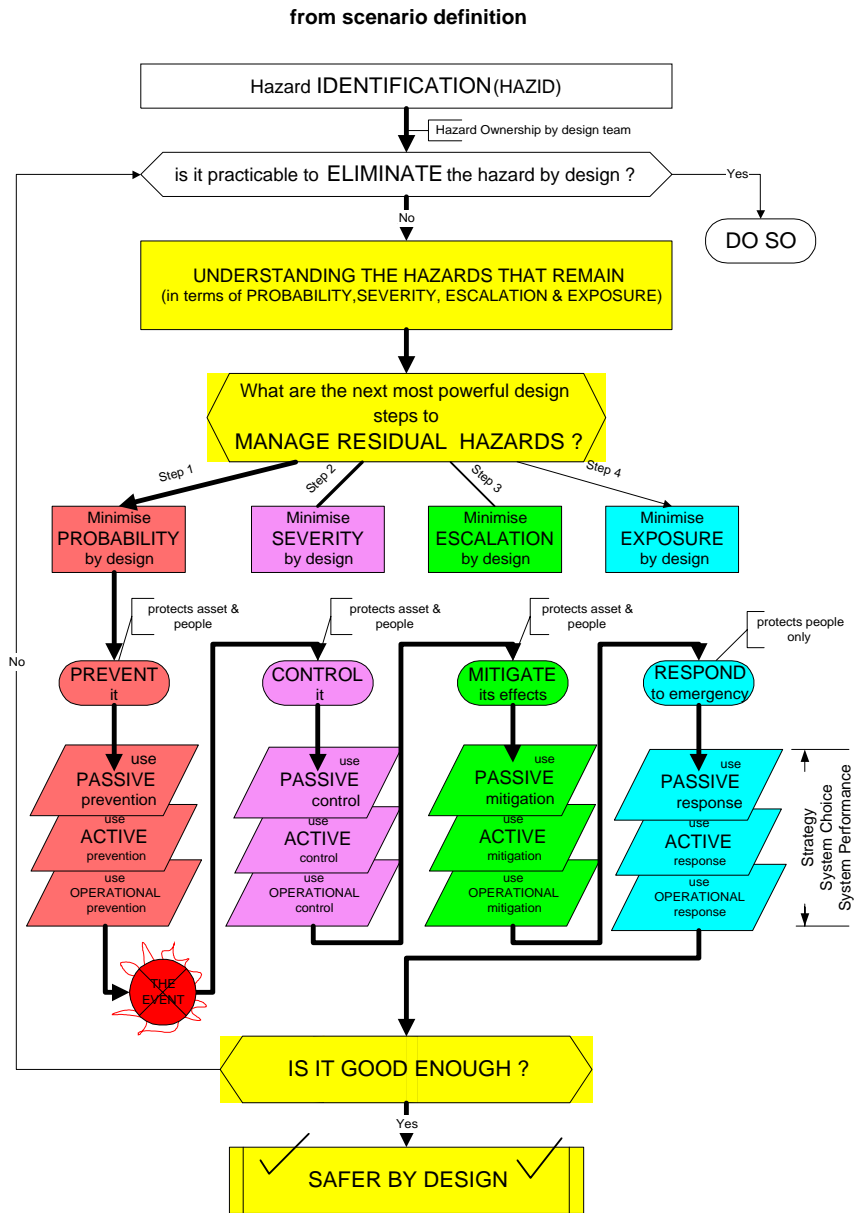
PASSIVE systems are more reliable than  
ACTIVE systems are more reliable than  
OPERATIONAL systems are more dependable than  
EXTERNAL systems

The hierarchy of measures is illustrated in Figure 3.4 taken from reference 32. The concepts of inherently safer design 'Inherent Safety' are discussed in detail in Section 2.7 of the Commentary.

Measures for detection, control, and mitigation should be investigated, including the implementation of an effective Safety Management System for the hazard which deals with all the issues above. Safety Management Systems are discussed in detail in Section 3.2 of the Commentary.

These issues should be addressed as early in a project as possible. Project management has a critical role to play in ensuring that safety issues are fully addressed at the correct stage by the appropriate discipline engineers.

The associated fire scenarios with (or without) the potential for escalation are also candidates for elimination, control and mitigation.



Major Accident Hazard Management Flowsheet

To 'Determine Explosion Loads'



**Figure 3.4 Prevention Control and Mitigation**

### 3.4 Determination of Explosion Loads

#### Load cases for explosion response

Two levels of explosion loading are recommended for medium and high risk installations by analogy with earthquake assessment: The *ductility level blast* (DLB) and the *strength level blast* (SLB). Low risk installations may be assessed using only the DLB, as the overpressures are likely to be low and the SLB is not likely to be critical in the design. The risk levels and frequencies may not be the same as for earthquake analysis. This reflects the fact that an explosion is perceived as a preventable event.

The *ductility level blast* is the design level overpressure used to represent the extreme design event. This is a high consequence event important for the establishment of survivability.

The *strength level blast* represents a more frequent design event where it is required that the structure does not deform plastically and that the SCEs remain operational. This load case is suggested for the following reasons:-

- An SLB event may give rise to an unexpected DLB by escalation if it is not considered in the assessment.
- The prediction of equipment and piping response in the elastic regime is much better understood than the conditions which give rise to rupture. The SLB enables these checks to be made at a lower load level often resulting in good performance at the higher level (strength in depth).
- The SLB offers a degree of asset protection.
- The SLB is a low consequence event important for the establishment of operability.

This topic is discussed in the Commentary in Chapters 5 and 6.

#### Determination of explosion design loads

Overpressure acts directly on loaded surfaces. This may be developed for each scenario using the predictive tools described in section 2.6.

Design explosion loads in the past have been derived from the a worst credible event assuming a gas cloud of maximal extent with stoichiometric composition ignited at the worst time in the worst position.

Frequently the *ultimate peak overpressure* ' $P_{ult}$ ' derived in this way is too large to be accommodated by the structure. Checks should be made to ascertain whether the cloud of maximal extent is feasible with respect to the shutdown philosophy and the isolatable inventories. ALARP arguments are appropriate and can be used to demonstrate that risk levels have been reduced to satisfactory levels which itself relies on frequency and risk arguments.  $P_{ult}$  will often correspond to an event with a return period out of proportion with the design life of the installation.

The accepted level above which the overall risk is considered intolerable relates to an individual risk of greater than  $10^{-3}$  per year or a TR impairment frequency of greater than  $10^{-3}$  per year. The overall individual risk from all hazards must be less than this value. If risks are in the intolerable region then risk reduction measures must be implemented, irrespective of cost. Hence the risk from other hazards may indirectly affect the acceptability of risk from explosions and these may need to be considered in setting the target risk levels for the explosion hazard.

A single event frequency of exceedance between  $10^{-4}$  and  $10^{-5}$  per year is considered a reasonable frequency for the *ductility level design event* or DLB, by analogy with the treatment of environmental and ship impact loads which are often considered at the  $10^{-5}$  level. In order to determine the DLB, an *exceedance curve* must be constructed which represents the frequency of exceedance of a given *space averaged peak overpressure*. This curve will enable the DLB overpressure case to be identified. If the event impinges directly on the TR, escape routes or means of escape then the target level should be the  $10^{-5}$  level. If the event impinges on one or more barriers before impinging on these SCEs then it may be argued that the  $10^{-4}$  level is more appropriate.

It should be emphasised that *duty holders* must set their own targets based on the risk to personnel on the installation, and considered within the ALARP framework. This framework requires *duty holders* to always seek to reduce risks, and only to argue against implementation of a measure if it is not reasonably practicable.

The *space averaged peak overpressure* for the compartment is used for determination of the design explosion load cases as it is more generally representative of the severity of the event. A local overpressure peak may be used to generate exceedance curves for the determination of load cases for local design of a blast wall for instance. Impulse exceedance curves may also be generated which take into account the duration of the load and its peak value; these give a better measure of the expected response of the target which will be dynamic in nature.

The SLB may then be identified from a *space averaged peak overpressure* exceedance curve, as that overpressure corresponding to a frequency one order of magnitude more frequent or with a magnitude of one third of the DLB overpressure whichever is the greater. The reason for the reduction factor of one third is related to the expected reserves of strength in the structure and the observation that the primary structure will often only experience received loads of this reduced magnitude. These topics are discussed in Chapter 6 of the Commentary.

### **Loads on equipment items**

The explosion loads on equipment items and pipework<sup>(24,33,34)</sup> must be determined and are referred to as *dynamic pressure loads* which may be directly obtained from CFD simulation results and consist of:

- Drag loads (similar to the Morison drag loads experienced in fluid flow) proportional to the square of the gas velocity, its density and the area presented to the flow by the obstacle.
- Inertia loads proportional to the gas acceleration and the volume of the obstacle.
- Pressure difference loads.
- Loads generated by differential movement of the supports.

Drag loads dominate for obstacles with dimensions less than 0.3m or on cylindrical obstacles less than 0.3m in diameter and, in particular, in regions of high gas velocity near vents. Pressure difference loads become important for obstacles with dimensions greater than 0.3m where they must be added to the drag loads. Care must be taken in interpreting the results of CFD simulations as the cell size/obstacle size ratio may make it difficult to obtain accurate pressure and flow information at points near the obstacle.

Equipment items in the interior of a compartment away from the vents will experience loads composed mostly of inertia loads due to gas accelerations. It is likely that these loads will, however, be lower than the drag and pressure difference loads experienced by items in the vent paths.

Exceedance curves for local dynamic pressures may be developed from simulations and used in the same way as for overpressures in deriving design dynamic overpressures for the DLB and SLB load cases. It is recommended that the DLB dynamic pressures are applied to SCEs of criticality 1 and that both the DLB and SLB overpressures are applied to SCEs of criticality 1 and 2 with the requirement for elastic response of the supports and that the SCEs would remain functional.

The methodology for the determination of explosion loads is illustrated in Figure 3.5. It has been noted by some experienced explosion loading specialists that it is very unlikely that designing to a very low probability event (say with an exceedance of  $10^{-6}$  per year) will be possible and if it is then it is unlikely to be an efficient solution.

Design explosion event peak overpressures and durations (or time histories) with known frequencies of occurrence will be required for the response analyses.

A number of explosion loading experts have suggested that a suitable load level for the representation of dynamic pressure loads is 1/3 of the *smoothed peak overpressure* local to the equipment item. The duration of the load should be chosen to match the impulse of the overpressure trace. This load must also be applied in the reverse direction. In open areas, such as the decks of FPSOs, these loads should also be applied in the vertical plane.

In general equipment items should be located to minimise obstruction of vents and be in-line with the predominant flow direction. Piping runs should be located behind structural elements if near vent areas. Supports and equipment items should be made as resistant to explosion loads as is reasonably practicable.

The low risk methodology appropriate for some medium and all low risk installations, follows that given above except that the simplifications described below may be acceptable.

- The strength level blast (SLB) overpressure is recommended but need not be considered.
- If a valid *nominal overpressure* is available for this installation type then use this as the DLB.
- If a *nominal overpressure* can be accommodated then use this overpressure with the corresponding duration and dynamic pressures for design and assessment.

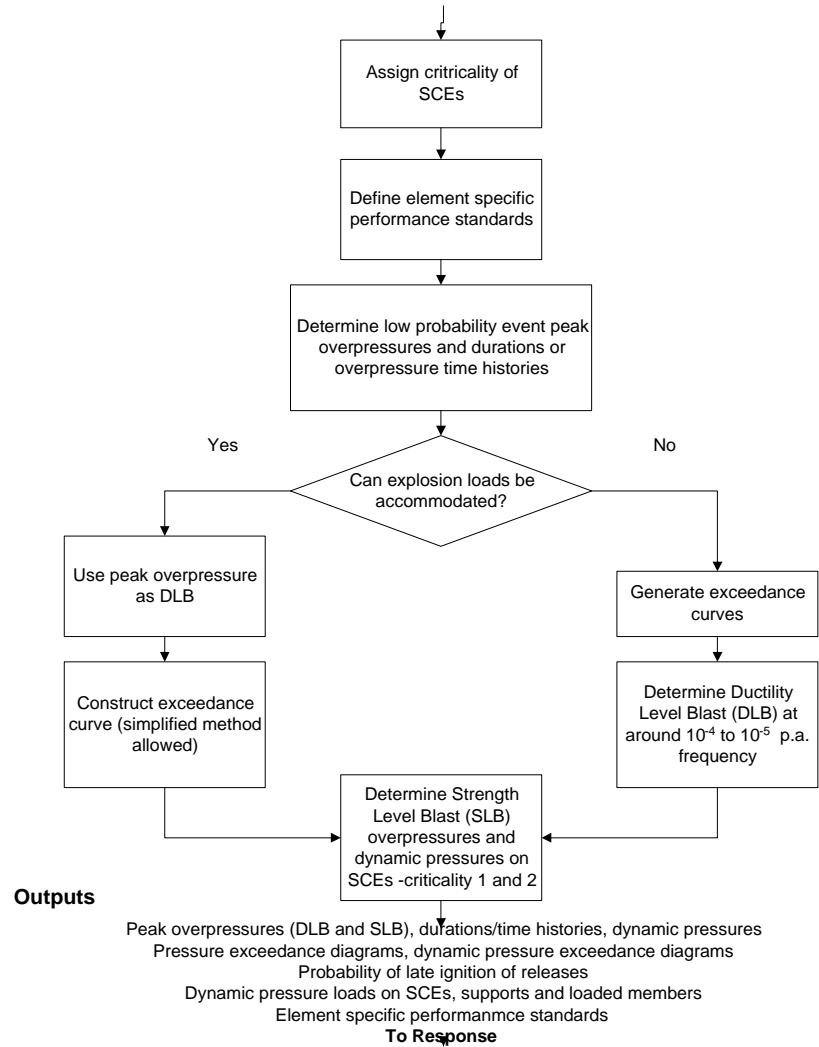
It must be borne in mind that *nominal overpressures* will only be representative values; which do not represent the variability of the overpressure distribution. This variability may be significant both for the structure and for equipment items, this must be established and considered for both overpressure and dynamic pressure loads.

Dynamic pressure loads for the DLB should be generated for criticality level 1 safety critical elements and vulnerable piping run locations.

A comparative assessment method may be used drawing on past experience from a demonstrably similar structure geometry and scenario. The nomination of a typical installation to represent a fleet of demonstrably similar, low risk platforms is acceptable.

**Inputs**

Geometry, large isolatable inventories. Release frequencies, material, rate and location. Shut down systems availability. Layout. Safety management systems Process design, detection control and mitigation measures. Ventilation conditions, wind speed and direction. Dispersion characteristics, ignition positions and types. Barrier capacities (optional), deluge. Fire preceding explosion thermal loading and response.



**Figure 3.5 Explosion load determination**

### 3.5 Response to explosions

Over the last ten years, many structures have been designed to resist uncertain explosion loads by the calculation of the capacity of the structure and the SCEs and the demonstration of *robustness* in the structure as reflected in an insensitivity of response to variations in load. This approach is to an extent scenario independent and may give added protection against unidentified scenarios and in particular combined fire and explosion scenarios.

The 'robustness' approach is still valuable and may be considered in addition to the more rigorous probabilistic methods now available which enable *design explosion loads* to be determined which should be accommodated by the structure and SCEs.

The methodology for the assessment of explosion response is discussed in detail in Chapter 6 of the Commentary and is illustrated in Figure 3.6.

Assessment based on prior exposure is applicable to explosion events, although it is unlikely that this information will be available unless the platforms are nearly identical and an explosion has been experienced on a similar platform which represents the DLB.

#### Load cases for explosion response

It is recommended that the structural assessment should be performed against the strength level blast (SLB) and the ductility level blast (DLB). The structural assessment should include the consideration of the capacities of the structure, including barriers, decks, supporting structures and other safety critical elements (SCEs) at the appropriate level of criticality.

For installations and compartments of medium or high risk, equipment items which are SCEs of criticality level 1 and 2 should be assessed against the SLB. SCEs of criticality 1 should also be assessed against the DLB.

If the general level of overpressure for the DLB is below the *threshold overpressure*  $P_{th}$  then the primary structure may be deemed to be designed by other load cases with no further analysis of this element being required. The threshold overpressure will be defined and determined in Part 3 of the Guidance.

The structural checks for the SLB consist of strength checks for the primary and secondary structure with the requirement of elastic response.

#### Simplified structural assessment methods

The structural checks for the DLB will consist of displacement and integrity checks for the primary and secondary structure taking into account the reserves of strength offered by ductile response and allowable local damage. For *medium and low risk installations*, these checks may be accomplished by the implementation of modified code checks as described in Section 6.10 of the Commentary. This should be followed by a non-linear 'ductility level' dynamic response analysis if the checks show failure to satisfy the relevant performance standards or ALARP cannot be demonstrated.

In all cases, it is imperative that connections and joints are suitably detailed to provide the ductility required to develop their reserves of strength. For barriers such as fire and blast walls, it will be necessary to check the ability of these elements to resist the DLB directly. These elements are often non-load bearing and it is often possible to check them in isolation.

One method of the demonstration of ALARP using a *strength level analysis* is to apply a static pressure load to the structure and observe, through code checks, when member failures occur. If the pressure is then ramped up in stages, there will come a point where the incidence of failures rapidly starts to increase and begins to take in the majority of the members. At this point it may be argued that it would be unreasonable to strengthen or change the member properties as it would impact on members designed by the other load cases. Design to this *equivalent static pressure* could then be said to be ALARP.

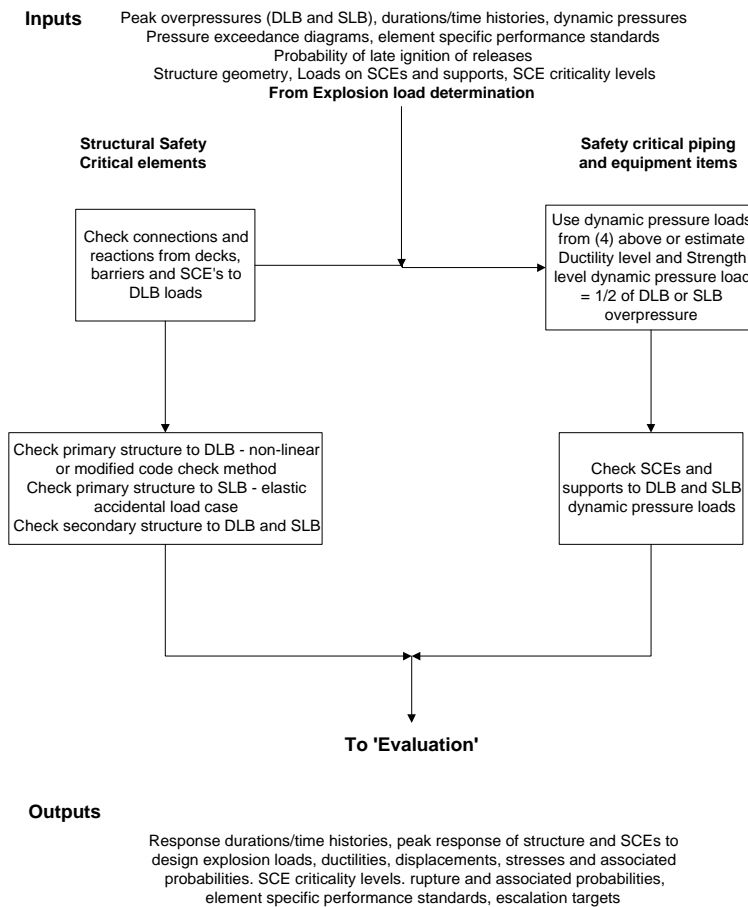
It is, however, unlikely that the differing levels of response to dynamic loads at the same peak level as determined by the natural periods of the target structural elements will be adequately represented without undue conservatism. The variability of pressure in the explosion load cases is also not represented in this method. The

validity of this method will depend on the severity of other load cases which have been used in the original design of the structure.

The transfer of conclusions and load characteristics from the analysis of a geometrically similar installation with similar structural and process characteristics is acceptable. The nomination of a typical installation to represent a fleet of low explosion risk platforms is acceptable. The use of a typical installation will be limited to the identification of general levels of severity of credible explosion events and is unlikely to be suitable for the local design of blast barriers for example.

For low risk installations and compartments, the structural assessment may be performed against the ductility level blast (DLB) only.

The performance of the structure and SCEs for these scenarios must then be tested against the appropriate high level and *equipment specific* (or low level) *performance standards*.



**Figure 3.6 Explosion response**

### 3.6 Evaluation

Upon conclusion of the consequence analysis described in Sections 3.4 and 3.5 above has been performed, the performance of the structure and SCEs should then be tested against the appropriate *low level or element specific performance standards*. The evaluation should be made for each scenario and for all scenarios considered together. This latter process will usually result in risk measures for the individual (Individual Risk IR), for the workforce (Potential of Loss of Life PLL) and for the installation as a whole. This process will involve evaluation against defined lower level, *element specific, performance standards*. These performance standards should be defined for:- all barriers, the (TR), the escapeways, the means of escape, systems for the isolation of large off-site inventories and for tall structures impacted by the explosion scenario under consideration, see Figure 3.7.

An evaluation of the environmental impact of any identified scenarios should be made at this stage.

For each hazard and scenario which has been identified, an evaluation should be made primarily of the possible consequences and risk to personnel then risks to the environment and the asset. It is unlikely that it will be possible to ensure the safety of personnel in the immediate vicinity of an explosion event. It will, however, be necessary to confine the consequences of the event and to assess possible effects of venting of the hot gases, strong shock response and the generation of projectiles.

The overall individual risk and the TR impairment frequency <sup>(41)</sup> from all hazards must be less than  $10^{-3}$  per year. If risks are in this intolerable region then risk reduction measures must be implemented, irrespective of cost. Hence the risk from other hazards may indirectly affect the acceptability of risk from explosions and these may need to be considered in setting the target risk levels for the explosion hazard.

Escalation targets should be identified including those which could give rise to further release of inventory and subsequent fires or explosions.

A risk acceptance matrix may be generated as described in Section 3.7 of the Commentary. This will enable a rational assessment of the level of acceptability of the risk.

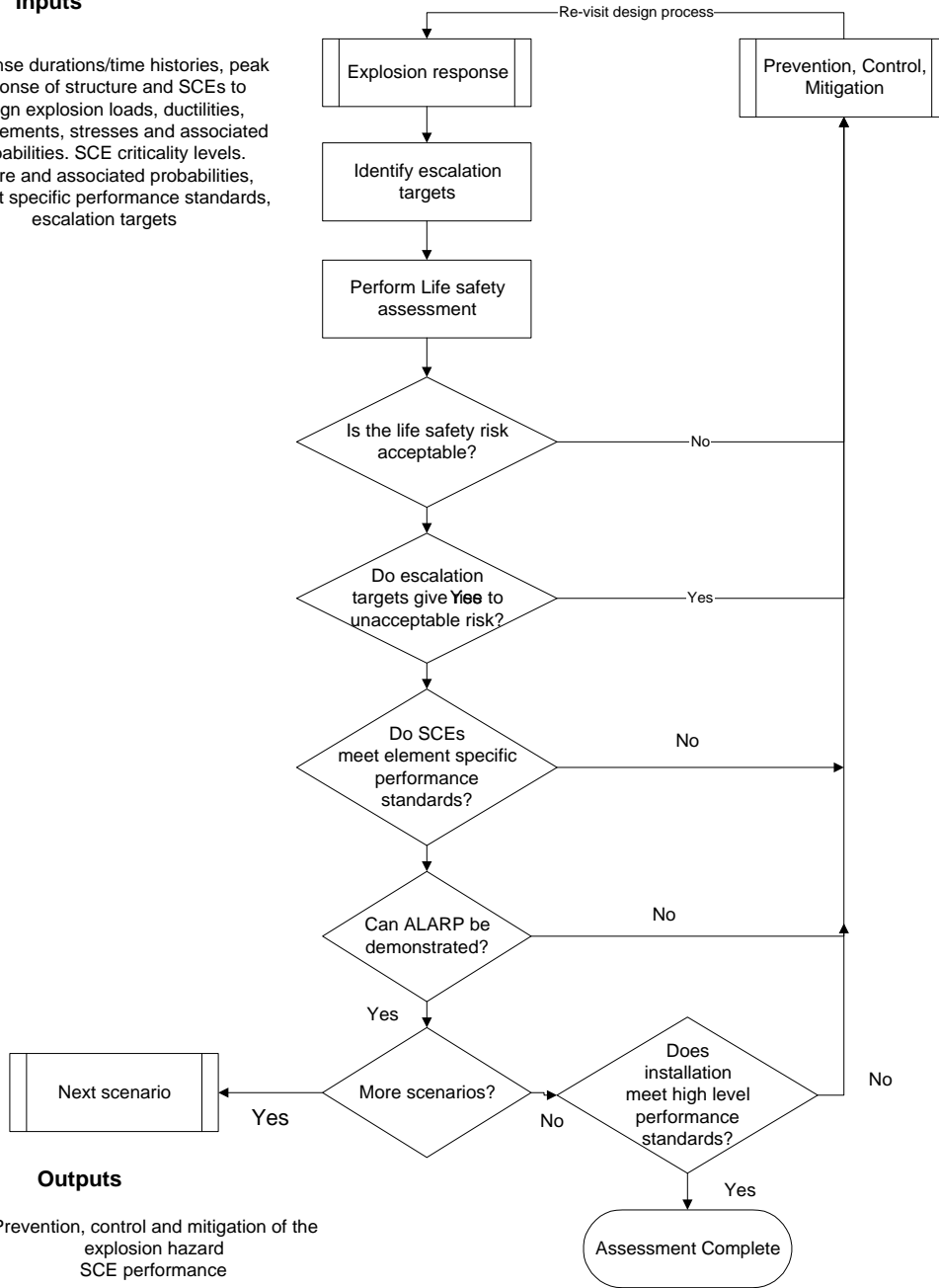
If the installation or any of the SCEs do not meet the performance standards or the level of risk is unacceptable, then a further ALARP iteration may have to be made.

Failure to achieve the performance standards or to demonstrate ALARP for any identified hazard will require modification to the installation or its operating procedures and a reconsideration of possible prevention, control and mitigation measures.

Once the evaluation process indicates acceptable response to a scenario, then the performance of the installation with respect to the remaining scenarios should be assessed.

**Inputs**

Response durations/time histories, peak response of structure and SCEs to design explosion loads, ductilities, displacements, stresses and associated probabilities. SCE criticality levels, rupture and associated probabilities, element specific performance standards, escalation targets



**Outputs**

Prevention, control and mitigation of the explosion hazard  
SCE performance

**Figure 3.7 Evaluation**

#### 4. SPECIAL FEATURES FOR THE ASSESSMENT OF EXISTING INSTALLATIONS

In the UK sector of the North Sea, it is a requirement (SCR)<sup>(29,41)</sup> that significant changes for an installation or its operation will require that the Safety Case is updated which in turn needs a re-assessment including the consideration of explosion hazards. Even if an installation has not been modified or its use has not been changed, a re-assessment is required every three years when the Safety Case is updated (triennial submission). Existing mobile installations entering UK waters also require assessment.

The assessment of existing structures differs from the assessment of a structure during design in three important respects, ie.

1. There is less scope for the reduction of the frequency of a release and scope for mitigation of the severity of an explosion may be limited.
2. Intervention may give rise to an additional hazard which must be assessed.
3. Information may be available relating to expected explosion loads, structural and equipment response from the detailed design or construction stage for the installation.

Information should be available from the previously submitted Safety Cases, approved for construction (AFC) or as-built structural, piping and layout drawings, operational structural integrity support computer models and design or post design analysis reports of the facility.

Use may be made of experience gained from the operation of an un-modified installation and from similar installations. The computer data files and design reports should be checked to confirm that they are a faithful representation of the present state of the facility and that the methods used for explosion loading and response are currently acceptable.

Should modifications be necessary to improve the safety performance of the facility, then the work to be undertaken should not in itself pose such hazards and risk to personnel that this compromises the gains to be achieved by such modifications. All modification work should be accompanied by hazard identification, assessment and other controls as determined by the Safety Management System as well as method statements for their implementation.

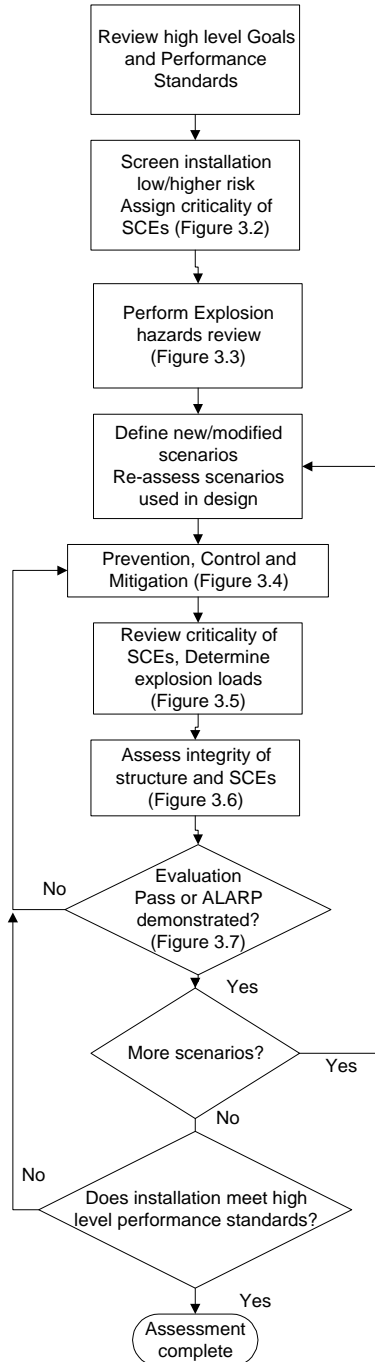
All temporary structures and equipment utilised during the modification work should be removed as soon as practicable after completion of the work.

The HSE reference 26 clauses 51 and 52, states “It should be borne in mind that reducing the risks from an existing plant ALARP may still result in a level of residual risk which is higher than that which would be achieved by reducing risks to ALARP in a similar, new plant. Factors which could lead to this difference include the practicality of retrofitting a measure on an existing plant, the extra cost of retrofitting measures compared to designing them on the new plant, the risks involved in installation of the retrofitted measure (which must be weighed against the benefits it provides after installation) and the projected lifetime of the existing plant.

All this may mean, for example, that it is not reasonably practicable to apply retrospectively to existing plant, what may be demanded by reducing risks (to) ALARP for a new plant (and what may have become good practice for every new plant).”

The overall individual risk and the TR impairment frequency (TRIF) from all hazards must still be less than  $10^{-3}$  per year. If risks are in this intolerable region then risk reduction measures must be implemented, irrespective of cost.

Figure 4.1 illustrates the process of explosion assessment for existing or modified structures. Some of the tasks correspond to those described in Sections 3.1 to 3.6. Reference should be made to these sections for detailed descriptions and background. The following sub-sections focus on the specific aspects relevant to the assessment of existing installations.



**Figure 4.1 Assessment of existing installations**

#### 4.1 Installation Risk Screening

It is recommended that a screening of an installation or compartment is performed giving a low, medium or high risk classification for the facility. This may be achieved by using information gained from previous explosion assessments or by following the methodology described in Section 3.1. This will enable the efficient targeting of resources according to the risk level of the installation and identify the important safety issues at an early stage of the assessment.

The ALARP framework requires *dutyholders* to always seek to reduce risks, and only to argue against implementation of a measure if it is not reasonably practicable. Here the number of options available are likely to be limited. The assessment tools described in this Guidance should be used to assess existing risk, rank different options, and review the reasonable practicability of implementation of any proposed changes.

For existing installations, the *individual risk* (IR) per annum from fire and explosion events will have been used in the demonstration of ALARP in the existing Safety Case for the installation. The total IR will be a good indicator of the appropriate level of sophistication of analysis and whether the installation is in the low, medium or high risk category. Proposed modifications to the facility may result in changes to these IR values.

A low *potential of loss of life* (PLL) for the installation may not be a good indicator for normally unmanned installations and ageing platforms with extended life, because of low occupancy. However, assuming the risks to any group of individuals is acceptable, the effort and cost involved in assessing risks and incorporating risk reduction measures should largely be justified on the basis of the potential for reducing the overall PLL.

It should be borne in mind that the methods considered adequate for hazard mitigation during preparation of a previous Safety Case may no longer be adequate or correct, as a consequence of improved understanding of technical integrity behaviour and loading, or new research.

Details of the existing Safety Critical Elements should be available enabling their classification into categories 1, 2 and 3 as described in Section 2.5. The high level performance standards for the facility should be defined or confirmed at this stage. The general approach should be to bring the SCEs up to the same level of integrity taking into account the criticality or consequences of failure and the difficulty in achieving the level of performance desired.

The number or proportion of existing SCEs vulnerable to explosion loads is also an indicator of the risk category for the installation. The risk associated with TR impairment under direct and indirect explosion loads combined with impairment of means of escape is Key.

The installation risk category (low, medium or high) may be defined as described in Section 3.1.

#### **4.2 Explosion Hazard Review**

For an explosion hazard, the first task to be performed is to review any previous hazard reviews and the impact of any changes or new knowledge. This may involve *design basis checks*, discussed in Section 6.7 of the Commentary and may also involve a survey of the installation.

A review should also consider which elements of the facility may be improved with respect to inherently safer design principles and what additional measures may be taken to improve the detection, control and mitigation of the explosion hazard. Fire hazard events will usually be considered in parallel as some scenarios will fall into either class depending on the ignition time relative to the release.

These checks will be required in UK waters, as an update to the installation Safety Case will be required.

#### **4.3 Scenario Definition**

New scenarios relating to intervention/process change/changes in process operating parameters will need to be identified and considered using the approach similar to that described in Section 3.2. New scenarios could arise during preparation, performance of the modifications these should be identified before design approval is granted. The scenarios considered during design may be materially changed due to consequent changes in layout, confinement and congestion.

#### **4.4 Prevent, Detect, Control, Mitigate**

The most effective way of dealing with a hazard is to eliminate it. If this is not possible, investigations into the means of reduction of the frequency of the initiating events should be considered. Mitigation of the consequences should then be investigated. (see Section 3.3).

#### 4.5 Determination of Explosion Loads

The explosion scenario used in the design of the facility may have been derived as a worst credible event assuming a gas cloud of maximal extent with stoichiometric composition ignited at the worst time in the worst position.

Where the design basis for overpressure determination does not take into account recent developments (post 1997), re-calculation of the DLB and SLB overpressures and dynamic pressures will be necessary using best practice as described in Section 3.4 and Chapter 5 of the Commentary.

ALARP arguments will need to be used to justify new explosion loads and any additionally required mitigation. It is recommended that probabilistic arguments as described in Section 3.4 and Chapter 5 of the Commentary should be used to develop appropriate design loads and a reliability or risk arguments be used to justify design load levels. If these levels are still not able to be accommodated by the structure and other SCEs, then a further ALARP iteration may then have to be made.

#### 4.6 Response to explosions

For high and some medium risk installations, the structural assessment will be performed against the strength level blast (SLB) and the ductility level blast (DLB). The structural assessment will include the consideration of the capacities of the structure, including barriers, decks, supporting structures and other *safety critical elements* at the appropriate level of criticality. SCEs of criticality level 1 and 2 will be assessed against the SLB, and SCEs of criticality 1 will also be assessed against the DLB. For low risk installations, the checks need only be made against the DLB.

One method of the demonstration of ALARP using a *strength level analysis* is to apply a static pressure load to the structure and observe, through code checks, when member failures occur. If the pressure is then ramped up in stages, there will come a point where the incidence of failures rapidly starts to increase and begins to take in the majority of the members. At this point it may be argued that it would be unreasonable to strengthen or change the member properties as it would impact on members designed by the other load cases. Design to this *equivalent static pressure* could then be said to be ALARP.

It is, however, unlikely that the differing levels of response to dynamic loads at the same peak level as determined by the natural periods of the target structural elements will be adequately represented without undue conservatism. The variability of pressure in the explosion load cases is also not represented in this method.

The validity of this method will depend on the severity of other load cases which have been used in the original design of the structure.

The process of response assessment for low and higher risk installations is described in Section 3.5 and illustrated in Figure 3.6.

#### 4.7 Evaluation

For each hazard or scenario which has been identified, an evaluation should be made of the possible consequences and risk to personnel, the environment and the asset.

If the installation or any of the SCEs do not meet the performance standards or the level of risk is unacceptable, the ALARP process as described in Section 2.3 must be continued.

Failure to achieve the performance standards, or to demonstrate ALARP for any identified hazard, will require modification to the installation or its operating procedures and a return to the prevention, control and mitigation activities.

Once the evaluation process indicates acceptable response to a scenario, the performance of the installation with respect to the remaining scenarios should be assessed. (see Section 3.6 and Figure 3.7)

The overall individual risk and the TR impairment frequency <sup>(41)</sup> from all hazards must be less than  $10^{-3}$  per year. If risks are in this intolerable region then risk reduction measures must be implemented, irrespective of cost.

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**APPENDIX A      ACKNOWLEDGEMENTS**

## APPENDIX A      ACKNOWLEDGEMENTS

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Most of the material in this document was taken from the following Basis Documents <sup>(1,2,3,5,6,8,9,10)</sup> written by the MSL Consortium members and material released to the Consortium <sup>(4,7)</sup> by members of the sponsoring organisations:

| <b>Document Title</b>   | <b>Organisation(s)</b>          | <b>Author(s)</b>                                  |
|---|---------------------------------|---|
| Data collection and appraisal   | MSL Engineering Ltd.            | Steve Walker                                      |
| Explosion hazards philosophy  | Genesis Oil and Gas Consultants | Rod Bleach  |
| Management of explosion hazards   | Genesis Oil and Gas Consultants | Rod Bleach  |
| Derivation of explosion loadings – method support dossier   | Century Dynamics Ltd.           | Greg Fairlie                                      |
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| <b>Advisory Panel Member</b> | <b>Organisation</b>  |
|------------------------------|--|
| Doug Angevine                | ExxonMobil   |
| Bassam Burgan                | Steel Construction Institute   |
| Brian Corr                   | BP Sunbury   |
| Per Endresen                 | Norwegian Petroleum Directorate  |
| Rick Grant                   | CBCL Ltd. (Vice chair, Committee K154, CSA Offshore structures standards-Canada) |
| Pat O'Connor                 | BP Houston (API SC2 Task group chairman – new RP on fire and blast)              |
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| Morten Sorum                 | Statoil  |
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| <b>Sponsor representative</b> | <b>Sponsoring organisation</b> |
|-------------------------------|--------------------------------|
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| Malcolm Birkinshaw            | HSE London                     |
| Stephen Connolly              | HSE Bootle                     |
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| Roland Martland               | HSE Bootle                     |
| Alan Richardson               | HSE Bootle                     |
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| Chris Wilson                  | UKOOA/Shell                    |

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| <b>Reviewer</b>                    | <b>Organisation</b>    |
|------------------------------------|------------------------|
| Nick Beesley                       | AMEC                   |
| Geoff Chamberlain/Jonathan Puttock | Shell Global Solutions |
| John Gregory                       | Consultant             |
| Mike Johnson/Phil Cleaver          | Advantica              |
| Henri Tonda                        | TotalFinaElf           |
| David Ward-Gittos                  | Halliburton            |

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**APPENDIX B: GLOSSARY OF TERMS**

## GLOSSARY OF TERMS

**A more comprehensive Glossary is included in the Commentary to include the additional terms used in that document.**

### **Accident**

See '*incident*'

### **Accidental event (AE)**

Event or chain of events that may cause loss of life, or damage to health, the environment or assets

NOTE 1 - The events that are considered in a risk analysis are acute, unwanted and unplanned. For instance; planned operational exposure that may be hazardous to health or to the environment, are usually not included in a risk analysis.

### **Active Mitigation**

Mitigation technique in which the release of suppressant is triggered as a result of flame or gas overpressure detection.

### **ALARP**

As Low As Reasonably Practicable, a concept that forms the primary basis for determining the tolerability of risks and the adequacy of arrangements for managing risks to health and safety. Duty holders (The owner or operator of an existing installation or the designer of a new one) have a responsibility to reduce risk to ALARP .

### **ALARP**

To reduce a risk to a level which is 'as low as reasonably practicable' involves balancing reduction in risk against the time, trouble, difficulty and cost of achieving it. This level represents the point, objectively assessed, at which the time, trouble, difficulty and cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained.

### **Artificial ventilation**

That ventilation which is not supplied from the action of the environmental wind alone

### **As low as reasonably practicable (ALARP)**

ALARP expresses that the risk level is reduced (through a documented and systematic process) so far that no further cost effective measure is identified. The requirement to establish a cost effective solution implies that risk reduction is implemented until the cost of further risk reduction is grossly disproportional to the risk reducing effect.

### **Availability**

The proportion of the total time that a component, equipment, or system is performing in the desired manner.

### **Availability**

The probability of the system being available to perform the function when required.

### **Blast Wall**

A structural division which has been designed expressly for the purpose of resisting blast loads.

### **Blast Wave**

A pressure pulse formed by an explosion.

### **Burning Velocity**

The rate at which the flame consumes the unburnt gas/vapor. Also the velocity of the flame relative to the unburnt gas/vapor.

### **Can**

Verbal form used for statements of possibility and capability, whether material, physical or causal

### **Computational Fluid Dynamics (CFD)**

A mathematical model in which the region of the flow is subdivided by a grid into a large number of control volumes.

### **Confined Explosion**

An explosion of a fuel-oxidant mixture inside a closed system (eg vessel or module).

**Confinement** is defined as a measure the proportion of the boundary of the explosion region which prevents the fuel/air mixture from *venting* or being released to the external atmosphere.

**Congestion** is a measure of the restriction of flow within the explosion region caused by the obstacles within that region.

### **Control**

Means of intervention permitted by the design (eg. pressure relief valves, emergency power supplies) safety hardware (eg. dump tanks, coolant sprays), or the presence of manually or automatically initiated ESD procedures which are intended to contain a developing situation so that escalation and a major accident may be avoided.

### **Cost Benefit Analysis (CBA)**

A quantitative technique to assess the overall value of a proposal taking into account its likely benefits and detriments.

**Deflagration**

The chemical reaction of a substance in which the reaction front advances into the unreacted substance at less than sonic velocity. Where a blast wave is produced which has the potential to cause damage, the term explosive deflagration may be used. (see Detonation)

**Design accidental event**

An accidental event for which SCEs on the installation should perform their function as designed.

**Design basis checks**

Design basis checks consist of checking the basis of the existing design for the installation and determining if the methods used for the design are acceptable in the context of the explosion hazard.

**Design explosion loads**

Explosion loads used for design. SCEs must be designed to resist these load levels within the constraints of the associated element specific performance standards.

**Detonation**

Mechanism for propagation of an explosion reaction through a flammable gas mixture which is more mechanical in nature and acts through shock pressure forces. It is a very rapid process and velocity is always greater than the speed of sound in the mixture (see Deflagration).

**Detonation**

An explosion caused by the extremely rapid chemical reaction of a substance in which the reaction front advances into the unreacted substance at greater than sonic velocity.

**Detonation Limits**

The range of fuel-air ratios through which detonations can propagate.

**Drag Coefficient**

An empirical multiplying constant used to relate the drag load on a structure to the stagnation overpressure.

**Drag force**

The drag load on a small obstacle due to the movement of gas past a small obstacle less than 0.3 m in the direction of flow, form drag – Presented Area x Pdrag

**Ductility level blast (DLB)**

Representative peak overpressure used in design ( $10^{-4}$  to  $10^{-5}$  p.a. frequency level) – Pduct

**Ductility level design event**

See DLB

**Ductility Ratio**

The ratio of the peak deflection to the deflection at first effective yield.

**Ductility ratio  $\mu$** 

The ratio of the maximum displacement of the element to the deflection required to cause first yield at the extreme fibres

**Duty holder**

An operator or owner who prepares a Safety Case pursuant to the SCR regulations <sup>(29)</sup>.

**Dynamic pressure**

Representative peak out of balance loads over target area, includes drag, pressure difference and gas acceleration effects. Used for calculation of loads on equipment and piping – Pdyn, sometimes referred to as dynamic overpressure.

**Element specific performance standard**

Measurable performance standard for specific key items or systems relating to systems' functionality, availability and survivability. (sometimes referred to as low level performance standard)

**Emergency Shutdown System (ESD)**

A safety shutdown system comprising detection, signaling and logical control, valves and actuators, which can, in tandem with alarm and direct control mechanisms, enable the safe and effective shutdown of plant and machinery in a controlled manner.

**Emergency Shutdown Valve (ESDV)**

A valve mounted in a pipeline, pipe or marine riser specifically for the purpose of cutting of the supply of its normal contents in an emergency.

**Equivalent static overpressure**

An overpressure derived from an overpressure trace with respect to a target which gives the same peak deflection when applied as a static load as the original trace.

**Essential safety system**

System which has a major role in the control and mitigation of accidents and in any subsequent EER activities

**Escalation**

Consequences subsequent to an explosion or other major hazard.

**Exceedance curve**

A plot of the value of a variable against the plot of the probability or frequency of exceedance of that variable.

**Expansion Ratio**

The ratio of burnt to unburnt gas volumes of a given mass of gas.

**Explosion**

A release of energy which causes a pressure discontinuity or blast wave. (see gas explosion)

**Explosion risk**

Risk from the initiating event and possible subsequent escalation.

**External explosion**

External or secondary explosions which may result as an unburnt fuel/air mixture comes into contact with the external (oxygen rich) atmosphere as it is vented from a compartment.

**Extreme events**

Events for which design is not reasonably practicable may result in loss of functionality of SCE's

**Fire**

A process of combustion characterized by heat or smoke or flame or any combination of these.

**Fire Ball**

This phenomenon, which may occur as the result of a deflagration of a vapor cloud that does not result in a blast wave. Alternatively, a fire, burning sufficiently rapidly for the burning mass to rise into the air as a cloud or ball.

**Fire Protection System**

An integrated detection, signaling and automated fire control system.

**Flammability Limits**

The range of fuel-air ratios which can support non-detonative combustion such as laminar and turbulent flames.

**Flash Fire**

The combustion of a flammable vapor and air mixture in which the flame passes through the mixture at less than sonic velocity, such that negligible damaging overpressure is generated.

**Forced Ventilation**

Ventilation by mechanical means, e.g. a fan.

**Frequency**

The number of occurrences per unit of time.

**Functionality**

The capacity of a system to perform the function required of it during and after a major accidental event.

**Gas explosion**

Gas explosions can be defined as the combustion of a premixed gas cloud containing fuel and an oxidiser that can result in a rapid rise in pressure

**Hazard**

The potential to cause harm, including ill health or injury; damage to property, plant, products or the environment; production losses or increased liabilities.

**Hazard Analysis**

The identification of undesired events that lead to the realisation of a hazard, the analysis of the mechanisms by which these undesired events could occur and usually the estimation of the extent, magnitude and likelihood of any harmful effects.

**Hazardous Substance**

A substance which by virtue of its chemical properties constitutes a hazard.

**Health, safety and environmental (HSE) management**

Those aspects of the overall management function (including planning) that develop, implement and maintain the HSE policy.

**Health, safety and environmental (HSE) policy**

A public statement of the intentions and principles of action of the company regarding its health, safety and environmental effects, giving rise to its strategic and detailed objectives.

**Health, safety and environmental management system (HSMES)**

The company structure, responsibilities, practices, procedures, processes and management system (HSEMS) resources for implementing health, safety and environmental management.

**High (Higher) risk methodology**

Methodology of assessment appropriate for High risk installations or compartments as defined in this Guidance.

**Hydrocarbon**

A hydrocarbon is a molecule comprised of carbon and hydrocarbon atoms.

**Impulse**

The integral of a force or load over an interval of time.

**Incident**

An event or chain of events which has caused or could have caused injury, illness and/or damage (loss) to assets, the environment or third parties.

*(The word 'accident' is used by some writers and organisations to denote an incident which has caused injury; illness and/or damage, but the term also has connotations of 'bad luck' in common speech, and is therefore avoided by others. In these guidances, only the term 'incident' has been used in the above sense which embraces the concept of 'accident'.)*

**Incident Wave**

The blast wave as it approaches a structure just before it impacts on its surface.

**Individual Risk (IR)**

The frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards.

**Initiating events**

The events which initiates an explosion event.

**Inventory**

The quantity and type of fuel stored. A platform inventory lists the fuel types and total volumes stored on board an installation. The term inventory is also used to describe the quantity and type of fuel stored in vessels and pipe assemblies.

**Laminar Flame**

A smooth surfaced flame with low burning velocity.

**Large Deflection Analysis**

A type of non-linear structural analysis based on the final deflected shape of the structure rather than the initial, undisplaced shape.

**Likelihood**

Term used to represent probability or frequency when a qualitative assessment is being performed.

**Loss Prevention**

The general term used to describe a range of activities carried out to minimize any form of accidental loss, such as damage to people, property or the environment or purely financial loss due to plant outage.

**Lower flammability limit (LFL)**

The lower level of gas concentration which will result in combustion of the gas. This is the same as Lower explosive limit (LEL).

**Low level performance standard**

See element specific performance standard.

**Low risk installation/compartment**

An installation or compartment identified as being low risk by the risk matrix and screening method described in this Guidance.

**Major Hazard**

An imprecise term for a large-scale chemical hazard, especially one that may be released through an acute event. Or, a popular term for an installation that has on its premises a more than a prescribed quantity of a dangerous substance.

**Medium risk installation/compartment**

An installation or compartment identified as being low risk by the risk matrix and screening method described in this Guidance.

**Mitigation**

Means taken to minimise the consequences of a major accident to personnel and the installation after the accident has occurred.

**Monitoring activities**

All inspection, test and monitoring work related to health, safety and environmental management.

**Natural Period**

The time required for a freely vibrating structure to complete one cycle of motion.

**Natural Ventilation**

The ventilation of an enclosure by natural means, either through the action of an external wind or gravitational forces.

**Nominal explosion frequency**

The frequency of occurrence of a release which is ignited and results in detectable overpressure (>50 mb). This is used as the top point in the simplified generation of an exceedance curve - Prexp

**Nominal explosion loads**

Representative nominal overpressures and nominal dynamic pressures on equipment. ranges, outliers and sensitivity measures.

**Nominal overpressures**

Nominal overpressures are defined as peak representative overpressures by installation/module type determined on a non-statistical basis from acquired experience or simulation for a demonstrably similar situation.

**Nominal Value**

Value assigned to a basic variable determined on a non-statistical basis, typically from acquired experience or physical conditions.

**Non-Linear Analysis**

A type of structural analysis that allows the geometry and/or the material properties to be non-linear.

**Overpressure**

The excess pressure above ambient conditions.

**Overpressure**

In a pressure pulse (blast wave), the pressure developed above atmospheric pressure at any stage or location is called the overpressure. Overpressure is also sometimes used to describe exposure of equipment to internal pressure in excess of its design pressure, but the term overpressurisation is preferred.

**Overpressure Loading**

Loading imparted to a body as a result of overpressure acting normal to the surface of the structure.

**Passive Fire Protection (PFP)**

A coating, cladding or free-standing system that provides thermal protection in the event of fire and which requires no manual, mechanical or other means of initiation, replenishment or sustainment.

**Passive Mitigation**

Mitigation technique that is 'non-triggered' and generally utilizes the kinetic energy of an explosion to disperse an extinguishing agent or suppressant.

**Peak Overpressure**

The peak value of an overpressure trace.

**Performance criteria**

Performance criteria describe the measurable standards set by company management to which an activity or system element is to perform.

*(Some companies may refer to performance criteria as 'goals', 'targets' or performance standards)*

**Performance standard**

A statement which can be expressed in qualitative or quantitative terms of the performance required of a system, item of equipment, person or procedure and which is used as the basis for managing the hazard.

NOTE - The term 'performance' is to be interpreted in a wide sense and include availability, reliability, capacity, mobilisation time, functionality, vulnerability, personnel competence, expressed as far as possible in a verifiable manner.

**Phenomenological models**

Simplified physical models, which seek to represent only the essential physics of explosions.

**Plastic Deformation**

That deformation which occurs following yield.

**Plastic Hinge**

A plastic hinge is a zone of yielding due to flexure in a structural member.

**Plastic Regime**

That region of structural behavior dominated by plastic response rather than elastic response. It is associated with plastic strain and large plastic deformations.

**Plastic Strain**

Strain beyond the elastic limit.

**Potential loss of life (PLL)**

The (fractional) no of individuals predicted to become fatalities over a specified period of time – usually one year.

**Practice**

Accepted methods or means of accomplishing stated tasks.

**Pressure difference**

The pressure difference across an obstacle greater than 0.3m in the direction of flow, calculated from the pressure time histories at the front and back of the obstacle. -  $P_{diff}$

**Prevention**

Means intended to prevent the initiation of a sequence of events which could lead to a hazardous outcome of significance (ie major accident). Such means include management systems applied to the design, engineering and construction standards, the operation of the installation, its inspection and maintenance.

**Primary means of escape**

The means of escape which was assumed during design.

**Primary Structure**

The structural components, whose failure would seriously endanger the safety of a significant part of the installation.

**Probability**

A number in a scale from 0 to 1 which expresses the likelihood that one event will succeed another.

**Procedure**

A documented series of steps to be carried out in a logical order for a defined operation or in a given situation.

**QRA**

Quantitative Risk Assessment: the quantitative evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused, together with the value judgements made concerning the significance of the results.

**Redundancy**

The performance of the same function by a number of identical - but independent means.

**Release**

The type and quantity of fuel which can possibly be ignited.

**Reliability**

The probability that an item is able to perform a required function under stated conditions for a stated period of time or for a stated demand.

**Representative peak overpressure**

Time averaged over 1.5ms and space averaged over the explosion affected area. – Prep

**Required endurance time**

The estimated time for people to travel from their work stations to the TR, then to the primary or secondary means of escape, allowing for the possibility of helping injured colleagues.

**Residual events**

Initiating events which cannot be eliminated by design or operating procedures.

**Rise Time**

The time taken for the overpressure to increase from zero to the peak overpressure.

**Risk**

The likelihood of a specified undesired event occurring within a specified period or in specified circumstances. It may be either a frequency (the number of specified events occurring in unit time) or a probability (the probability of a specified event following a prior event), depending on the circumstances.

NOTE - Risk may be expressed qualitatively as well as quantitatively. Probability may be expressed as a probability value (0-1, dimensionless) or as a frequency, with the inverse of time as dimension. The definition implies that risk aversion (i.e. an evaluation of risk which places more importance on certain accidental consequences than on others, where risk acceptance is concerned) should not be included in the quantitative expression of risk. It may be relevant to consider on a qualitative basis certain aspects of risk aversion in relation to assessment of risk and its tolerability. The implication of the definition is

further that perceived risk (i.e. subjectively evaluated risk performed by individuals) should not be included in the expression of risk-

**Risk acceptance criteria (RAC)**

Criteria that are used to express a risk level that is considered tolerable for the activity in question

NOTE - RAC are used in relation to risk analysis and express the level of risk which will be tolerable for the activity, and is the starting point for further risk reduction according to the ALARP-principle. Risk acceptance criteria may be qualitative or quantitative.

**Risk Analysis**

The quantified calculation of probabilities and risks without making any judgements about their relevance.

**Risk analysis**

Use of available information to identify hazards and to estimate the risk

NOTE The term risk analysis term covers several types of analyses that will all assess causes for and consequences of accidental events, with respect to risk to personnel, environment and assets. Examples of the simpler analyses are SJA, FMEA, preliminary hazard analysis, HAZOP, etc.

NOTE 2 - Quantitative analysis may be the most relevant in many cases, involving a quantification of the probability and the consequences of AEs, in a manner which allows comparison with quantitative RAC.

**Risk Assessment**

The quantitative evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused together with the value judgements made concerning the significance of the results.

**Risk Evaluation**

The evaluation of the likelihood of undesired events and the likelihood of harm or damage being caused, together with the value judgements made concerning the significance of the results and their tolerability, including issues of risk perception where appropriate.

**Robustness**

Insensitivity of response to variations of load.

**Safety critical element (SCE)**

Any structure, plant, equipment, system (including computer software) or component part whose failure could cause or contribute substantially to a major accident is safety-critical, as is any which is intended to prevent or limit the effect of a major accident.

**Secondary means of escape**

Means of escape which should be available if the primary means of escape is not available.

**Serviceability Limit**

A design limit beyond which the structure may become unserviceable, for example, a specified maximum deflection.

**Shock Load**

The load imparted to a structure by a passing shock wave.

**Shock Wave**

A pressure pulse formed by an explosion in which a sharp discontinuity in pressure travels as a wave through a gas at a supersonic velocity.

**Should**

Verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required

**Societal Risk**

The relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards.

**Smoothed overpressure**

Overpressure trace which has been smoothed by using a moving average over a period of 1.5 milliseconds (1 millisecond or ms equals one thousandth of a second)

**Space averaged overpressure**

A peak overpressure for a compartment/area or installation which is the average of all measured or simulated peak overpressures within a compartment at all times during the explosion. It is assumed in the case for measured overpressures that they have been *smoothed*.

**Stoichiometric mix**

Air/fuel mixture such that it contains exactly the required amount of oxygen to completely consume the fuel.

**Stoichiometric Mixture**

A mixture of air and fuel such that complete combustion may just occur.

**Strain Hardening (work hardening)**

The tendency of an elastic-plastic material to exhibit increased resistance to high strains.

**Strength level analysis**

An explosion response assessment where the SCEs including structure and supports are required to remain elastic. An elastic method is used for structural response with code/utilization checks as the performance standard.

**Strength level blast (SLB)**

Representative peak overpressure used to test robustness of equipment and structure. Elastic structural analysis is appropriate.

**Survivability**

The ability of a system to function in the conditions of an accidental event for the time required.

**Threshold overpressure**

Peak overpressure below which explosion assessment need not be performed ( $P_{th}$ ).

**Time Domain**

A solution technique for structural dynamics in which results are obtained at regular time intervals when a time variable force or other load is applied.

**Turbulence**

Rapid irregular local fluctuations in physical variables, such as velocity or concentration, that arise due to the presence of eddies within the flow.

**Turbulent Burning Velocity**

The burning velocity of the flame when turbulence is present in the flammable mixture.

**Turbulent Flame**

A flame burning in a turbulent flammable mixture.

**Ultimate overpressure**

Peak representative overpressure resulting from a CFD simulation where it is assumed that the area is engulfed in a stoichiometric gas cloud and ignited at the worst position and time. – Pult

**Uncertainty**

Doubt or lack of knowledge

**Unconfined Vapor Cloud Explosion**

Defined as for vapour cloud explosion and is an imprecise term.

**Unity Checks**

A summation of non-dimensional terms in an equation in structural design, each of which relate to a component of loading or structural response. A summation greater than unity may indicate failure of the member.

**Upper flammability limit (UFL)**

The fuel concentration above which combustion will not occur. Same as upper explosive limit (UEL).

**Vapor Cloud Explosion (VCE)**

The preferred term for an explosion in the open air of a cloud made up of a mixture of a flammable vapor or gas with air.

**Vapour Cloud Explosion (VCE)**

The preferred term for an explosion of a cloud made up of a mixture of a flammable vapour or gas with air in open or semi-confined conditions.

**Vent**

An opening through which gas escapes from a confining enclosure as a result of the expansion caused by combustion.

**Ventilation**

The process by which an enclosure is supplied with fresh air. Ventilation rates are often given for an enclosure in units of air volume changes per hour.

**Venting**

The escape of gas through openings (vents) in the confining enclosure.

**Verification**

Examination to confirm that an activity, product or service is in accordance with specified requirements.

**Volume Production**

The overall rate of increase in volume caused by the combustion process.

**Water Deluge System**

A network of small bore pipe work nozzles connected to the firewater main which is capable of delivering the design water spray to the protected area.

**Wellbay**

The area of the topsides structure which accommodates the wellheads.

**Withstand**

The ability to function as required by the element specific performance standards during and after the influence of an accidental load.

**Yield Point**

The stress at which a steel sample departs from linear elastic behavior to plastic deformation in a standard tensile test.

**Yield, Dynamic**

The apparent yield stress exhibited by metals such as steel when they are strained at a rate which is significantly faster than the normal testing rate.

**Yield, Effective**

For materials which exhibit no clear yield point – such as mild steels at elevated temperatures, the stress corresponding to a particular plastic strain, often 0.2% (Proof Stress).