HSE ASSESSMENT OF EXPLOSION RISK ANALYSIS IN OFFSHORE SAFETY CASES

P W M Brighton, P J Fearnley and I G Brearley
Health & Safety Executive, Offshore Safety Division, Merton House, Stanley Road, Bootle, Merseyside L20 3DL

In the past two years HSE has assessed around 250 Safety Cases for offshore oil and gas installations, building up a unique overview of the current state of the art on fire and explosion risk assessment. This paper reviews the explosion risk methods employed, focussing on the aspects causing most difficulty for assessment and acceptance of Safety Cases. Prediction of overpressures in offshore explosions has been intensively researched in recent years but the justification of the means of prevention, control and mitigation of explosions often depends on much additional analysis of the frequency and damage potential of explosions. This involves a number of factors, the five usually considered being: leak sizes; gas dispersion; ignition probabilities; the frequency distribution of explosion strength; and the prediction of explosion damage. Sources of major uncertainty in these factors and their implications for practical risk management decisions are discussed.

Key Words: offshore, safety cases, explosion, dispersion, QRA

INTRODUCTION

Following the coming into force of the Offshore Installations (Safety Case) Regulations 1992 [1] on 31 May 1993, operators have submitted around 250 Safety Cases to the Offshore Safety Division of the Health and Safety Executive (HSE). These cover a wide range of installations: large integrated oil and gas platforms such as those in the Brent and Forties fields; clusters of small gas platforms typical of the southern basin of the North Sea; floating production, storage and off-loading vessels (FPSOs), being introduced on many of the newer small developments; semi-submersible and jack-up mobile drilling units (MODUs); accommodation barges, or "flotels". After 30 November 1995, existing installations must have had their Safety Cases accepted by HSE if they are to continue operating. New projects are required to submit a Design Safety Case before completion of the design. Safety Cases are also required for combined operations and for abandonment of fixed installations.

This requirement has imposed a strict limitation on the resources available to HSE to assess each Safety Case and to raise and resolve issues with the operators. The assessment has been a multi-disciplinary exercise led by "case managers" from the Operations Branch. Much of the technical work has been undertaken by four Technology Units covering: 1) structural integrity and naval architecture; 2) topsides facilities and pipelines; 3) process safety and fire and explosion analysis; and 4) external hazards and evacuation, escape and rescue.

The overall goal of the Safety Case as regards major hazards is [1] "to demonstrate that all hazards with the potential to cause a major accident have been identified, and 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". Major steps in this demonstration are likely to be:

- a description of the installation, plant and procedures;
- the design specification and operating limits;
- hazard identification;
- risk evaluation;
- identification and specification of risk reduction measures and associated performance standards;
- and confirmation that no further measures to reduce risks are reasonably practicable.

A key concern of HSE assessment is that for each of these steps the scope and methodology of the study are described, that sources of information are clear and that clear conclusions or recommendations are passed on to the next step. Above all, the individual steps should fit together to form a complete and logically consistent whole, ie a "demonstration".

This assessment of the overall approach is complemented by testing the quality of the work in selected areas, for instance where risks are relatively high, or novel approaches to risk reduction are employed. Pursuing these points may require discussion with the operator or production of supporting detailed information. Where major concerns arise about the overall methodology, issues are raised with the operator which may require additional work to revise the Safety Case and in some cases may result in changes to the safety arrangements and procedures.

The topic of explosions has given rise to much discussion of this nature because of the large potential consequences, the significant frequency of gas leaks and not least the difficulties of predicting explosion phenomena, as evidenced by the continuing large research effort. The aim of this paper is to review the findings of these assessments focussing on areas which have created most difficulty. Through the Safety Cases HSE has perhaps a uniquely panoramic vantage point on the methodologies employed by all the offshore operators and the many risk analysis consultancies they have employed. Significant variations in the approaches have become apparent.

Because of the confidential nature of Safety Case submissions, only limited detail can be given in this paper, except where practitioners have chosen to publish material in the open literature or conferences. However it is hoped that this will suffice to promote more open discussion and comparison of methodologies in future so that all concerned can make best use of available information to demonstrate adequate safety on offshore installations.

FIRE AND EXPLOSION HAZARD MANAGEMENT

In the report [2] on the Piper A disaster, Lord Cullen recommended not only the establishment of the Safety Case regime, but also (Recommendation 19) that new regulations were needed on fire and explosion protection. These were to set goals for safety from these hazards, rather than to prescribe solutions as had been the wont of the regulations in force in 1988. This recommendation has been implemented by the coming into force in 1995 of the Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations [3], which have been given the acronym PFEER. PFEER also realises another Cullen recommendation, for goal-setting regulations on evacuation, escape and rescue.

While the Safety Case Regulations call for an overall demonstration, PFEER sets subsidiary goals requiring arrangements to be made, and justified by an assessment, for prevention, detection, control and mitigation of loss of containment of flammable material and subsequent fire or explosion. A key requirement is that *performance standards* need to be set to specify the performanace of these arrangements and to enable their continued efficacy in practice to be monitored.

In consultation with HSE, the offshore industry has produced a guide on fire and explosion hazard management (FEHM) [4] which sets out an overall strategy which should assist in attaining the regulatory goals of PFEER. It is based on a "life-cycle" approach originally developed for electrical and electronic systems, but has been broadened in scope to highlight opportunities for enhancing inherent safety and to address all safety systems. It summarises the activities which need to be carried out, the decisions which need to be taken and the optimum timing in the lifecycle of an installation from concept through design, commissioning, operation, modification to abandonment. It also aims to provide a means of integrating all those who contribute to risk management including all the different design disciplines, risk assessors, fire and explosion scientists, operators and auditors.

Involvement in preparation of this guide has helped us understand the relationship between the key steps typical of a safety case demonstration listed in the Introduction above. In particular it has highlighted the performance standards as the essential link between the demonstration on the one hand and the practical achievement of a safe offshore operation on the other.

The FEHM Guidelines [4] identify performance standards for safety arrangements as the key features of the specification of each system. They comprise:

- *functionality:* the capacity of a system to perform the function required of it by the fire and explosion analysis (eg application rate of deluge water);
- *availability (safety integrity):* the probability of the system being available to perform the function when required;
- *survivability:* the ability of the system to function in the conditions of an accident for the time required (eg integrity of a fire barrier after absorbing energy from an explosion).

In the goal-setting regime these features of a system need to be determined by the range of fire and explosion scenarios which it is designed to meet or survive. This is in contrast to the tendency of earlier guidance to prescribe performance standards without reference to the particular features and hazards of each installation.

This paper is a review of approaches to explosion analysis in the Safety Cases. However the above explanation has been included as there will be several references to how this analysis is related to performance standards, as the key influence on safety in practice.

HAZARD IDENTIFICATION

Comprehensive hazard identification is fundamental. What has not been identified cannot be analysed; moreover, there can be no assurance that adequate safeguards exist.

Clearly a major source of explosions on offshore installations is the inventory of hydrocarbons, either on the topsides or in the reservoir in the case of drilling operations. High-pressure gas is always recognised as a problem but it is sometimes overlooked that condensate and oil releases under pressure can form explosible mists. This hazard can also occur with diesel, fuel oil and other materials stored or pumped under pressure [5].

The Safety Case Regulations identify any explosion causing death or serious injury, whatever the cause, as a major hazard (see Ref 1, paras 5-8). Other causes often overlooked are:

- hydrogen explosions from equipment such as batteries and electrochlorination units;
- cylinders of flammable gases such as acetylene;
- accidental detonation of explosives;
- air ingress into vessels during maintenance;
- explosions in flare systems where air ingress is a possibility;
- explosions of high-pressure accumulators and other air receivers due to oil contamination;
- BLEVEs from fire impingement on vessels containing volatile liquids.

Often preventive measures and good standards of design, operation and maintenance will be the key elements in demonstrating adequate management of such risks, but there may be some benefit from simple mitigative measures such as careful location and orientation to reduce the probability of ignition or minimise the consequences if an explosion occurs.

A final category of explosion arises in combined operations, where for instance a flotel or drilling rig is alongside an operating production platform. Gas released from process equipment on the fixed installation might arrive at the mobile in flammable concentrations. This hazard would be covered in a Combined Operation Safety Case. Under the transitional arrangements these Safety Cases are not required for operations ceasing before 30 November 1995, so information from these is limited as yet.

Root Causes of Leaks

Analyses of fire and explosion risks in Safety Cases for fixed installations commonly start with identification of the items of plant and equipment containing hydrocarbon inventories and proceed to calculate leak frequencies using generic data for each item of plant. We believe it is important to try to identify more clearly what the dominant root causes of these leaks will be in a specific situation, whether specific maintenance procedures, particular process conditions (eg sand erosion) or failure of critical overpressure protection devices.

Often these causes have been reviewed in HAZOPs or other safety review exercises, but the link between these and the QRA exercise is often obscure. There is a tendency in HAZOPs to stop the questioning process when a protective device is present to limit a deviation, without considering the consequences of failure of such devices. If this link is established, then the risks of everyday operations can be managed with greater regard to the major hazard potential. The information on potential consequences is also useful for identifying the most critical protective devices, assessing the integrity required of them, and setting appropriate performance standards, eg for testing and maintenance.

In many of the Safety Cases for MODUs there has been more attention to identifying and reviewing preventive measures. Here the dominant source of explosions is usually gas from blow-outs. Historically the main location of such explosions is in the shale-shaker and mud-handling areas where gas will break through if well control is lost and de-gassing equipment is overwhelmed. Well operations specialists within HSE are responsible for reviewing the standards of prevention equipment such as the blow-out preventers and drilling and well-control procedures.

Installation Fault Schedule or Hazard Management Summary

With the large number of scenarios identified in many offshore Safety Cases it is difficult to get an overview of the scope and implications of the work. One is often referred to bulky tomes containing pages and pages of event trees. It does greatly help to have a tabular presentation of the range of events considered and their potential consequences. A reference numbering system for each event and cross-referencing to the relevant parts of the safety case provides a valuable indexing function. The fault schedule should also highlight the measures for prevention, detection, control and mitigation of each hazard again showing where the description and characteristics are described in detail.

Table 1 provides a possible layout based on an example in Ref 4. As a whole such a schedule is a valuable indication of the completeness of the analysis. We also believe it is important and effective for drawing out the practical implications for design specifications, procedures, maintenance etc, ie in identifying the areas where performance standards are needed. Ref 4 also recommends this as important for achieving adequate communication and documentation between different stages of a project, particularly to the operators as those primarily responsible for maintaining and testing safety equipment and for implementing procedural safeguards.

PREDICTION OF GAS EXPLOSION OVERPRESSURES

Methods for predicting explosion overpressures in confined or congested volumes on offshore installations have been reviewed in a number of recent publications [6-11]. A major Joint Industry Project is currently in progress at Spadeadam to provide better validation of these methods by carrying out experiments in a rig representing a full-scale offshore module. Associated with this is a model evaluation exercise in which developers of explosion analysis methods were invited to make blind predictions of the results [12]. In return for submitting predictions modellers will receive certain of the test results. The aim of this is to produce an evaluation of the models in accordance with guidelines recently issued by the European Communities [13].

Review of the offshore safety cases has shown methods being used across the whole spectrum of complexity described in Refs 6-11 from simple "venting guidelines" to three-dimensional computational fluid dynamics. Operators and designers do not always appear aware of the limitations of applicability of the methods used. Some examples of common problems follow.

Table 1. Typical Example from Hazard Management Summary

Notes to Table 1:

i) The format and layout of Table 1 is an example similar to one already in use. Each organisation should develop a specific design suitable for their own needs.

ii) The company Safety Management System would identify and define responsibilities for specific hazard management activities. Designated personnel should have sufficient training and/or documentation to fulfil their responsibilities.

iii) The table could be expanded to include the role; an indication of the importance (criticality) of each system; allocation of responsibilities; emergency response actions; escalation potential; contribution to risk, etc. However the document should not contain so much information that it is unmanageable.

HAZARD	STRATEGY	POTENTIAL DAMAGE	FREQUENCY	HAZARD MANAGEMENT SYSTEM		
				PREVENTION	**CONTROL**	**MITIGATION**
Cellar Deck, Vapour cloud explosion	Minimise overpressure	Minimal structural. Possible missiles	Remote/ occasional	Standard hydrocarbon plant procedures Optimise natural ventilation	Limit the use of temporary obstruction (eg scaffolding) High vent area, limit congestion Minimise/assess effects of any permanent modification	Blast resistance of structure, walls and separator supports
Gas ingress to Temporary Refuge (TR) or utilities	Prevent ingress and ignition	Loss or damage to TR or utilities. Death or injury of occupants	Improbable	Control of modifications bringing gas release points closer to TR/utilities Hydrocarbon plant procedures and controls applied to gas/live oil plant within 30m of TR/utilities	TR inlet gas detection to initiate ventilation shutdown Electrical isolation within TR/utilities	Not appropriate
Top Deck; compressor gas jet fire	Isolate, depressurise and allow to burn out. personnel to shelter in TR	Low possibility of structural weakening	Probable - occasional	Standard hydrocarbon plant procedures Control of heavy lifts	Emergency Shutdown System (ESD) Depressurisation system Fire & Gas detection ESD/ depressurisation/ F&G lock-outs	Emergency response procedures Passive protection to flare structure

The method of Cubbage and Simmonds has been widely used for estimating explosion overpressures in mud-handling and shale-shaker areas on MODUs. Claims have been made for pressure relief by failure of bulkheads at pressures of 0.2-0.4 bar. This overlooks a restriction on the validity of the method to vent panels relieving at less than 20 mbar and with an area density of less than 24 kg/m^2 [6]. The relief provided by bulkhead failure may be limited by the inertia of the panels in opening out in response to the rapid explosion loading.

Recent fixed platform designs have featured open modules in which attempts have been made to reduce explosion overpressures by maximising vent areas, aligning the main process vessels to minimise flow resistance and other simple layout considerations [10,14]. It now becoming clear from published [15,16] and unpublished studies that such efforts may be unavailing for large hydrocarbon processing modules because of the strong influence of small scale congestion such as pipework and cable-trays, which in practice can add significantly to the blockage area.

Many of the empirical methods of explosion prediction are based on experiments in which only relatively large obstacles were included (eg Ref 17). There has been a tendency to use such models as "scoping" tools in the conceptual design stage of new projects when the detail of small-scale congestion is unknown. We now have a number of examples where subsequent analysis with a model capable of representing the effects of small-scale congestion gave much larger overpressure values (eg 3 bar with a local peak of 6 bar compared to 0.5 bar from a "semi-empirical" model [16]). Such deviations can also occur where a more sophisticated model is used at the conceptual design stage but only the major equipment is included in the analysis.

EXPLOSION RISK ANALYSIS

Almost all practical conclusions about explosion safety in Safety Cases involve some estimation of the risk. Particularly for older installations, decisions on where to spend money on upgrades often turn on cost-benefit analysis in which risk is on one side of the balance. For small new platforms, there is more prospect of making deterministic arguments that the maximum possible explosion can be accommodated without threatening overall rig safety. Even then there are risks to personnel in areas subject to explosions which cannot be averted completely. As noted in the last section the larger hydrocarbon processing modules on new platforms may still be subject to maximum explosion overpressures of several bar at which major structural damage is likely.

To estimate the frequency of explosions on a platform requires consideration of a number of factors which are all subject to uncertainty. In examining the Safety Cases we have found that the basis of these estimates is often harder to unravel than the more well-defined, if difficult, problem of estimating the explosion overpressure for a specific scenario. The five key factors usually considered for processing equipment on fixed production installations are as follows:

Range of hole sizes The analysis is usually based on three or four fixed hole sizes to represent the continuum of possible leak sources. These should cover a range of leak rates from about less than 1 kg/s to over 50 kg/s. Typically the frequency of releases over three leak sizes are in the ratio 90:9:1, i.e. 90% of leaks are small, 9% medium and 1% large. Some Safety Cases have limited the analysis to relatively large holes (eg >25mm) without any clear justification that smaller leaks are innocuous. This can have a very significant effect on the final risk results because of the strong dependence of leak frequency and other factors (see below) on hole size.

Frequencies of leaks are normally computed by application of generic component failure data to the results of the parts count. For process equipment, there should be a detailed parts count of flanges, valves, pumps etc. In some Safety Cases where this had not been done initially, subsequent review has shown significantly higher predictions of leak rates; even where a parts count is done, uncertainties can amount to a factor of 2 [18]. Where HAZOPs or incident data indicate some problem area of particular concern then explicit frequency analysis of preventive systems failure may be used but this is exceptional. Particular process conditions such as sour gas, or sand erosion, may also make the use of generic data questionable.

For existing platforms it is important to look at the total leak rates for the platform (typically a few a year) and check whether they are consistent in number and size with operating experience - in some Safety Cases this has resulted in an uprating of predicted leak frequencies. It is also important to highlight the total leak rate for new platforms so that experience can be monitored and and the basis of the risk estimates checked. HSE and the offshore industry have set up a database which should facilitate such comparisons in the future [29].

Gas dispersion Given a specific leak scenario there are various approaches to determining whether a flammable accumulation can occur. Quite often, a purely statistical approach is taken looking at the ratio of delayed ignition or explosions to leaks reported in offshore databases. In other cases (eg Ref 19) a simple dispersion calculation is made using the perfect mixing assumption of uniform concentrations (often known as the "continuously stirred tank reactor" model). This indicates whether explosive concentrations can occur and if so for how long. Note however that in reality, concentrations will be non-uniform and there will be a chance of an explosion even when the average concentration is below the lower flammable limit. More sophisticated approaches to the dispersion problem are also emerging (eg Ref 20).

An advantage of this more physical approach is that it allows some consideration of factors such as different gas detector locations, varying ventilation rates or blowdown times on the potential for explosions. Such information can be used for identifying key performance standards for these systems, such as the number of detectors needed to achieve a desired detection probability or response time to initiate blowdown, and for identifying potential improvements in performance.

Ignition probabilities Although it is recognised that there are great uncertainties in these, the values used for immediate ignition are fairly standard, deriving from two main sources [18,21]. They are however highly dependent on the leak rate and this magnifies the uncertainty in the overall risk stemming from differences in hole sizes chosen for analysis. Approaches to delayed ignition are more varied with account sometimes being taken of gas dispersion calculations, or of the number of potential ignition sources in a given module. Such modelling efforts inevitably involve an element of guesswork but are useful in emphasising the areas of concern on a particular platform. A review of the data and their influence on offshore risk predictions has recently been completed for HSE [22].

Explosion probabilities Many Safety Case analyses of explosion risks contain an additional factor reflecting the chance that even if delayed ignition does occur, the resulting explosion will not necessarily equate to the module full of a quiescent stoichiometric fuel-air mixture assumed in most overpressure predictions. The latter situation is still often cited as the "worst case" even though the enhancement of explosion overpressure by turbulence induced by high-pressure releases has been identified in experiments.
Various methods have been put forward for assigning a probability distribution for the explosion overpressure. These are based on different combinations of: experimental datasets with varying concentrations (eg data shown in Fig 1 of [19]), sometimes in conjunction with an assumption that ignition can occur randomly within the flammable range; looking at the probabilities of different concentrations (derived from gas dispersion studies) and ignition positions; and on historical data on damage from offshore explosions. Because of the different definitions it is hard to compare the different approaches and more discussion and interchange between technical experts is needed on this aspect. Bruce [23] has published a description of one such methodology including quantification of the statistical uncertainties.

Such studies have been encountered in a number of Safety Cases and result in a probability distribution of explosion overpressures (see Figure 1 for a typical, but fictitious, example) between 0 and the maximum value, usually taken as that calculated by a model for the quiescent stoichiometric fuel-air mixture filling the module. Where the maximum overpressures exceed levels at which it is feasible to provide blast protection, such curves have been used to support arguments that a lower level of provision will nevertheless protect against the majority of explosions so as to make risks as low as reasonably practicable.

Damage probabilities The treatment of the response of the main structure to explosions in Safety Cases is outside the scope of this review. Guidance on methodology has been published [14]. In many cases secondary release of hydrocarbons and fire may be a more important mode of escalation than direct structural damage. This was demonstrated by the Piper A disaster where the inquiry [2] found that an explosion of between 30 and 80 kg of condensate in Module C broke through into module B and ruptured small pipework, probably a 4-inch condensate line close to the dividing wall.

Predictions of such damage in Safety Cases are disturbingly divergent. According to some, damage to a module can start at 0.3 bar and be virtually complete at 0.6 bar. This is supported by data from studies related to damage of industrial plant from blast waves from military attack [10]. Others claim to have evidence that no significant damage will occur below 1 bar. Probabilities of damage against overpressure are sometimes used, but in other cases these are combined inextricably with the explosion probabilities making comparisons difficult.

Such broad estimates are not particularly helpful.in identifying particular weaknesses in module layouts. There may be potential for relatively small-scale improvements to process pipe mountings and the like but this is not often addressed in Safety Cases. Vulnerability of emergency systems such as fire mains and personnel address cabling are however normally addressed qualitatively as one of the "forthwith" recommendations of Lord Cullen ([2], Recommendation 69).

Structural analysis codes are beginning to be applied to examining explosion resistance of piping [24,25]. Another aspect of structural response that merits more attention in future is the "strong vibration" resulting from the transient response of the platform to the impulsive reaction forces from venting of an explosion. Studies conducted for HSE [26] indicate that this vibration can have serious effects on emergency equipment remote from the site of the explosion unless suitable performance standards for design of equipment are applied. This is another factor rarely explicitly included in current explosion risk analysis studies.

Uncertainty in Explosion Risk Analysis for Fixed Installations

With the large number of factors involved there is potential for a large variation in predictions of explosion risks on offshore installations. Moreover, we have not considered additional aspects of evaluating risk to individuals such as human vulnerability factors and probabilities for successful evacuation and escape. Benchmark exercises on risk analysis for onshore installations have shown that differing assumptions and analysis methods can produce risk results differing by several orders of magnitude [27].

Our assessment of offshore Safety Cases indicates that differences in predictions of risk from loss of containment of hydrocarbons between platforms may reflect differences in methods, data and assumptions rather than real differences in safety levels. In some instances our discussions with operators have led to reworking of the analysis and significant changes in predicted risks.

To seek some further indication of the extent of this variability we have devised a simple hazard index for the hydrocarbon risk. Intuitively, this will be dependent upon the oil, gas and condensate inventories. In addition, compactness of an installation is considered to affect the risk. Consequences of explosions tend to be greater and escalation is more likely for compact installations, eg because of impingement of jet fires on neighbouring equipment or the temporary refuge. Accordingly, such an index was defined as a weighted sum (in the ratios 1:3:10 for oil:condensate:gas) of the inventories divided by the area of the installation excluding the accommodation.

Figure 2 shows a plot of this index versus the predicted individual risk from hydrocarbon releases extracted from a number of Safety Cases. The installations were all fixed jackets except for one FPSO as indicated. At the upper end of the hazard index range, where large integrated platforms tend to cluster, the variation in take into account the availability and reliability of the identified items of key protective equipment. This allowed the overall frequency of impairment of ERS to be assessed as a function of the availability/reliability of protective systems. By varying the availability figures in the event trees it was possible to define a minimum availability which would be required for the frequency of ERS impairment to be acceptably low. In this way a minimum availability performance standard was defined for each item of critical equipment. This can be used to optimise the preventive maintenance schedules for such equipment.

At the end of the assessment summary tables were prepared out lining the identified scenario, potential for escalation, potential for ERS impairment, protection philosophy (Basis of Safety) to avoid ERS impairment, equipment required to assure the Basis of Safety, and performance standards required of the critical equipment. These tables were intended as a reference point for future use when modifications are proposed as the succinctly spell out the logic of the protective measures and provide a framework against which it is possible to assess if modifications may compromise the Basis of Safety.

In the assessments perform it was frequently not possible to find a sound logic for items of protective equipment currently installed. In some areas dual protection was provided by different protection techniques but systems had not been suitably maintained and thus overall protection reliability was deficient. By identifying key protective measures and prioritising these for maintenance, inspection and testing, the protection reliability is improved and costs minimised.

In terms of availability performance standards it is necessary to use equipment failure rate data. Such data specific to the platforms considered was scarce and thus it was necessary to fall back on generic failure rates from published sources. Having identified the critical facilities and defined test schedules a database of equipment failure rates will be built up based on test results and performance in "demand" situations. Periodic cross reference of the database contents with data assumed in the event tress will allow the chosen availability performance standards to be verified in the future and maintenance schedules to be modified as appropriate to maintain the required equipment availability.

CONCLUDING REMARKS

The methodology developed and described above follows a logical development of accident scenarios on a platform and matches the chosen protection measures to the hazard and risk. In all cases the prime concern is for safety of personnel and thus the methodology focuses on potential consequences of identified accident scenarios on the Evacuation, Escape and Rescue facilities provided on the installation.

The approach allows protection facilities to be optimised and hence provides for cost effective design for a new installation (or modification to an existing one) and provides assistance in defining cost effective maintenance and inspection schedules for existing installations.

MODU Safety Cases have generally emphasised improved well-control procedures and equipment and better knowledge of hydrocarbon reservoir characteristics to support claims that the current risk of explosions is significantly lower than the historical average. It is hoped that the improved reporting and recording [29] of offshore leaks will in due course provide statistically significant data that such a trend is occurring.

CONCLUSIONS

From the above review of explosion risk analysis several general issues emerge:

Validation of consequence models

Safety Cases generally have not featured discussion of the validation of consequence models used which typically cover two-phase flow-rates from leaks, gas dispersion as noted above, pool and jet fires, and smoke dispersion as well as explosions. It needs to be confirmed that the uncertainties inherent in all these methods do not affect the overall argument for safety significantly. Safety Cases are not academic exercises in theoretical physics and HSE is not looking for the best models to be used in an absolute sense. For one thing the very fact that accidents are "random" makes the input data into models themselves uncertain. Nevertheless there are examples of models being used outside clearly stated limits of applicability: justifying that models are fit for purpose and properly used are, we believe, both parts of the "demonstration" that the regulations require. Recent guidelines [13] should help developers of models and their customers to identify the information needed to check that models are fit for their purpose.

Sensitivity Analysis

A linked issue is that of sensitivity of QRA results. This has two main aspects. It can be used to assess the implications of uncertainty in models. Rather than make more refined calculations of explosion overpressure if a simple model has been used, it is open to the operator to attempt to demonstrate that higher predictions would not greatly increase the risk predictions. Conversely an understanding of the sensitivity of QRA results may lead to a decision to employ more sophisticated modelling techniques for specific scenarios.

The second aspect is the use of QRA to rank the importance of safety systems. Varying the failure probability of a particular system such as the blowdown system will reveal whether that system has an important effect on risks. If it does then better testing and maintenance may be a reasonably practicable improvement to increase reliability and reduce risks. On the whole, offshore QRAs do not seem designed to facilitate such sensitivity studies - perhaps the new generation of computational tool-kits will make this much easier.

Performance Standards

The last point is closely linked to the issue of performance standards. A large number of assumptions about systems performance are built into Safety Case QRAs and are thereby implicitly set as performance standards. For explosions possible examples are: speed of the shutdown system; the need to keep vent paths clear of obstructions; maintenance of and modifications on or near blast walls. Safety Cases do not always identify these assumptions very clearly, indeed they may be buried in a QRA reference document, and this tends to undermine our confidence that a system exists for implementing or maintaining the standards which have been assumed. This area is an important link between our technical safety case assessment and our operational inspection of platforms, and also clearly a key to confirming to the operator's satisfaction, as well as to HSE's, that acceptable levels of risk are being achieved and maintained on the installation itself.

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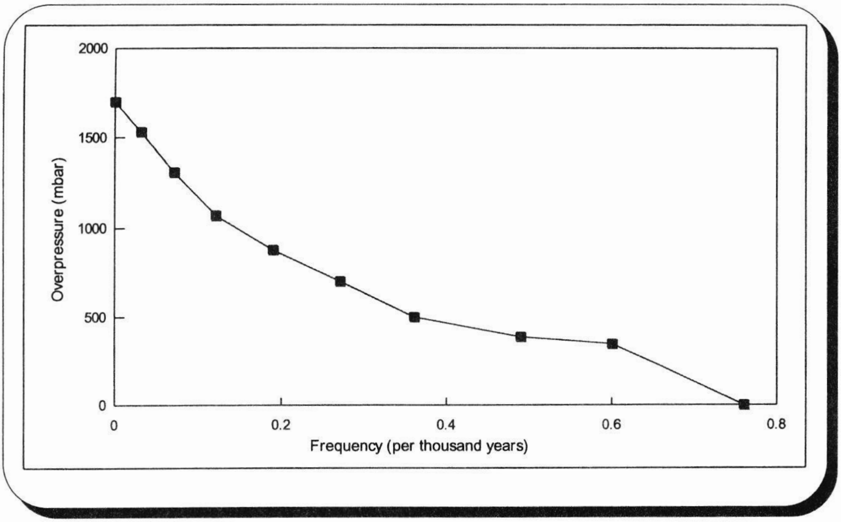

Figure 1. Example of cumulative probability distribution for explosion overpressure in a single module.

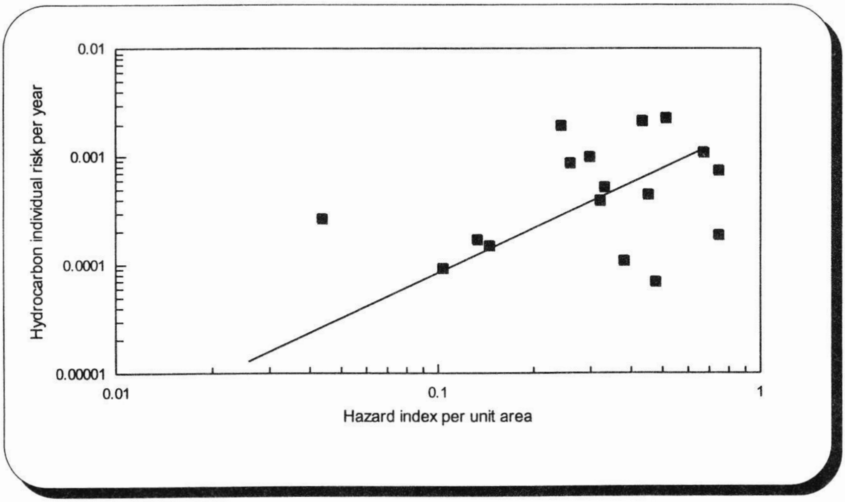

Figure 2. Individual risk from loss of containment of hydrocarbons versus hazard index for selected fixed installations in the North Sea. The line has been drawn in by eye.