Hazard Installations Directorate
Offshore Division

Fire, Explosion and Risk Assessment Topic Guidance

Issue 1

Revision sheet

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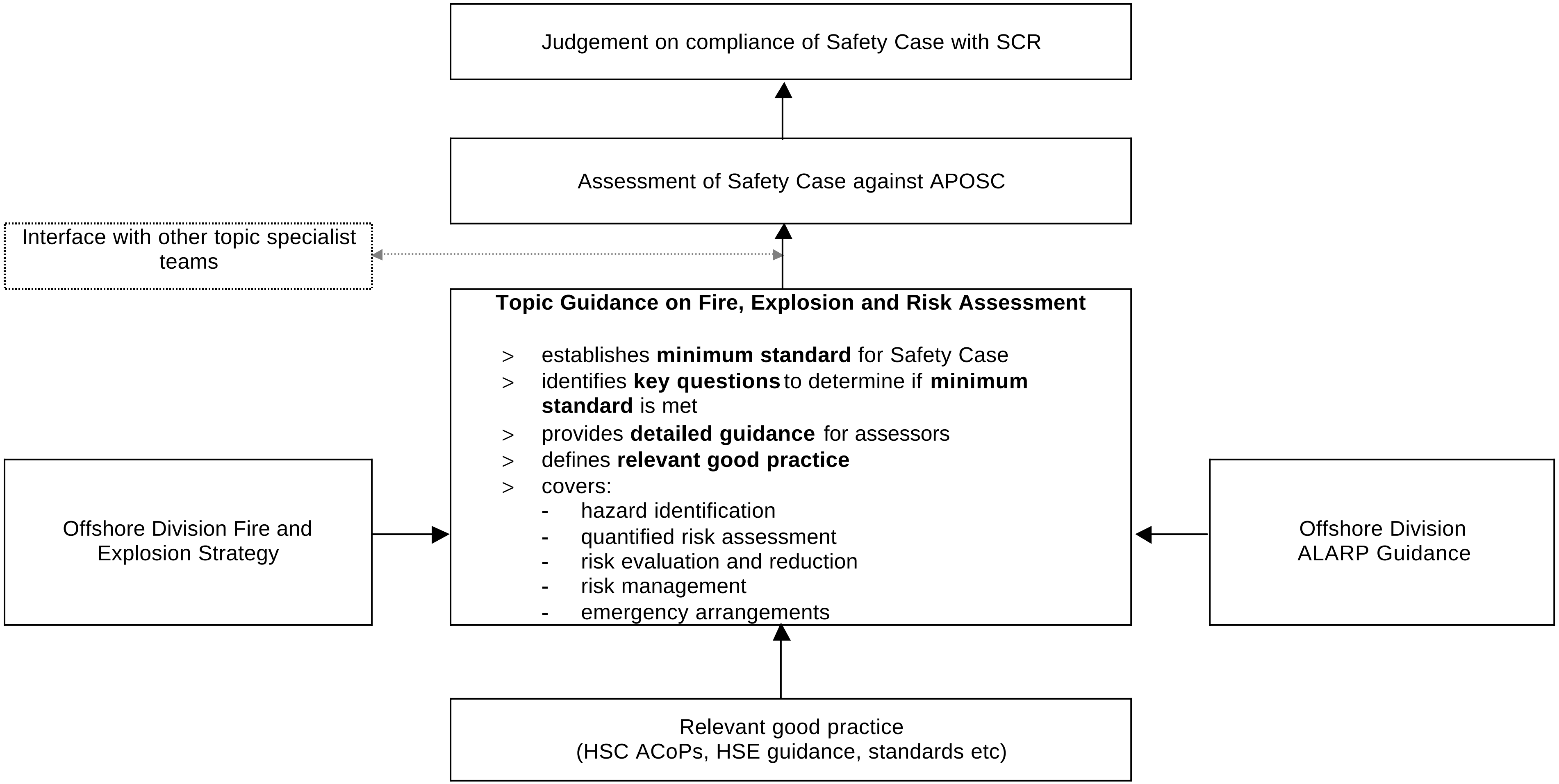
Overview of Topic Guidance



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1 Introduction

This document provides guidance for assessors of Safety Cases on the topic of fire, explosion and risk assessment. It serves as a supporting reference to the *Safety Case Handling and Assessment Manual* (SCHAM).

The overall objective of this guidance is to promote greater consistency and effectiveness in the assessment of Safety Cases, and provide greater transparency for duty holders. It provides the rational basis upon which to reach decisions as regards the acceptability of Safety Cases.

Specifically, this document:

- expands on existing guidance, ie *Assessment Principles for Offshore Safety Cases* (APOSC) (HSE, 1998a);
- incorporates the requirements of the *Guidance on ALARP for Offshore Inspectors - Making an ALARP Demonstration* (SPC 38); and
- defines relevant good practice[1], in accordance with HSE's framework document on *Assessing Compliance with the Law in Individual Cases and the Use of Good Practice*.

It is emphasised that this document provides *guidance* only, not a prescriptive assessment format. This recognises that the goal-setting regulatory regime for the offshore industry, ie *Offshore Installations (Safety Case) Regulations, 1992* (SCR), is now well established and considerable assessment experience and expertise has been built up. This document is therefore intended as a useful checklist for experienced assessors, whilst at the same time providing an essential introduction for new assessors.

Section 2 provides an overview of the Topic Guidance, whilst *Sections 3-7* contain the detailed guidance sub-divided according to the grouping of principles in APOSC. *Section 8* lists the key supporting references.

This document contains no new requirements for duty holders as regards the content of Safety Cases or the criteria by which the acceptability of a Safety Case is judged.

[1] The generic term for those standards for controlling risk which have been judged and recognised by HSE as satisfying the law when applied to a particular relevant case in an appropriate manner.

2 Overview of Topic Guidance

2.1 General

The principles by which HSE evaluates Safety Cases are set down in APOSC, which in turn complement the interpretative guidance contained in *A guide to the Offshore Installations (Safety Case) Regulations 1992* (HSE, 1998b). As well as the principles of Safety Case assessment, APOSC contains guidance on the information and demonstrations which duty holders must provide to comply with the principles.

This document expands on APOSC, providing more detailed guidance on aspects relevant to fire, explosion and risk assessment, and setting out the minimum standard which should be achieved to comply with the assessment principles. It draws on industry's own guidance in this area, principally the *Guidelines for Fire and Explosion Hazard Management* (GFEHM) (UKOOA, 1995), and incorporates the requirements of Offshore Division's ALARP Guidance (SPC 38), which in turn draws on 'R2P2' (HSE, 2001) and the ALARP 'trilogy' (see Section 8).

This document provides an up-to-date link to the primary standards, codes of practice and design guidance pertinent to the assessment and control of fire and explosion hazards on offshore installations. Specifically, it defines good practice relevant to the offshore industry, as required by the framework document on *Assessing Compliance with the Law in Individual Cases and the Use of Good Practice*. This guidance also draws on Offshore Division's *Fire and Explosion Strategy*.

The interrelationship between the Topic Guidance and other relevant guidance is shown in *Figure 2.1*.

2.2 Scope and Format of Guidance

The scope and format of this guidance are drawn from the 'Control of major hazards' section of APOSC, covering the following aspects:

- hazard identification;
- quantified risk assessment (QRA);
- risk evaluation (ie evaluation of the acceptability of the risk) and risk reduction;
- risk management (concerning the measures in place to eliminate, prevent, detect, control and mitigate major fire and explosion hazards, and their associated performance standards); and
- emergency arrangements.

Figure 2.2 illustrates the scope of the Topic Guidance, showing the link to APOSC and SCR, and the interface with other topic specialist teams. The interface with other topic specialist teams is defined in further detail in *Appendix A*.

Sections 3-7 of this guidance cover each of the above aspects in further detail. Specifically:

- they establish the **minimum standard** which must be met for a Safety Case to be considered acceptable. This draws on the existing provisions of the SCR guidance and APOSC.

- they identify the **key questions** for the assessor to consider in determining whether the minimum standard has been met. This draws on:
  - SCR guidance;
  - APOSC;
  - PFEER ACoP (HSE, 1997);
  - UKOOA GFEHM; and
  - Offshore Division ALARP Guidance (SPC 38).

- they provide **detailed guidance** for assessors, define **relevant good practice** and make reference to other useful standards and guidance.

Particular aspects of APOSC which are expanded on in this document are:

- *QRA*: this document breaks down the QRA into its component parts (selection of representative events, frequency estimation etc) to provide further guidance on what constitutes a 'suitable and sufficient' QRA, in accordance with the requirements of SCR Schedules 1-3; and
- *Risk evaluation and reduction*: this document incorporates the requirements of SPC 38.

The focus of this guidance is on SCR Reg 4(1) design Safety Cases for fixed installations, Reg 5 Safety Cases for mobile installations, and Reg 9(2) and 9(4) revisions. Safety Cases for combined operations and abandonment are not explicitly covered.

2.3 How to Use this Guidance

This guidance has been developed to support (not replace) the professional judgement exercised by Offshore Division inspectors in the assessment of Safety Cases. Although it identifies the key questions for assessors to consider, it is ultimately for assessors themselves to decide, based on the merits of each Safety Case, which issues to raise with the duty holder.

The criteria for non-acceptance of a Safety Case are set down in SCHAM. Those of particular relevance to fire explosion and risk assessment include:

- factual information required by the regulations is not contained in the Safety Case;
- the relevant assessment principles from APOSC are not all addressed in the Safety Case;
- there are inadequacies in the potential major accident hazard identification and risk assessment process which are likely to render the basis for risk management decisions invalid; and
- further risk reduction measures are reasonably practicable.

The minimum standard set out in this guidance reflects these criteria by drawing directly on the relevant provisions of SCR and APOSC. Therefore assessment against the minimum standard set down here provides the basis for acceptance (or otherwise) of the Safety Case.

Figure 2.1 Interrelationship between Topic Guidance and other Guidance and Regulations

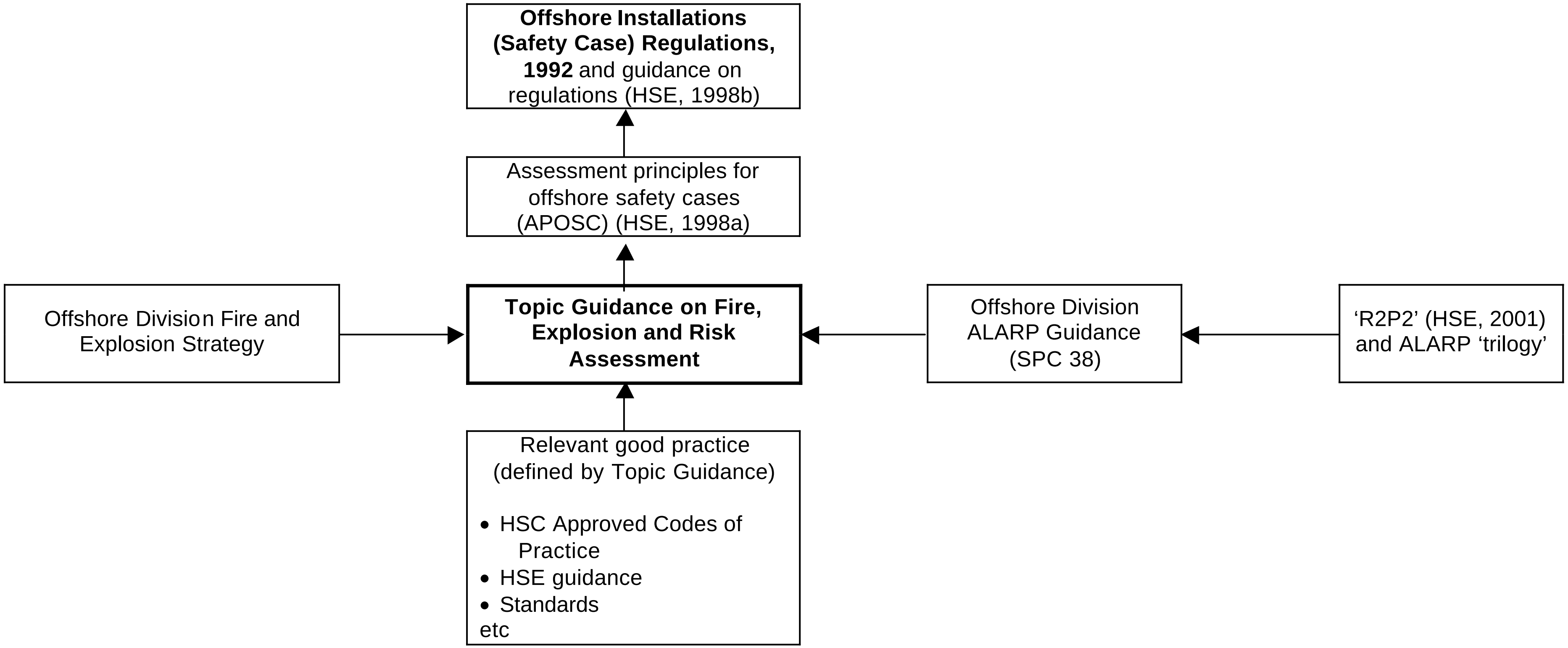


Figure 2.2 Scope of Topic Guidance for Fire, Explosion and Risk Assessment

Interface with other topic specialist teams (Appendix A)	Aspects covered:		APOSC Ref (Para No.s)	SCR Ref
Human factors Mechanical integrity Pipelines Process integrity Well operations	**Hazard identification**	• use of a systematic process for hazard identification • application of appropriate hazard identification methods • identification of combinations or sequences of events leading to a major accident • consideration of the various existing (and potential future) activities on an installation as potential initiators of a major accident	38-48	Reg 8(1)(c)
Mechanical integrity Process integrity Structural integrity (interface with escalation analysis)	**Quantified risk assessment**	• approach to application of QRA • suitability and sufficiency of QRA - selection of representative set of events - event frequency estimation - hazard assessment - consequence assessment - escalation analysis - risk assessment	75-77	Sch 1 – 3
Control systems Human factors Mechanical integrity Pipelines Process integrity Structural integrity Well operations	**Risk evaluation and reduction**	• approach to risk evaluation • criteria for elimination of less significant risks • consideration of reasonable practicability • consideration of relevant good practice and application of sound engineering judgement • consideration of people exposed to exceptional risks • consideration of uncertainty • identification and implementation of risk reduction measures	49-68 78-89	Reg 8(1)(d)
(as above)	**Risk management**	• description of measures to manage major accident hazards • application of principles of inherent safety • strategy for prevention of major accident hazards • provision of appropriate detection measures • provision of appropriate control and mitigation measures • PFEER summary	90-105 117-119	Sch 1 – 3 Reg 8(1A)
EER	**Emergency arrangements**	• consideration of anticipated conditions during an emergency • sufficiency of protection of TR • demonstration that frequency of TR impairment is below 10^{3} per year and ALARP • performance standards and endurance times for access to TR	106-112 122-129 135-137	Sch 1 – 3

3 Hazard Identification

3.1 Background

Hazard identification is a crucial step in QRA, as hazards which have not been identified will not subsequently be assessed and mitigated. SCR requires that a duty holder *'include in the safety case sufficient particulars to demonstrate that … all hazards with the potential to cause a major accident have been identified'* [Reg 8(1)(c)]. APOSC sets out four principles by which the adequacy of the hazard identification may be judged and these are reproduced below as the minimum standard which should be achieved.

3.2 Minimum Standard

It should be clear that a systematic process has been used to identify all reasonably foreseeable major accident hazards specific to the installation (*APOSC Para 38*)

The hazard identification methods applied should be appropriate to the magnitude of the hazards involved(*APOSC Para 41*)

A systematic process should have been used to identify where a combination or sequence of events could lead to a major accident (*APOSC Para 43*)

The sequence of particular activities and their relationship (in time) with other foreseeable future activities in relation to the installation should be considered as potential major accident hazard initiating events (*APOSC Para 46*)

3.3 Key Questions

The key questions which the assessor may wish to consider in determining whether the Safety Case complies with the minimum standard are as follows:

3.3.1 Methodology for hazard identification

- *Has the appropriateness of the methodology for undertaking the hazard identification process been explained ? (APOSC Para 39)*
- *Has an evaluation been made of the effects of failure of prevention, detection, control and mitigation measures ? (APOSC Para 45)*
- *Has a thorough, structured, systematic and auditable approach been adopted ? (APOSC Para 42 and UKOOA GFEHM Sec 4.3.1)*
- *Has a team of suitable composition been employed ? (UKOOA GFEHM Sec 4.3.1)*

3.3.2 Scope of hazard identification

- *Have all intended significant operations and activities associated with the installation been considered ? (APOSC Para 42 and UKOOA GFEHM Sec 4.1 and 4.3.1)*

- *Have all reasonably foreseeable causes (initiating events) been considered ? (APOSC Para 44 and UKOOA GFEHM Sec 4.1)*

- *For fixed installations, have the anticipated well workover and well servicing operations and their relationship (in time) to other activities on the installation and any connected activities been considered ? (APOSC Para 47)*

- *Have all foreseeable fires and explosions been addressed ? (UKOOA GFEHM Sec 4.3.1)*

3.3.3 Output of hazard identification

- *Is there a clear link between the hazard identification, the evaluation of risks and the description of the measures taken and arrangements made to manage risks to ALARP ? (APOSC Para 48)*

- *Has the hazard identification process been fully documented ? (UKOOA GFEHM Sec 4.3.1)*

3.4 Detailed Guidance for Assessors

A hazard identification technique appropriate to the complexity of the installation, the stage of the installation in its lifecycle and the scale and nature of the hazards on the installation should be employed, eg

- Hazard and operability study (HAZOP);
- Failure Modes and Effects Analysis (FMEA);
- Safety reviews;
- Industry standard or bespoke checklists;
- Job safety analysis; and
- Human error identification methods.

Safety reviews undertaken as part of SCR 9(4) Safety Case submissions should take account of such factors as:

- plant or process modifications (including the cumulative effect thereof);
- changes in reservoir conditions;
- incidents and near misses; and
- new knowledge.

The hazard identification exercise should be based on suitable reference information, eg

- Process Flow Diagrams (PFDs);
- Piping and Instrumentation Diagrams (P&IDs);
- Layout plans;
- Equipment lists;
- Process data sheets; and
- Operating and maintenance philosophy.

Appropriate consideration should be given to the various hazardous inventories on an installation, eg:

- process oil/gas/condensate;
- process additives (eg methanol);
- fuels (eg diesel, aviation fuel) and lubricants;
- bottled gas;
- explosives and detonators;

- Chemicals; and
- ordinary combustibles.

Appropriate consideration should be given to the potential for release of the downhole annulus gas inventory for gas-lifted wells.

The various potential causes (or initiating events) of fire and explosion events should be identified, eg

- Internal causes
  - incorrect equipment or material specification;
  - defective material or equipment;
  - pressure outside design limits;
  - temperature outside design limits;
  - vibration;
  - corrosion;
  - erosion;
  - human error;
  - external loading; and
  - impact.
- External causes
  - helicopter crash;
  - ship collision; and
  - extreme weather.

The hazard identification team leader should be independent of the project under study.

3.5 Relevant Good Practice

3.5.1 HSC/E publications

- SCR Guidance (Reg 8, Para 103)
- APOSC (Paras 38-48)
- PFEER ACoP (Reg 5, Paras 41-59)

3.5.2 Other relevant good practice

ISO/DIS 17776 Petroleum and natural gas industries – offshore production installations – guidelines on tools and techniques for identification and assessment of hazardous events (ISO, 1999). This standard advises on the tools and techniques which may be used for hazard identification and risk assessment. It covers all types of risk on offshore production installations, including fire and explosion risks. The standard covers hazard and risk assessment concepts, methods for hazard identification and risk assessment, and risk management (including risk reduction). The annexes to ISO 17776 provide more detail on individual hazard identification and risk assessment techniques, including job hazard analysis, fault tree analysis, event tree analysis, HAZOP studies, FMEA, physical effects modelling, QRA, cost-benefit analysis and safety integrity level (SIL) assessment.

UKOOA Guidelines for Fire and Explosion Hazard Management, UKOOA (1995). The UKOOA GFEHM provide a framework for life-cycle management of fire and explosion hazards on an installation. The management process set down in the guidelines covers various activities from hazard identification, through hazard assessment, to specification of remedial measures, their implementation and verification. Section 4 of these guidelines cover the identification and assessment of fire and explosion hazardous events. This includes hazard identification, selection of events for analysis, initiating event frequency analysis, characterisation of fire and explosion hazardous events, consequence analysis, escalation analysis and risk assessment. The guidance covers the broad objectives and approach applicable to each stage of the analysis but does not cover the details of the assessment methodology. The guidance covers both new design and assessment of existing installations.

3.6 Other Standards and Guidance

API 14J, Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities (API, 1993b). Section 7 of this document covers hazard analysis, which is defined as the systematic procedure for identifying, evaluating and controlling potential hazards in a facility. The standard gives an overview of the application of hazard analysis and then describes the various hazard analysis methods, focusing on hazard identification techniques, ie 'checklist', 'What If ?' analysis, HAZOP studies, FMEA and fault tree analysis.

CMPT Guide to Quantitative Risk Assessment for Offshore Installations (CMPT, 1999). This guide provides a comprehensive introduction to QRA for the offshore industry, covering all types of major hazard. It includes a selection of data and simple analytical techniques that may be used in performing QRAs, with reference to more sophisticated databases and computational techniques. Sections 6 and 7 of the guide are the main sections covering hazard identification (including failure case selection). This covers the various techniques for hazard identification (eg reviews, checklists, HAZOP studies etc), followed by the selection of failure cases (or initiating events) and accidents scenarios (the various possible outcomes of the initiating event).

IADC North West European HSE Case Guidelines for MODUs (IADC, 2002). These guidelines were developed primarily to support IADC members in preparing HSE cases that would enable MODUs to move between different sectors of the North Sea without necessitating revision of the HSE case. They cover HSE management, the MODU description, hazard identification and risk assessment, emergency response and the justification for continuous operation. Parts 4.1 and 4.2 cover hazard identification and risk assessment, including the hazard identification process, interrelationship between different hazards, qualitative and quantitative risk assessment techniques and explosion analysis. Attachments list the major hazards associated with MODUs, give a proforma for a 'compartment study' and detail good practice in QRA.

4 Quantified Risk Assessment

4.1 Background

SCR requires '*a demonstration, by reference to the results of a suitable and sufficient quantitative risk assessment, that the measures taken or to be taken … will reduce risks to the health and safety of persons to the lowest level that is reasonably practicable*' (Schedules 1-3). PFEER specifically requires that a duty holder perform (and record) an assessment of major accidents involving fire or explosion, including '*an evaluation of the likelihood and consequences of such events*' [Reg 5(2)(b)]. Both sets of regulations refer to the UKOOA GFEHM, which contain further details on various aspects of the assessment of fire and explosion hazardous events (Section 4 of the Guidelines).

The assessment of fire and explosion risks is the essential first step in the effective management of such risks throughout the life-cycle of an installation. It informs the selection of risk reduction measures and the establishment of appropriate performance standards for those measures. The assessment is an on-going process to ensure that, as changes to an installation occur, fire and explosion risks are maintained ALARP.

4.2 Minimum Standard

The approach adopted for the application of QRA to major accident hazard risk evaluation should be clear *(APOSC Para 75)*

The QRA should be suitable and sufficient *(SCR Sch 1-3)*

4.3 Key Questions

The key questions which the assessor may wish to consider in determining whether the Safety Case complies with the minimum standard are as follows:

4.3.1 General

- *Has the approach to the application of QRA been summarised ? (APOSC Para 77)*
- *Is the chosen assessment technique appropriate to the assessment being made ? (SCR Guidance Para 165)*
- *Is the scope, quality and rigour of the QRA commensurate with the level of risk on the installation ? (SCR Guidance Para 165)*

4.3.2 Scope of QRA

- *Has a representative selection of events been analysed, ie encompassing the range of foreseeable hazardous events ? (UKOOA GFEHM Sec 4.1)*
- *Does the QRA identify the factors which influence the way an event may occur and develop, and which will affect the ability of any of the measures put in place to deal with the hazard ? (PFEER ACoP Para 52)*

- *Does the QRA identify the causes, characteristics, likelihood and consequences of fire and explosion hazards ? (PFEER ACoP Para 55)*

4.4 Detailed Guidance for Assessors

4.4.1 Selection of representative set of events

The events selected should be a representative and sufficient set for the purposes of risk assessment.

The basis for selection of the representative set of events should be explained. This should include consideration of such factors as:

Initial release:

- leak size
- leak duration
- composition of hydrocarbon
- phase (gas/liquid/two-phase)
- leak location
- leak orientation
- cause of release
- process conditions
- ESD/blowdown operates or fails
- installation operating regime

Event outcome:

- ignition characteristics (timing/location)
- wind direction and speed
- ventilation conditions
- protective systems (eg deluge) operate or fail
- installation POB
- personnel distribution

The selection of the representative set of events should have regard to the nature of releases which have occurred on North Sea installations (see *Offshore Hydrocarbon Release Statistics*, published annually on HSE web site), including any installation-specific data.

The basis for selection of representative hole sizes or release rates should be explained and should be appropriate to the characteristics of the installation.

Any criteria used for eliminating possible fire and explosion events from further consideration in the QRA should be justified.

4.4.2 Event frequency estimation

Hydrocarbon leak frequencies (or other base event data) used should be justified in the context of the installation-specific circumstances.

The methods used to derive event frequencies (eg parts count, fault tree analysis, event tree analysis, human error analysis) should be described and should be fit for purpose and used correctly.

Equipment failure rate data used should be appropriate to the type, standard/design, use and operating conditions of the equipment.

The use of any generic failure rates or probabilities should be justified by reference to an analysis of the sensitivity of the conclusions of the QRA to such data.

Estimates of, or assumptions made about, the availability, reliability and response time of protective systems (including any human components thereof) should be realistic and adequately justified.

Estimates of, or assumptions made about, the probability of ignition and detection of a hydrocarbon release should be realistic and adequately justified.

Appropriate consideration should be given to common cause or common mode failures.

Regarding the use of exceedance curves for estimating the probability of exceedance of a given level of explosion overpressure:
- the basis for the derivation of such curves should be explained;
- the means of accounting for uncertainty in the exceedance curves should be explained;
- the derivation of the curves should be statistically sound.

4.4.3 Hazard assessment

Source terms

The models, data and assumptions used to characterise the source of a hydrocarbon leak should be described.

The source term models should be fit for purpose and used correctly.

Users of source term models should be aware of the limits of applicability and validation of the models and any use outside these limits should be justified.

The uncertainties associated with representation of the source term should be recognised and the sensitivity of the conclusions of the QRA to these uncertainties should be considered.

Dispersion

The models, data and assumptions used to estimate the dispersion of a hydrocarbon leak should be described.

The dispersion models should be fit for purpose and used correctly.

Users of dispersion models should be aware of the limits of applicability and validation of the models and any use outside these limits should be justified.

Justification should be provided for the use of any models which pre-date the current version of the model and for the on-going validity of results generated by previous versions of the model.

Advanced models (eg CFD) should only be used by suitably competent persons and the results should be subject to appropriate checks by another competent person.

The uncertainties associated with modelling the dispersion of hydrocarbon leaks should be recognised and the sensitivity of the conclusions of the QRA to these uncertainties should be considered.

The dispersion analysis should consider a suitable range of wind/ventilation conditions, in particular low wind conditions in naturally-ventilated offshore modules

Assurance should be provided of the validity of the of the air flow pattern used as the basis for the dispersion modelling in relation to actual conditions within/around the module/structure of interest.

Consideration should be given to the potential for gas/vapour to migrate from one area of an installation to another, eg via drains, HVAC systems, process connections etc

Fire hazard assessment

The models, data and assumptions used to quantify fire hazards should be described.

The fire models should be fit for purpose and used correctly.

Users of fire models should be aware of the limits of applicability and validation of the models and any use outside these limits should be justified.

Justification should be provided for the use of any models which pre-date the current version of the model and for the on-going validity of results generated by previous versions of the model.

Advanced models (eg CFD) should only be used by suitably competent persons and the results should be subject to appropriate checks by another competent person.

The uncertainties associated with fire modelling should be recognised and the sensitivity of the conclusions of the QRA to these uncertainties should be considered.

Appropriate consideration should be given to the range of types of fire which could occur on offshore installations, ie

- jet fires;
- pool fires;
- running liquid fires;
- flash fires;
- fireballs;
- well blowout fires;
- gas 'pool' fires;
- confined and unconfined fires;
- fuel and ventilation-controlled fires;
- fires on the open deck, within a module or on the sea surface; and
- fires involving ordinary combustibles as well as those involving hydrocarbons.

Adequate consideration should be given to the effects of confinement on fires, in particular the increased lateral (or vertical) spread of flames, which may create additional hazards to personnel, equipment and structures

A suitable assessment should be made of the generation and dispersion of smoke in fire for the purpose of assessing the effect of smoke at key locations on the installation.

Consideration should be given to the potential for ventilation-controlled fires to occur and the particular hazards of such fires, eg increased concentrations of carbon monoxide, potential for large external flames or release of unburned hydrocarbon vapour.

Explosion hazard assessment

The models, data and assumptions used to estimate explosion overpressures should be described.

The explosion models should be fit for purpose and used correctly.

Users of explosion models should be aware of the limits of applicability and validation of the models and any use outside these limits should be justified.

Justification should be provided for the use of any models which pre-date the current version of the model and for the on-going validity of results generated by previous versions of the model.

Advanced models (eg CFD) should only be used by suitably competent persons and the results should be subject to appropriate checks by another competent person.

The uncertainties associated with explosion modelling should be recognised and the sensitivity of the conclusions of the QRA to these uncertainties should be considered.

Appropriate consideration should be given to the range of types of explosion which could occur on offshore installations, ie

- explosions in unconfined, congested areas (eg on the deck of an FPSO);
- explosions in confined areas (eg within a room or module);
- explosions within equipment or structures (eg an explosion within a flare header);
- external explosions (eg following a confined, vented explosion);
- physical explosions (eg catastrophic failure of a pressure vessel);
- mist explosions; and
- Boiling Liquid Expanding Vapour Explosions (BLEVE).

The explosion modelling should consider a suitable range of potential ignition locations/times having regard to the distribution of actual ignition sources within the affected area and the worst case ignition location/time.

The explosion modelling should include an accurate and sufficiently detailed representation of the geometry within the area of interest.

Clear justification should be provided for the assessing explosion hazards for one module or installation on the basis of its ‘similarity’ with another module or installation for which detailed results have been generated.

Consideration should be given to the effects of blast from possible external explosions, including any channelling effects which may act to enhance the blast overpressure.

4.4.4 Consequence assessment

Fire consequence assessment

Appropriate consideration should be given to the effects of fire on people, equipment and structures.

Appropriate consideration should be given to the various mechanisms by which fire can harm people, eg:

- heat (eg thermal radiation, inhalation of hot gases);
- obscuration of vision;
- oxygen depletion; and
- inhalation of toxic gases.

The criteria used for harm to people and damage to equipment and structures due to fire should be appropriate and correctly used.

The criteria used for impairment of safety functions (eg TR, evacuation and escape routes) due to fire should be appropriate.

Appropriate consideration should be given to the various modes by which smoke from a fire may enter the TR. This should consider both the TR as it is intended to function and various degraded states. As well as the TR, consideration should be given to other key locations on the installation, eg evacuation and escape routes, outside muster points, control rooms etc

The assessment should consider the harm which might arise from fire throughout the duration of the incident and the associated response of people on the installation, eg initial harm, and harm during mustering, evacuation and escape.

Explosion consequence assessment

Appropriate consideration should be given to the effects of explosions on people, equipment and structures.

Appropriate consideration should be given to the various mechanisms by which explosions can harm to people, eg:

- primary effects of overpressure (eg lung or ear damage);
- secondary effects of overpressure (eg collapsing structures);
- tertiary effects of overpressure (eg whole body translation);
- impact from missiles projected by the explosion; and
- heat.

The criteria used for harm to people and damage to equipment and structures due to explosion should be appropriate and correctly used.

The criteria used for impairment of safety functions (eg TR, evacuation and escape routes) due to explosion should be appropriate.

The output of the explosion modelling should be suitable for the purpose of assessing the response of equipment and structures to blast, ie:

- overpressure (peak/average), duration, rise time and impulse;
- local values of the above variables at a point of interest; and
- information to be able to assess drag loadings.

as appropriate.

The assessment should consider the harm which might arise from explosion throughout the duration of the incident and the associated response of people on the installation, eg initial harm, and harm during mustering, evacuation and escape.

Appropriate consideration should be given to the combined effects of fire and explosion.

Toxic gas consequence assessment

An assessment of the effects of exposure to toxic gases (eg hydrogen sulphide) should be performed where this constitutes a major accident hazard.

Appropriate criteria for harm to people and impairment of safety functions should be used.

4.4.5 Escalation analysis

A systematic, structured approach to escalation analysis should be adopted to determine if and how an event can escalate to endanger personnel.
The escalation analysis should comprise:

- identification of the mechanisms by which an initial event could escalate to impinge on key systems or facilities (eg TR, evacuation and escape facilities);
- evaluation of the effects on installation safety systems and how this may affect subsequent escalation; and
- evaluation of the probability of each escalation path and the time duration from the initial event.

Appropriate consideration should be given to the actions of key personnel in responding to an incident, taking into account the effects of smoke, heat and the scale of the incident.

4.5 Relevant Good Practice

4.5.1 HSC/E publications

- SCR Guidance Reg 8, Paras 103 and Sch 1, Para 165
- APOSC Paras 75-77
- PFEER ACoP Reg 5, Paras 41-59

4.5.2 Other relevant good practice

UKOOA Guidelines for Fire and Explosion Hazard Management, UKOOA (1995). The scope of these guidelines is described in Section 3.5.2 above.

Interim Guidance Notes for the Design and Protection of Topside Structures against Fire and Explosion (SCI, 1992). The scope of these guidance notes is detailed in Section 6.5.2 below. In the context of QRA, they provide introductory information on fire and explosion hazards, detail the effects of fire and explosion on personnel and provide methods for the assessment of fire and explosion loads on structures and the associated response of such structures.

ISO/DIS 17776, Petroleum and natural gas industries – offshore production installations – guidelines on tools and techniques for identification and assessment of hazardous events (ISO, 1999). The scope of this standard is described in Section 3.5.2 above.

4.6 Other Standards and Guidance

CMPT Guide to Quantitative Risk Assessment for Offshore Installations (CMPT, 1999). The scope of this guide is outlined in Section 3.6 above. Sections 8-23 of the guide (supported by Annexes IV - XVI) are the main sections concerning QRA. They cover frequency estimation, consequence modelling, assessments for specific hazards (blowout, riser/pipeline leaks and process leaks) and presentation of the risk results. Detailed in the guide are simple assessment tools for different types of hydrocarbon event (dispersion, fire, explosion etc), impact criteria (for personnel and structures) and data sources for assessment of event frequencies and outcome probabilities.

NORSOK Standard Z-013, Risk and Emergency Preparedness Analysis (NORSOK, 2001b). The purpose of this standard is to establish requirements for the effective planning, execution and use of risk and emergency preparedness analysis (EPA). The standard covers: establishment and use of risk acceptance criteria; planning, execution and use of risk and EPA; specific requirements relating to QRA; and risk and EPA throughout the installation lifecycle. Annexes to the standard cover various topics, including accident cause and consequence analysis, databases and computer software, cost-benefit analysis, scenario-based design and probabilistic explosion simulation.

IADC North West European HSE Case Guidelines for MODUs (IADC, 2002). The scope of these Guidelines is outlined in Section 3.6 above.

5 Risk Evaluation and Reduction

5.1 Background

This section concerns evaluation of the acceptability of risks, and identification and implementation of risk reduction measures. SCR requires that a duty holder *'include in the safety case sufficient particulars to demonstrate that … risks have been evaluated and measures have been, or will be, taken to reduce the risks to persons affected by those hazards to the lowest level that is reasonably practicable'* [Reg 8(1)(d)].

APOSC sets out various principles concerning risk evaluation and reduction and these are reproduced below as the minimum standard which should be achieved. This section also draws on Offshore Division's ALARP guidance (SPC 38).

5.2 Minimum Standard

The approach adopted for major accident hazard risk evaluation should be clear (*APOSC Para 49*)

Any criteria for eliminating less significant risks from detailed consideration in the major accident hazard risk evaluation should be explained (*APOSC Para 51*)

A systematic identification of possible major accident hazard risk reduction measures should have been undertaken (*APOSC Para 83*)

The reasoning for or against the choice of particular risk reduction measures to be implemented should be clear. Decisions on the implementation of identified risk reduction measures should have taken reasonable practicability into account (*APOSC Para 85*)

In deciding what is reasonably practicable, the case should show how relevant good practice and judgement based on sound engineering principles have been taken into account (*APOSC Para 53*)

Additional preventive or protective measures are not reasonably practicable when it can be shown that there would be a gross disproportion between their cost (in money, time or trouble) and the reduction in risk they would achieve (*APOSC Para 56*)

The Safety Case should demonstrate that conclusions reached using QRA have taken uncertainty into account (*APOSC Para 78*)

Where remedial measures are proposed to reduce the level of risk, the intended timescale for implementing such measures should take into account the extent of such risks and any practical issues involved in implementing the measures (*APOSC Para 88*)

The assessment should take account of people exposed to exceptional risks (*APOSC Para 66*)

5.3 Key Questions

The key questions which the assessor may wish to consider in assessing whether the Safety Case complies with the minimum standard are as follows:

5.3.1 Overall approach

- *Does the Safety Case summarise the duty holder's approach to risk evaluation, including the methods and criteria used to demonstrate that risks from major accident hazards have been reduced to ALARP ? (APOSC Para 50)*

- *Does the ALARP demonstration contain elements of the following process:*
  - *identification and consideration of a range of potential measures for further risk reduction;*
  - *systematic analysis of each of the identified measures and a view formed on the safety benefit associated with each of them;*
  - *evaluation of the reasonable practicability of the identified measures;*
  - *the implementation (or planned implementation) of the reasonably practicable measures; and*
  - *recording of the process ?*

  (Offshore Division ALARP Guidance)

5.3.2 Identification of risk reduction measures

- *Does the duty holder keep risks and risk reduction measures under review to take account of changing circumstances, advances in technology, new knowledge and information ? (APOSC Para 84)*

- *Does the Safety Case challenge the adequacy of existing measures and consider any additional identified practicable measures ? (APOSC Para 84)*

- *Has a balanced and integrated approach to the choice of risk reduction measures been adopted (ie risk reduction measures not viewed in isolation from one another) ? (APOSC Para 86)*

5.3.3 Use of quantitative risk criteria

- *Has the duty holder followed common practice in setting the maximum tolerable level of individual risk of fatality at 10^{-3} per year and the broadly acceptable level of individual risk in the range 10^{-5} – 10^{-6} per year ? (APOSC Para 64)*

- *For risks in the broadly acceptable region, is vigilance maintained to ensure that risks remain broadly acceptable ? (APOSC Para 60)*

- *In the intermediate risk region, are risks known, controlled and ALARP ? (APOSC Para 61)*

- *For risks close to, or above, the tolerable level, has due account been taken of the potentially large benefits to be gained by taking additional risk reduction measures ? (APOSC Paras 62 and 63)*

5.3.4 Consideration of relevant good practice

- *Does the duty holder have in place suitable controls to address all significant hazards and do these controls, as a minimum, implement authoritative good practice (or achieve similar standards of prevention/protection), irrespective of the specific risk estimates ? (Offshore Division ALARP Guidance and R2P2)*

- *Where relevant good practice is not clearly established (or may not adequately safeguard against the risks under consideration) has the significance of the risks been systematically assessed to determine what actions need to be taken ? (APOSC Para 54)*

- *In considering what measures are to be introduced, has account been taken of foreseeable harsh conditions, unusual operating schedules and novel designs of wells or equipment ? (APOSC Para 55)*

5.3.5 Consideration of uncertainty

- *Have conclusions reached solely on the basis of the QRA results taken into account the uncertainties associated with these results ? (APOSC Para 79)*

- *Have QRA arguments to justify not implementing identified risk reduction measures taken due account of engineering judgement and relevant good practice ? (APOSC Para 82)*

5.3.6 Implementation of risk reduction measures

- *Are remedial work programmes risk-based ? (APOSC Para 89)*

- *What consideration has been given to the implementation of temporary measures (eg additional management controls or restrictions on operations) to reduce risk until remedial measures are in place ? (APOSC Para 89)*

5.3.7 Consideration of people exposed to exceptional risks

- *Has attention been paid to any critical groups of people who may be exposed to risks higher than the average for the installation as a whole ? (APOSC Para 67)*

- *Has attention been paid to risks which appear low solely by virtue of low occupancy of the affected areas (eg a normally unattended installation) ? (APOSC Para 68)*

5.4 Detailed Guidance for Assessors

5.4.1 Overall approach

To assist in the ALARP decision-making process, duty holders may refer to useful guidelines developed by UKOOA (UKOOA, 1999a). These guidelines provide a framework for risk-related decision support to assist duty holders in striking the right balance between codes and standards, good practice, risk-based analysis, company values and societal values. A summary of the guidelines is provided in Section 5.5 below.

Duty holders for Mobile Offshore Drilling Units (MODUs) may also refer to the International Association of Drilling Contractors (IADC) North West European HSE Case Guidelines for MODUs (IADC, 2002). These guidelines set out the process for demonstrating that risks are

ALARP and the information which should be included in the Safety Case. Section 5.6 below contains a summary of the IADC HSE Case Guidelines.

5.4.2 Identification of risk reduction measures

In identifying candidate risk reduction measures, consideration should be given to a range of measures involving inherently safer design, prevention, detection, control and mitigation.

The risk reduction measures considered may range from items of equipment and physical systems through to operational procedures, managerial structures and planning.

Risk reduction measures which have been implemented on installations for which 9(4) Safety Cases were submitted during 2001 are listed in Table 5.1 below.

Table 5.1 Examples of Risk Reduction Measures Implemented on Existing Installations (2001)

Type of measure	Description
Prevention (ie reduction of likelihood)	*Leak prevention* • Removal or strengthening of small bore pipework connections • Isolation of disused wells at production header as well as Xmas tree and venting of flowlines back to tree • Decommissioning of redundant equipment • Improvements to systems of work • Implementation of competence management and assurance system • Improvements to PTW system • Improvements in integrity assurance *Ventilation* • Removal of wind walls • Enhancement of HVAC in process modules *Ignition control* • Monitoring of gas turbine exhaust system temperature
Detection (ie transmission of information to control point)	*Gas detection* • Installation of ultrasonic leak detectors • Installation of additional IR beam detectors *Fire detection* • Installation of additional fire detectors
Control (ie limitation of scale, intensity and duration)	*Emergency shutdown (ESD) systems* • Installation of high integrity check valve on gas re-injection header *Blowdown and flare systems* • Installation of additional blowdown valves *Explosion control* • Initiation of water deluge on detection of gas • Removal of redundant equipment
Mitigation (ie protection from effects)	*Active fire protection* • Replacement of deluge system piping *Passive fire protection* • Uprating of fire walls *Blast protection* • Uprating of blast walls *Temporary Refuge* • Re-location of Main Control Room to TR • Re-definition of TR • Enhancement of mustering facilities • Protection of external staircase • Provision of airlock doors • Provision of dedicated HVAC system for TR

	Evacuation and escape • Installation of additional emergency lighting on escape route • Provision and maintenance of proper training in the use of evacuation and escape facilities • Provision of alternative escape routes *Fire-fighting equipment* • Installation of new foam monitors *Manning* • Reduction of POB

5.4.3 Demonstration that risks are ALARP

For risks lying below the maximum tolerable, but above the broadly acceptable level, it is expected that:

- the nature and level of risks are properly assessed and the results used properly to determine control measures;
- the residual risks are not unduly high and kept ALARP; and
- the risks are periodically reviewed to ensure that they still meet the ALARP criteria.

Duty holders should not assume that if risks are below the maximum tolerable level, they are also ALARP. This should be demonstrated through:

- application of relevant good practice and sound engineering judgement; and
- consideration of what further measures can be adopted to reduce risks ALARP.

In essence, the duty holder's ALARP demonstration should address the question "What more could I do to reduce risks, and why haven't I done it ?"

The degree of rigour of the ALARP demonstration should be proportionate to the level of risk associated with the installation.

In choosing between design options, duty holders should:

- consider risks throughout the whole life-cycle of the project;
- choose the option which achieves the lowest level of residual risk, provided grossly disproportionate risks are not incurred; and
- confirm that the residual level of risk is no greater than that achieved by the best of existing practice for comparable functions.

5.4.4 Consideration of group risk

Duty holders may find it helpful to consider group risk in their demonstration that risks are ALARP. This allows consideration to be given to events which, although low in frequency, may cause multiple injuries or fatalities. Group risk can presented in the form of either potential loss of life (PLL), ie the number of statistical fatalities per year, or a plot of cumulative frequency versus number of fatalities (FN curve). If individual risk has been calculated, the PLL may be estimated from:

PLL = Average IRPA x POB/(fraction of time an individual spends offshore)

An advantage of the above approach is that consideration can be given to risk aversion, ie the aversion society has to large consequence accidents (see Section 5.4.5 below). Duty holders should justify any criteria they adopt for group risk.

5.4.5 Cost-benefit analysis

Duty holders may find it helpful to apply cost-benefit analysis (CBA) in deciding whether a risk reduction measure is reasonably practicable. CBA is a numerical assessment of the cost of implementing a design change or modification and the likely reduction in fatalities that this would be expected to give. CBA should be applied cautiously in support of (not as a replacement for) sound engineering judgement.

Duty holders should justify any figures they use for the 'value of preventing a fatality' (VPF). A suitable factor for 'gross disproportion' should be included taking into account the overall level of risk associated with the installation, the potential for multiple fatalities and uncertainty in the analysis.

Duty holders should make an appropriate assessment of the 'sacrifice' (ie money, time and trouble) of implementing a particular risk reduction measure. This should take full advantage of the opportunity to reduce shutdown costs (ie by implementing the risk reduction measure during planned shutdown) and exclude consideration of the ability to pay.

5.4.6 Consideration of uncertainty

Uncertainties in the QRA should be recognised and addressed. There should be a bias towards health and safety if the conclusions drawn from the QRA are to be credible. Where the uncertainties are large, a suitably cautionary approach should be taken, eg by adopting inherently safer designs.

In considering uncertainty, duty holders may refer to guidelines developed by UKOOA (UKOOA, 1999b). These guidelines seek to promote awareness of the sources of uncertainty in QRA, the means of addressing these uncertainties, and the key benefits and limitations of undertaking an analysis of uncertainty. A summary of the UKOOA guidelines on uncertainty is given in Section 5.6 below.

5.5 Relevant Good Practice

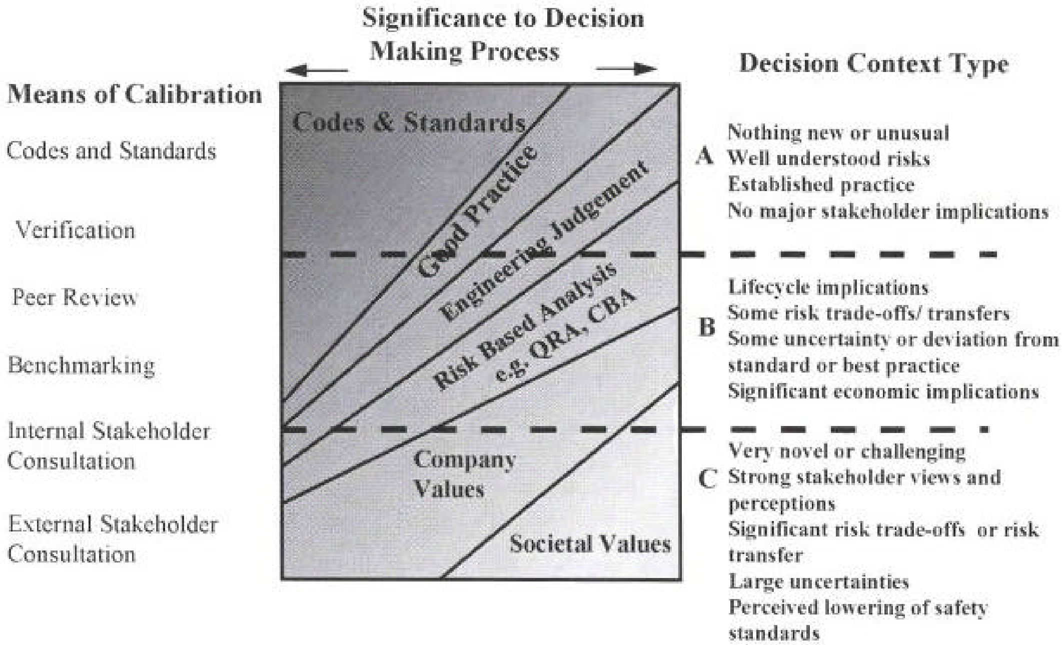
5.5.1 HSC/E publications

- SCR Guidance Reg 8, Paras 103-7
- APOSC Paras 49-68 and 78-89

5.5.2 Other relevant good practice

UKOOA Framework for Risk-Related Decision Support (UKOOA, 1999a). These guidelines were developed in recognition of the need to make risk-related decision making more open, transparent, soundly-based and appropriate for the context. The framework provides a structured and integrated approach that enables the various business, technical and social factors to be considered and used to establish a sound basis for decision-making. The framework is reproduced below.

A decision support framework for major accident hazard safety



In many common engineering situations ('Type A' decision context), what is reasonably practicable may be determined simply by reference to the relevant code or current practice. In other cases ('Type B' decision context) the use of risk assessment and cost-benefit analysis may be appropriate. Where new or potentially controversial activities are proposed, or where there are large risk implications or uncertainties ('Type C' decision context), then it may also be appropriate to consider more carefully the views and perceptions of all the stakeholders, such as the workforce, investors, regulatory bodies and the likely public or media response.

Complex design decisions, such as those associated with fixed offshore installations in the UKCS, will often fall into the Type B context. By contrast many design decisions relating to MODUs fall into the Type A context.

5.6 Other Standards and Guidance

CMPT Guide to Quantitative Risk Assessment for Offshore Installations (CMPT, 1999). The scope of this guide is outlined in Section 3.6 above. Sections 24-26 of this guide cover uncertainties in QRA, risk criteria and risk reduction measures. In Section 24, the guide lists sources of uncertainty, the means by which these can be quantified and the uses of sensitivity analysis. In Section 25, approaches to risk evaluation are described and criteria for individual and group risk are listed. Cost-benefit analysis techniques are also documented. In Section 26 the approach to the identification and evaluation of risk reduction measures is described and various risk reduction alternatives listed under the categories of concept selection, fire and blast protection, evacuation and collision.

IADC North West European HSE Case Guidelines for MODUs (IADC, 2002). The scope of these guidelines is outlined in Section 3.6 above. Section 4.2.6 of these guidelines (Risk Reduction and ALARP Justification) sets out the process of demonstrating that risks are ALARP and the information which should be included in the Safety Case. This accords with the principles contained in APOSC in requiring a systematic identification and assessment of risk reduction measures, including consideration of relevant good practice and application of sound engineering judgement. Specific guidance is provided on 'tolerability' and 'ALARP' and the distinction between these concepts.

UKOOA Guidelines on Quantitative Risk Assessment Uncertainty (UKOOA, 1999b). In these guidelines, uncertainty in QRA is categorised into three types:

- Type 1: parameter uncertainties;
- Type 2: model uncertainties; and
- Type 3: issues of overall adequacy/quality.

The guidelines note that (as of 1999) only limited analysis of uncertainty had been carried out in QRA studies of offshore installations, mostly of Type 1 uncertainties. The approach suggested in the guidelines is to undertake a conservative assessment of risk together with a limited sensitivity analysis of key parameters. This will provide an initial appraisal of the robustness of the QRA results. If this approach is unsuccessful, then a more rigorous assessment of uncertainty may be required, for which the guidelines describe various approaches. The guidelines note that uncertainty analysis itself is subject to uncertainties and therefore that a balance must be struck between the efforts to ensure a suitable and sufficient QRA, any uncertainty analysis on the QRA and the overall requirements of the decision-making process.

6 Risk Management

6.1 Background

This section concerns the information provided in the safety case on the measures which have been taken to eliminate, prevent, detect, control and mitigate fire and explosion hazards. Schedules 1-3 of SCR require inclusion in the Safety Case of:

Particulars of the plant and arrangements for –

(a) the detection of the presence of toxic or flammable gas
(b) the detection, prevention and mitigation of fires

A description of the arrangements made or to be made for protecting persons on the installation from hazards of explosion, fire, heat smoke, toxic gas and fumes during any period while they may need to remain on the installation following an incident which is beyond immediate control …'

Schedules 1-3 of SCR also require a demonstration that the above measures will reduce risks ALARP. PFEER requires the selection of appropriate measures as part of the assessment of major accidents involving fire or explosion (Reg 5). It also specifically requires a duty holder to take measures to prevent, detect, control and mitigate fire and explosion (Regs 9, 10, 12 and 13).

APOSC (Paras 90-105) contains various principles on the topic of risk management and these are produced below as the minimum standard which should be achieved. Also covered here is the requirement of SCR [Reg 8(1)A] to include a summary of the PFEER assessment in the Safety Case.

6.2 Minimum Standard

Measures taken to manage major accident hazards should be described (*APOSC Para 91*)

The Safety Case should explain the approach to the application of the principle of inherently safer design to new field or installation design, or to plant on an existing installation undergoing modification (*APOSC Para 96*)

The strategy for the prevention of major accident hazards should be explained (*APOSC Para 98*)

Appropriate detection measures should be provided for any reasonably foreseeable event which would require an emergency response (*APOSC Para 101*)

Appropriate control and mitigation measures should be in place for the protection of everyone from the consequences of a major accident (*APOSC Para 104*)

The PFEER Summary should include sufficient information on the results of the assessment to show that there are appropriate measures and adequate arrangements to secure effective emergency response (*APOSC Para 117*)

6.3 Key Questions

The key questions which the assessor may wish to consider in determining whether the Safety Case complies with the minimum standard are as follows:

6.3.1 Description of measures to manage major accident hazards

- *Has a hierarchical approach to managing major accident hazards been taken, including:*
  - *elimination and minimisation of hazards by design (inherently safer design);*
  - *prevention (reduction of likelihood);*
  - *detection (transmission of information to control point);*
  - *control (limitation of scale, intensity and duration); and*
  - *mitigation of consequences (protection from effects) ? (APOSC Para 92)*

- *Has the highest priority been given to inherently safer design and measures to prevent and control major accident hazards ? (APOSC Para 93)*

- *In the design process:*
  - *is due consideration given to inherent safety ?*
  - *are fire and explosion risks addressed ?*
  - *are such risks reduced ALARP through sound engineering design (primarily) and management controls ? (APOSC Para 94)*

- *For existing installations, does the Safety Case address the scope for improving inherent safety and the measures to prevent and control major hazards ? (APOSC Para 95)* (See Section 5.4.2 for examples of prevention and control measures which have been implemented on existing installations)

6.3.2 Inherent safety

- *Has the hazard management strategy been developed at a suitably early stage in the design process, in order to maximise the opportunity to incorporate inherent safety ? (APOSC Para 97)*

- *Have fire and explosion hazards been designed-out, where practicable ? (PFEER ACoP Para 93)*

6.3.3 Preventive measures

Prevention concerns the measures in place to:

- prevent the uncontrolled release of a flammable substance;
- prevent the hazardous accumulation of the release; and
- prevent ignition of the release,

in accordance with the definition in the PFEER ACoP (Reg 9) and UKOOA GFEHM (Section 5.3).

- *Are the preventive measures adopted appropriate to the current stage of the installation's life cycle ? (APOSC Para 99)*

- *Are the arrangements for managing the hazards associated with simultaneous operations described ? (APOSC Para 100)*

- *Are appropriate measures in place to*
  - *prevent the uncontrolled release of a flammable substance;*

- *prevent the hazardous accumulation of the release; and*
- *prevent ignition of the release ?*

(UKOOA GFEHM Section 5.3)

- *Are the preventive measures derived from the identification and assessment of major accident hazards ? (PFEER ACoP Para 92)*

- *Do the preventive measures achieve sufficient levels of reliability and availability to meet the demands placed upon them ? (PFEER ACoP Para 94)*

- *Are adequate procedures and equipment in place for control of:*
  - *hot work;*
  - *use of non-Ex rated electrical equipment;*
  - *maintenance activities;*
  - *modifications;*
  - *start-up and shutdown of plant and equipment; and*
  - *storage, handling and use of flammable substances ?*

  (PFEER ACoP Para 96)

6.3.4 Detection measures

Detection measures are the measures in place to identify hazardous conditions on the installation and transmit this information to the point at which control action is instigated.

- *Is detection provided for reasonably foreseeable events requiring emergency response, including:*
  - *potentially hazardous accumulations of flammables, uncontrolled hydrocarbon releases, hydrocarbon fires and fires from other sources; and*
  - *smoke, toxic gas or fumes entering the TR and accommodation area ?*

  (APOSC Para 103)

- *Are the detection measures derived from the identification and assessment of major accident hazards ? (PFEER ACoP Para 102)*

- *Do the detection measures achieve sufficient levels of reliability and availability to meet the demands placed upon them ? (PFEER ACoP Para 103)*

- *Is the detection equipment appropriately located, taking account of the type of incident, how it may develop and the capacity of the equipment to respond and to relay the right information for effective control action to take place ? (PFEER ACoP Para 103)*

- *Are the detection measures automatic, where reasonably practicable ? If not, are adequate alternative arrangements in place ? (PFEER ACoP Para 103)*

- *Do the detection measures ensure the timely detection of flammable and explosive atmospheres, and toxic gas where appropriate, at locations where their presence presents a risk to people, eg*
  - *accommodation and work areas;*
  - *control points;*
  - *enclosed or partially enclosed escape routes; and*
  - *evacuation and escape points ?*

  (PFEER ACoP Para 104)

- *Has the duty holder established effective contingency arrangements for circumstances when all or part of the detection system is unavailable ? Do the detection systems remain operational in an emergency to the extent necessary ? (PFEER ACoP Para 105)*

- *Does the selection of the detection systems take into account the conditions and characteristics of the hazardous event and the environmental and operating conditions in the area ? (UKOOA GFEHM Section 7.1)*

- *Do the detection systems have adequate coverage, response time and sensitivity ? (UKOOA GFEHM Section 7.1)*

6.3.5 Control measures

Control measures are the measures in place to limit the scale, intensity and duration of hazardous events on the installation, eg emergency shutdown systems, blowdown and flare systems, bunding and drainage, and explosion control systems.

- *Are the control measures derived from the identification and assessment of major hazards ? (PFEER ACoP Para 123)*

- *Is control equipment of fail-safe design, as far as is reasonably practicable ? (PFEER ACoP Para 124)*

- *Is plant used to limit the spread of fire, where appropriate, operable from a remote location ? (PFEER ACoP Para 125)*

- *Are suitably-staffed control points provided which can be used safely, so far as is reasonably practicable, for the period necessary to control the emergency ? For normally unattended installations have appropriate emergency control arrangements been made ? (PFEER ACoP Para 126)*

- *Do the control measures provide for the timely and effective shutdown of systems which could exacerbate the emergency ? Can emergency shutdown be initiated from the control point ? (PFEER ACoP Para 127)*

6.3.6 Mitigation measures

Mitigation measures are the measures in place to protect people from the effects of hazardous events on the installation, eg passive and active fire protection, blast protection, fixed and portable fire-fighting equipment.

- *Are the mitigation measures derived from the identification and assessment of major accident hazards ? (PFEER ACoP Para 132)*

- *Are the measures appropriate for the hazards and do they:*
  - *include provision of appropriate fire-fighting media and portable equipment;*
  - *provide for automatic systems, or manual operation where this can justified by assessment; and*
  - *provide adequate levels of protection for key locations (eg TR, escape routes) and emergency systems ?*

  (PFEER ACoP Para 133)

- *Are fire and blast barriers capable of providing the insulation, stability, integrity and overpressure resistance identified as necessary for the period required to protect* *personnel, structures and plant ? Have any conflicts between the provision of fire and blast protection been identified and an appropriate balance been achieved ?(PFEER ACoP Para 134)*

- *Do active systems deliver the required quantities of fire-fighting media within the required time and to the required locations ? (PFEER ACoP Para 135)*

- *In determining what portable equipment is provided, has the duty holder taken into account:*
  - *the numbers and location of personnel on the installation;*
  - *the practicality and effectiveness of its use; and*
  - *the hazards and availability of other systems ?*

  (PFEER ACoP Para 136)

- *Has the duty holder considered suitable contingency arrangements, eg*
  - *operational arrangements*
  - *diversity and redundancy in protective systems*

  to ensure that mitigation measures remain effective in an emergency ? (APOSC Para 137)

6.3.7 PFEER Summary

- *Does the summary of the PFEER (Reg 5) assessment include sufficient information on the results of the assessment, in particular covering:*
  - *the events and risks;*
  - *the measures which have been selected; and*
  - *the establishment of performance standards,*

  to show that the arrangements are adequate to ensure that risks from major accident hazards are ALARP ? (SCR Guidance Para 108)

6.4 Detailed Guidance for Assessors

The following sections provide more detailed guidance on the elimination, prevention, control and mitigation systems relevant to the OSD 3.2 fire, explosion and risk assessment team.

6.4.1 Inherent safety

The following principles should be adopted, where possible:
- *substitution*: use of less hazardous materials
- *simplification*: use of simpler process systems
- *intensification*: reduction of inventory of hazardous materials
- *attenuation*: reduction of temperature and/or pressure of hazardous materials, or use of inert diluents

Examples of the application of inherently safer design principles to offshore installations are as follows:
- concept selection:
  - multiple (vs single) jackets
  - subsea (vs topsides) development
- operating philosophy:
  - unattended (vs manned) installations
  - pre-drilling of wells

- avoidance of simultaneous hazardous operations

- process design:
  - minimisation of HP/LP interfaces
  - use of non-flammable or low flammability materials
  - simplification of processing
- plant design and layout:
  - segregation of hazardous inventories (eg risers, separators etc)
  - reduction of congestion and confinement
  - enhancement of natural ventilation
  - reduction of particular hazards (eg dropped loads)
  - selection of suitable materials of construction (eg corrosion resistant)
  - use of non-intrusive instrumentation
  - design to minimise, or facilitate easier, inspection and maintenance
  - minimisation of piping joints

6.4.2 Preventive measures

Ventilation

The provision of natural ventilation, and the design, construction, installation, operation and maintenance of mechanical ventilation systems on offshore installations should be in accordance with relevant good practice (see Section 6.5 below)

Consideration should be given to:

- locating hazardous plant in the open air
- minimising congestion and 'dead' areas around likely leak sources
- optimising natural and mechanical ventilation
- reducing the distance from potential leak sources to the open air
- controlling the size of process areas

The adequacy of natural ventilation of complex installations, and mechanical ventilation of large, complex spaces, should be confirmed by CFD modelling or wind tunnel testing, supported by measurements.

Consideration should be given to the provision of ventilation, over and above that required by relevant good practice, as a risk reduction measure.

Measurements of the adequacy of ventilation should ensure that any potential for 'short-circuiting' of the flow is identified.

Ignition control

The number of potential ignition sources should be minimised as far as reasonably practicable.

Areas where leaks of flammable substances could occur should be identified and equipment within these areas should be designed to reduce the likelihood of ignition of such substances.

Hazardous areas on an installation should be classified in accordance with relevant good practice (see Section 6.5 below).

Consideration should be given to the need to isolate non-essential electrical equipment in the event of a major gas emergency.

Procedures should be in place to control the use of temporary equipment, which may present an ignition source.

Direct-fired equipment should be located (or suitably protected) so as to avoid providing an ignition source for flammable releases.

Permit-to-work (PTW) and isolation procedures should follow relevant good practice.

Gaseous inerting systems

The design, construction, installation, operation and maintenance of gaseous inerting systems should be in accordance with relevant good practice (see Section 6.5)

In selecting gaseous inerting systems, consideration should given to their effectiveness for prevention of fire and explosion and any potential adverse impacts on health and safety, eg

- noise;
- turbulence/high velocity;
- oxygen depletion;
- low temperature; and
- hazardous decomposition products.

and appropriate measures taken.

6.4.3 Detection measures

General

Fire and gas systems should be designed, constructed, installed, operated and maintained in accordance with relevant good practice (see Section 6.5).

The fire and gas system should have facilities to allow testing of field devices, internal functions and executive outputs.

Fire and gas detectors should be subject to regular testing and maintenance.

The information required from the fire and gas system at control points should be considered at the design stage.

The rationale for selection of the type, location and alarm/action settings of fire and gas detectors should be explained.

The fire and gas system should be of fail-safe design.

Gas detection

The provision of gas detection for non-hazardous areas (eg in HVAC intakes) should ensure that there is sufficient time available following detection to complete the necessary shutdown actions.

The calibration of gas detectors should be based on the relevant range of hydrocarbons.

Information on the level or quantity of gas present should be available at a control station

Provision for the detection of toxic gas (if required) should be integrated into the fire and gas system

Consideration should be given to provision of a suitable combination of detectors, eg acoustic detectors for early leak detection and infra-red detectors (point/beam) for detection of gas accumulation.

Real-time ventilation surveys should be used to confirm the adequacy of the operation and sensitivity of the gas detection system

Appropriate consideration should be given to the capability of the gas detection system to detect, and respond effectively, to:
- small leaks;
- large, rapidly accumulating leaks; and
- heavier-than-air, slumping releases.

Fire detection

An appropriate range of devices to detect fire should be provided, eg
- point heat detectors;
- optical flame detectors;
- smoke detectors;
- fusible plugs;
- frangible bulbs; and
- CCTV.

Flammable liquid release

An appropriate range of devices to detect liquid releases should be provided, eg
- low level alarms for process vessels;
- high level alarms for open drains;
- oil mist detection; and
- seal leakage alarms.

6.4.4 Control measures

Bunding and drainage

Bunding and drainage should be provided in all areas which have a source of liquid hydrocarbons so as to minimise the fire risk.

Hazardous and non-hazardous drains should be physically separate.

Hazardous closed drains should be separate from open drainage systems

The design of the drainage system should limit the maximum spread of a spill and attempt to minimise any escalation arising from the spill.

The extent of bunding should take account of any liquid trajectory from the point of release.

Drains should be capable of collecting and disposing of all or most of the hydrocarbon release and the applied fire water.

Explosion control: installation layout

The layout of equipment should follow relevant good practice (see Section 6.5).

The layout and location of equipment and pipework should be such as to minimise congestion and confinement, and limit module volumes.

Specific measures which would limit the achievable blast overpressure are as follows:
- orientation of vessels parallel to the direction of venting;
- avoidance of long, narrow modules; and
- minimisation of obstructions across openings in the module boundary

Explosion control: venting

The design, construction, installation and maintenance of explosion vents should follow relevant good practice (see Section 6.5).

The performance of blast relief and ventilation panels should be verified by suitable type testing.

Particular hazards which should be taken account of in the provision of explosion venting systems are:

- the risk to personnel from the vent discharge;
- the potential for obstruction of the vent; and
- the effects of ignition of the unburnt vent discharge gases.

The uncertainty as to the precise reduction of blast overpressure achieved by venting should be recognised.

Explosion control: activation of water deluge

The activation of water deluge on detection of gas can provide an effective means of reducing the overpressure which would be generated by subsequent ignition of the gas. However in adopting this strategy the following should factors be taken into account:

- the dependence of any risk reduction on the effectiveness of gas detection;
- the creation of turbulence, hence an increased rate of pressure rise (initially);
- the low benefit of deluge activation in confined situations (low flame speeds);
- the potential for displacement of gas to a more hazardous location;
- the increased probability of ignition (eg due to water entering electrical equipment);
- the capability of the deluge system to provide explosion mitigation in addition to its primary function, ie fire protection; and
- the potential for enhanced corrosion of equipment.

6.4.5 Mitigation measures

Active fire protection

Active fire protection (AFP) systems should be designed, constructed, installed, operated and maintained in accordance with relevant good practice (see Section 6.5)

AFP systems should be suitably located and protected from the effects of fire and explosion.

It should be recognised that directed deluge systems designed in accordance with current good practice cannot be relied upon to protect vessels against jet fire attack.

The final selection of the type of AFP and quantities/rates of application should be based on fire analysis and evaluations of fire-fighting systems.

AFP systems and equipment should be suitable for the intended duty and environment.

The ability of the AFP system to perform its intended function should take account of the response time of the system.

For automatic AFP systems manual release stations should be provided at suitable locations.

In providing AFP systems, the hazard of extinguishment of fires (leading to gas/vapour accumulation and the associated explosion hazard) should be recognised.

Passive fire protection

Passive fire protection (PFP) of essential systems and equipment (or enclosures containing such systems and equipment) should be provided where failure in a fire is intolerable.

Where PFP is required to provide protection following an explosion, it should be designed and installed such that deformation of the substrate caused by an explosion will not affect its performance.

Selection of the PFP systems should take into account the duration of protection required, the type of fire which may be experienced and the limiting temperature for the structure or equipment to be protected.

PFP should be subject to regular inspection and maintenance against defined performance standards.

Blast protection

The detailed design of blast protection is outside the remit of this guidance. However the specification of explosion loads for the design of blast protection should be in an appropriate format (see Section 4.4.4)

A decision to use a design overpressure less than the predicted maximum should be based on a evaluation of the residual risk to persons on the installations.

Fire-fighting equipment

Portable fire-fighting equipment should be provided in accordance with relevant good practice (see Section 6.5)

The extinguishing media of portable fire-fighting equipment should be appropriate to the anticipated type of fire.

6.5 Relevant Good Practice

6.5.1 HSC/E publications

- SCR Guidance Reg 8, Paras 108-109
- APOSC Paras 90-105 and 117-119
- PFEER ACoP Regs 9, 10, 12 and 13

6.5.2 Other relevant good practice

IMO Code for the Construction and Equipment of Mobile Offshore Drilling Units (IMO, 2001). The purpose of the MODU code is to recommend design criteria, construction standards and other measures for MODUs in order to minimise the risks to such units, to the personnel on board and to the environment. The MODU code was first adopted in 1989 and subsequently updated in 1991 and 1994. Chapter 9 covers fire safety.

Interim Guidance Notes for the Design and Protection of Topsides Structures against Explosion and Fire (SCI, 1992). The Interim Guidance Notes (IGN) were issued in January 1992 and have been supplemented by a series of Technical Notes (TN), of which those relevant here are:

TN1: Fire resistance design of offshore topside structures, 1993

TN2: Explosion Mitigation Systems, 1994
TN4: Explosion Resistant Design of Offshore Structures, 1996
TN5: Design Guide for Stainless Steel Blast Walls, 1999

The IGNs provide a reference framework for the design and protection of topsides structures against fire and explosion. They set out the broad design and assessment philosophy, provide detailed design guidance for fire and explosion resistance, then recommend an integrated strategy.

The detailed design guidance covers:

- fire and explosion scenarios;
- the prediction of fire and blast loads;
- information on explosion mitigation systems, and passive and active fire protection; and
- approaches for determining the response of plant and structures to fire, blast and missiles.

At the time of preparation of this guidance the IGNs were in the course of being updated, under sponsorship from UKOOA and HSE. The objective is to develop guidance for designers and duty holders to use during the design of, and in making operational modifications to, offshore installations. The guidance is intended to achieve international acceptance and foster the creation of a consensus of views between regulators and industry. It is intended that the revised guidance will incorporate a simplified and codified approach, moving from a UKOOA "Type B" approach to a "Type A" approach (see Section 5.5.2).

ISO 13702, Control and mitigation of fires and explosions on offshore production platforms – requirements and guidelines (ISO, 1998). This standard is presented a series of objectives, functional requirements and guidelines, defined as follows:

- Objectives: the goals to be achieved by the control and mitigation measures
- Functional requirements: the minimum criteria which shall be satisfied to meet the stated objectives
- Guidelines: recognised practices which should be considered to determine that the necessary measures are implemented

The standard covers installation layout, control of ignition, control of spills, emergency power systems, fire and gas systems, active and passive fire protection, explosion mitigation and protection, evacuation, escape and rescue and inspection, testing and maintenance.

ISO 15138, Heating, ventilation and air-conditioning (ISO, 2000). ISO 15138 provides guidance for design, testing and commissioning of HVAC and pressurised systems and equipment on offshore production installations. It includes ventilation of production areas and states that natural ventilation is preferred over mechanical (or artificial) ventilation where practical.

UKOOA Guidelines for Fire and Explosion Hazard Management, UKOOA (1995). The scope of these Guidelines is outlined in Section 3.5.2 above. Section 5 of the Guidelines provides guidance on inherent safety and prevention. Section 6 is concerned with the selection and specification of systems for fire and explosion detection, control and mitigation. Section 8 details the various options available for detection, control and mitigation.

6.6 Other Standards and Guidance

ANSI/API RP 500 - 1998, Recommended Practice for Classification of Locations for

Electrical Installations at Petroleum Facilities of Class 1 Division 1 or Division 2 (API, 1998). API RP 500 is the primary US standard for area classification and also covers ventilation of hazardous areas. The standard defines adequate ventilation as 'ventilation that is sufficient to prevent the accumulation of significant quantities of vapour-air or gas-air mixtures in concentrations above 25 % of their lower flammable (explosive) limit'. API RP500 describes a number of possible strategies for achieving adequate ventilation.

API RP 2A. This standard was first published in 1997 and contains limited guidance for the design of fixed offshore installations for accidental loading, including fire and blast. At the time of preparation of this guidance API were in the process of developing a new standard *Design and Assessment of Offshore Structures for Fire and Blast*. It is anticipated that the new standard will contain (i) redefined 'exposure categories' for fire and blast, to distinguish higher and lower risk installations and (ii) detailed guidance for the protection of offshore structures against fire and blast loading, representing modern best practice which is applicable to all offshore installations. API's motivation for development of the new standard includes the recent rise in deepwater developments utilising floating installations.

API RP 14G, Recommended Practice for Fire Prevention and Control on Open Type Offshore Production Platforms (API, 1993a). This document presents recommendations for minimising the likelihood of fire and for designing, inspecting and maintaining fire control systems. It is applicable to fixed, open-type offshore production installations. The standard covers fire prevention practices, fire detection and alarms, fire control, portable fire extinguishers, inspection, testing and maintenance, personnel safety and orientation, and passive fire protection.

API RP 14J, Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities (API, 1993b). This document assembles useful procedures and guidelines for planning, designing and arranging offshore production facilities, and performing hazard analysis on open-type production facilities. The standard covers containment and prevention measures, basic facilities design concepts, hazard mitigation and personnel evacuation, platform equipment arrangements and documentation requirements.

BS 5306, Fire Extinguishing Installations and Equipment on Premises (BSI, 1992). BS5306 gives guidance on the selection, installation and maintenance of automatic water sprinkler and spray systems. It also covers carbon dioxide, halon systems, foam and extinguishing powder systems. The standard gives guidance on installed equipment for fire service use and portable extinguishers. More detailed information is given in the specialised parts of this standard. It covers occupational safety, control equipment, halogenated hydrocarbons, dry powder and fire safety.

BS 5925:1991, Ventilation principles and designing for natural ventilation (BSI, 1991). BS5925 gives recommendations on the principles which should be observed when designing for natural ventilation of buildings. The standard is aimed at indoor situations and, whilst useful for background information, its applicability is limited for outdoor areas such as air movement within an 'open' module. It is however referenced by many of the other standards.

BS EN 60079-10: 1996, Electrical apparatus for explosive gas atmospheres, Part 10. Classification of hazardous areas (BSI, 1996). BS EN 60079-10 is the current standard which deals with the classification of hazardous areas where flammable gas or vapour risks may arise in order to assist selection and installation of apparatus for use in such hazardous areas. The area classification should be carried out by those who have knowledge of the properties of flammable materials, the process and the equipment.

The standard gives guidance on the procedure for classifying areas in which there may be an explosive atmosphere. Recommendations are given on how to depict the various zones on drawings. The standard provides information on:

- safety and area classification (principles and objectives);
- procedure for area classification, based on consideration of sources, zones types and extents;
- effect of ventilation (natural or artificial);
- documentation of the classification process (drawings, data sheets and tables).

BS IEC 61508, Functional safety of electrical/electronic/programmable electronic safety-related systems (BS IEC, 1998/2000). IEC 61508 is the major international standard for safety related systems comprised of electrical and/or electronic and/or programmable electronic components. It is intended for use as a stand-alone standard and as a framework for preparation of application sector standards.

The standard presents a lifecycle approach including risk assessment, design, integration, testing, modification and maintenance and safety management. It is based on the identification of safety function and all components required to achieve function (including humans) and their associated safety integrity. It adopts a risk based approach for the determination of the required safety integrity. It introduces the concept of safety integrity levels (SIL 1-4) which are associated with target failure rates and configurations of redundant and diverse channels of protection. It covers not only programmable electronics, but also electromechanical and solid state electronic systems.

The complete standard comprises 7 parts:
- Part 1: General requirements;
- Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems;
- Part 3: Software requirements ;
- Part 4: Definitions and abbreviations ;
- Part 5: Examples of methods for the determination of safety integrity levels ;
- Part 6: Guidelines on the application of Parts 2 and 3; and
- Part 7: Overview of techniques and measures.

Engineering Handbook on the Design of Offshore Facilities to Resist Gas Explosion Hazard (Czujko, 2001). This handbook arises out of the Gas Explosion Engineering JIP (in part sponsored by HSE) and provides guidance for the design and strength assessment of topsides structures against the effects of accidental gas explosions. Emphasis is given to:

- structural safety and reliability;
- the use of risk analysis methods;
- the use of numerical methods to compute (i) gas explosion loads (with the help of CFD) and (ii) load effects (with the use of non-linear finite element methods); and
- the application of probabilistic methods in the quantification of uncertainties in gas explosion loads and load effects.

Chapter 2 covers the principles of inherent safe design of topside structures against gas explosion loads, and Chapter 4 covers gas explosion loads, including deterministic and probabilistic approaches.

IADC North West European Guidelines for MODUs (IADC, 2002). The scope of these guidelines is outlined in Section 3.6 above. Section 3 of the guidelines contains advice on what should be included in the Safety case as regards the MODU, its systems and equipment, the activities likely to be carried out and the environmental conditions in which it can operate.

International Convention for the Safety of Life at Sea (IMO, 2002a). Chapter II-2 of SOLAS covers fire protection, fire detection and fire extinction. In 2002 this part of the Convention was completely revised. The new format focuses on the 'fire scenario process' rather than ship type. The regulations cover fire prevention, detection and suppression, following through to escape. Specific system-related technical requirements have been moved to the new *International Fire Safety Systems Code* (see below).

International Fire Safety Systems Code (IMO, 2002b). One of the features of the revision to SOLAS (see above) is the allowance for alternative (or novel) designs and arrangements as opposed to prescriptive fire safety requirements. The purpose of the FSS Code is to provide international standards for fire safety systems required by revised SOLAS Chapter II-2, under which it is made mandatory. The FSS code covers a range of fire prevention, fire-fighting and fire protection systems. It also covers fire and smoke detection, fire pumps and means of escape.

IP (2002), Model Code of Safe Practice for the Petroleum Industry: Part 15 Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids. This publication is an update IP Model Code of Safe Practice for the classification of hazardous areas in the petroleum industry. It provides a methodology to comply with the area classification requirements under the new *Dangerous Substances and Explosive Atmospheres Regulations, 2002* (DSEAR). The new Code: applies recent understanding in modelling two-phase releases; takes account of high-pressure releases and mist and spray formation; has been broadened to encompass petrochemical as well as petroleum installations; and specifically covers LPG. Subjects covered by the Code include: scope, applicability and definitions; guide to classifying hazardous areas; the technique of hazardous area classification using direct example and point source approaches; how to classify typical facilities such as storage tanks and road tanker loading; the classification of drilling rigs, onshore and offshore; basis and application of point source methodology; the effect of ventilation; the selection of electrical equipment; and ignition risks arising from non-electrical equipment. In IP15 adequate ventilation is referred to as 'the achievement of uniform ventilate rate of at least 12 air changes per hour, with no stagnant area'.

NFPA 15, Standard for Water Spray Systems for Fire Protection (NFPA, 1985).

NORSOK Standard H-001, Heating Ventilation and Air-conditioning (NORSOK, 2001a). Rev 4 of this standard is fully aligned with ISO 15138 but includes additional requirements and guidelines specific to the Norwegian petroleum industry. The scope of this standard is as per ISO 15138.

NORSOK Standard N-003, Actions and Action Effects (NORSOK, 1999). This standard specifies general principles and guidelines for the determination of actions and action effects for the structural design and design verification of structures. It applies to all types of offshore structures. Section 8.2 of the standard covers fire and explosion loads, in particular how to quantify such loads and how they should be specified for the purpose of determining structural response. Combined fire and explosion loading is discussed.

NORSOK Standard S-001, Technical Safety (NORSOK, 2000). This standard describes the principles and requirements for the development of the safety design for offshore production installations, fixed platforms, semi-submersibles and vessels. This standard, together with ISO 13702, defines the required standard for implementation of technologies and emergency preparedness to establish and maintain an adequate level of safety for personnel, environment and material assets.

SI611 - Offshore installations: Guidance on fire fighting equipment, (HMSO, 1980). Although this SI611 has now been revoked, this document provides useful guidance on the provision of fire-fighting equipment on offshore installations. It covers fire and gas detection, fire alarms, remote control safety equipment, fire mains, hydrants/hoses/nozzles, water deluge systems/monitors, sprinkler systems, fixed extinguishing systems and portable/non-portable fire-fighting equipment.

7 Emergency Arrangements

7.1 Background

The descriptive information required under SCR (Schedules 1-3) includes a description of the provision for

(a) temporary refuge;
(b) routes from locations where persons may be present to temporary refuge and for egress therefrom to points from where the installation may be evacuated;
(c) means of evacuation at those points; and
(d) facilities within temporary refuge for the monitoring and control of the incident and for organising evacuation.

PFEER also requires that *the duty holder shall make appropriate provision for –*

(a) areas for persons to muster safely;
(b) safe egress from accommodation and work areas, and safe access to muster areas, temporary refuge, and evacuation and escape points; and
(c) safe evacuation and escape points [Reg 14(1)].

This section concerns the aspects of the emergency arrangements relevant to the OSD 3.2 fire, explosion and risk assessment team, namely the arrangements for temporary refuge (including access to it and evacuation from it) and the conditions under emergency control arrangements are required to be effective. These are covered by four APOSC principles (Paras 106, 122, 127 and 135) which are reproduced below as the minimum standard which should be achieved.

7.2 Minimum Standard

Arrangements for controlling an emergency should take account of the anticipated conditions during possible emergency scenarios (*APOSC Para 106*)

The arrangements for TR should provide sufficient protection to enable people to muster safely, to permit the emergency to be assessed, and to allow the appropriate parts of the emergency response plan to be executed (*APOSC Para 122*)

There should be sufficient evidence to demonstrate that the frequency within which accidental events will result in a loss of TR integrity, within the minimum stated endurance time, does not exceed of the order of 1 in 1000 per year. This frequency should be reduced to a lower level wherever reasonably practicable. Where the frequency is close to 1 in 1000 per year, there should be convincing arguments that it is not reasonably practicable to reduce it further (*APOSC Para 127*)

Performance standards and endurance times should be indicated for access routes and evacuation routes, embarkation points and totally enclosed motor propelled survival craft (TEMPSC) (*APOSC Para 135*)

7.3 Key Questions

7.3.1 Effective Operation of Emergency Arrangements

- *Has appropriate account been taken of the ability of emergency control measures (eg ESD, blowdown and flare systems) to function (a) in the presence of potentially flammable mixtures of hydrocarbons, (b) during or after a fire and (c) following the mechanical shock of an explosion ? (APOSC Para 108)*

- *Has account been taken of the extent to which an emergency system may be partially or totally ineffective, eg due to incident damage, latent defects or components which are out of service at the time at which a major accident occurs ? (APOSC Para 109)*

- *Is it clear how emergency systems (eg ESD, HVAC systems) are intended to act in controlling emergency situations ? (APOSC Paras 110 and 111)*

- *Have the expected consequences of a shutdown delay or failure of the ventilation systems, and the contribution this would make to the escalation of a major accident scenario, been taken into account ? (APOSC Para 112)*

7.3.2 Temporary Refuge

- *Is the TR a place where personnel can muster safely in the event of an emergency, monitor and assess the developing situation and take the necessary control action or initiate evacuation from the installation ? (APOSC Para 123)*

- *Are there sufficient available safe access routes from all potentially occupied locations to a TR ? (APOSC Para 124)*

- *Are appropriate performance standards for the TR in place which take account of, for example, the size and layout of the installation and the numbers and distribution of persons on board (POB). Has allowance been made for the hindering effects of injuries, darkness, smoke and damage to access and exit routes ? (APOSC Para 125)*

- *Does the description of the TR include an explanation of how the system will withstand the effects of fire, explosion, smoke and toxic gas, including secondary effects such as impacts. Will the TR deliver the required functions for as long as is necessary during major accidents ? (APOSC Para 126)*

- *Does the assessment of the frequency of loss of TR integrity consider:*
  - *loss of structural support;*
  - *deterioration of life support functions at TR locations; and*
  - *loss of command communication functions ?*

  (APOSC Para 128)

- *In estimating the endurance time for access routes, has account been taken of the time needed for people to travel from their work stations to a TR, possibly helping injured colleagues ? (APOSC Para 136)*

- *As exit and evacuation routes may be required some time after the development of a major accident, are they protected accordingly ? (APOSC Para 137)*

- *Are muster points usable, and access and egress routes passable, for the time required to safeguard personnel, based on the major accident scenarios which have been identified and assessed ? Has priority been given to the protection of access and egress routes over providing personal protective equipment (which should be regarded as a last resort) ? (PFEER ACoP Para 145)*

7.4 Detailed Guidance for Assessors

7.4.1 Escape routes

Escape routes should, wherever practicable, be designed to remain passable by position rather than protection, ie external escape routes should be physically separated from explosion vent panels, sacrificial walls and open hazardous modules. Where this is not possible alternative routes should be provided which are unlikely to be affected in the same incident.

The dimension of escape routes should be adequate for the number of people who may be required to use them and should have adequate vertical clearance.

7.4.2 Temporary refuge

The TR should have sufficient capacity to protect the maximum POB of the installation.

The TR should maintain the safety of personnel during the period required for completion of the evacuation process, taking into account the time to;

- complete the full muster at the TR;
- account for personnel not reporting to their assigned muster stations;
- evaluate the situation and make decisions;
- initiate responses to minimise the consequences and control the emergency (if possible);
- complete the evacuation (if required); and
- a contingency for unforeseen circumstances.

In assessing loss of TR integrity, the following should be taken into account (as appropriate):

- Loss of structure, eg
  - collapse of supporting structure
  - impairment of exterior fabric of an enclosed TR
- Loss of life support, eg due to
  - ingress of smoke or gas
  - excessive heat stress
  - oxygen deficiency
  - toxic gas accumulation
- Loss of command communication, eg
  - loss of communications within TR, between multiple TRs or with third parties
  - loss of ESD
  - loss of F&G and monitoring
  - loss of emergency power/lighting

Where it is not possible for a person to reach a TR under certain conditions, consideration should be given to alternative arrangements to allow safe evacuation of these people.

Where a control station (not within the TR) is required to be occupied in an emergency it should be possible for the personnel at the control station to subsequently reach a TR if the situation makes it necessary.

7.5 Relevant Good Practice

7.5.1 HSC/E publications

- APOSC Paras 106-112, 122-129 and 135-137
- PFEER ACoP Reg 14

7.5.2 Other relevant good practice

Interim Guidance Notes for the Design and Protection of Topsides Structures against Explosion and Fire (SCI, 1992). The scope of the IGN is described in Section 6.5.2 above. Section 2.3 and 2.4 of the IGN cover the basic requirements for temporary refuge, evacuation and escape.

ISO 13702, Control and mitigation of fires and explosions on offshore production platforms – requirements and guidelines (ISO, 1998). The scope of this standard is described in Section 6.5.2. Section 14 of ISO 13702 gives the objectives and functional requirements for evacuation, escape and rescue and Section B12 provides the corresponding guidelines.

7.6 Other Standards and Guidance

IADC North West European HSE Case Guidelines for MODUs (IADC, 2002). The scope of these guidelines is outlined in Section 3.6 above. Sections 4 and 5 of these guidelines detail the information which should be included in the Safety Case as regards temporary refuge, evacuation and escape. This covers the assessment of TR impairment frequency, demonstration of the adequacy of the design, construction and equipment of the TR, demonstration of the adequacy of TR integrity and demonstration of the suitability and sufficiency of evacuation and escape systems.

NORSOK Standard S-001, Technical Safety (NORSOK, 2000). The scope of this document is outlined in Section 6.6 above.

8 Supporting References

8.1 Relevant Good Practice

8.1.1 HSC/E publications

HSE (1997), Prevention of fire and explosion, and emergency response on offshore installations. Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations, 1995. Approved Code and Practice and Guidance, L65, Health and Safety Executive, 1997.

HSE (1998a), Assessment principles for offshore safety cases, Health and Safety Executive, 1998.

HSE (1998b), A guide to the Offshore Installations (Safety Case) Regulations 1992, L30, 2nd Ed, Health and Safety Executive, 1998.

8.1.2 Other relevant good practice

IMO (2001), Code for the Construction and Equipment of Mobile Offshore Drilling Units – Consolidated, International Maritime Organisation, 2001.

ISO (1998), Petroleum and natural gas industries - control and mitigation of fires and explosions on offshore production platforms - requirements and guidelines, ISO/FDIS 13702: 1998E.

ISO (1999), Petroleum and natural gas industries – offshore production installations – guidelines on tools and techniques for identification and assessment of hazardous events, ISO/DIS 17776.

ISO (2000), Petroleum and natural gas industries – offshore production installations – heating, ventilation and air-conditioning, ISO 15138:2000(E).

SCI (1992), Interim Guidance Notes for the Design and Protection of Topsides Structures against Explosion and Fire, SCI-P-112/078, Jan 1992.

UKOOA (1995), Guidelines for Fire and Explosion Hazard Management, United Kingdom Offshore Operators Association, Issue 1, 1995.

UKOOA (1999a), Industry Guidelines on a Framework for Risk-Related Decision Support, United Kingdom Offshore Operators Association, Issue 1, May 1999.

8.2 HSE ALARP Guidance

Offshore Division ALARP Guidance:

Guidance on ALARP for Offshore Division Inspectors - Making an ALARP demonstration, Semi-Permanent Circular 38, Health and Safety Executive (available on HSE web site).

ALARP Trilogy (available on HSE web site):

Assessing compliance with the law in individual cases and the use of good practice.

Policy and Guidance on reducing risks as low as reasonably practicable in Design.

Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable.

R2P2 (available on HSE web site):

HSE (2001), *Reducing risks, protecting people: HSE's decision making process,* Health and Safety Executive.

8.3 Offshore Division Fire and Explosion Strategy

Fire and Explosion Strategy, Offshore Division, February 2003.

8.4 Other References

API (1993a), Recommended Practice for Fire Prevention and Control on Open Type Offshore Production Platforms', API 14G, 3rd Ed, American Petroleum Institute, 1993.

API (1993b), Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities, API 14J, 1st Ed, American Petroleum Institute, 1993.

API (1998), Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities of Class 1 Division 1 or Division 2, ANSI/API RP 500 – 1998.

BS IEC (1998/2000), Functional safety of electrical/electronic/programmable electronic safety-related systems, BS IEC 61508.

BSI (1991), Ventilation principles and designing for natural ventilation, BS 5925:1991.

BSI (1992a), Fire Extinguishing Installations and Equipment on Premises, BS5306 (last amended 1992).

BSI EN (1996), Electrical apparatus for explosive gas atmospheres, Part 10. Classification of hazardous areas, BS EN 60079-10: 1996.

CMPT (1999), A Guide to Quantitative Risk Assessment for Offshore Installations, Centre for Marine and Petroleum Technology, Publication 99/100, J Spouge (Ed).

Czujko J (Ed) (2001), Engineering Handbook on the Design of Offshore Facilities to Resist Gas Explosion Hazard, CorrOcean, 2001.

HMSO (1980), Offshore installations: Guidance on fire fighting equipment, Department of Energy, HMSO, May 1980 (updated in 1990).

IADC (2002), North West European HSE Case Guidelines for MODUs, International Association of Drilling Contractors, Working Draft – January 2002.

IMO (2002a), International Convention for the Safety of Life at Sea (SOLAS), Revised Chapter II-2: Construction – Fire protection, fire detection and fire extinction, International Maritime Organisation, 2002.

IMO (2002b), International Code for Fire Safety Systems (FSS Code), International Maritime Organisation, 2002.

IP (2002), Model Code of Safe Practice for the Petroleum Industry: Part 15 Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids, Institute of Petroleum, 2nd Ed, Aug 2002.

NFPA (1985), Standard for Water Spray Systems for Fire Protection, National Fire Protection Association, NFPA 15, 1985

NORSOK (1999), Actions and Action Effects, N-003, Rev 1, Feb 1999

NORSOK (2000), Technical Safety, Standard S-001, Rev 3, Jan 2000.

NORSOK (2001a), Heating Ventilation and Air-conditioning, Standard H-001, Rev 4, Nov 2001

NORSOK (2001b), Risk and Emergency Preparedness Analysis, Z-013, Rev 2, 2001

UKOOA (1999b), Guidelines for Quantitative Risk Assessment Uncertainty, United Kingdom Offshore Operators Association, Issue 1, March 2000.

9 Abbreviations

ACoP	Approved Code of Practice
AFP	Active fire protection
ALARP	as low as reasonably practicable
APOSC	Assessment principles for offshore safety cases (HSE guidance)
CBA	Cost-benefit analysis
COMAH	Control of Major Accident Hazards Regulations, 1999.
EER	Evacuation, Escape and Rescue
EPA	Emergency Preparedness Analysis
ESD	Emergency shutdown
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
GFEHM	Guidelines for Fire and Explosion Hazard Management (by UKOOA)
HAZOP	Hazard and Operability Study
HSC	Health and Safety Commission
HSE	Health and Safety Executive
HSE case	Health, Safety and Environment case
IADC	International Association of Drilling Contractors
IGN	Interim Guidance Notes
IP	Institute of Petroleum
IRPA	Individual risk per annum
ISO	International Standards Organisation
MODU	Mobile Offshore Drilling Unit
OSD	Offshore Division
OIAC	Offshore Industry Advisory Committee
PFEER	Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations, 1995

PFP	Passive fire protection
POB	Persons on board
PTW	Permit-to-work
QRA	Quantified Risk Assessment
R2P2	Reducing risks, protecting people (HSE document)
SCHAM	Safety Case Handling and Assessment Manual
SCR	Offshore Installations (Safety Case) Regulations, 1992
SIL	Safety integrity level
SRAM	COMAH Safety Report Assessment Manual
TEMPSC	Totally enclosed motor propelled survival craft
TR	Temporary Refuge
TN	Technical Note
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association
VPF	Value of preventing a fatality

Appendix A

Interfaces with Other Topic Specialist Teams

The topic of fire, explosion and risk assessment has various interfaces with other topics which are considered as part of Safety Case assessment. The main interfaces are identified in *Figure 2.2* and detailed further in *Table A1* below.

Table A1 Interface of Fire, Explosion and Risk Assessment Team with other Topic Specialist Teams

Aspect	Interfacing team	Interface issues
Hazard identification	Control systems Human factors Mechanical integrity Pipelines Process Integrity Well Operations	• Consideration of: - control system failure - human error (APOSC Paras 69-71) - mechanical failure - pipeline failure (within Safety Buffer Zone); - loss of process integrity - deviations from normal well operating and servicing parameters as potential causes of major accident hazards.
Quantified risk assessment	Mechanical integrity Process integrity Structural integrity	• Effects of fire and explosion on integrity of plant, equipment and structures
Risk evaluation and reduction	Control systems Mechanical integrity Pipelines Process integrity Structural integrity Well operations	• Consideration of changing circumstances, advances in technology, new knowledge and information in identifying risk reduction measures (APOSC Para 84) • Selection of reasonably practicable risk reduction measures, taking into account relevant good practice and engineering judgement (APOSC Paras 53-65, 85-87) • Implementation of reasonably practicable risk reduction measures (APOSC Paras 88-89)
	Human factors	• Consideration of people as a component of control and mitigation measures (APOSC Paras 69-71)
Risk management	Control systems Mechanical integrity Pipelines Process integrity Structural integrity Well operations	• Application of principles of inherently safer design (APOSC Paras 96-97) • Provision of appropriate prevention, detection, control and mitigation measures (APOSC Paras 98-105) • Establishment of performance standards for above measures (SCR Schedules 1-3)
Emergency arrangements	EER	• Conditions under which emergency control arrangements are required to be effective (APOSC Paras 106-112) • Arrangements for temporary refuge (including access to it and evacuation from it) (APOSC Paras 122-129, 135-137)