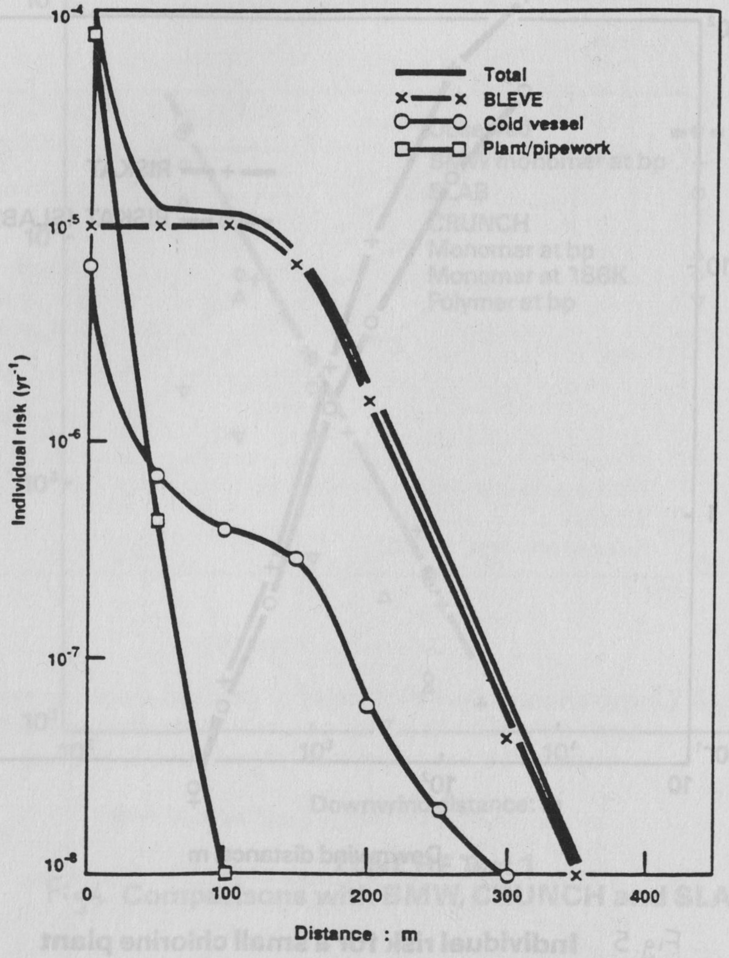

Fig.6 - Variation of individual risk with distance.

AN APPROACH TO THE QUANTITATIVE EVALUATION OF SAFETY ON EXISTING MOBILE DRILLING UNITS

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Older Mobile Drilling Units were designed without appropriate cognisance of the impact of major fires and explosions on accommodation, muster areas, escape routes and evacuation facilities. Whilst measures can be taken to reduce the potential loss of life and other undesirable consequences to tolerable levels within the bounds of acceptable cost, the options are often limited by the inherent configuration of the installation. This paper illustrates the evaluation of the Potential Loss of Life (PLL) for selected hardware upgrades to mitigate quantifiable fires and explosions on a typical installation. A demonstration is thereby provided of techniques to establish the requisite level of hardware upgrades on the basis of aiming for a risk 'As Low as Reasonably Practicable'.

Keywords; Quantitative Risk Assessment, Mobile Drilling Units, Cost-Benefit Analysis, Potential Loss of Life.

INTRODUCTION

The Quantitative Approach to Safety Assessment

A concept central to the new UK offshore legislation in place from mid-1992, is that of self-determination on the part of rig owners, of accident prevention and mitigation systems on the basis of 'ALARP' (risk levels As Low As Reasonably Practicable). The correct adoption of the ALARP principle should be demonstrated within a Technical Safety Assessment, which will be the major constituent of the Safety Case. Where major items of hardware and equipment are proposed, the Health and Safety Executive (HSE) will expect to see a cost-benefit analysis in the Safety Case particularly where

(a) Benefits in terms of the reduction in risk and Potential Loss of Life (PLL) are quantifiable,

and

(b) The level of proposed hardware and equipment does not meet the risk targets pre-determined by the rig owner or operator and agreed by the HSE.

In addition, where the impact on risk figures may be less calculable, proposals for hardware upgrades should be based on other quantitative means such as evacuation analysis.

Quantification is to include estimation of the frequency of major hazards and their consequences including where appropriate, estimates of the number of fatalities. The effects of risk reduction and mitigating measures can be included. By this means, the benefits of hardware upgrades can be weighed against the cost of the accidents which they are designed to prevent or mitigate. This is an iterative process illustrated in Fig. 1.

Improvements to safety management procedures may offer the most cost-effective ways of reducing risk. Hence management options may be exhausted before hardware or equipment upgrades are considered. However safety management is outside the scope of the present paper.

The limitations of QRA must all times be recognised and the data presented herein are produced at a non-refined level and are included for illustrative purposes only.

Application to Existing Mobile Drilling Units

This paper illustrates the evaluation of the PLL for selected hardware upgrades to mitigate quantifiable fires and explosions on a typical installation. An illustration is thereby provided of techniques to establish the requisite level of hardware upgrades on the basis of aiming for a risk 'As Low as Reasonably Practicable'.

The most significant hazard to MODUs, in terms of number of fatalities, is blowout. Older MODUs were designed without appropriate cognisance of the impact of major fires and explosions on accommodation, muster areas, escape routes and evacuation facilities. Whilst measures can often be taken to reduce the PLL and other undesirable consequences to tolerable levels within the bounds of acceptable cost, the options are often limited by the inherent configuration of the installation. Examples of systems or facilities which may be evaluated in terms of the PLL include the following, which is not an exhaustive list;

- Passive fire and explosion protection to spaces which may serve as a Temporary Safety Refuge (TSR).
- Passive fire and explosion protection to muster stations and 'additional refuges'.
- Additional or improved evacuation facilities
- Explosion mitigation.
- Specified emergency systems.

The mitigation of fire and explosion hazards for which quantification is either more limited or not feasible, will be equally important to the development of a Technical Safety Assessment. Such hazards may include fires in storage spaces or electrical equipment. The systematic evaluation of these hazards is not discussed at depth in the present paper.

THE ROLE OF QRA WITHIN THE NEW REGULATORY REGIME

The new regulatory regime in the UK will establish the importance of performing a QRA within the Safety Case. The general overview is that risk targets should not be imposed by regulation but should be consistent with current standards and fulfil the 'ALARP' principle. This principle should be applied whenever a risk is found to be between the bounds of acceptability and intolerability, and implies a Cost Benefit Analysis.

QRA is an element that should not be ignored in decision-making on risk since it is the only discipline capable, however imperfectly, of allowing comparisons of a sort to be made, other than of a purely qualitative kind. This said, the numerical element must be viewed with great caution and treated as only one parameter in an essentially judgemental exercise.

In practice, it is recognised that QRA can be applied with effect only to certain aspects of offshore safety, in particular fire, explosion and evacuation/escape studies. The Cullen Report stated that it is desirable to estimate the frequency of accidental events which would have serious consequences. It also recommends that although a QRA may be used to address major hazards, it is essential to systematically review minor or other hazards which are not amenable to QRA because their frequency cannot be estimated. Thus fires within utility rooms or stores, their impact on safety functions, and potential for spreading, should be considered systematically by techniques such as Failure Mode and Effects Analysis (FMEA).

A central issue is the capability of the accommodation to serve as a TSR where personnel can be protected from external hazards, eg. gas, fire or smoke, in order to control the emergency or to organise escape and evacuation. In the event of a major incident, many platform personnel are likely to be inside the accommodation, some asleep. Their protection until they can be alerted and collected at muster points is of primary importance. The capability of the TSR to withstand these hazards will be determined largely by the breathability of the air within it until the external fire boundary breaks down.

For existing installations the question of how to ensure an appropriate level of safety is significantly different from the case for a new installation. Options for design changes are fewer, at least with respect to major features such as layout. The anticipated useful remaining life of the installation needs to be considered in conjunction with costs and weight penalties of upgrades. However certain stipulations, such as that for the TSR, are unequivocal. Whilst the age of an existing installation may have some influence on the means of introducing the requirement for a TSR, there is limited scope for adjusting the requirement itself.

METHODOLOGY OF A TECHNICAL SAFETY ASSESSMENT

The methodology to be adopted in a Technical Safety Assessment will be described in relation to Fig. 1.

Identification of Hazards

The Technical Safety Assessment must demonstrate that a thorough and systematic approach has been taken to identify incidents which could result in hazardous events causing injury to personnel or significant damage to the installation. For each hazard the systems and equipment installed to respond to and mitigate the effects of the event should be identified. The favoured technique for drilling units is FMEA. The alternative technique, Hazard and Operability Studies, is favoured for production units. However a form of HAZOP using modified guidewords could be applied to drilling units.

Typical hazards can be categorised as follows:

- blowout
- other well related fire and explosions including mud and completion fluids
- other causes of fire, for instance electrical equipment
- impacts and collisions involving both ships and helicopters
- loss of stability
- station holding failure
- dropped objects
- structural failure
- toxic or radioactive release
- extreme weather conditions.

It is possible that several hazardous events may occur simultaneously or sequentially as a result of escalation hence relevant combinations will need to be identified and the consequences considered as for single events.

The most severe hazards will be those which affect the integrity of the TSR. Options for the layout and protection to be afforded to the TSR should be evaluated using the iterative scheme demonstrated in Fig. 1. This should include a smoke and gas ingress study.

Control, Suppression and Mitigating Measures

Management and hardware control systems should be described in advance of the hazard identification to which they will form a necessary input. Having derived the PLL for major accidents (step 7 of Fig 1), management issues may be exhaustively reviewed before consideration is given to hardware aspects. The Technical Safety Assessment will analyse hardware control and suppression systems to ensure that they are adequately protected and that they are able to survive accident events. It should be demonstrated that having survived these events, the systems are reliable in performing the functions for which they are intended.

Should the risk of a major accident exceed pre-determined criteria, the effects of additional prevention measures will be evaluated. Where these are not practicable additional control or mitigating measures should be considered.

Probability Assessment

Estimates for the probabilities of major accident events may be based on information from published sources or from databases. Where necessary, the likelihood of major failures which may originate from more than one equipment failure or originating incident should be evaluated using fault tree analysis. Event tree analysis may be used to estimate the probability that various consequences will arise from a given failure.

Many minor accidents are also amenable to failure rate or statistical analysis.

Consequence Analysis

Consequence analysis should be carried out using codes which model the following accident types;

- pressurised release of gas and liquid, single or two phase
- jet fire
- pool fire
- gas dispersion, both partially confined and unconfined
- unconfined vapour cloud explosion/fireball
- partially confined explosion.

Evacuation

The process of evacuation itself carries risk. The following factors which are essential for safe evacuation should be investigated:

- accident detection and alarm system
- escape route integrity under accident conditions
- viability and accessibility of evacuation systems under accident conditions
- integrity of the accommodation and Temporary Safe Refuge (TSR), particularly against fire and smoke ingress
- integrity of the control centre.

Safety management aspects such as evacuation drills and command structure are also important.

Potential Loss of Life

The PLL, together with the probability of the accident itself, is a crucial figure in the 'ALARP' process. Should any event be shown to have a PLL that is high by accepted criteria, additional accident prevention or mitigation methods should be evaluated. It must be emphasised that the PLL, as with other measures of risk, should be utilised only to compare design or hardware options in terms of cost/benefit aspects.

Evaluation of Minor Hazards

The likelihood of certain minor hazards can be estimated and these should be investigated to ensure that sufficient control measures exist and that the likelihood of escalation is minimised, again based on the 'ALARP' principle.

Overall Risk Level

The Technical Safety Assessment could culminate in an estimate of the overall risk level for the installation. However the overall risk level will not be seen by the HSE as the sole measure of the acceptability of the Safety Case. This will be judged in comparison with current standards taking into account the measures taken to reduce risk.

HAZARD IDENTIFICATION

Most of the significant hazards pertaining to drilling units are readily apparent and a checklist-type approach can be employed. However it pays to study individual compartments or areas, systems, and activities on a methodical basis and FMEA is a common technique for identifying hazardous situations, or limitations of mitigation and suppression systems. Each part of the unit is investigated for failure modes and causes. The effects of failure, together with mitigating or eliminating factors, are then listed. Detailed discussion and analyses of each part of the unit can then take place when the FMEA is over, signalling the end of the hazard identification exercise.

The FMEA considers the effect of the failure in terms of both internal and external events. Although this naturally leads to some duplication, because what is internal to one area is external to another, it leads to a more comprehensive assessment. The failure mode is considered primarily with respect to the most common major hazard types, eg. fire and explosion, together with other initiating events which may affect emergency systems. However, recognising that these reflect the high consequence contribution to risk, attention is also paid to the lesser hazards which may have a cumulative contribution.

The new UK regulations emphasise the need to specifically analyse emergency systems, to ensure that they can withstand accident conditions as far as is practicable. On a typical MODU, emergency systems will include the following;

- emergency shutdown
- essential electrical supplies
- communications
- fire/gas detection
- fire suppression
- ballast control
- emergency windlass disconnect
- emergency riser disconnect
- well control

It should be noted that propulsion may be considered an 'emergency system' if propulsion is required to move away rapidly from a blowout.

EXAMPLE OF QRA; EVALUATION OF THE BENEFIT OF HARDWARE UPGRADES TO MITIGATE BLOWOUT

General Comments

In this section, the application of QRA is illustrated by means of analysing the benefits of the addition of anti-fire and anti-blast barriers or systems on a typical, hypothetical MODU.

The limitations of QRA must be stressed at all times. No claim is made that the methods described herein would lead to estimates of fatalities that are accurate to much within an order of magnitude in any given incident. However the assumptions made and techniques used enable different degrees of protection to be evaluated, on a comparative basis.

Aside from stability impairment as a whole, blowout represents the most probable major accident to be suffered by a MODU. The likelihood of blowout is perhaps one order of magnitude higher on a MODU than on a fixed production platform. Only about one-third of offshore blowouts ignite. However, those that do, and many of those that do not, have catastrophic consequences.

The most important tool in judging the benefit of hardware upgrades to mitigate blowout is the PLL. This is defined in the present example, simply as the estimated number of fatalities per drilling operation. Generally, evaluation of the PLL could be the ultimate, concluding target of a Safety Case. The owner or operator could use these data to decide whether the relevant upgrade should be implemented: the regulatory authority may require explanation of the costings involved, to ensure that risk criteria on the principle of 'ALARP' have been appropriately applied. The owner or operator may take into account other criteria, such as projected loss of income due to a blowout incident, which would raise the acceptable cost threshold.

The Hypothetical MODU

The hypothetical unit selected is a propulsion-assisted semi-submersible with a central drillfloor. The accommodation which is on one side of the unit and over two levels, contains the main control space on the upper level and is to be adapted as a TSR. The helideck is on top of the accommodation.

Results

Appendix A describes a model which demonstrates the evaluation of various levels of fire and blast protection to the TSR. Results from the present approximate example are listed in Table 1.

Discussion

The estimated benefits of enhanced fire and blast protection are not as great as might be expected. Certainly, the improvements to the TSR have a lower impact than would be expected on a production installation, particularly one being newly designed. A new design would take into account the position of the TSR and access to it based on the most likely fire and explosion scenarios. The low impact of the improvements discussed in respect of installations of the present hypothetical configuration, is seen to have two main causes;

- the main risk is due to blowout rather than process fire, and an ignited blowout may have catastrophic, uncontrollable consequences regardless of the degree of protection afforded to the TSR. Whilst many process fires could be 'sat out', an ignited blowout could drastically impair evacuation and rescue and ultimately destroy the TSR regardless of its protection.

- A blowout may render some or all escapeways to the TSR unusable, since the TSR is isolated on one side of the installation and the layout and configuration does not allow easy access to it. This may be counterbalanced by the presence of lifeboat stations (for which protection against fire and blast may be recommended) elsewhere on the installation, however the degree of protection afforded to the TSR may be immaterial to many personnel outside it at the initiation of the accident.

OTHER APPLICATIONS OF QRA

Other safety measures which will require consideration in the new regulatory regime, and for which estimates may be derived of their benefit in reducing fatality rates, include provisions for protection of emergency functions.

Within the TSR, there should be three separate facilities;

- radio communications
- control
- emergency command

Demarcation between spaces serving these functions is desirable. However, ergonomic considerations will prevail with the objective that control of an emergency should not be hindered by a design that is dedicated to routine or administrative functions.

It is to be expected that on the majority of existing MODUs, the following emergency functions should be included in the TSR, or should have a degree of protection commensurate with it;

- fire and gas detection
- fire fighting control
- alarm
- communications both internal to the rig and external
- well control
- emergency power

On the majority of existing MODUs, control centres within the accommodation can be readily adapted to incorporate these functions; or they may already be incorporated. There remains some flexibility on the extent of these functions to be served from the TSR. For instance, the required type of fire fighting control and degree of well control could be determined by fault tree and other analyses, with practicability a prime consideration. Emergency power may be located separately if given protection similar to that of the TSR.

The inclusion of other functions within the TSR may be the subject of analysis for the PLL. Particular examples on existing MODUs are;

- emergency mooring disconnect
- emergency riser disconnect
- ballast control

On many existing MODUs these functions are non-centralised. Determination of the benefits of their centralisation is relatively straightforward, using more detailed consequence analysis allied to fault tree analysis. There is insufficient space to describe these techniques herein.

Many other significant hardware changes to reduce the level of risk to a typical unit cannot be readily quantified. This includes as an example, protection to emergency power supplies. However measures such as this may be covered by prescription. Non-quantifiable measures which are not specifically covered by prescription, for instance fire suppression or fire barriers within utilities, should be treated on the basis of consequences alone. However such measures are generally less expensive than the hardware upgrades discussed above, and on a space by space basis, existing provisions are usually either adequate or can be upgraded cheaply by, for instance, improved detector coverage.

ESCAPE AND EVACUATION

An escape and evacuation study is most suitably carried out as part of the QRA process demonstrated in Appendix A. This process will identify manned locations from which access to evacuation facilities, perhaps lifeboat, liferaft or ladder, may not be possible. Accordingly, the benefits of additional evacuation means may thus be incorporated into the quantification procedure. The process will also identify the locations at which personnel survival equipment, such as breathing apparatus, should be placed.

Many older, existing MODUs are equipped with multiple muster stations. Consistent with the shape of the installation and the intrinsic path of the escapeways, it is often to be recommended that these should remain. However muster stations external to the TSR will be prone to fire, smoke and explosion effects. These muster stations should be protected against radiation and blast, incident radiation levels from a topsides blowout being immediately dangerous to life. However depending on the configuration of the installation, and on the escape and evacuation analysis, it may be necessary to have sufficient lifeboat capacity adjacent to the TSR for all crew in the event of other escapeways becoming impaired after crew have sheltered in the TSR.

This will enable the TSR to fulfil its desired role, whilst the remaining muster stations may be required by personnel unable to reach the TSR.

Should the highest grade fire protection not be proposed for the TSR, then the QRA may rely on evacuation analyses incorporating assumptions for hurried evacuation which may be difficult to substantiate. In such cases, where mustering and the launching of lifeboats may not be carried out fully according to plan as laid out in drills, additional evacuation facilities may be required to ensure that the assumptions do not give an optimistic result. These additional facilities could include, for instance, liferaft capacity for all crew and additional ladders, or an escape chute.

DISCUSSION AND CONCLUSIONS

A technique has been demonstrated for the estimation of the benefits of hardware upgrades in reducing risk levels on a typical existing MODU. By such techniques, justification for recommended improvements can thus be provided when the resultant benefits are weighed against their cost. As a particular example, an estimation of the benefits of measures proposed to protect the TSR, has been presented. The methodology has been developed to meet the intent of the new 'goal setting' regulations in the UK, however it is pertinent to MODUs operating in all regions where the risk acceptance criteria may differ.

The estimation of benefits deriving from other quantifiable measures to reduce risk levels, has been discussed. These measures include relocation and centralisation of control functions.

ACKNOWLEDGEMENTS

The author is grateful for the help and encouragement provided by G Jones and J Stansfeld, of the Safety Technology Department, Lloyd's Register.

CASE	A	B	C	D	E	F	G	C′	E′	F′	G′
PLL X 10^{-3}	9.5	8.7	8.7	7.8	7.8	8.7	7.8	8.2	6.7	8.0	6.5

Refer to Table 4 for case description

TABLE 1 POTENTIAL LOSS OF LIFE DUE TO BLOWOUT

DESCRIPTION OF OUTCOME	OUTCOME FREQUENCY (PER WELL DRILLED)
Topsides jet fire/topsides pool fire	7.2×10^{-6}
UVCE/topsides jet fire/topsides pool fire	7.7×10^{-6}
Pollution by oil and gas	2.8×10^{-5}
Topsides pool fire	1.4×10^{-6}
Pollution by oil	3.2×10^{-6}
Topsides jet fire	7.4×10^{-5}
UVCE/topsides jet fire	5.0×10^{-5}
Pollution by gas	2.9×10^{-4}
UVCE/sea surface gas fire/sea surface pool fire	6.6×10^{-6}
Pollution by oil and gas	1.5×10^{-5}
Pollution by oil	2.5×10^{-6}
UVCE/sea surface gas fire	6.6×10^{-5}
Pollution by gas	1.5×10^{-4}

NB. Data are representative only.

Multiply by factor of 3.9 to convert to basis of per unit year (assuming typical drilling deployment)

TABLE 2 OUTCOME FREQUENCIES FOR BLOWOUT EVENTS

Flame length	67m
Flame diameter	13m
Max Flux	280kW/m^2
Distance from flame axis to flux of 37.5kw/m^2	26m (corresponding to failure of unprotected load bearing structural steel within 20min.)
Distance from flame axis to flux of 11kw/m^2	34m (corresponding to third degree burns, assumed to lead to instant fatality)
Distance from flame axis to flux of 4kw/m$_2$	42m (corresponding to impairment of escapeways).

TABLE 3. PARAMETERS OF AN IGNITED BLOWOUT MODELLED AS A 60 KG/S RELEASE FROM A 9⅝" CASING

Case	Fire Protection	Blast Protection
A	A60 on upper level of IFE	None
B	A60 on IFE and roof	None
C	A60 on IFE and roof	ON IFE and roof
D	H120 on IFE and roof	None
E	H120 on IFE and roof	On IFE and roof
F	A60 on IFE and roof	Each elevation and roof (excluding port elevation)
G	H120 on IFE and roof	Each elevation and roof (excluding port elevation)

TABLE 4. EVALUATION OF POTENTIAL LOSS OF LIFE CASES

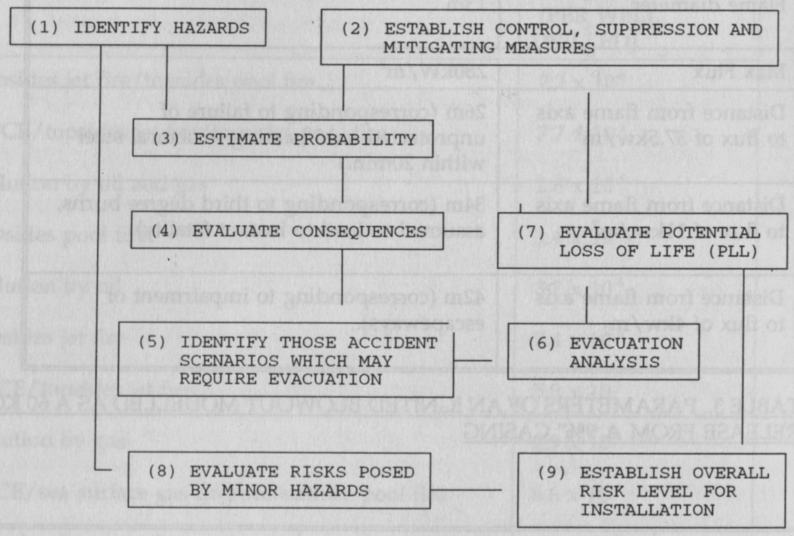

FIG. 1. STEPS IN QRA

APPENDIX A

ESTIMATION OF POTENTIAL LOSS OF LIFE DUE TO BLOWOUT

Basic Data

Likelihood of Blowout For the present hypothetical example, a blowout frequency of 7×10^{-4} per well drilled is assumed. The accident outcome frequencies are listed in Table 2, these data being derived by event tree analysis which takes into account the likelihood that the unit can disconnect and move away from the blowout. Detailed discussion of the likelihood and consequences of blowout is outside the scope of the present paper.

Consequences of Blowout The parameters of a jet fire of an ignited blowout modelled as a 60kg/s release from a 9⅝" casing are detailed in Table 3.

Whilst these conditions represent the mean, a smaller or greater discharge rate will not strongly affect the present analysis since the consequences will in each case be similarly severe within the confines of the platform.

An Unconfined Vapour Cloud Explosion (UVCE) is assumed to yield an overpressure of 0.2 bar. UVCEs also generate lethal radiation levels to people directly exposed to the flame.

The large quantity of oil released during a topsides oil blowout could not be dealt with by the rig drains. Oil would accumulate on the drillfloor and overflow down stairways and other gaps. The whole of the central part of the installation would be engulfed, although muster stations would not be affected. Radiation levels would approach $100\mathrm{kW/m^2}$. Oil would fall onto the sea surface and if ignited, could impair evacuation by lifeboat or other means.

A subsea blowout will result in a bubbly flow of gas and development of a 'subsea plume' with the shape of an inverted cone. The velocity of the gas as it breaks the surface, for all reasonable water depths, will be of the order 5 m/s. If the gas ignites, the resulting sea surface gas fire will have a flame that is laminar, instead of turbulent as in the case of a topsides blowout. Radiation levels from laminar flames are typically one order of magnitude less than those from turbulent flames, and in this case will be insufficient to affect escapeways or shelter areas, although the columns may fail quickly if direct flame impingement were to take place. However radiation levels beneath one or more lifeboat stations may be high, preventing the use of that lifeboat.

Oil released from a subsea blowout could cover much of the sea surface beneath the installation depending on wind and current. Radiation levels would lie in the range 50 - $100\mathrm{kW/m^2}$ at the sea surface. Radiation would not be sufficient to impair escapeways or muster stations in the short term, however a pool fire beneath a lifeboat station would prevent use of that lifeboat.

The times to failure of important structural components are important parameters. For the purpose of the present example, analytic or numerical techniques were not utilised and commonly tabulated data were adopted instead. As an example, it is assumed that an A60 firewall would be penetrated in 20 minutes by a heat flux of 37.5kw/m^2 from a jet fire.

An estimate of the distribution of personnel about the installation is required. For the present hypothetical example, it is assumed for instance, that there are 40 personnel present in the accommodation, and a total complement of 80. The likelihood of survival of personnel outside the accommodation is dependent on the degree of shelter and the accessibility and vulnerability of escape routes.

Evaluation of the PLL

It is assumed that the hypothetical MODU has no blast protection, and only one A60 firewall on the upper level of the Inward Facing Elevation (IFE). It is assumed that the IFE is on the starboard side of the accommodation. H120 barriers must be added to the IFE, unless a risk analysis shows a lower grade barrier to be acceptable.

A range of fire durabilities must be evaluated in order to demonstrate that the risk is ALARP. Fire protection need be applied essentially only to the IFE and roof. However it should be applied to at least 20% of the length and depth of the adjacent elevations.

Blast analysis has shown that overpressures of 0.2 bar may be imposed on the TSR by a UVCE. The disposition of blast protection, ie. which surfaces should be so protected, must be considered. Owing to the indiscriminate nature of a UVCE, more surfaces may require blast protection than require fire protection. The cases detailed in Table 4 will be evaluated.

It is further necessary to consider the integrity of the fire protection after it has been subject to blast, in those cases where both fire and blast protection is assumed. It is assumed in cases A to G that each blastwall loses its stated fire resistance after being subject to the initial blast. However, in additional cases denoted C′, E′, F′, G′, it will be assumed that each blastwall retains its stated fire resistance.

Note that blast protection to the floor of the TSR has not been investigated. It could be beneficial as protection against a UVCE deriving only from a subsea blowout, and not from a topsides blowout. Most deck structures are estimated to withstand overpressures approaching 0.5 bar. Furthermore it is judged that blast protection to the outboard side of the accommodation is not justified. This elevation will be in the lee of the blast wave and in this location the effect of flame acceleration by obstacles is unlikely to be felt.

The likelihood of fatality of personnel at a given location is estimated in respect of the effects of thermal radiation and overpressure on the following;

- people immediately exposed.
- people who may not be immediately exposed, but who may not be able to escape, and who may only have short term protection.
- fire resistant and blast resistant walls.

Evacuation in itself can be dangerous and it is important to assess the scenario-dependent risk of evacuation. It is assumed that evacuation by helicopter would not be attempted during a blowout. The success rate of evacuation by lifeboat is based on other published work. A fatality rate of 0.04 is assumed, an average figure for all weather conditions. The number of personnel who successfully enter the lifeboats is assumed to follow a linear distribution, from zero after 27 minutes from the initial incident, to the entire remaining evacuees present at the muster station (subject to lifeboat capacity) after 37 minutes. The fatality rate for personnel evacuation into the sea is 0.11. This figure is averaged for weather conditions and is a mean figure for the use of liferafts or passing directly into the sea. The above data, like others used in the present paper, are simplified figures used only to derive the present hypothetical example.

The PLL is estimated for each of the event tree outcomes presented in Table 2 and for each level of fire or blast protection A to G′. The estimated total PLL is found by summing over each case A to G′. These results have been presented in Table 1.