PROCEEDINGS

INTERNATIONAL WORKSHOP
Fire & Blast Considerations in the Future Design of Offshore Facilities

June 12-14, 2002
Houston, Texas, USA

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SUMMARY

These Proceedings have been prepared as a record of the International Workshop on Fire and Blast Considerations in the Future Design of Offshore Facilities. The Workshop was held in Houston, Texas on June 12-14, 2002. Included in the proceedings are the keynote presentations and theme papers presented at the Workshop as well as white papers prepared by seven Working Groups ahead of the Workshop, around which much of the discussion at the Workshop was organized. The Working Group subject areas included philosophy and management processes, safe design practice, blast loading and response, fire loading and response, floating production systems, exploration and drilling operations and regulation and certification. Each of the Working Groups presented a summary of the outcome of their discussions over the duration of the Workshop and these are included herein with each of the Working Group papers.

ACKNOWLEDGEMENTS

This was the first Workshop on the subject of fire and blast design for offshore facilities supported by the Minerals Management Service (MMS). The success of the event is attributable to many people and organizations, including the many Workshop Sponsors, including major oil companies, classification societies, engineering companies, specialist consultants and international regulatory bodies. The time, effort and advice of each of the Technical Advisory Panel members is gratefully acknowledged with special recognition of the personal investment from the Chairs and co-Chairs of the Working Groups. Worthy of particular mention is the expertise, experience and guidance provided by Charles Smith and his colleagues in the Minerals Management Service especially Paul Martin.

Finally the excellent special interest presentations of Henri Tonda with TotalFinaElf and Ricardo Rios de Campos Rosa with the Agência Nacional do Petróleo, are also gratefully acknowledged.

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WG1: Philosophy and Management Processes

Chair: JOHN ALDERMAN, RRS Engineering

Co-Chair: DONNIE CARTER, BP America, Inc.

WG2: Safe Design Practice

Chair: JOHN WISHART, Technip-Coflexip

Co-Chair: DAVID KEHN, Mustang Engineering

WG3: Blast – Load and Response

Chair: DOUG ANGEVINE, ExxonMobil

Co-Chair: DARREL BARKER, ABS Consulting

WG4: Fire – Load and Response

Chair: BEN POBLETE, LRNA

Co-Chair: JOEL KRUEGER, BP America Inc.

WG5: Floating, Production and Storage Systems

Chairs: RAJIV AGGARWAL, ABB

Co-Chair: BOB GILBERT, University of Texas, Austin

WG6: Exploration and Drilling Operations

Chair: MALCOLM SHARPLES, ORTC

Co-Chair: CONN FAGAN, DNV

WG7: Regulation and Certification

Chair: KEN RICHARDSON, ABS

Co-Chair: KENT DANGTRAN, ABS

WORKSHOP PROGRAM

WEDNESDAY June 12, 2002

DAY 1

7:30 – 9:00	Registration (Coffee & Pastries)
9:00 – 9:10	Welcome Remarks (J.Bucknell, MSL)
9:10 – 9:30	Keynote Speech: **Regulatory Perspective,** Elmer Danenburger III, Chief Engineering and Operations Division, MMS
9:30 – 9:50	Keynote Speech: **Industry Perspective,** Patrick O'Connor, Chair, API Task Group for Fire and Blast, BP
9:50 – 10:10	Keynote Speech: **Certification Body,** Kenneth Richardson, Vice President Engineering, American Bureau of Shipping
10:10 – 10:30	**BREAK**
10:30 – 11:00	Theme Paper: **Design Philosophy and Management Processes,** Graham Dalzel, BP
11:00 – 11:30	Theme Paper: **Fire: The State of the Art,** Ben Poblete, LRNA
11:30 – 12:00	Theme Paper: **Blast: The State of the Art,** Vincent Tam, BP
12:00 – 1:30	**LUNCH –** Special Interest Presentation: **Petrobras P36 Accident Investigation,** Ricardo de Campo Rosa Rios, Agéncia Nacional do Petroleo (ANP)
1:30 – 2:00	Theme Paper: **International Perspective,** David Galbraith, UKOOA / HSE
2:00 – 3:00	Introduction to the Working Groups – J. Bucknell, MSL Overview from Work Group Chairs: WG 1: Philosophy and Management Processes - J. Alderman, RRS WG 2: Safe Design Practice – J. Wishart, Technip - Coflexip WG 3: Blast – Loads and Response – D. Angevine, ExxonMobil WG 4: Fire – Loads and Response – Ben Poblete, LRNA WG 5: Floating, Production and Storage Systems – R. Aggarwal, ABB WG 6: Exploration and Drilling Operations – M. Sharples, ORTC WG 7: Regulation and Certification – K. Dangtran, ABS
3:00 – 3:30	**BREAK**
3:30 – 5:00	Working Groups 1st Session
Evening	**RECEPTION**

THURSDAY June 13, 2002

DAY 2

8:00 – 8:30 Coffee & Pastries
8:30 – 9:00 Keynote Speech: **Fire & Blast in Offshore Installations,**
Captain Daniel Ryan II,
Chief, Marine Division, United States Coast Guard
9:00 – 9:30 Theme Paper: **Large Scale Testing – Jet fires,**
Alex Wenzel, Director, South West Research Institute
9:30 – 10:00 Theme Paper: **Large Scale Testing – Blasts,**
Gary Shale, Advantica Technologies Limited
10:00 – 10:30 **BREAK**

10:30 – 12:00 Working Groups 2nd Session
12:00 – 1:00 **LUNCH**

1:00 – 3:00 Working Groups 3rd Session
3:00 – 3:30 **BREAK**

3:30 – 5:00 Working Groups **Final Session**

FRIDAY June 14, 2002

DAY 3

7:30 – 9:00 Coffee & Pastries
9:00 – 9:30 Discussion Paper: **Deepwater Project Presentation**
9:30 – 10:00 Special Interest Presentation: **FPSO Girassol**,
Henri Tonda, TotalFinaElf

10:10 – 10:30 **BREAK**

10:30 – 12:00 Reports on Working Groups : Group Chairs

ADJOURN

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INTRODUCTION

The first MMS Workshop on the subject of fire and blast design for offshore facilities was held in Houston Texas on June 12-14, 2002. The Workshop attracted a gathering of over 150 participants with wide international representation including each of the major regions of offshore oil and gas development. The objectives of the Workshop were as follows:

- To provide a forum for sharing the worldwide industry knowledge and experience in regard to the design of offshore facilities for fire and blast events.
- To compare and contrast different practices in a number of subject areas including philosophy and management processes, safe design practice and fire and blast loading and response assessment.
- To identify if and where future research and development may assist industry.
- To produce a record of the proceedings and a web site for dissemination of the shared learning to interested parties.

The aim of these proceedings is to provide a record of the papers, presentations, discussions, conclusions and recommendations from the Workshop for future dissemination. The document is organized into a number of sections. This first section provides a summary of the presentations and the white papers prepared for discussion in the parallel Working Group sessions and reports on the outcomes of the discussions of these sessions. This section has been largely reproduced from an article published in the September 2002 issue of the FABIG newsletter, with the kind permission of the author, Dr. Bassam Bergan. The following sections contain the keynote presentations, special interest presentations, theme papers and the white papers that formed the basis of the discussions within the Working Groups.

WORKSHOP SUMMARY

This first section provides a summary of the presentations and the white papers prepared for discussion in the parallel Working Group sessions and reports on the outcomes of the discussions of these sessions. This section has been largely reproduced from an article published in the September 2002 issue of the FABIG newsletter, with the kind permission of the author, Dr. Bassam Burgan.

Keynote presentations

Regulatory perspective

The first keynote presentation of the workshop was by Elmer Danenburger III, Chief Engineering and Operations Division, MMS. The presentation gave a perspective from the Regulator. Mr Danenburger III put into perspective the importance of the offshore continental shelf, this being the largest source of oil in the USA, with over 560 million barrels per year. He stressed the increasing importance of the topic of fires and blast as larger and deeper water developments became more common. He presented data that showed a trend of declining number of fatalities and set a target for the industry of a year with zero fatalities. He also presented fire accident statistics that showed 474 OCS fires in the period 1997-2002. Of these, 92% caused less than $25,000 damage, and 2% (9 fires) caused damage in excess of $1,000,000. Of the latter, three fires were of a catastrophic nature, two of which were caused by blowout and one by a release from a corroded pipe. The fires had caused 2 fatalities and 29 injuries. A third of these accidents was caused by compressor or generator operations and a further quarter by welding operations.

He foresaw a design regime that had room for both best practice prescriptive rules and performance-based goal setting design that leaves scope for innovation. This contrast of design approaches became a topic of considerable discussion throughout the workshop.

Industry perspective

Pat O'Connor (BP UTG Houston) who is currently the vice-chair of API SC-2 and chair of the API task force "Design of offshore structures for fire and blast loading" gave the industry perspective in the second of the keynote presentations. He contrasted North Sea and GoM practices, describing the former as an advanced technology based culture and the latter as one of pragmatic approach to design. There had been some 6,000 platforms constructed in GoM, the design of which tended to be repetitive, the majority being small open platforms, and the sector had had an excellent safety record, derived from the inherently safe nature of these installations. North Sea platforms on the other hand are in deeper water, larger, more congested, less open and with high flow rates, thereby necessitating a different approach to design.

He briefly described recent and ongoing API work on API 75 "philosophy, management and processes", API 14J "safe design practice" and the new API fire and blast design guidance and went on to introduce the Working Groups responsible for the White Papers which were to be discussed during the workshop.

Certification body perspective

Kenneth Richardson, vice-President, Engineering of the American Bureau of Shipping gave the certification body perspective in the third keynote presentation. He said that classification society rules have to date been prescriptive and this approach had been successful. However, he felt that the change to performance-based design was inevitable if the rules were to extend to complex deepwater offshore facilities. He cited the IMO and revised edition of the SOLAS convention that have adopted performance-based rules, and ABS guidelines on the application of performance based rules. He also talked about the role that could be played by classification societies in the collection and sharing of information, due to their unique position as a recipient of designs from across the industry.

US Coast Guard perspective

Captain Daniel Ryan II, Chief Marine Division of the US Coast Guard, gave an overview of the activities and responsibilities of USCG (Eighth District), including countering terrorist threats, rescuing mariners in distress, catching drug smugglers, stopping illegal migrants, and protecting the marine environment. He also alluded to the resource constraints given the breadth of responsibilities of the USCG. The offshore oil and gas operations within the jurisdiction of USCG is vast with over 4,000 platforms and 172 mobile drilling units and production of 340 million barrels crude oil and 4.7 trillion cu ft natural gas. Captain Ryan II gave a breakdown of the population of offshore platforms, 3,000 being unmanned and 1,000 manned platforms. Of the latter, deepwater platforms (>1000ft) comprise 6 TLPs, 3 Spars, 1 Semi-Sub FPS, 3 Mini-TLP and 1 Compliant Tower.

He spoke about the lack of any comprehensive guidance on fire and blast relating to offshore oil and gas facilities, but said that this is currently being addressed. He made specific reference to the extension to the code of federal regulation (Proposed Rulemaking 33, CFR, Subchapter N). These regulations apply to all activities occurring on the OCS. The revision is needed to cope with new developments in the offshore industry, to fully address existing legislation, to effectively implement interagency agreements, to respond to comments received from the advanced notice of proposed rulemaking, and to address casualty investigation findings. This rulemaking improves the level of safety in the workplace for personnel engaged in OCS activities and specifically fire protection equipment, systems fire, protection facilities and accommodation spaces. He also referred to the guide to structural fire protection (Navigation & Vessel Inspection Circular No. 9-97, NVIC 9-97). He explained that fire and blast issues have become of greater concern to USCG with the increase of larger deepwater facilities in GoM (the deepwater facilities in GoM account for 50% of the Gulf's oil production). Captain Ryan II also described the MOU between USCG and MMS signed 16 December 1998, identifying the areas of interest and the lead agency responsibilities associated with MODUs and fixed and floating OCS facilities.

Theme papers

Design philosophy and management processes

In the first theme paper of the workshop, Graham Dalzell, BP discussed design philosophy and hazard management processes. He described hazard management as a balancing act; balancing prevention with protection, fire and explosion hazards with marine, weather and structural hazards, people with plant, generic with specific requirements. He also discussed inherently safer design, saying that it had fewer hazards (e.g. less processing), fewer causes (less and better trained people), and fewer consequences. He said that to design inherently safer facilities, we must determine what is dangerous, why it is dangerous and whether there is a safer way of achieving the same objective. He also stressed the need for resources and leadership to achieve inherently safer design. This included ownership of the hazards by the design team, allowing sufficient time to properly assess these hazards and investment in solutions that offered integrity and reliability. Graham also traced the development of design processes through codes, process safety management (hazard analysis, people and plant), safety case approach (hazard analysis, risk assessment and demonstration of ALARP) and integrated hazard management, which he described as comprising:

- Hazard understanding (cause, severity, consequence)
- Basic building blocks (codes, people, plant, processes)
- Hazard strategy (managing each hazard)
- Systems required to manage the hazards
- Performance standards to be achieved
- Embedding and communicating the strategy

Graham concluded by summarising the performance indicators that could be measured (code compliance, risk numbers, safety systems, design process, hazard understanding and meeting commitment). He said that these indicators could be measured against codes and standards, minimum prescribed requirements, engineering judgement, qualitative risk assessment, quantitative risk assessment (QRA) and stakeholder opinion.

Fire: the state of the art

Ben Poblete (Lloyds Register) gave the second theme paper, entitled “Fire: the state of the art”. He commented on fire regulations pre-Piper Alpha, saying that these were embodied in local regulations, class society and in-house company rules, standards (API, USCG, SOLAS), standard fire curves and were largely prescriptive. He also commented briefly on the hydrocarbon jet and pool fire research and improvements in fire protection post Piper Alpha. He described the changes that occurred in the UK, starting with the Cullen Report, revocation of certification schemes, introduction of safety case regulations (UK SI 1992 No. 2885), emphasis on hazard identification and management, competent body services and verification schemes. The combination of these changes and factors led to a move from prescriptive to goal setting design. He contrasted this with USA practice where which is largely prescriptive, and cost, schedule and weight driven.

Ben went on to discuss risk management stating the key elements to be identification, analysis, consideration, judgement, implementation and communication. He also ranked risk management in terms of maturity, from compliance based, through knowledge based, data based, model based to the ultimate omniscient based risk management. He predicted a move in the future to performance based fire design with potential for innovation, clarity and economy.

Blast: the state of the art

Vincent Tam (BP) presented the third theme paper entitled "Blast: the state of the art". He started by explaining the difference between deflagration (with overpressures from a few mb to a few bars and generally associated with hydrocarbon explosions) and detonation (with overpressures in excess of 18 bars). He went on to discuss some explosion fundamentals, their damage potential and explosion event trees (release, dispersion, ignition, exploding, loading, response). He described the factors that influence explosion characteristics and the magnitude of loading (pressure and drag) generated from an explosion; these are fuel type and concentration, ignition location, confinement and congestion and active and passive control measures.

Vincent gave a historic perspective, starting with the Cubbage and Simmonds explosion model (1954) and its misuse in later years. He discussed the Flixborough accident (1974) and the research on unconfined congested explosion that this lead to, as well as the small and medium scale testing and model development of the late 1970's and 80's. This was followed after Piper Alpha by an era large scale testing and model validation. Vincent mentioned the following milestone JIP's:

- Blast and Fire Engineering Phase 2 (coordinated by The Steel Construction Institute), 1994-1997. This was the first project to undertake large-scale testing and formal model evaluation. It demonstrated that much larger explosion overpressures than previously shown can be generated with stoichiometric gas/air mixtures and that model predictions of such explosions could vary by several orders of magnitude.
- Explosion model evaluation projects MEGA and EME (coordinated by The Steel Construction Institute), 1994-1998. These projects led to European Model Evaluation Protocols, which were used in Phase 2 to carry out the model evaluation against the large-scale test results.
- Blast and Fire Engineering Phase 3a (coordinated by Advantica), 1997-1998. The project considered the effect of larger venting areas (than Phase 2), deluge systems and ignition positions.
- Gas dispersion project (coordinated by BP), 1999-2000. This project looked at gas dispersion and build-up at large scale. It showed that gas build-up time was very small (10's of seconds), that leaks can generate additional ventilation in certain conditions and that local stagnant zones of gas can develop.
- Blast and Fire Engineering Phase 3b (coordinated by Advantica), 2000-2002. This project undertook large-scale explosions with realistic (rather than stoichiometric) gas/air mixtures. The tests generated much lower overpressures than equivalent tests with stoichiometric mixtures, but presented greater modeling challenges.

Vincent concluded by stressing the need to consolidate this knowledge in the form of design guidance.

Guidance initiatives

David Galbraith gave an international perspective of explosion and fire guidance and standards initiatives. He summarised the recent and current initiatives as follow:

- USA: API Task group for fire and blast and MMS Workshop (current)
- UK: UKOOA / HSE new explosion and fire guidance (current)
- Canada: Revision to CSA S471
- Norway: Norsok Standards Z-013, N-003 (both published)

He mentioned that the current phase of the UKOOA/HSE project which aims to produce updated explosion design guidance is attempting to tackle the problem in a codified fashion (UKOOA Decision Making Framework Type A). The new guidance will also introduce the concept of bounding design cases which may be used at concept and FEED stage. He also introduced the idea of tabulated explosion loads for different types of installation and facility areas. He said that such loads my be modified by factors which account for specific physical conditions (production rate, compression pressure, gas composition, number of production trains, module footprint, confinement, module aspect ratio).

David contrasted this with the more rigorous and probabilistic based Norwegian approach covered by Norsok Standards (Z-013 Risk and preparedness analysis and N-003 actions and action effects). The procedure requires establishing leak scenarios, cloud size distribution, explosion loads (fro CFD simulations), consequences and presenting risk picture (report). He said that this approach, which was closely adhered to in Norway) required a large number of analyses (CFD and QRA).

David also mentioned Canadian Petroleum Board Regulations, in particular CSA standard S471 which has a section dealing with accidental loads and refers to the Norsok N-003 and Z-013 / ISO for loadings and other NORSOK documents. This is currently being updated and reference to the UKOOA/HSE proposed methodology is likely to be made. David concluded by mentioning the relevant ISO Standards (ISO 13702 Control and mitigation of fires and explosions and ISO 19901-3 Topside structures, which is currently on hold pending completion of the UKOOA/HSE and API work).

Large scale testing: jet fires

Alex Wenzel (Southwest Research Institute) discussed medium and large scale fire test methods. In the context of compartment fires, he addressed the oxygen consumption calorimetry test, ASTM E84 Tunnel Test and ISO 9705 Room Test. He stated that, whilst significantly more expensive than small scale tests, these intermediate to large-scale tests have the advantage that they account for the effects of scale on fire performance of products and systems. He also discussed the Fire Resistance Furnace Test (ASTM E119, IMO A754) and its role in determining the performance of decks and bulkheads, the fire endurance test for pipes (IMO A753) and pool fire tests. He described the role of the International Jet Fire Working Group and its role in developing a laboratory scale jet fire test procedure for evaluating PFP materials. He concluded with a discussion of fire models and the need to validate such model using test data at small, intermediate and large scale.

Large scale testing: Blast

Garry Shale (Advantica) discussed the history of large scale explosion testing, starting with the repeated obstacle tests in a 45m long rig carried out in the wake of the Flixborough disaster. He went on to describe the 1/3 scale tests carried out after Piper Alpha using oxygen enrichment techniques to enhance the reactivity of the gas (as a means for accounting for scale effects). This was followed by an overview of the large scale tests carried out within a number of joint industry projects (Phase 2, 3a and 3b). He said that Phase 2 and 3a showed that very high overpressures can be generated with stoichiometric air-gas mixture filling the entire volume. Phase 3b which included large scale tests with partial fill and realistic releases, showed that overpressures can be significantly reduced under such circumstances. He said that Advantica have used the results in the development of a risk assessment package. He also briefly mentioned the role of large scale testing in product performance demonstration.

Explosion & fire Analysis for FPSO Girassol, off Angola

Henri Tonda, TOTALFINAELF, presented a case study looking at the explosion and fire analysis of the FPSO Girassol. At 300x60m, this is the world's largest FPSO at present. It has a topsides operating weight of 28,000 tons, a production plateau and oil treatment capacity of 200,000 bopd and oil storage capacity of 2 million bbl. It has a 140 person accommodation module located on the aft of the facility.

The company's ALARP policy was adopted, namely design to avoid accidents; where accidents may occur, aim to reduce their effect. In addition to SOLAS requirements, the following active and passive fire safety design measures were applied:

Active: deluge and foam all cargo tank area, deluge on chains, life boats & in Risers' I tubes, water curtains and monitor for sea pool fire.

Passive: access tunnel between TSR and free fall lifeboats, maximum plating topside deck, bunds (transverse and longitudinal).

The explosion 'avoidance' design philosophy followed the following strategy:

- Eliminate leaks in critical areas (no gas equipment between hull & topside decks, no PV breakers between 2 decks)
- Facilitate natural dispersion (topside deck at 7 m, maximum grating, no fire walls on topside, no equipment (except hull piping) between decks, large structures down wind, no escape tunnel)
- Avoid ignition (no equipment between hull & topside decks, no supply birthing in process area, gas detection on hull deck, air lock in all buildings, no doors directly toward process)

The philosophy to reduce the effect of explosions followed the following strategy:

- Avoid confinement (maximize dispersion, spread of equipment on all hull's surface)
- Avoid congestion (topside deck at 7 m, minimum equipment on hull)
- Use deluge where necessary (below all topside deck)

- Protect accommodation module and critical equipment (accommodation far from topside and capable of resisting credible explosions, cargo tanks deck capable of resisting credible explosions, E/I building resists as much as process equipment, large, open and empty area between LQ and topsides, reinforcement of equipment supports, risers esdv)

To avoid cargo tank explosions, submerged pumps, individual PV breakers, 2 gas inert networks, 2 gas inert units, continuous O2 control in cargo tanks and continuous gas hydrocarbon control in ballast were used. To reduce cargo tank explosion damage the topside deck was located at 7m (this is the only reasonable design measure to resist to a cargo tank explosion).

Henri went on to describe in some more detail the company's ALARP criteria. Consequences were divided into four categories:

- Minor: Consequences local to where incident occurs
- Significant: Consequences are limited to one zone (or ''module'') of the FPSO. Possible off-site effects, 3rd party interest not endangered.
- Major: Consequences extend to several zones (or ''modules'') of the FPSO; 3rd party interest endangered, but not threatened.
- Catastrophic: Consequences extend to all the FPSO, 3rd party interest threatened, and impact on the environment

Major incidents with a frequency of 10-2-10-1 are class I and improvements are deemed necessary. Significant accidents with a frequency of 10-3-10-2 are class II and are a target for improvements whereas minor accidents with a frequency 10-3-10-4 are class III and are considered a remote risk.

Gas cloud size distribution was evaluated as a function of frequency and these were assessed against the ALARP criteria, leading to identification of the credible accident scenarios. These scenarios were analysed and the overpressure values (dry and deluged) were determined and used in the design.

In the case of pool fire scenarios, the criteria stipulated that the fire may be harmful if:

- smoke content > 1%
- CO content > 1500 mg/m^3 during 30 mn
- CO^2 content> 100 000 mg/m^3
- air temperature> 150°
- radiation level > 6.3 kW/m^2

The pool fire scenario assumed a fully plated deck with no equipment, 42 m^2 (14x3m) pool filled with 2147 kg (initial thickness 0.06m) of stabilised oil and wind speed 5 m/s perpendicular to hull coming from sea.

White Paper Discussion Groups

Work Group 1 – Philosophy and Management Processes

Chair: John Alderman, RRS

This paper outlined a basic fire and explosion management strategy for offshore facilities. It described the overall hazard management system (HMS) as a framework of guidance (applied to every design decision, to all elements of the project and to all stages of the lifecycle of the facility) to allow consistent and methodical evaluation and management of hazards and risk. The fire and explosion management strategy is an integral part of the HMS. Timely application of this process is essential so that every opportunity to minimize hazards is identified and considered while it can still be implemented cost effectively. The paper defined risk as the product of probability and consequence and ranked risk reduction concepts and mitigation measures.

The paper also addressed the key elements in the implementation of a HMS. It described the following implementation strands:

- Hazard understanding (causes and likelihood, severity, consequence, escalation potential and risk)
- Hazard elimination or minimization (by designing out, inherently safe design, reduction of damage potential at source, reduction of impact on people and facility and elimination of escalation chains and impact on safety critical elements).
- Hazard management strategy (prevention, control, mitigation, escalation reduction/control, emergency response, evacuation and rescue)
- System choice (design codes and standards, passive systems, active systems, operational systems and external systems). For each system specified, performance standards must be set giving due regard to the role, functionality, reliability, availability and survivability.
- Demonstration that the risk acceptability criteria have been satisfied using, for example, the ALARP concept
- Documentation covering the hazards, causes, severity, consequences, routes to escalation, overall risk picture for the facilities, operating limits, chosen strategies for each hazard, prevention, detection, control, mitigation and evacuation systems for each hazard strategy and minimum performance standards for the systems

The paper describes the key elements of a successful HMS as one that has appropriate leadership that sets goals (for fewer hazards, causes and consequence, reduced severity and more effective residual hazard management). It requires adequate human and financial resources and is willing to invest more in capital costs in return for greater reliability, increased life and reduced operating costs. Success also depends on a detailed fire and explosion design plan, an understanding of the risk drivers associated with different design concepts leading to a justifiable selection of design concept, a strategy for reduction of residual risk for the chosen design concept, a demonstration of acceptability of the reduced risks and implementation of the strategy in the design, construction and operation of the facility.

The paper adds that a fire and explosion design strategy must balance a balancing a number of technical and economic factors, including protection of personnel, value of a business, nature and cost of major incidents that could potentially occur, potential business interruption and amount of loss acceptable to company.

Work Group 2 – Safe design practice

Chair: John Wishart, Technip-Coflexip

The objective of this work group was to discuss how the hazard management systems can be implemented through safe design practice through a series of specific deliverables, actions, or requirements by a project (i.e. a HSE design plan). The paper described different HSE goals and fire and blast deliverables that may be appropriate to different project stages (select, define/FEED, execute). The white paper went on to introduce the concept of a risk matrix (having frequency as one of the matrix dimensions and severity as the other) as a means of ranking risk within the context of a fire and blast hazard management process. Adding the frequency and severity ratings derives a risk rating. Through this it is possible to identify those hazards that need additional mitigation or control. In general, design teams should adopt a hierarchical approach to managing the hazards as described in the first white paper. The ability to implement mitigating measures in accordance with the hierarchical approach is constrained by the balance between risk reduction and factors such as implementation cost, impact on schedule, practicality, etc.

Fire and blast layout design guidance was also addressed recognizing that platform layouts can have a major influence on reducing the impact of hazards associated with fire and blast. The paper presented examples of commonly applied guidelines for layout design. It also addressed the impact on layout of facility and production processing types and the impact on layout of deep versus shallow water development.

The paper went on to address design credible scenarios and methods of identification of such scenarios. These included selection of worst case scenario, scenario identification from industry, company, or similar experience, use of generic release scenarios or from release analysis and studies. This was followed by a discussion of design prevention features to reduce or eliminate design credible release scenarios. Areas of discussion included application of Safety and Environmental Management Plan (SEMP), increased predictive maintenance and inspection (leak detection, dropped object, work permit / administrative controls, operating integrity). In the case of ignition prevention, issues covered include the hierarchical approach (WG1) to managing ignition prevention, elimination or prevention through layout and material selections, detection (the role of instrumentation and personnel), control and mitigation (ventilation, containment, drains, process and electrical isolation and loss of containment. Types of fire and gas detection and emergency procedures associated with detection as well as confidence issues in detection systems were considered.

Design features that limit the magnitude of an incident resulting from a release were considered (process isolation and blowdown, release control and drainage and process and fluid conditions), so were design features which limit the consequence (passive and active fire protection and application rate of water spray or foam. The concluded with a brief overview of emergency and response considerations, egress, escape and muster considerations and human response in an emergency situation.

The work group discussions of the white paper led to identifying the following needs:

- Clear management of "how to" design process and acceptance criteria including philosophies and guidelines. This includes practical guidance on demonstration of acceptability whether ALARP or other acceptance criteria (qualitative or quantitative) and on fire and blast goals relating to people, environment and assets.
- Need for a definitive technology / understanding to provide appropriate bid strategy blast specifications by the end of Define/FEED stage.
- Finally, the group confirmed that there was no consensus on the approach to blast in GoM. One operator did blast analysis on all platforms (small, large, shelf, or offshore); generally operators are doing blast analysis on the larger more complex platforms.

Work Group 3 - Explosion loading and response

Chair: Doug Angevine, ExxonMobil

The white paper starts with a review of project stages and, for each stage, the interactions of blast assessment (inputs and outputs), the impact and effectiveness of blast assessment and the blast assessment methodologies that may be appropriate. At the "Select" phase, the paper surmises that each option is evaluated with respect to regulatory requirements, codes, standards or certification requirements and company recommended practice. This should be undertaken not only for explosions, but also all other significant hazards and contributes to concept selection. The introduction of new technology to reduce the likelihood or consequence of an explosion should also take place at this stage. Information needed to evaluate explosion overpressure at the "Select" stage includes general location of the facility and environmental conditions, general layout, reservoir characteristic, structural scheme and process information. The paper considers that the form of explosion assessment at this stage might be limited to drawing on experience from previous project, or that it might extend (programme permitting) to a coarse explosion load analysis.

The "Define" (FEED) phase of a project should identify (and subsequently implement) the explosion hazard management strategy. Performance standards of safety systems are developed. Project cost and schedule (timing of explosion modelling versus delivery dates of the structural steel) are considered. Detailed explosion modelling (CFD) is performed coupled with "what-if" design scenarios. Information available at this stage for explosion analysis should include reserved space and estimated weight of the process equipments, structural design philosophy and primary concept, construction and tow-out / installation philosophy, proposed delivery schedule for primary steel, process design philosophy (and impact on characteristics of hydrocarbon release in terms of duration, size and gas characteristic). The results, coupled with the structural design and layout concept will determine whether explosion overpressure is a concern. This is the ideal time to cost-effectively propose and implement inherently safe engineering design options and minimize maintenance intensive explosion mitigation measures (e.g. detection, isolation, vent systems and water sprays).

In the "Execute" phase the strategies developed in the previous phases are implemented to meet the required performance standards as well as demonstrate and documents that these goals have been achieved. To achieve this, further interaction is necessary between all the disciplines. A more detailed model will be used towards the middle of this phase to verify the final blast overpressure values for the AFC design. It is also during this phase of the project when quantitative risk analysis would be utilized to determine the most credible explosion overpressure (if there are design concerns) that could not be eliminated, isolated, controlled or mitigated to use in further decision-making purposes.

The paper went on to address issues relating to blast load prediction. It made reference to a methodology adopted by some companies, whereby two levels of explosion loading are defined, namely design and ductility level blast loads. Under the former (derived from an exceedance diagram), the primary structure is required to behave elastically whereas local plastic deformations are tolerated under the latter (which has a frequency of occurrence one order of magnitude less than the former).

The paper went on to describe briefly and qualitatively the different methods of explosion load assessment under the headings of “level of effort required”, “usefulness”, “limitations”, “benefits”, “rigour”, “input and output”, “pitfalls”, “conservatism” and “misconceptions”. It did not, however, attempt to recommend any one method or combination of methods in any particular situation or stage of the project. The methods addressed under these headings were:

- Screening methods
- Simplified methods (e.g. TNO Multi-Energy, Baker-Strehlow, TNT Equivalence)
- Phenomenological models
- General computational fluid dynamics (CFD) models
- Explosion CFD models

The paper goes on to discuss structural response to blast, commencing with performance criteria. These are described in terms of response limits (typically ductility ratio and member end rotation or a ratio of mid-span deflection to component length). Ductility is determined by dividing the maximum deflection by the deflection at the elastic limit and is an indicator of the plasticity of the component at peak response and a measure of reserve capacity. End rotations or deflection/span ratios are used to ensure the geometry of the component is maintained to the degree necessary during response. Typically, both response limit types are used to determine adequacy of a component.

The paper briefly describes the various structural response assessment methods, commenting on the applicability, strengths and weaknesses of each method. It covers screening assessment, simplified methods (SDOF, pressure-impulse diagrams, equivalent static models) and linear and non-linear dynamic finite element analysis.

The paper concludes by raising a series of additional considerations which include non-structural items, ancillary areas, capsule response, impact of structural response on systems, projectiles, escalation, interaction with fire. The paper also raised for discussion two fundamental issues relating to blast design, namely:

- Use of tabular values of blast loads
- Use of the concept of a “dimensioning” blast load (defined as a load of such a magnitude that when applied to a simple elastic analysis model with conventional

code checks for an accidental load case, results in members dimensioned to resist the worst case credible event or 'Ductility Level' blast).

The work group discussions of the white paper raised the following issues that warranted inclusion or further consideration:

- The blast load and response assessment (and more generally the hazard assessment) effort should reflect the size and complexity of the facility
- Consideration should be given to use of similar facility design as starting point, thereby reducing the hazard assessment effort
- The importance of all disciplines being involved in assessment/design process should be stressed, and so is the importance of building in inherent safety.
- The process should address life cycle management of change for future platform modifications
- Blast loads need to be finalized and main structure analyzed early in the project execution stage
- Use of max blast load as design criteria for other (non-structural) disciplines should be considered
- More guidance is needed on dispersion modeling
- Explosion CFD codes are the most widely used tool for developing blast loads, but there is a need for model evaluation protocol to ensure confidence in such programs. Furthermore, the differences between the different CFD codes should be understood.
- Emphasize the importance of duration, drag loads and over-pressure for design, not just headline overpressure values
- Mitigation by water deluge can be modeled by some CFD codes, but not all issues associated with water deluge are fully understood
- The concept of a "dimensioning explosion" was discussed but not resolved; the group felt there were pros and cons
- Residual strength of the structure after an accidental event should be addressed
- The importance of good connection details should be emphasized.

Work Group 4 - Fire loading and response

Chair: Ben Poblete, Lloyds Register and Joel Krueger, BP

This paper commences by describing the process of undertaking a fire hazard assessment process and is broadly aligned with the methodologies described in the first white paper "philosophy and management processes". It then presents a similar discussion to that in the "blast loading and response" white paper on the impact of the introduction of fire hazard management at different stages of a project on the relationship between safety and cost. The paper also discusses the order of preference to manage a fire hazard during engineering design (passive, active, operational and external systems thereby minimising personnel intervention). Throughout the paper, a contrast between prescriptive and goal setting design is struck, without recommending one approach over another. For the goal setting approach, broad categories of performance goals (time to egress & evacuate, business interruption cost, environmental damage, damage to reputation) are noted.

Prescriptive hazard identification is described as that which is based on following the requirements of code, standards and regulations and is considered to the least demanding in engineering input. However, the paper notes that some such documents now permit a performance-based approach to design. The latter can lead to benefits in cost, better appreciation of damage potential and innovation. The approach requires categorisation of the hazard, and in the case of structural hazard, the paper uses a simple risk matrix approach. If a more detailed fire hazard analysis is performed then the design must identify which systems are deemed critical for safe production. This is where the major safety functions are identified and defined as well as performance standards are needed to demonstrate acceptability.

The credible fire hazards must be characterised in order to be properly considered in the design. A prescriptive approach would typically use area classification rules, fire classification (A or H) and required duration of fire resistance (e.g. 60, 120, etc.) available in codes and standards. Where a performance based approach is adopted, the fire scenarios have to be characterised (e.g. fire geometry and thermal characteristics) for further use in the design process. The paper recognises a number of issues (shutdown system/blowdown, detection, automatic/manual response, active/passive fire protection, effects of barriers/layers of protection, isolation/reduction/mitigation/segmentation of inventories, effect of fire confinement) that will affect fire characteristics and summarises a number of available mathematical models for jet and pool fires (which in themselves will introduce simplifications, thereby affecting the resulting characteristics). Mathematical models are also given for smoke modelling and for accounting for the effect of blowdown. Data on impact of heat and smoke on personnel and equipment is summarised.

The paper went on to discuss methodologies for assessing the response of structures to fire. It covers a screening method based on using room temperature AISC code checks with 0.2% strain elevated temperature values of the yield stress and allowing unity ratios up to 1.5. It also covers a methodology referred to as a design level analysis, consisting of a conventional linear elastic analysis with 'hot' members being assigned reduced stiffness and members whose temperature exceeds predefined values (400ºC in the case where 0.2% strain values of stress are adopted) being eliminated from the analysis. A brief mention is also made of ultimate analysis, using time-temperature history as input, as well as the non-linear material data for the steel at elevated temperature.

A number of additional issues came up in the workgroup discussions, and these included:

- The need to specifically cover living quarters and retro-fits
- Any new recommendations should not be applied retrospectively to existing facilities
- Taking benefit for active systems from a regulatory standpoint
- Training of the workforce
- The trade-off between CAPEX and OPEX in fire hazard assessment
- Use of prescriptive design for 'small' platforms and performance based for larger deepwater platforms

- Secondary member protection and coatback issues
- Need of a better approach to codified fire engineering (possibly based on the Eurocode)
- Performance of vessels/equipment in fire
- Applicability of some prescriptive rules and practices (e.g. 250kW, minimum thickness specifications, etc.)
- Deluge design strategies (area versus equipment)
- Smoke modeling
- Impact of PFP application on construction program

Work Group 5 – Floating production and storage systems

Chair: Rajiv Aggarwal, ABB Lummus Global Inc

The paper starts by identifying the FPSO sub-systems which must be considered in a hazard assessment and lists the type of incident associated with each sub-system. It identifies process, riser and well operations as the main potential fire and explosion hazards and states that the accidental fire and blast loads should not be combined with extreme environmental loads, neither should fire or explosion damaged FPSO be expected to withstand such loads.

The paper states that GoM conditions favour sea rather than helicopter rescuegiving rise to a favourable emergency evacuation philosophy requiring less time for evacuation and hence reducing the design requirements for temporary refuge and escape routes. This may lead to location of temporary refuge at lower levels and reducing the need for protected escape routes.

The paper lists the API standards relevant to FPSO design. In particular, API RP 2FPS provides the guidelines for treatment of fire and blast on FPSO. It addresses the issues of protection to personnel, escape routes, TR, emergency evacuation plan, life saving equipment and alarm systems. The 2000 edition introduced a risk based decision approach for dealing with accidental events. The fire protection requirements for the marine components are addressed by RCS Rules, flag state administration requirements (if applicable), and international requirements. Interface of the marine and industrial components of a FPSO creates a design and operational challenge, requiring analysis of the hazards to tailor the fire protection and systems to suit the overall facility.

A review of GoM fire and blast incidents on TLP, Spar, and Semisub (MODU) installations since 1995 is presented. Also included are incidents that occurred in deepwater fixed jacket platforms in water depths more than 1,000 ft and in compliant tower platforms. The review led to the following observations:

- A total of 66 incidents occurred during 1995 to 2002 period due to either equipment failure, human error, or a combination.
- 54 of the incidents were attributed to equipment failure.
- Human error was responsible for a small number of incidents; this may be due to better training and procedures on these major installations.

An analysis of the equipment failures showed that 28 were due to compressors/generators failures, 7 due to welding, 4 were associated with insulation, 8 with electrical equipment, 4 due to leaks, and 15 due to other unspecified items.

The paper considered that the safety of FPSO's should be considered in the context of the following focus areas:

- Lay-out/ arrangements
- The floating/buoyancy and stability function
- Hydrocarbon storage area (the tanks)
- Exposure of personnel and means of escape
- Risers and possible hydrocarbon release from risers and subsea installations
- Lack of actuarial data on leak and ignition frequencies and consequences
- Simultaneous operations

The paper goes on to review the fire and blast considerations in the design of FPSO's in other parts of the world. This includes greater reliance on fire and blast walls due to constraints on layout arrangement. Furthermore, the fact that all the modules are located at the same elevation on an FPSO somewhat invalidates the use of data from more conventional platforms in the risk assessment. Mooring will influence the movement of the FPSO and hence the ventilation conditions. Movement may also lead to increased spread of a pool fire. A gas cloud tends not to be restricted to a certain area, but dictated by the release scenario, thereby necessitating more rigorous dispersion analysis. Fires and explosions have the potential to threaten the stability of an FPSO (hull and bulkheads) and hence this risk needs to be addressed. The critical areas identified are the turret area, process area, cargo tanks and pump room. Factors that contribute to higher fire and explosion risks on FPSO's include storage of large quantities of crude, gas clouds accumulating from the cargo tank vent posts and engine room fires/explosions. The risk picture is somewhat modified on an adapted tanker FPSO where the accommodation module is at the aft of the facility. Protection of the cargo tanks is of paramount importance; reducing deck heat exposure (top of tanks), proper location of the cargo tank vents and directing explosion products away from the tanks are important risk reducing measures.

The paper also summarizes some mitigating measures that are specific to FPSO's. The elongated shape allows good separation between process and accommodation areas, weathervaning FPSO ensures that the accommodation area remains upwind of any hydrocarbon hazards, good natural ventilation of process and turret areas and an ability to abandon the field in an emergency. On FPSO's with forward accommodation, a fire/blast wall is usually located between the turret and accommodation areas.

The paper concludes with a brief description of the fire and blast considerations for two specific examples from the Norwegian sectors, namely Heidrun TLP and Åsgard A FPSO.

Work Group 6 – Exploration and drilling operations

Chair: Malcolm Sharples, Offshore Risk and Technology

The paper commences by making the case that existing prescriptive IMO and Classification rules are appropriate for MODU's as the nature of hazards relevant to MODUs is relatively predictable for units of relatively standard design and typical drilling applications. It anticipates that the revision to the IMO Convention on the Safety of Life at Sea which opens the door to accepting fire safety requirements that are performance based may have a role in assessing hazards where new designs incorporate features not currently addressed by prescriptive standards or where applications fall outside the scope of current experience. Furthermore, it did not see a role for risk-based design of standard units in standard applications. The paper argues that MODU's are more like ships than offshore installations and as such should be subject to the IMO rules. In addition, as they are offered competitively to the operators of leases, prescriptive requirements are seen as offering a more level playing field.

The paper goes on to describe the approach of the IMO's MODU Code (revised 1989) with respect to fire and explosions, the main principles of which are limiting and segregating combustibles, provision for containment and detection, Provision for a variety of systems for extinguishing fires, provision of resistance to blast (through open design, segregation and mandatory use of structural fire-rated bulkheads and decks).

The paper goes on to suggest that many of the requirements imposed on MODUs would be overly conservative for many of the smaller offshore platforms in the Gulf of Mexico and that training of personnel is much more rigorous on MODUs and the MODUs themselves are much more substantial structures than many of the platforms on which they perform work.

The paper then reviews accident records to establish whether there are any gaps in prescriptive requirements than need to be addressed. However, it recognises that much of the historic data is based on experience of drilling in shallower water and lower temperature/pressure regimes than anticipated future applications. It states that blast has not been a major issue on MODU's due to the open nature of these structures and the lack of process inventory. Fire on the other hand has been addressed in the past two years through comprehensive amendments to Chapter II-2 of the SOLAS Convention. The review concludes that the accidental events are those essentially already anticipated by the prescriptive requirements and no gaps exist in the equipment and arrangements that require further regulation.

The paper goes on to give an overview of the prescriptive passive and active fire protection rules and concludes that the industry as a whole is satisfied with the current practice of prescriptive application of fire and blast issues developed using Classification rules and the IMO MODU Code.

The paper attracted significant written comment (published as an attachment to the paper) from the UK HSE, fundamentally disagreeing with many of the statements made.

The work group discussions recognised that the hazards on drilling units are relatively easily predictable for standard operations and that risk assessment on existing units in general does not result in significant modifications regarding fires and explosions. Standard of drilling plant is not followed up by any independent party (unless done voluntarily) and there are monthly inspection by MMS. The suitability of drilling unit for a particular well is determined by the Operator.

There is a need to address novel applications and new technology for which a performance-based approach (in part or whole) may be appropriate. New technologies which might change the risks that include underbalanced drilling, dual gradient drilling, artificial seabed, MWD (improvements), increased use of DP and reluctance to disconnect in deepwater. There are also new applications that impact the risks such as deepwater drilling, temporary storage, methanol usage and storage, extended well testing/early production, dual fuel systems, conversion from accommodation unit. With respect to hazard analysis, the work group considered that this was not necessary for standard design in standard applications, but that there is a need to assess non standard aspects of a well and may use qualitative methods. Guideline was needed as to when such assessment is necessary.

Work group 7: Regulation and certification

Chair: Kenneth Richardson, ABS

No white paper was available at the time of the workshop. The work group discussed existing worldwide practice for regulation and certification of fire and blast design of offshore facilities, compared different approaches and reviewed recent initiatives/opportunities for attaining greater consistency or harmonization. They summarised the different practices as follows:

- Gulf of Mexico: Prescriptive-based; no blast requirements; benign environment; class societies taking active role to classify floating structures.
- Brazil: Utilizes Formal Safety Assessment; ANP was established; now in the process of developing a format for their regulatory regime
- UK sector of the North Sea: Safety case approach; acceptance criteria established for ALARP; operators are self-regulating
- Canada: Combination approach; influenced by Ocean Ranger; move to harmonize with the ISO standards

West Africa: Prescriptive based regulations may be more suitable; regulators may not have the necessary technical resources to review multiple alternative design approaches

The consensus among the Participants of the Workshop was that the event was of substantive value and particularly timely for US industry as it moves towards the development of significantly deeper water discoveries with larger and more complex facilities. It was noted that industry, through the American Petroleum Institute (API) had recognized the need to develop a common approach for the fire and blast design of certain new facilities in the Gulf of Mexico and had established a Task Group to develop a new Recommended Practice in this area. Patrick O'Connor, chairman of the API Task Group and a significant contributor to the Workshop expressed the view that the Workshop provided an important opportunity to receive industry input to the API draft. The API document is planned for issue in early 2004.

Keynote Presentations

As written version of the speeches were not available, the copies of the slides used for illustrations are attached for each keynote speech preceded by a short abstract of the speech prepared from written notes taken during the workshop.

Keynote Presentation by Elmer P. Danenburger III on Regulatory Perspective

The first of the keynote presentations was made by Elmer P. Danenburger III on regulatory perspective of consideration of fire and blast in future design of offshore structures.

Mr. Danenburger stressed the increasing importance of fire and blast considerations as larger and deeper water developments becoming more common in offshore continental shelf (OCS). OCS is the largest source of oil, with more than 560 million barrels per day, in the USA.

He presented statistics of fire and blast events for the period 1997-2002. Out of 474 OCS fires, only 2% (nine events) caused damage in excess of $1 million, whereas, 92% caused damage worth less than $25,000. A third of these events were caused by compressor or generator operations and a quarter of the events by welding operations. For the excessive damage category, three fires were considered catastrophic, 2 of which were caused by blow-out and one by leakage from a corroded pipe. The fires had caused 2 fatalities and 29 injuries. He presented further data showing a trend of declining number of fatalities and suggested target for the industry should be zero fatality per year.

Mr. Danenburger envisioned a design regime that had room for both the best practice prescriptive rules and performance-based goal setting design that leaves scope for innovation. This contrast of design approaches set the tone for topic of discussions throughout the workshop deliberations.

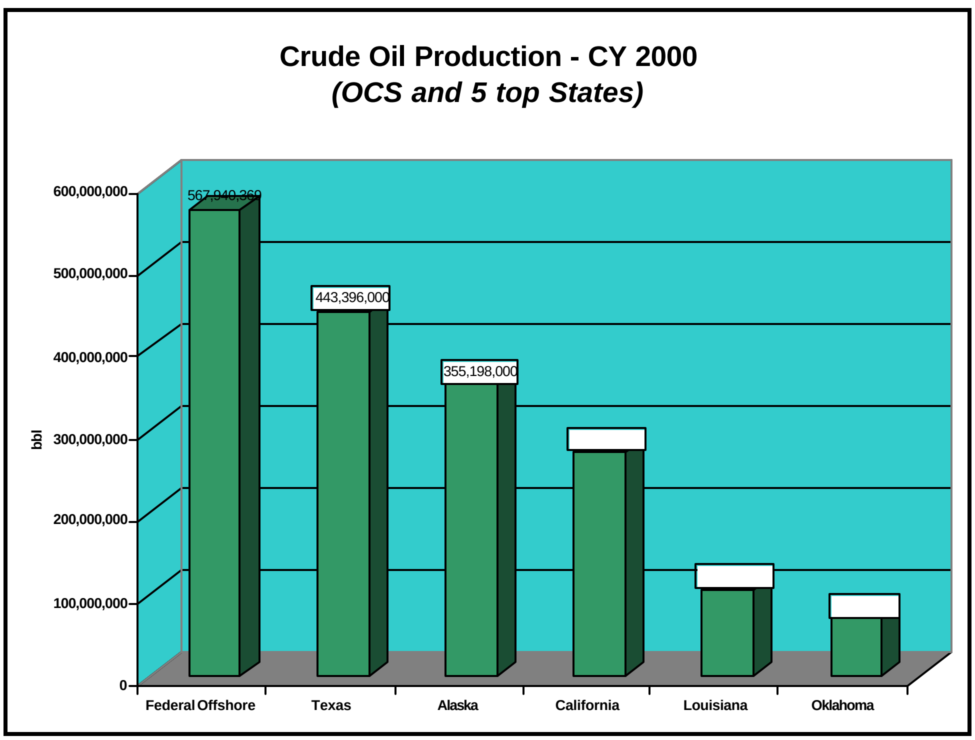
Twenty slides as presented are attached.

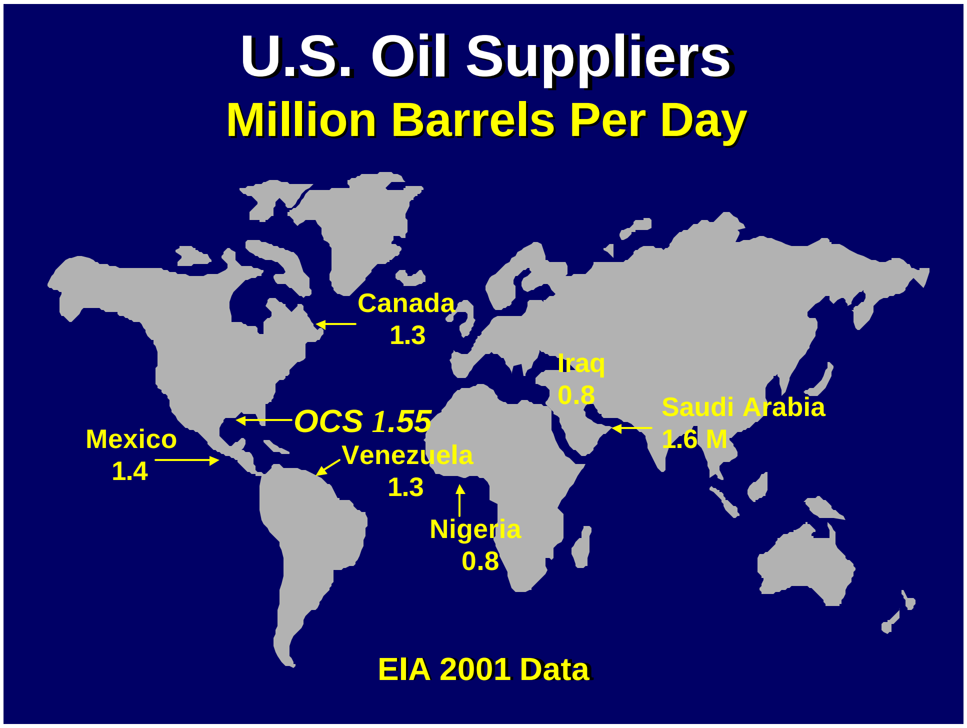
Workshop: Fire and Blast Considerations in the Design of Offshore Facilities

Elmer P. Danenberger III

Chief, Engineering and Operations Division

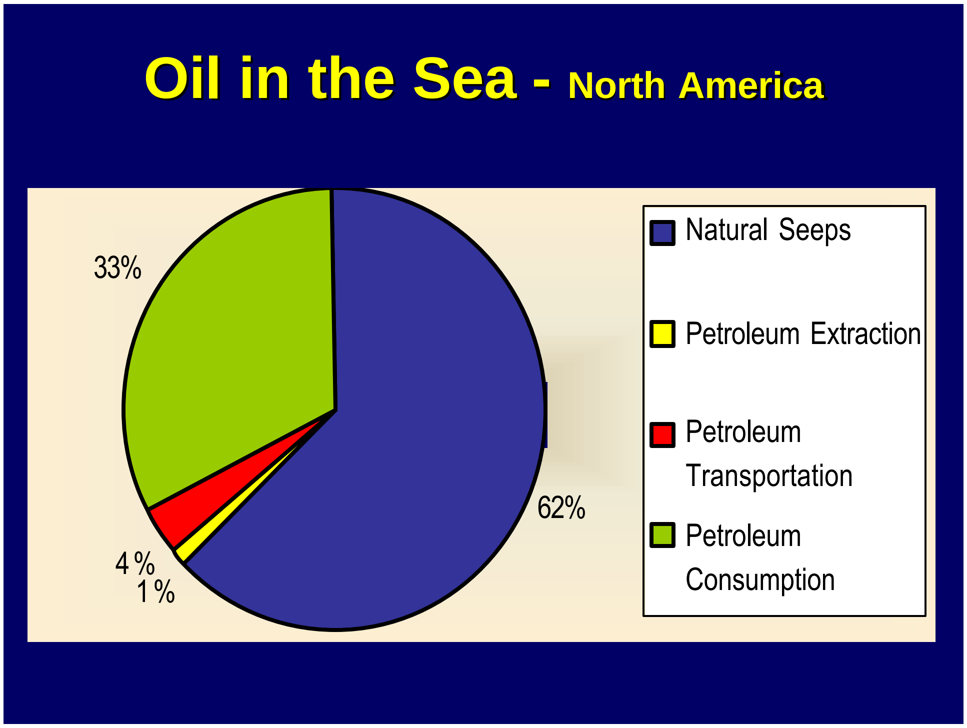
Minerals Management Service

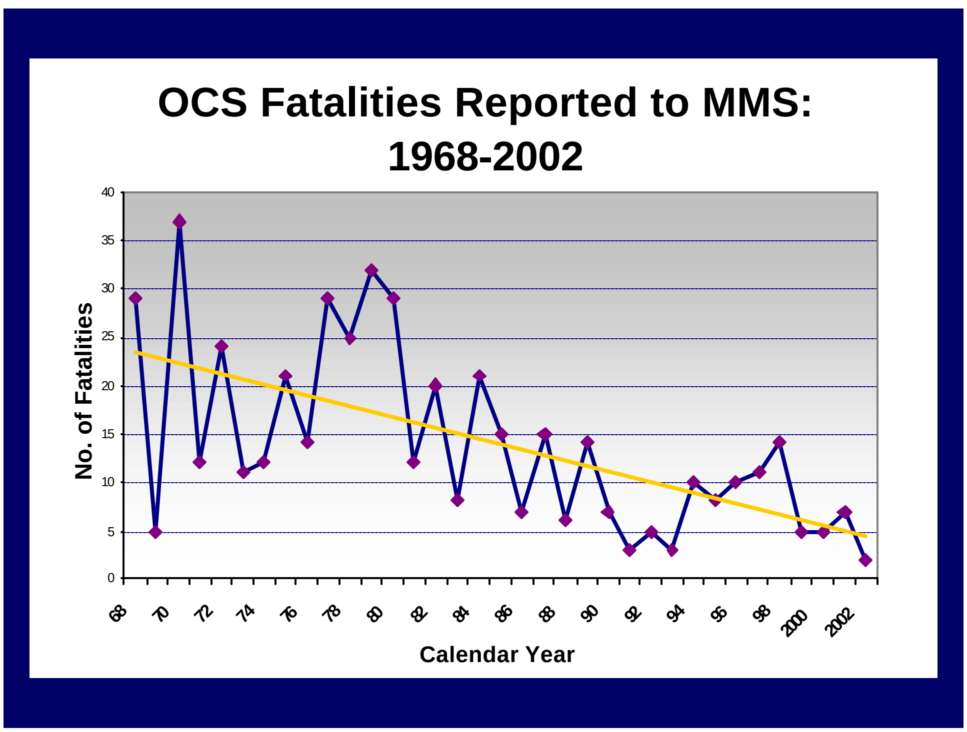




Oil in the Sea, ***National Research Council, 2002***

	North America	*Worldwide*
Natural Seeps	**61.5%**	**47.3%**
Petr. Extraction	**1.2**	**3.0**
Petr. Transp.	**3.5**	**11.8**
Petr. Consumption	**32.3**	**37.9**


Oil in the Sea - North America
33%
62%
4 %
1 %
Natural Seeps
Petroleum Extraction
Petroleum Transportation
Petroleum Consumption


OCS Fatalities Reported to MMS: 1968-2002
No. of Fatalities
Calendar Year

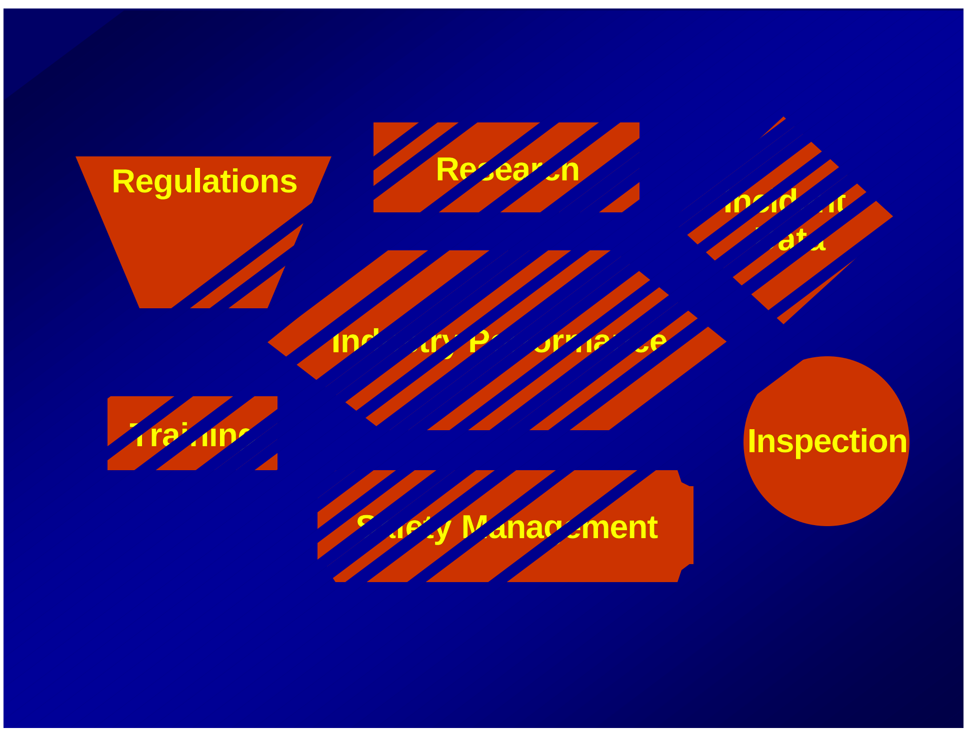
National SAFE Award Winners and Finalists

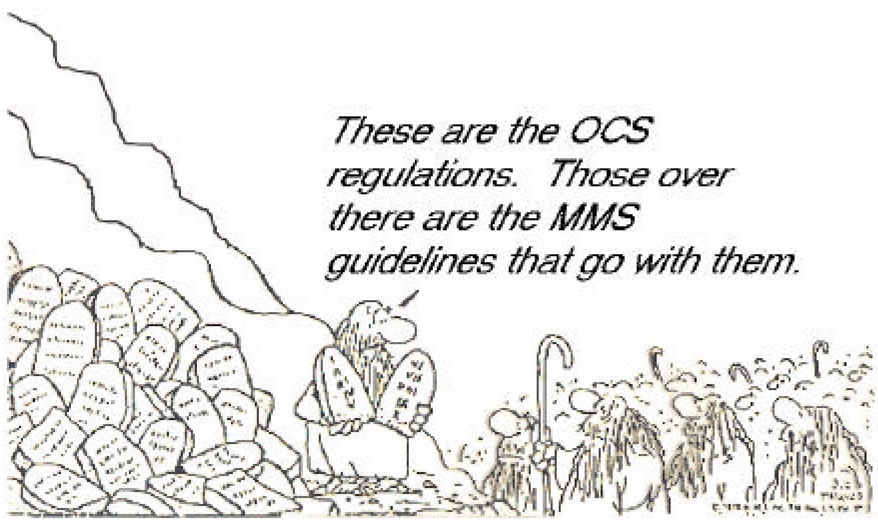
ExxonMobil Kerr McGee

Dominion E&P ATP, Aviara, Murphy, Nexen

Diamond Offshore Global SanteFe, H&P

Danos and Curole Marine Contractors





Subpart B, Plans

- **"If you don't know where you're going, you'll end up somewhere else."** ***--Yogi Berra***

Subpart Q, Decommissioning

- **Consolidates abandonment requirements**
- **Reduced removal requirement for deepwater**
- **Supports rigs-to-reefs program**

Platform R&R

Rigs-to-Reefs: world-famous original
Rigs-to-Roosts: habitat for migrating birds
Rigs-to-Reels: making movies
Rigs-to-Rockets: satellite launches
Rigs-to-Refuges: rescue stations
Rigs-to-Resistors: power generation
Rigs-to-Reform: prisons

Platform R&R
(continued)

Rigs-to-Roulette: casinos, recreation
Rigs-to-Rotors: wind power
Rigs-to-Re-gasification: LNG facilities
Rigs-to-Roe: aquaculture
Rigs-to-Rx's: medicine
Rigs-to-Recovery: hospitals, shelters
Rigs-to-Renewables: alternative energy

OCS Fires - 1997 - 2001

melinda.mayes@mms.gov

- 474 Fires
- 92% < $25,000 property damage
- 98% < $1 million
- 2 fatalities; 29 injuries

•1997-2001: 9 Major fires (> $1 million property damage)

-2 well control incidents
-2 vessel collisions with platforms
-engine room pump
-condensate pump
-condensate flow during cutting
-tank overflowed on hot generator exhaust
-explosion in engine compartment of jackup barge

3 Catastrophic Fires (loss of facility)

- 2 blowouts

- Hole (corrosion) in platform piping

-Systems and Activities

-1/3 - compressors and generators

-1/4 - welding operations

-8% - glycol reboiler systems

-8% - pumps

-7% - electrical equipment (transformers, mud-pit motors, lighting circuits, power cord adapters, etc.)

-How Extinguished

- -handheld chemical extinguishers: 44 %
- -wheeled or fixed chemical systems: 4 %
- -fixed water systems: 5.5 %
- -water systems from vessels: 4.5 %
- -more than one of the above: 27%
- -misc.(stomping with feet, fire loop, hoses): 3%
- -self-extingished: 7%

Keynote Presentation by Pat O'Connor on Industry Perspective

Drawing heavily from his work with API SC-2 (vice-chair) and API Fire and Blast Task Group (chair), Mr. O'Connor provided the industry perspective of design considerations for fire and blast in future offshore facilities.

In particular, he contrasted Gulf of Mexico (GoM) practices and North Sea practices, describing the former as having more pragmatic approaches to design whereas, the later being an advanced technology based culture.

There are some 4000 platforms constructed in GoM. The design of these platforms had been repetitive and majority being open small platforms. The installations had an excellent safety record derived primarily from inherently safe design of the installations. The North Sea platforms on the other hand, are in deeper water; they are larger, more congested and less open with higher flow rates. These factors required a different culture of hazard management.

Under this perspective, Mr. O'Connor presented a brief overview of the on-going API RP draft on Fire and Blast, API work on API 75 'Philosophy, management and processes', and API 14J, 'Safe design practice'.

After outlining the context for the workshop, Mr. O'Connor described the purpose and the composition of each of the seven work groups, which would present their white papers for discussion in subsequent group meetings.

Eight slides as presented are attached.

International Workshop

FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES

AN INDUSTRY PERSPECTIVE

Mr. Patrick O'Connor (bp UTG Houston)

Vice-chair API SC-2: Offshore Structures Committee

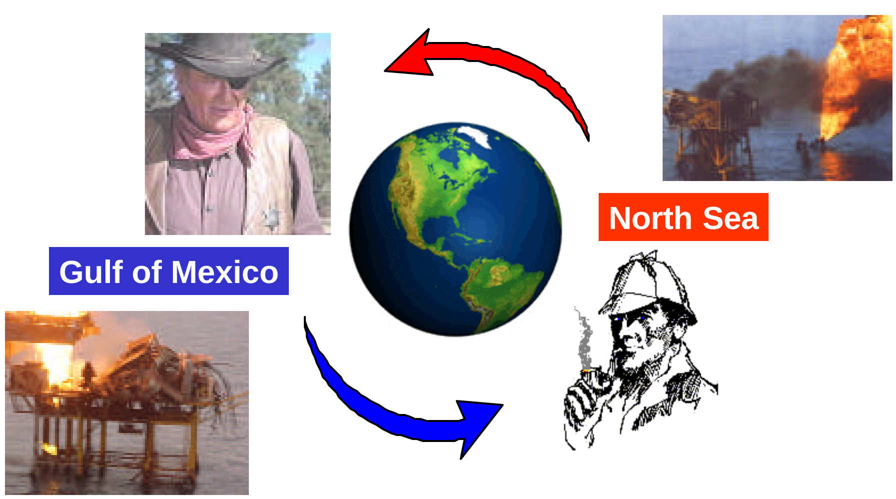
Chairman API Task Group:
Design of Offshore Structures for Fire and Blast Loading

HOUSTON, TEXAS JUNE 12 14, 2002

International Workshop

FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES

INTRODUCTION & BACKGROUND



HOUSTON, TEXAS JUNE 12 14, 2002

International Workshop

FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES

THE NEEDS OF INDUSTRY

- **Typical Gulf of Mexico Facilities**
  - **Inherently low risk**
  - **Excellent safety record**

- **Future Deepwater Developments**
  - **New design challenges**
    (larger, congested facilities, high flow wells)
  - **Guidance to manage risks**
  - **Maintain excellent safety record**

HOUSTON, TEXAS JUNE 12 14, 2002

International Workshop

FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES

Other initiatives around the world:

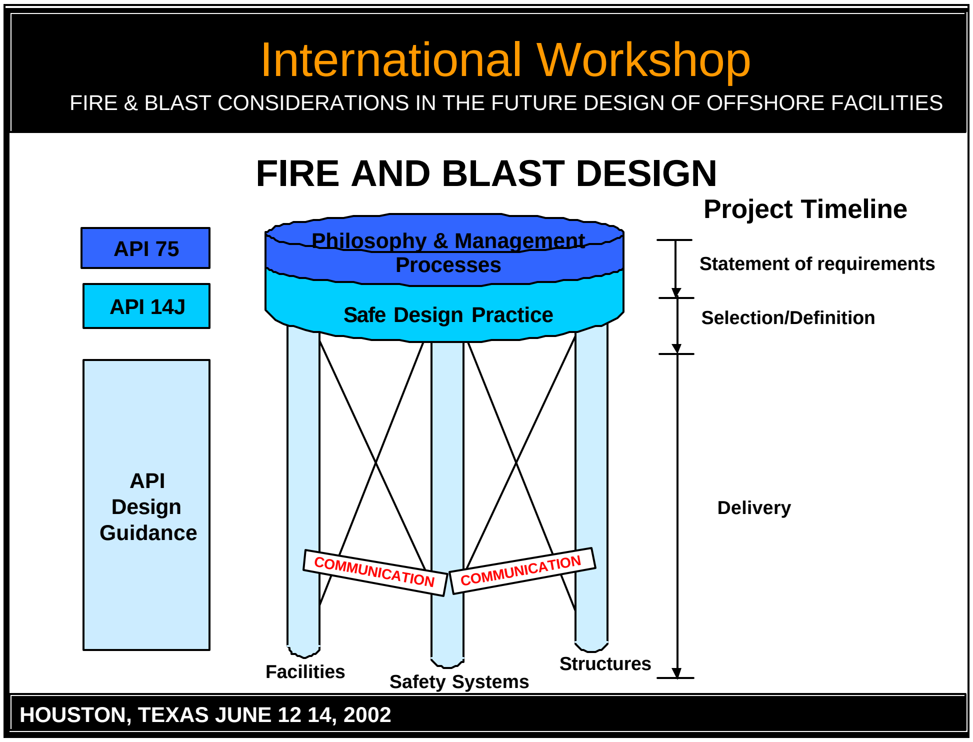
UK North Sea — UKOOA, HSE Health & Safety Executive

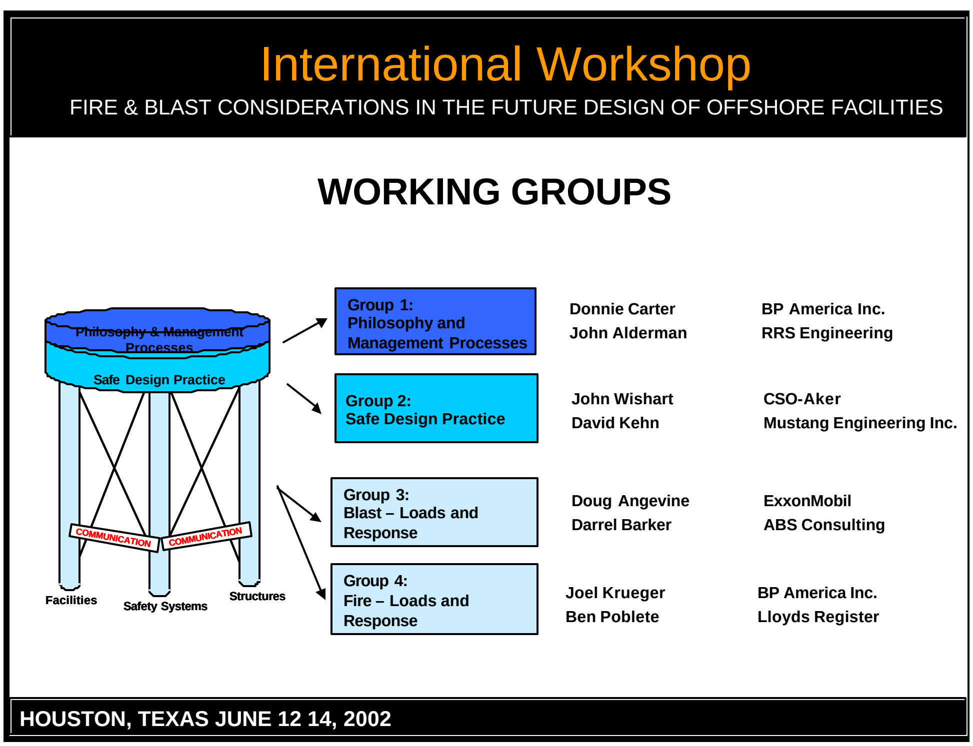
Canada — Canadian Standards Association

Norway — DNV, NORSOK

Other National Standards

HOUSTON, TEXAS JUNE 12 14, 2002


International Workshop
FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES
FIRE AND BLAST DESIGN
API 75
API 14J
API Design Guidance
Philosophy & Management Processes
Safe Design Practice
COMMUNICATION
COMMUNICATION
Facilities
Safety Systems
Structures
Project Timeline
Statement of requirements
Selection/Definition
Delivery
HOUSTON, TEXAS JUNE 12 14, 2002


International Workshop
FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES
WORKING GROUPS
Philosophy & Management Processes
Safe Design Practice
COMMUNICATION
COMMUNICATION
Facilities
Safety Systems
Structures
Group 1: Philosophy and Management Processes
Donnie Carter
John Alderman
BP America Inc.
RRS Engineering
Group 2: Safe Design Practice
John Wishart
David Kehn
CSO-Aker
Mustang Engineering Inc.
Group 3: Blast – Loads and Response
Doug Angevine
Darrel Barker
ExxonMobil
ABS Consulting
Group 4: Fire – Loads and Response
Joel Krueger
Ben Poblete
BP America Inc.
Lloyds Register
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International Workshop

FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES

OTHER SPECIAL CONSIDERATIONS

Group 5: Floating Production and Storage Systems	Bob Gilbert Rajiv Aggarwal	University of Texas, Austin ABB
Group 6: Exploration and Drilling Operations	Malcolm Sharples Conn Fagan	ORTC DNV
Group 7: Regulation and Certification	Ken Richardson Kent Dangtran	ABS ABS

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International Workshop

FIRE & BLAST CONSIDERATIONS IN THE FUTURE DESIGN OF OFFSHORE FACILITIES

Thank you for your attention

Looking forward to a lively event

HOUSTON, TEXAS JUNE 12 14, 2002

Keynote Presentation by Kenneth Richardson on Certification Agency Perspective

In his presentation, Mr. Richardson confirmed that the classification society rules had been prescriptive and largely accepted by the industry. However, he felt that more and more complex installations were being planned in deeper waters of GoM which would inevitably change the prescriptive rules in favor of performance-based design considerations in near future.

He further asserted that the IMO and the revised edition of the SOLAS convention had already adopted performance-based rules. ABS guidelines also provides for the application of the performance-based rules.

Mr. Richardson indicated that the classification societies being the recipient of designs from all over the industry are in a unique position to help in collating and sharing information.

No slides were presented.

Keynote Presentation by Capt. Daniel Ryan II on US Coast Guard Perspective

Capt. Daniel Ryan II in his keynote address provided a short overview of the responsibilities of the US Coast Guard (Eighth District) highlighting the safety and security aspects in GoM.

He outlined the territorial jurisdiction of the 8th district in GoM which covers over 4000 platforms, 172 drilling units, and production of 340 million barrels of crude oil and 4.7 trillion cu ft of natural gas. Out of the 4000 platforms, 3000 are unmanned and 1000 are manned platforms. Of the manned platforms, the deeper water (more than 1000ft water depth) platforms comprise1 semi-sub FPS, 1 compliant tower, 3 mini-TLPs, 3 SPARs, and 6 TLPs. The deeper water facilities account for more than 50% of the GoM's oil production.

Capt. Ryan elaborated on the Memorandum of Understanding between USCG and MMS identifying areas of interest and agency responsibilities associated with MODUs, fixed and floating OCS installations.

Capt. Ryan acknowledged that no comprehensive guidance on fire and blast issues relating to the offshore installations were available in federal regulations. However, he made specific reference to the extension of the code of federal regulation, proposed Rulemaking 33, CFR, Subchapter N; 33 CFR 143.120, which needed revisions to cope with new developments in offshore industry. The revisions would address existing legislations, effectively implement interagency agreements; respond to comments received from the advanced notice of proposed rulemaking, and would address casualty investigation findings. The changes would improve the level of safety in workplace for personnel engaged in OCS activities, specially, fire protection equipment, systems fire, protection facilities and accommodation spaces. He also referred to the guide to structural fire protection, Navigation and Vessel Inspection Circular No. NVIC 9-97.

Forty-two slides as presented are attached.

"International Workshop – Fire & Blast Considerations in the Future Design of Offshore Facilities"

Houston, TX

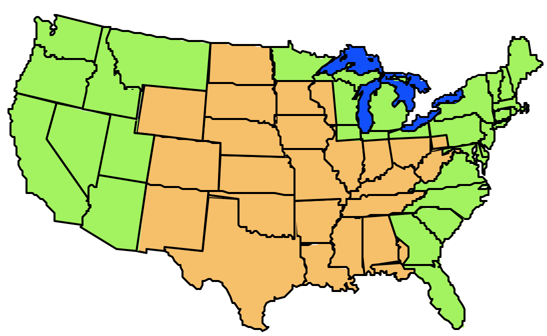
13 June 2002

CAPT Daniel F. Ryan II, Chief of the Marine Safety Division, Eighth Coast Guard District, New Orleans, LA (504) 589- 6271

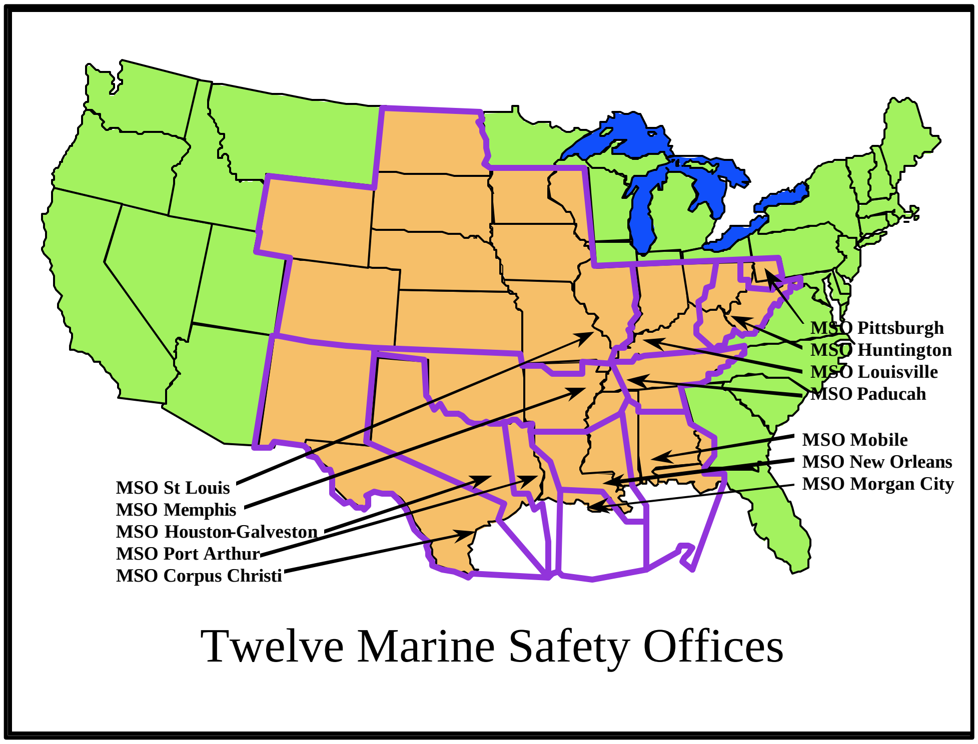
Agenda

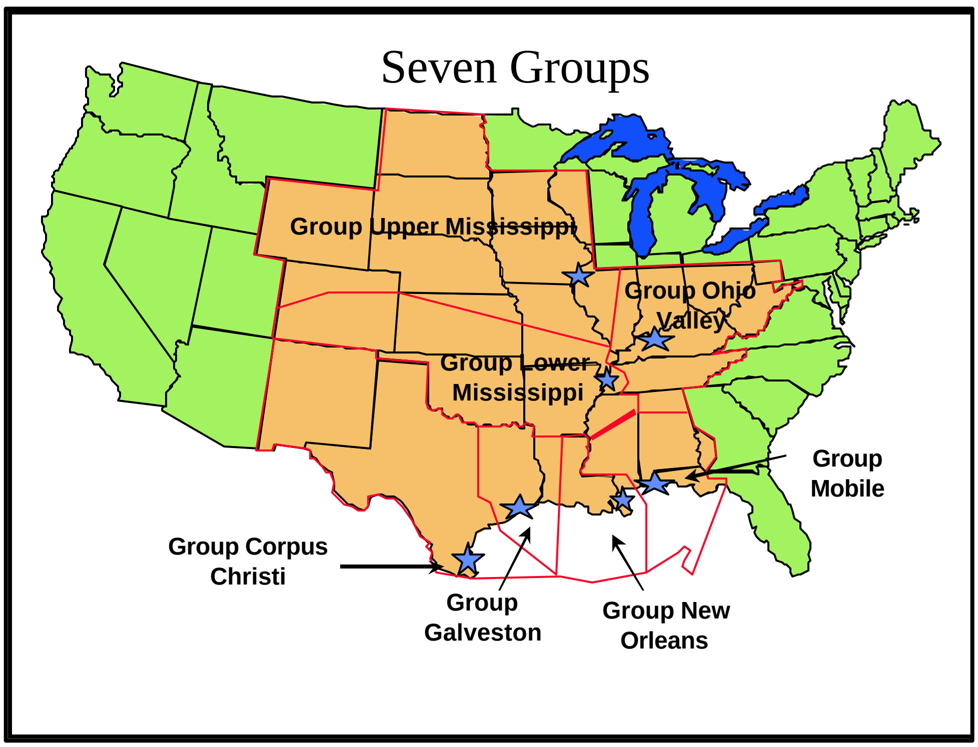
- Quick D8 Overview
- CG Port Security Actions
- CG Regs, Policy, Etc., on Fire & Blast

Eighth Coast Guard District Personnel



* 2,854 Active Duty CG Members Assigned to D8 Units
* 186 Civilian CG Employees in D8
* 176 Mobilized CG Reservists of 1,102 Assigned to D8
* 5,977 CG Auxiliary Members in 3 Regions


MSO Pittsburgh
MSO Huntington
MSO Louisville
MSO Paducah
MSO Mobile
MSO New Orleans
MSO Morgan City
MSO St Louis
MSO Memphis
MSO Houston-Galveston
MSO Port Arthur
MSO Corpus Christi
Twelve Marine Safety Offices


Seven Groups
Group Upper Mississippi
Group Ohio Valley
Group Lower Mississippi
Group Mobile
Group Corpus Christi
Group Galveston
Group New Orleans

District Comparison

	Groups	MSOs	AIRSTAs	STAs	Cutters	ANT Teams	AUX Regions	Top 40 Ports
ATLANTIC AREA								
D1	6	5	1	25	28	10	2	2
D5	6	4	2	23	21	9	2	5
D7	5	6	4	20	34	10	1	4
D8	7	12 (4)	**3 (1)**	**15**	42	15	3	17
D9	5	8	2	32	10	9	3	5
LANTAREA TOTALS:	**29**	**35**	**13**	**115**	**135**	**53**	**11**	**33**
PACIFIC AREA								
D11	4	3	5	13	16	4	2	3
D13	5	2	3	12	15	4	1	3
D14	1	3	1	2	10	1	1	0
D17	0	3	2	2	14	1	1	1
PACAREA TOTALS:	**10**	**11**	**11**	**29**	**55**	**10**	**5**	**7**

U.S. Ports Ranked By Cargo Tons Handled
Year 2000

1.	**Port of South LA**	**217.7**	**13.**	**Mobile**	**54.1**
2.	**Houston**	**191.4**	**14.**	**Pittsburgh**	**53.9**
3.	New York, NY/NJ	138.6	15.	Los Angeles	48.1
4.	**New Orleans**	**90.7**	16.	Valdez	48.0
5.	**Corpus Christi**	**83.1**	17.	Tampa	46.4
6.	**Beaumont**	**82.6**	18.	Philadelphia	43.8
7.	**Huntington**	**76.8**	19.	Norfolk	42.3
8.	Long Beach	70.1	20.	Duluth-Superior	41.6
9.	**Baton Rouge**	**65.6**	21.	Baltimore	40.8
10.	**Texas City**	**61.5**	22.	Portland, OR	34.3
11.	**Plaquemines**	**59.9**	**23.**	**St Louis**	**33.3**
12.	**Lake Charles**	**55.5**	**24.**	**Freeport, TX**	**30.9**

Five Of The Top Ten U.S. Fishing Ports Are in the Eighth Coast Guard District, Totaling 114.2 Million Pounds Landed Each Year

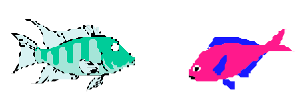
Empire-Venice, LA

Cameron, LA

Intercoastal City, LA

Morgan City-Berwick, LA

Pascagoula-Moss Point, MS



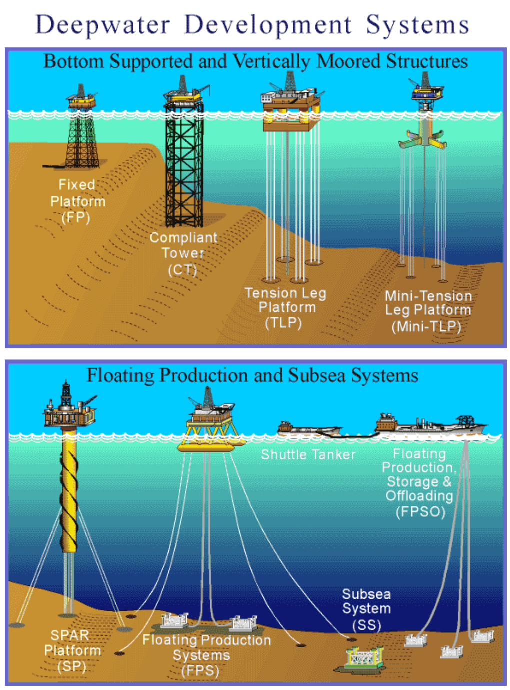
Offshore Oil Industry

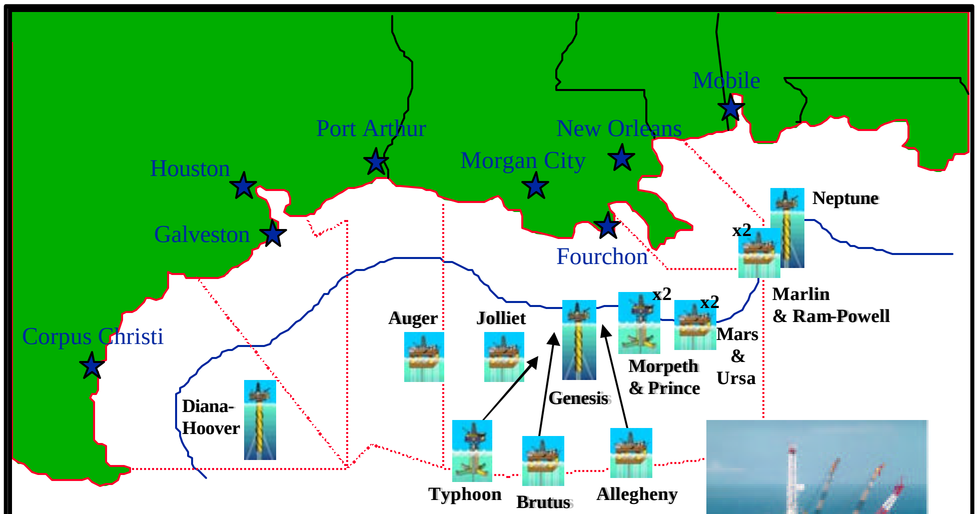
- 6,500 oil & gas wells
- 4,000+ platforms
- 172 mobile offshore drilling units
- 340 million barrels crude oil
- 4.7 trillion cu ft natural gas
- Louisiana Offshore Oil Port (LOOP) 16% of US Imported Crude
- 12 "deepwater" production facilities

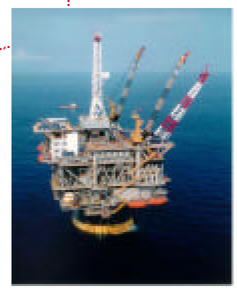
Offshore Production

Shelf:
- 4,000+ Fixed Platforms
  - 1,000 Manned
  - 3,000+ Unmanned

Deepwater (>1,000'):
- 6 TLPs
- 3 Spars
- 1 Semi-Sub FPS
- 3 Mini-TLP
- 1 Compliant Tower

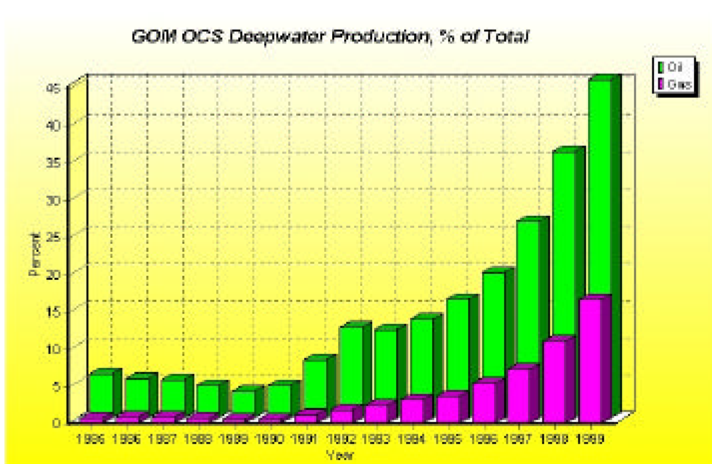


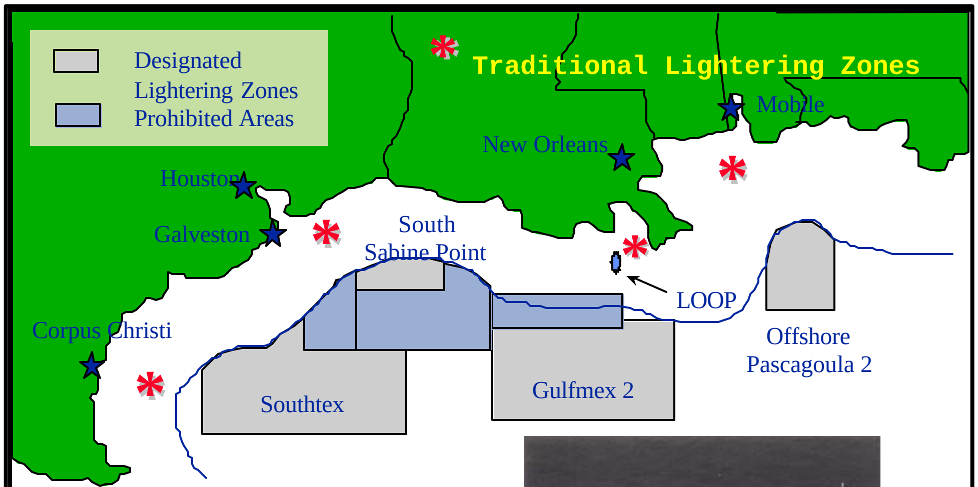




Offshore Deepwater Projects

Offshore
Deepwater Production

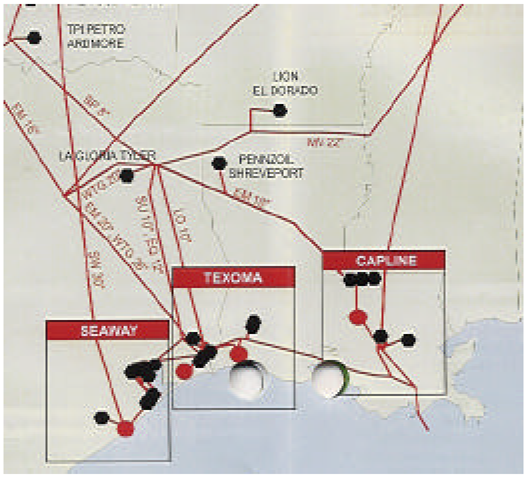




Lightering Zones
and
Prohibited Areas

30% of Nations Crude Oil

Strategic Petroleum Reserve



Seaway - 5 Piers

Texoma – 6 Piers

Capline – 2 piers

Freeport, TX – 232M Bbls

Winnie, TX – 170M Bbls

Hackberry, LA – 222M Bbls

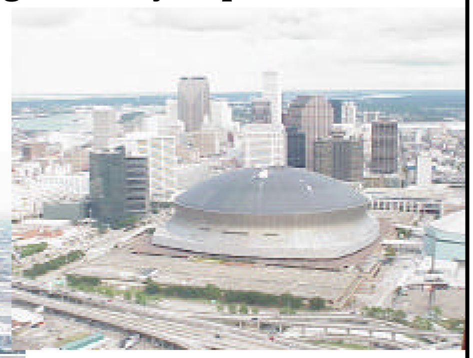
Plaquemine, LA – 76M Bbls

Rivers Lock & Dam

Petrochemical Plant

Oil Refinery

High Density Population Area



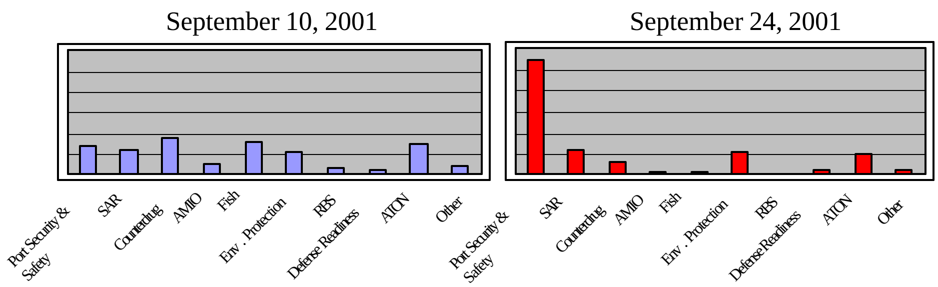
Passenger Vessel

Military Shipments

Inland Refinery

Inland Chemical Plant

Relative Mission Resources

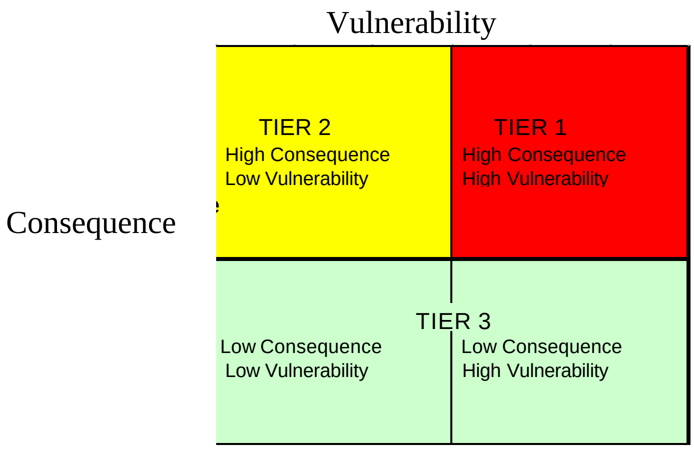


1% > 52% > 15% > 25%

D8 Risk Assessment

- ID Targets:
  - Petroleum Infrastructure
  - Other Hazardous Chemicals Infrastructure
  - Transportation system on, over, beneath, beside water.
  - Symbolic/Historic Structures Near Water
  - Locks, Dams, Water “Control” Structures
  - Gathering Places
  - Power Plants
  - Military Ports & Ports of Embarkation

D8 Methodology



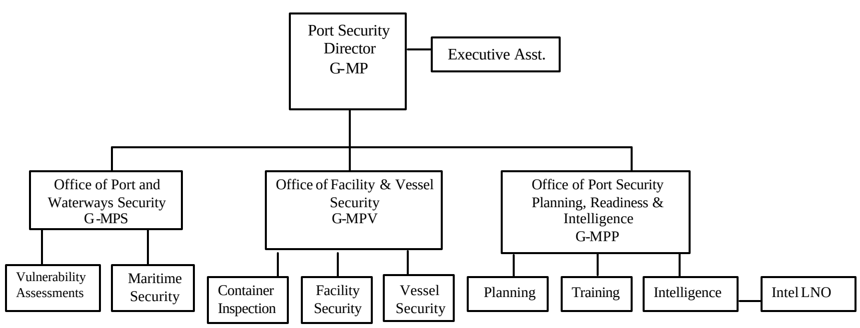
(391 - Tier 1 Assets in D8)

D8 Post September 11th Actions

- Training & Re-arming "Rivers" MSOs & Groups
- Mobilized Reservists up to 716, now 176
- Increased use of the Auxiliary
- Increased presence on the Waterfront
- Major Cutter(s) in GOM & Naval Assets
- Marine Security & Safety Team (MSST)
- Obtained additional PS/WMD Training
- Re-defined Mission Priorities

- **District Homeland Security Staff Established (also G-MP at HQ)**
- **Planning & Organization by Sector**
- **CO's Conference to obtain Field Input**
- **Increased Intelligence Liaison w/Other LE Agencies**
- **Obtained Secure Comms**
- **Provide Sustainability Guidance**

PORT SECURITY DIRECTORATE (G-MP)



Office of Port and Waterways Security (G-MPS)

- Port Vulnerability Assessments
- Foreign Port Assessments
- Domestic PSU Program
- Port Security Program
- Anti-Terrorism/Force Protection
- MTS Critical Infrastructure Protection (CIP)
- Port Security R&D / TSWIG
- DOD Maritime Security Coordination
- Model Port Initiative (Port)

Office of Facility & Vessel Security (G-MPV)

- PAX Vessel Terminal Security
- Waterfront Facility Security
  - Access Control
- Offshore Facility Security
- Container Inspection Program
- PAX Vessel Security
- PAX Vessel and Terminal Security Plan Review
- Waterfront Facility Security Plan Review
- Vessel Security/Plan Review
- Model Port Initiative (Facility)
- Piracy
- Partnerships with: Maritime Security Council, AAPA, APA, AWO, ILA/ILWU, ICCL, PVA

Office of Waterways Security Planning, Readiness, & Intelligence (G-MPP)

- Port Access Control Program
  - Special Interest Vessel Program
  - VSL Advance Notice Management
  - Crew & Passenger Lists
- National Port Security Committee (Chaired by G-MP)
- Homeland Security Strategy
- Maritime Domain Awareness
- PS Rating Program Manager
- Contingency Planning/Exercises
- Security Communications/Info/Intel Sharing
- Maritime Security Training
- DOT Security WG
- Outreach:
  - NPRN- Strategic Ports – Port Readiness Committees
  - ICMTS Security Subcommittee
  - Port Security Committees (Local)
  - DOT Security Working Group
- G-MP Directorate Support

CG Initiatives at International Maritime Organization (IMO)

- Automatic Identification Systems (AIS)
- Government Obligations
- Means of Ship Alerting
- Container Security
- Container Security (Customs Container Security Initiative)
- Port Facility Security
- Seafarer Identification
- Ship Security
- Port Vulnerability Assessments

"Applicable" USCG References to Fire & Blast:

- **Outer Continental Shelf Lands Act (OCSLA) - 43 United States Code (USC) 1331 et seq**
- **33 Code of Federal Regulations (CFR), Subchapter (Sub) N, Parts 140-147, "Outer Continental Shelf Activities"**
- **Proposed Rulemaking 33 CFR, Sub N, Parts 140-147, Federal Register 07 December 1999, Docket# USCG-1998-3868 http://dms.dot.gov**
- **46 Code of Federal Regulations (CFR), Subchapter (Sub) I-A, Parts 107-109, "Mobile Offshore Drilling Units (MODUs)"**
- **Memorandum of Understanding (MOU) between Minerals Management Service (MMS), Department of Interior, and United States Coast Guard (USCG), Department of Transportation; signed 16 December 1998**
- **Marine Safety Manual (MSM), Volume II (Material Inspection), Section B (Domestic Inspection Program), Chapter 8 (Offshore Activities) www.uscg.mil/hq/g-m/nmc/pubs/msm/vol2.htm**
- **Navigation & Vessel Inspection Circular No. 9-97 (NVIC 9-97), "Guide to Structural Fire Protection" www.uscg.mil/hq/g-m/nvic**
- **MMS Enforcement of USCG Regulations for Fixed Platform Inspections on the OCS, Federal Register 07 February 2002, Docket# USCG-2001-9045**

MOU Between USCG/MMS; signed 16 December 1998

This MOU defines the responsibilities of the MMS and the USCG relating to managing the activities of MODUs, fixed, and floating systems. It is designed to minimize duplication and promote consistent regulation of facilities under the jurisdiction of both agencies. This MOU does not apply to deepwater ports.... The table contained in the MOU lists the lead agency for system responsibilities associated with MODUs and fixed and floating OCS facilities. Other agency roles are identified where applicable (i.e. casualty investigation, pollution, etc).

MOU covers from construction, through installation, and continues for the life of the MODU/installation. The lead agency is responsible for coordinating with the other agency as appropriate. The MMS and USCG will work together to develop standards necessary to implement this MOU.

Areas of "Interest" from USCG/MMS MOU:

SYSTEM	MODU	FIXED	FLOATING
Structure	USCG 46CFR, Sub I-A	MMS	USCG/MMS 33CFR, 143.120
Damage Stability	USCG 46CFR, Sub I-A	MMS	USCG/MMS 33CFR, 143.120
Fire Detection & Extinguishing	USCG 46CFR, Sub I-A	USCG 33CFR, Sub N	USCG 33CFR, 143.120
Structural Fire Protection	USCG 46CFR, Sub I-A	USCG 33CFR, Sub N	USCG 33CFR, 143.120
Hazardous Areas	USCG 46CFR, Sub I-A	USCG 33CFR, Sub N	USCG/MMS 33CFR, 143.120
Accommodations	USCG 46CFR, Sub I-A	USCG 33CFR, Sub N	USCG 33CFR, 143.120
Gen'l Arrangements	USCG 46CFR, Sub I-A	USCG 33CFR, Sub N	USCG 33CFR, 143.120

33 CFR, Subchapter N, Fixed Platforms (present regulations): deals with - personnel; workplace safety & health; lights & warning devices; means of escape; personnel landings; guards & rails; lifesaving appliances; fire fighting equipment; operations; and safety zones.

33 CFR, Subchapter N, Fixed Platforms (proposed regulations): deals with all of the present regulations in greater detail and includes requirements for - fire protection equipment; systems fire protection facilities; and accommodation spaces.

33 CFR 143.120, Floating OCS Facilities (present regulations):

--The owner or operator of the facility must submit to the USCG for approval all plans and information listed in of 46 CFR, Subchapter I-A (Mobile Offshore Drilling Units), Part 107 (Inspection and Certification), Subpart C (Plan Approval), which relate to the facility.

--The facility must comply with requirements of 46 CFR Subchapter F (Marine Engineering); 46 CFR Subchapter J (Electrical Engineering); and 46 CFR, Subchapter I-A (Mobile Offshore Drilling Units), Part 108 (Design and Equipment). These requirements do not apply to production systems on the facility.

33 CFR 144, Floating OCS Facilities (proposed regulations):

--Has specific requirements, but still references 46 CFR Subchapter F; Subchapter J; and Parts 107 and 108 of Subchapter I-A.

QUESTIONS???

Special Interest Presentation by Henri Tonda on Design for Fire and Blast in FPSO Girassol

Mr. Tonda presented a case study for the fire and blast analysis of the FPSO Girassol. Being world's largest FPSO, Girassol measures 300m x 60m and has operating weight of topside as 28,000 tons. It has oil treatment capacity of 200,000 bpd and has a storage capacity of 2 million bbl. 140-person accommodation module is located aft of the facility.

The design against fire and blast loading was primarily managed using TotalFinaElf's 'accident avoidance' policy, which is similar to 'ALARP'. Where accidents may occur, four different consequences were investigated to identify their effects:

1. Catastrophic: consequences engulf all of the FPSO; threaten third party interest and cause significant impact on environment.
2. Major: consequences extend to several modules (zones) of the FPSO and third party interest endangered but not threatened.
3. Significant: consequences are limited to one module (zone) of the FPSO; offsite effects are possible but third party interest not endangered.
4. Minor: consequences are localized at the incident area.

Major incidents with a frequency of 10^{-2} to 10^{-1} are categorized as Class I for which improvements are deemed necessary. Significant events with a frequency of 10^{-3} to 10^{-2} are Class II, which makes them targets for improvements. Minor events with frequency of 10^{-4} to 10^{-3} are considered to be of remote risk.

Besides conforming to the requirements of SOLAS, additional active and passive fire safety design measures were adopted. These included, for deluge and foam in all cargo tank area, deluge on chains, lifeboats and in riser 'I' tubes, water curtains and monitor for sea pool fires (Active), and access tunnel between TR and free fall lifeboats, max. plating on topside deck and bunds (Passive). Mr. Tonda also provided details of pool fire criteria, which were used to analyze such fire scenarios.

To avoid the occurrence of blast events, the strategies included: (a) elimination of leaks in critical areas (no gas equipment between hull and top decks, no PV breakers between decks), (b) allow natural dispersion (max. grating, no fire walls on topside, no equipment except hull piping between decks), and (c) avoid ignition (no supply birthing in process area, gas detection on hull deck, air lock in all buildings, no doors towards process area).

To reduce effect of blasts, the strategies included: (a) avoid congestion, (b) avoid confinement, (c) protect accommodation module and critical equipment, and (d) use deluge where necessary.

Mr. Tonda further detailed the measures taken to avoid cargo tank blasts and the measures taken to reduce damage should such blast event occurs.

Forty-five slides as presented are attached.


Fire & Blast 2002 :
Fire & Blast consideration in the future design of offshore facilities
12-14 June 2002
Explosion & fire Analysis for FPSO Girassol 1350 mWD off Angola
Henri Tonda
Risk analysis& Reliability Department


elf exploration angola
GIRASSOL

First phase development:

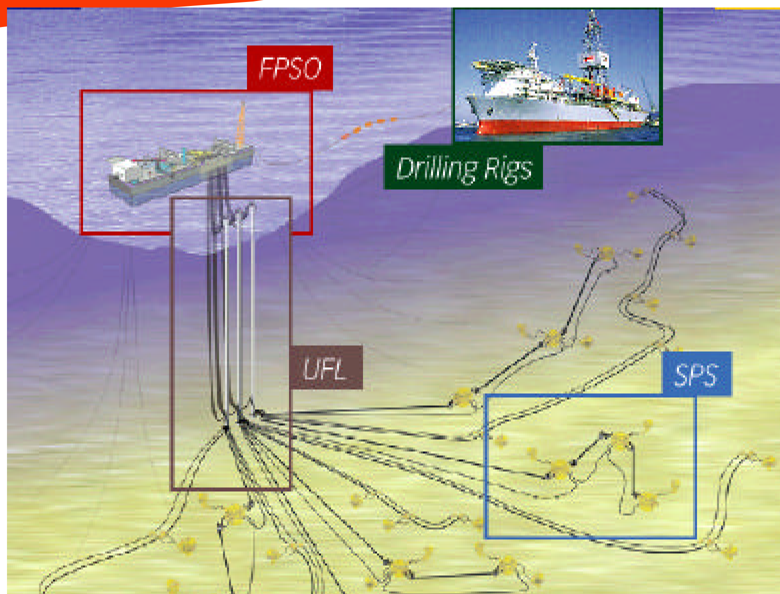
- 725 million barrels
- 2.5 billion USD
- 39 sub-sea wells
- 60 km of flow lines + 77 km of umbilical
- the largest FPSO never built
  - *oil storage: 2 million barrels*
  - *oil treatment: 200,000 bopd*
- 1400 m water depth

Fire & Blast 2002 Houston

Geographical location

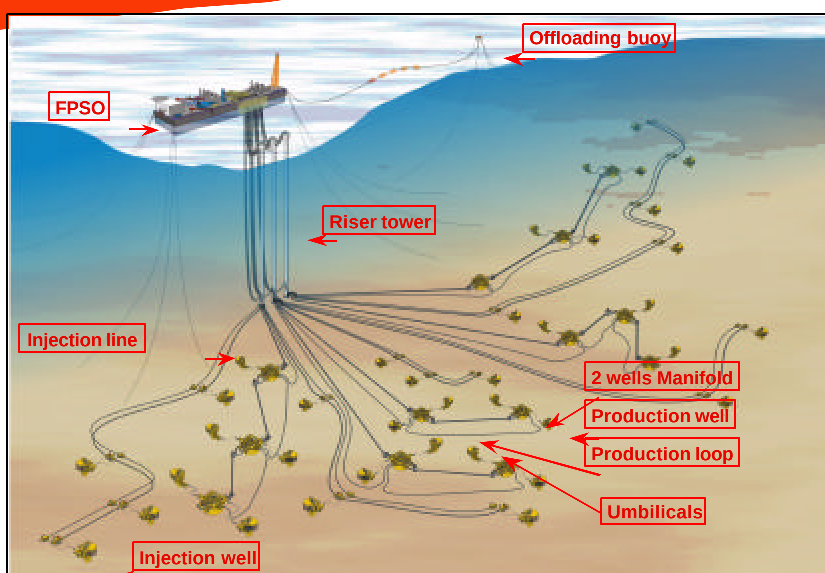
Fire & Blast 2002 Houston

Four main systems

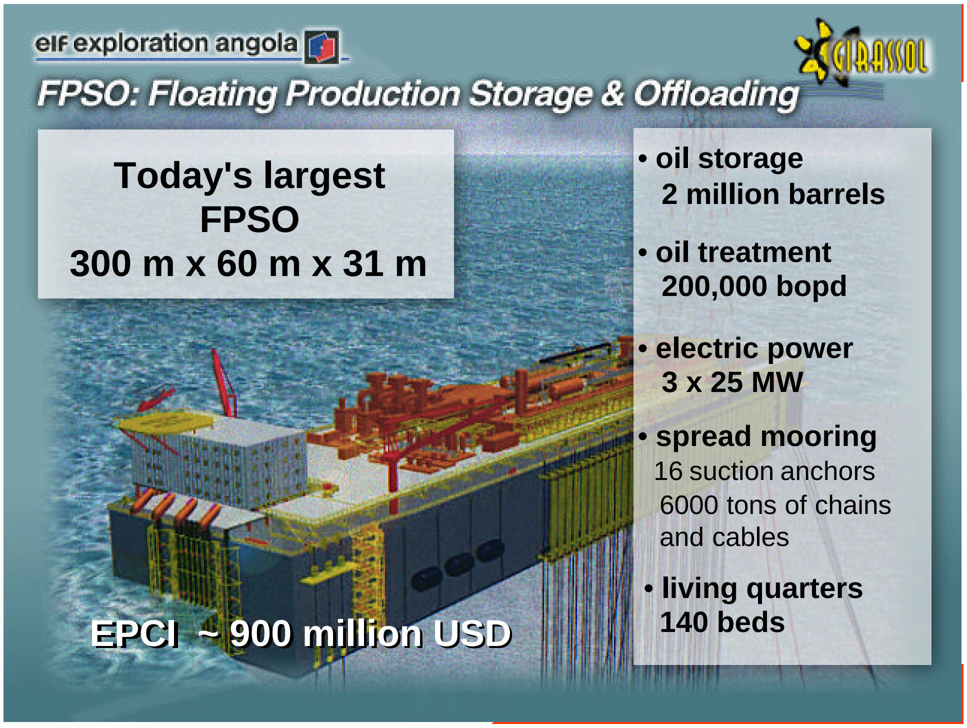


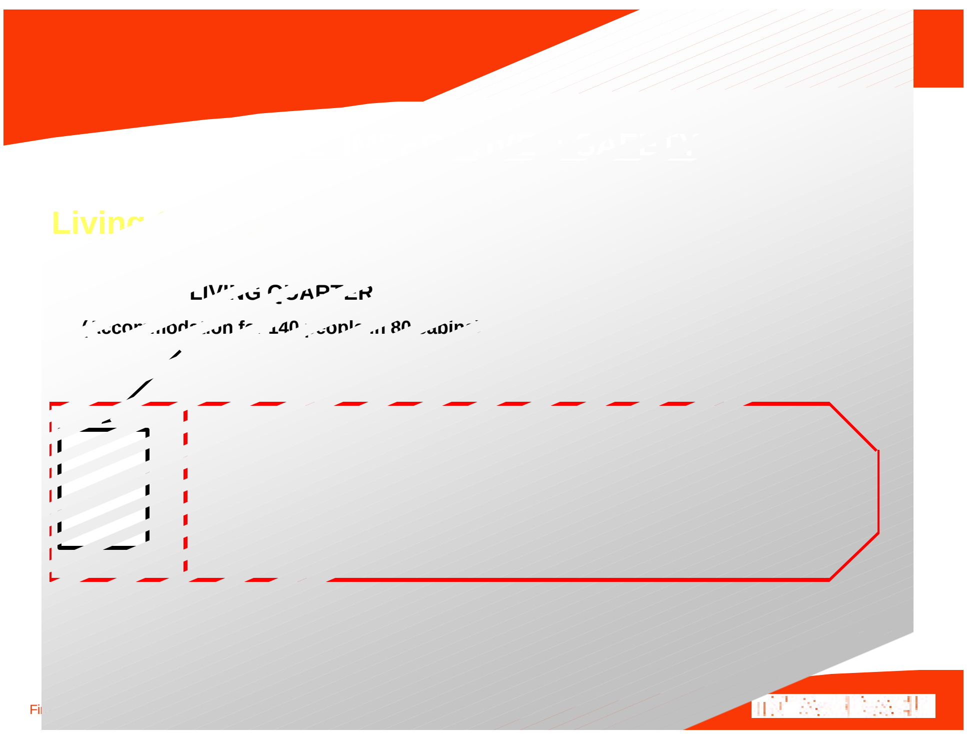
Fire & Blast 2002 Houston

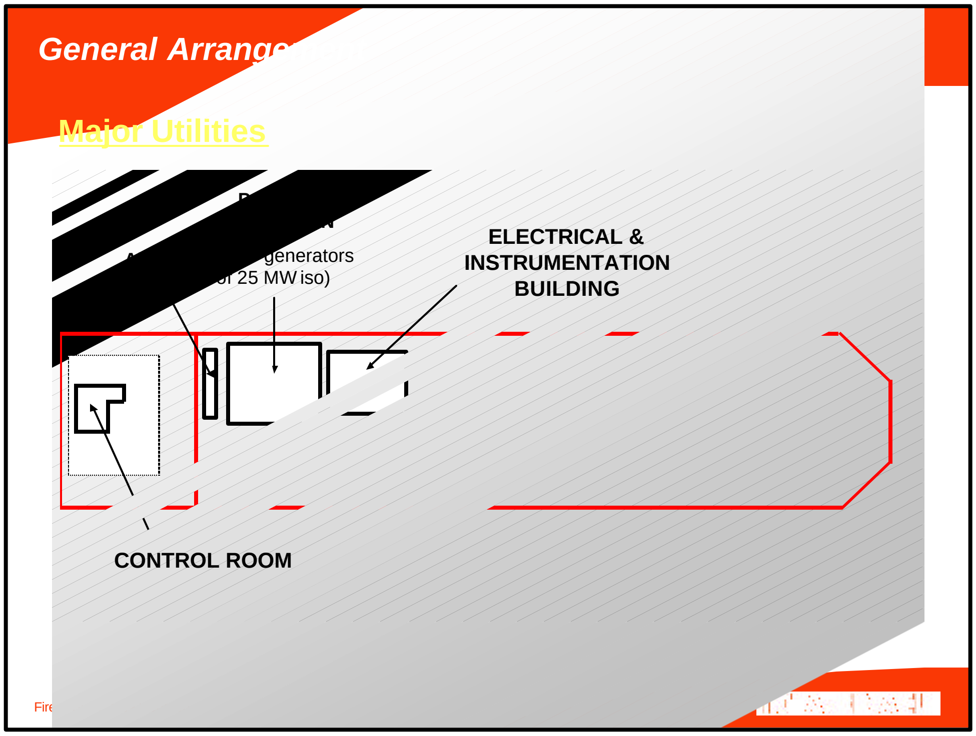
Field development scheme

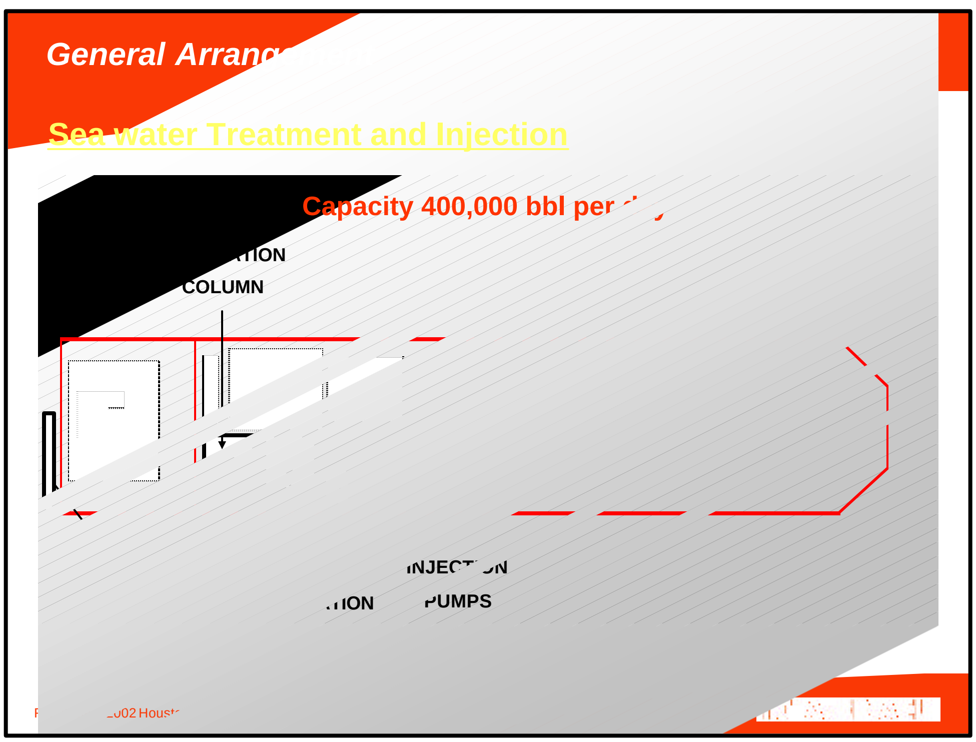


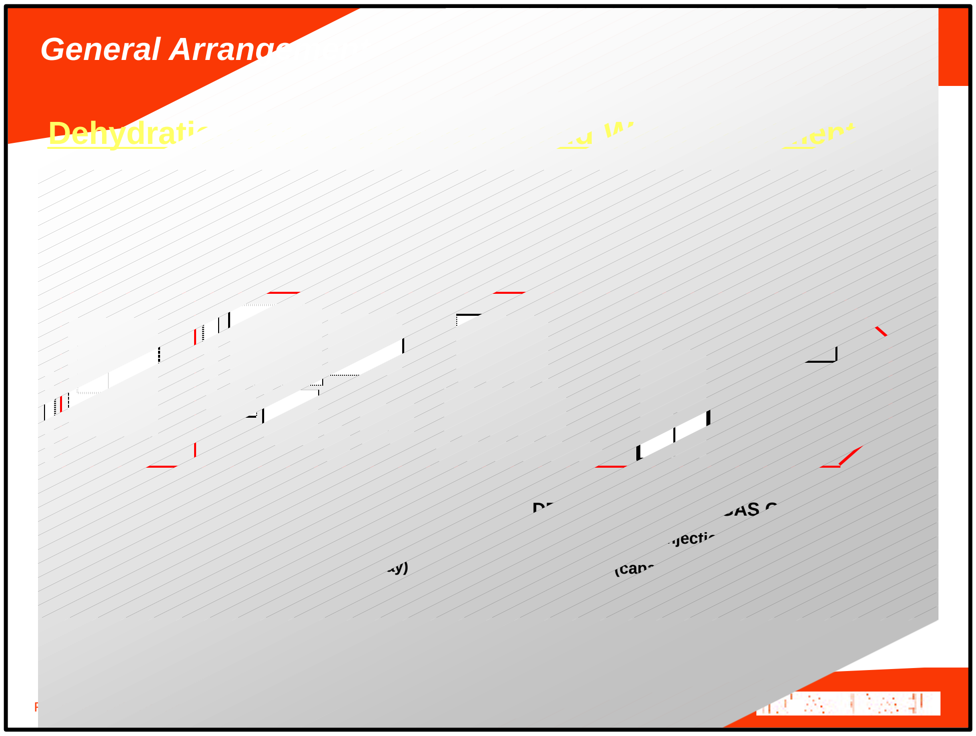
Fire & Blast 2002 Houston

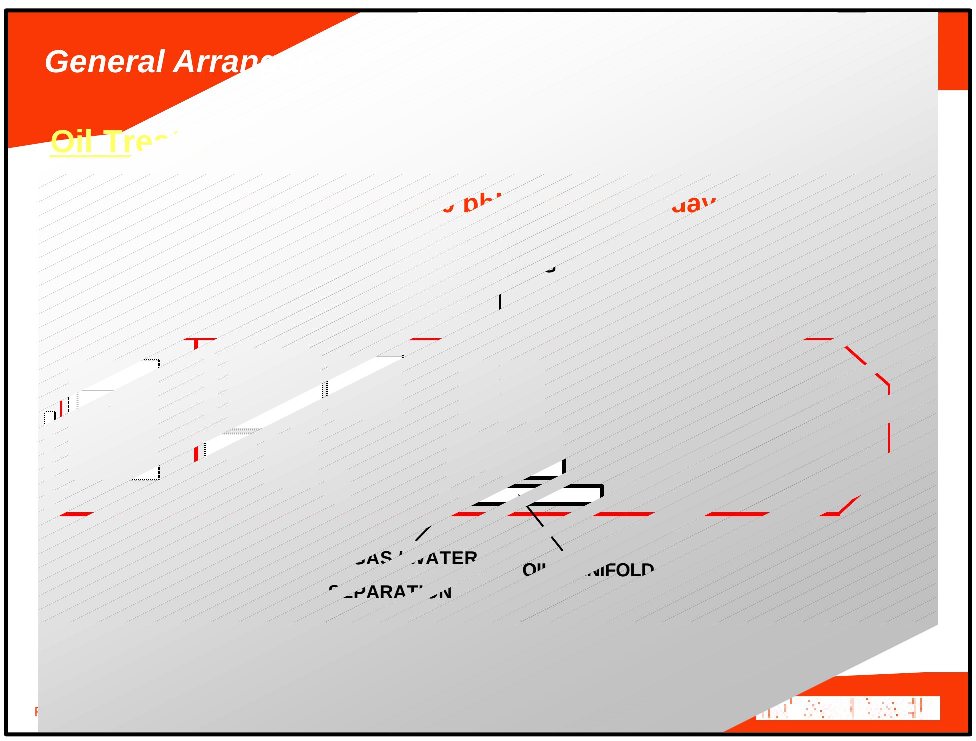

elf exploration angola
GIRASSOL
FPSO: Floating Production Storage & Offloading
Today's largest FPSO
300 m x 60 m x 31 m
• oil storage
2 million barrels
• oil treatment
200,000 bopd
• electric power
3 x 25 MW
• spread mooring
16 suction anchors
6000 tons of chains and cables
• living quarters
140 beds
EPCI ~ 900 million USD

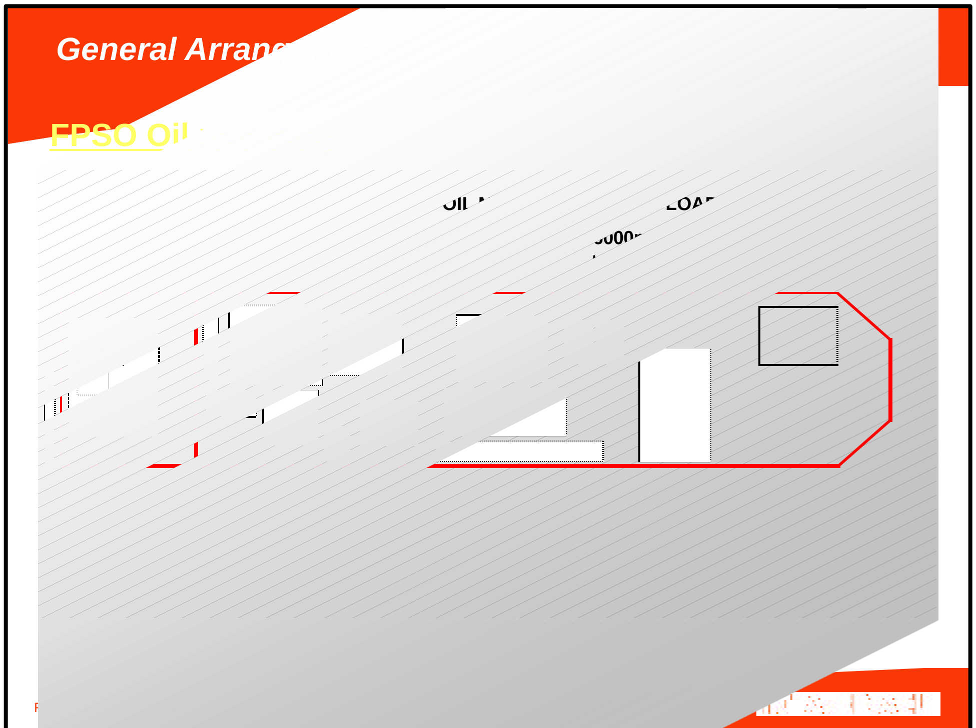


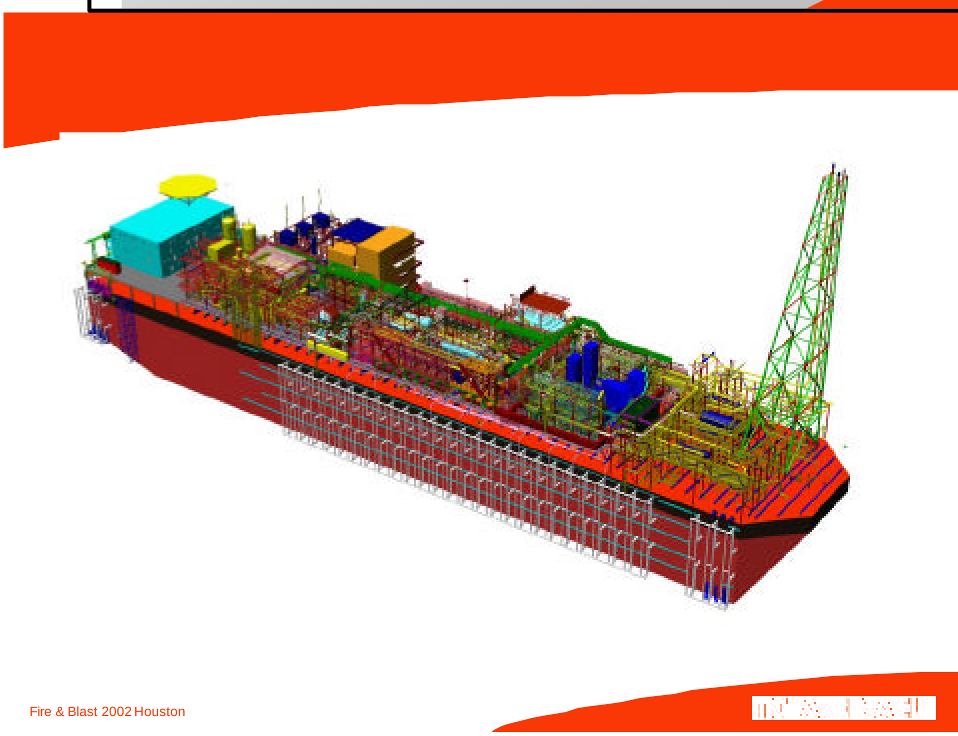

Major Utilities
generators
25 MW iso)
ELECTRICAL &
INSTRUMENTATION
BUILDING
CONTROL ROOM


Sea water Treatment and Injection
Capacity 400,000 bbl per
COLUMN
PUMPS


General Arrang
Dehydrati


General Arran
Oil Tre




Fire & Blast 2002 Houston

Fire & Blast 2002 Houston

Major accidental Scenarios & Design

Standard TFE ALARP design policy :

1 - Priority: design to AVOID Accidents

2 - If accident, design to REDUCE EFFECT of accident .

Fire & Blast 2002 Houston

Specific Fire safety design

* Active:
  - deluge & foam & water curtains all cargo tank area
  - deluge on chains, life boats & in Risers' I tubes
  - monitor for sea pool fire
  - avoid flasgh back of flammes through cargo piping (cand
* Passive
  - access tunnel between TSR and Free fall lifeboats
  - maximum plating topside deck
  - bunds (transverse and longitudinal)
  - no pump rooms

Fire & Blast 2002 Houston

Fire & Blast 2002 Houston

Specific Fire Safety Design

Building Fire protection:

In addition to SOLAS

* Active:
  - foam in Machinery Room floor deck
  - water mist : diesel pump and HPU rooms

* Passive
  - No process equipment in MR
  - hazardous equipment in individual Fire walls rooms in I
  - fire floors to avoid spread of fire between MR & LQ
  - Totally fire isolated EI building levels

Fire & Blast 2002 Houston

1 - AVOID explosions
- 1-1 avoid leaks in worst areas
- 1-2 facilitate natural dispersion
- 1-3 avoid ignition

2 - If explosion, to REDUCE EFFECT of explosion
- 2.1 avoid confinement
- 2.2 avoid congestion.
- 2.3 use of deluge if necessary
- 2.4 protect Accommodation and critical equipment.

Fire & Blast 2002 Houston

Specific Explosion Safety Design

1 - AVOID explosions

*leaks : - no gas equipment between hull & topside decks
- PV breakers not between 2 decks

*dispersion: - topside deck at 7 m
- maximum gratting
- no fire walls on topside
- no equipment (except hull piping) between decks
- large structures down wind
- no escape tunnel

*ignition: - no equipment between hull & topside decks
- no supply's birthing in process area
- gas detection between 2 decks
- air lock in all buildings
- no doors directly toward process

Fire & Blast 2002 Houston

2 - If explosion to REDUCE EFFECT of explosion

* confinement:- idem dispersion
- spread of equipment on all hull's surface

* congestion: - topside deck at 7 m
- minimum equipment between 2 decks

- deluge below all topside deck
- limited damage:
  - accommodation far from topside,
  - Accommodation resists to credible explosions
  - cargo tanks deck resists to credible explosions
  - E/I building resist as much as process equipment
  - large, open and empty area between LQ and topsides
  - reinforcement of sensible equipment supports
  - risers esdv in safe explosion area

Fire & Blast 2002 Houston

1 - to AVOID cargo tank explosion
- isolated cargo tanks-->submerged pumps
- Individual PV breakers
- 2 gas inert networks
- 2 gas inert units
- continuous O2 control in cargo tanks
- continuous gas hydrocarbon control in ballast

2- to REDUCE cargo tank explosion damage
- topside deck at 7 m
- there is no other reasonable design to resist to a cargo tank explosion

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- ALARP Criteria
- Critical gas releases ?
  - On topside deck
  - between decks (upper deck area)
- Explosion calculations (Flacs)
- Structure calculations for sensitive equipment
  - LQ
  - Hull deck
  - cargo piping
  - Sensitive process equipment

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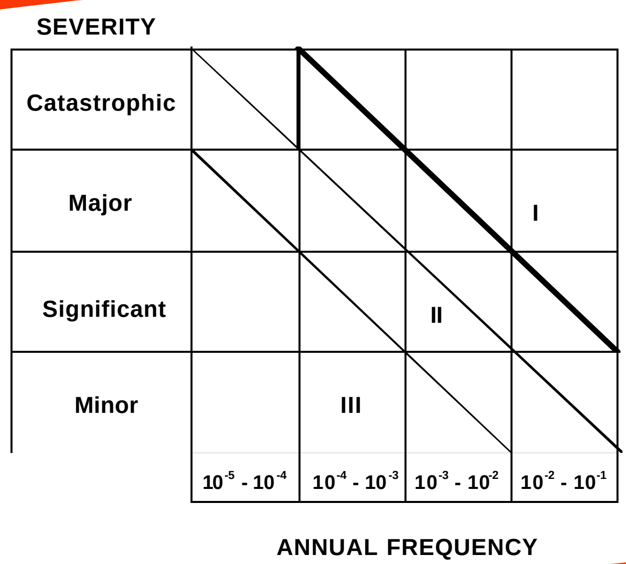
Company ALARP criteria



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Company ALARP criteria (cont'd)

I : Improvement deemed necessary
II : Target for improvement
III : Remote risk.

Consequences categories

Minor:	Consequences local to where incident occurs
Significant:	Consequences are limited to one zone (or ''module'') of the FPSO. Possible off-site effects, 3rd party interest not endangered.
Major:	Consequences extend to several zones (or ''modules'') of the FPSO; 3rd party interest endangered, but not threatened.
Catastrophic:	Consequences extend to all the FPSO, 3rd party interest threatened, and impact on the environment: destruction of - Living quarter - or hull deck - or large oil process vessel (200m3)

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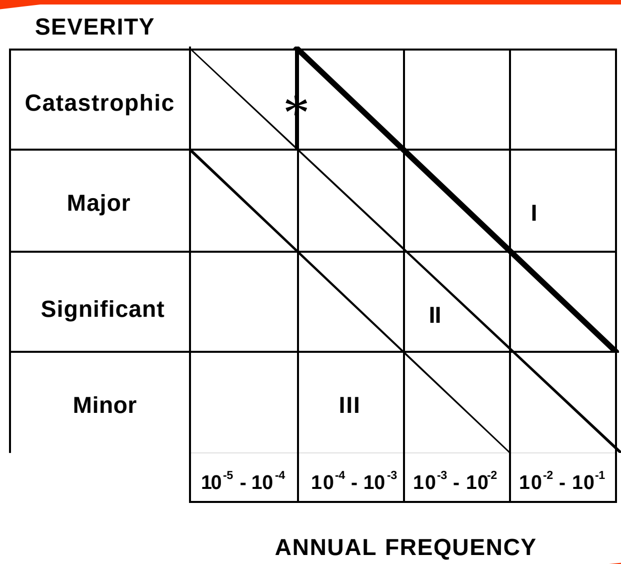
Critical gas clouds?



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Critical gas clouds ?

- Frequency of all catastrophic explosions (Fce) shall be < 1 10-4 /y

- Check that Fcexp are not > 1.10-4

  - Fexp= F(gas cloud) x F(ignition) x F(late ignition) > 1.10-4
  - F(gascloud) > 1.10-4/ (Fignition)/F(late ignition)
  - F(gascloud) >3.10-3

- **Check that all gas clouds that have frequency > 3 10-3 (ALARP catastrophic frequency) do not create a catastrophic explosion** that destroy LQ or Hull deck or large oil process vessels (200 m3)

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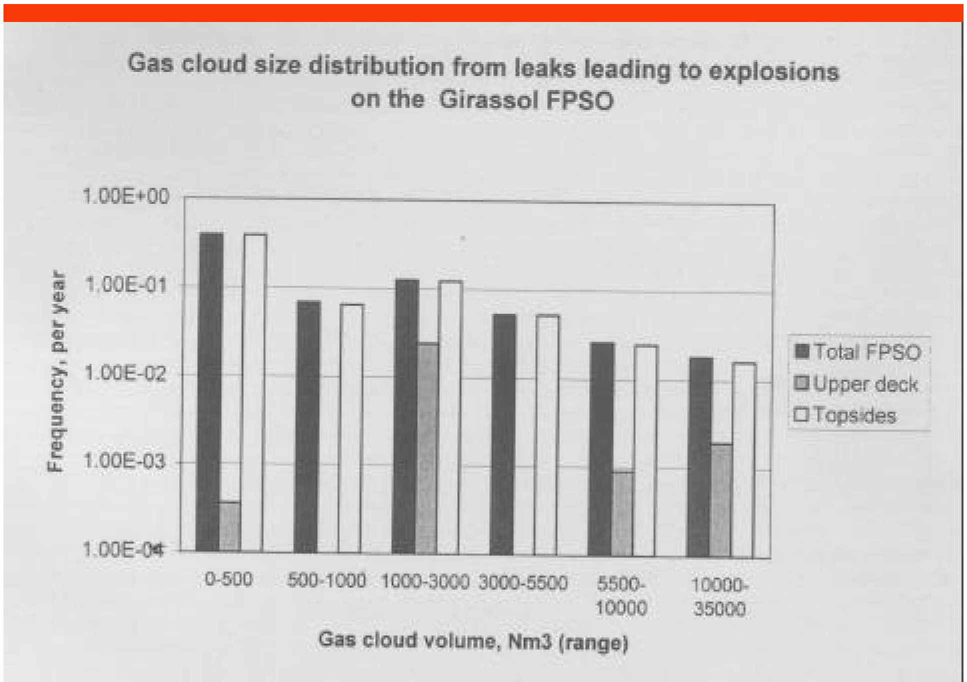

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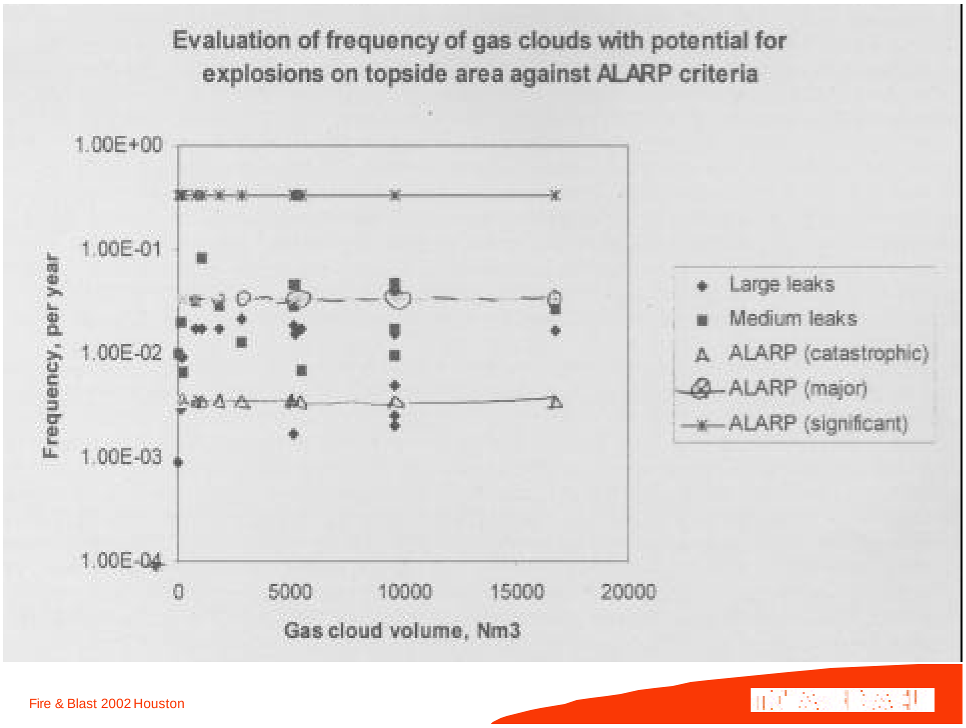
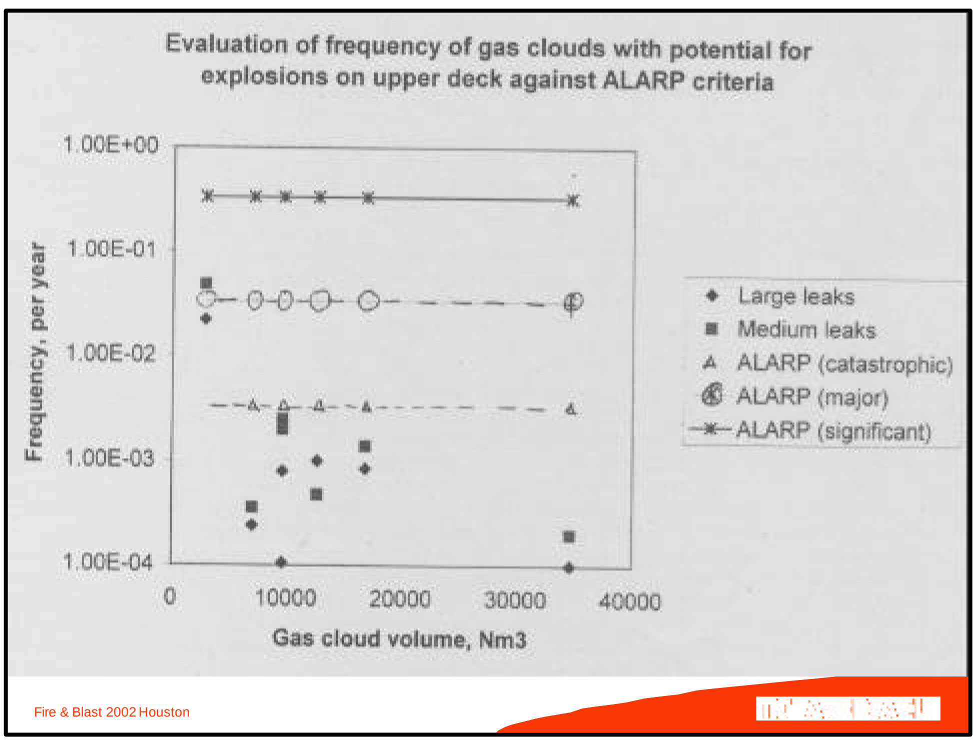

Evaluation of frequency of gas clouds with potential for explosions on topside area against ALARP criteria
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
Frequency, per year
0
5000
10000
15000
20000
Gas cloud volume, Nm3
Large leaks
Medium leaks
ALARP (catastrophic)
ALARP (major)
ALARP (significant)
Fire & Blast 2002 Houston


Evaluation of frequency of gas clouds with potential for explosions on upper deck against ALARP criteria
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
Frequency, per year
0
10000
20000
30000
40000
Gas cloud volume, Nm3
Large leaks
Medium leaks
ALARP (catastrophic)
ALARP (major)
ALARP (significant)
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Credible accident scenarios

LOCATION	SEGMENT NUMBER	DESCRIPTION	GAS CLOUD SIZE, NM3	PRIORITY [3]
Upper deck	23	Gas lift jumper (including riser)	12600	1
	22	Gas lift manifold	2800	3
	22	Gas lift manifold	950	6
Topside	20	Gas injection manifold	16800	2
	5	First stage separator	9600	4
	19	Fifth stage compression	5500	5
	22	Gas lift manifold	2800	

Table 1: Credible accident scenarios

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Large leak gas injection riser – Floater deck

Volume of gas : 155 * 30 * 7 = 32550m3 positioned at z=0m

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CRITICALITY (CRIT)	DESCRIPTION
1	Protection of personnel; emergency and evacuation facilities
2	Protection of assets, prevention of escalation (domino effects) ultimately affecting safety of personnel
3	Protection of assets, mainly heavy equipment

	TAG NUMBER	DESCRIPTION	BASIS FOR SELECTION	PROTECTION OF	CRITIC	OF INTEREST	NB OF PANELS	PANEL DIM (M*M)	NB OF POINTS	POSITION	REMARKS
1	PY-981 a/b/c	Turbo-generator	Structural, dropped object	Assets	3	Support and tip	3	3 panels at z=8, 1 covering plating at z=7	12	yes (at 2 heights, 2 per generator)	P1 area subject to detail investigation in present analysis
2	UA511 a/b	Turbo-compressors	Structural, dropped object	Assets	3	Support	1	Panel covering base of skid, z=8	1	yes, at +8m	
3	UB-501	LP gas compression	Structural, dropped object	Assets	3	Support	1	Panel covering base of skid, z=8	2	yes, at +8m	
4	UB-512 a/b	HP compression	Structural, do, escalation	Assets	3	Support	1	Panel covering base of skid, z=8	1	yes, at +8m	
5	UA-511 c	Technical room, comp	Structural	Assets	3	Net loading (dp)	2	S-facing wall (10*5)	0	No	
6	UA-800	Glycol regeneration	Structural	Assets	3	Support	1	Covering the base of skid at z=8	0	yes, at +8m	
7	UA-707 a/b	Desulphation pack	Structural, dropped object	Assets	3	Net loading (dp)	2	20*18, z=8, 15	4	yes, at z = 8&12.5 (above and below filter and near outside support)	
8	UA-801	Fuel gas package	Structural, dropped object	Assets	3	Support	1	10*10, z=8	0	Yes	
9	UA-830	Air compression	Structural, dropped object	Assets	3	Support	1		0	No	
10	UB-890	Methanol injection	Structural, dropped object	Assets	3	Support	1		0	No	
11	UB-901	Chlorination unit	Structural, dropped object	Assets	3	Support	1	30*15, z=23	2	yes, at top and bottom of unit	
12	UA-401	Hydrocyclone pack	Structural, dropped object	Assets	3	Support	1		0	No	
13	PY-982-2/3	Diesel generator	Structural, dropped object	Assets	3	Support and tip	2	Base (z=8m) of both, N-side of both	0	yes, at +8m	

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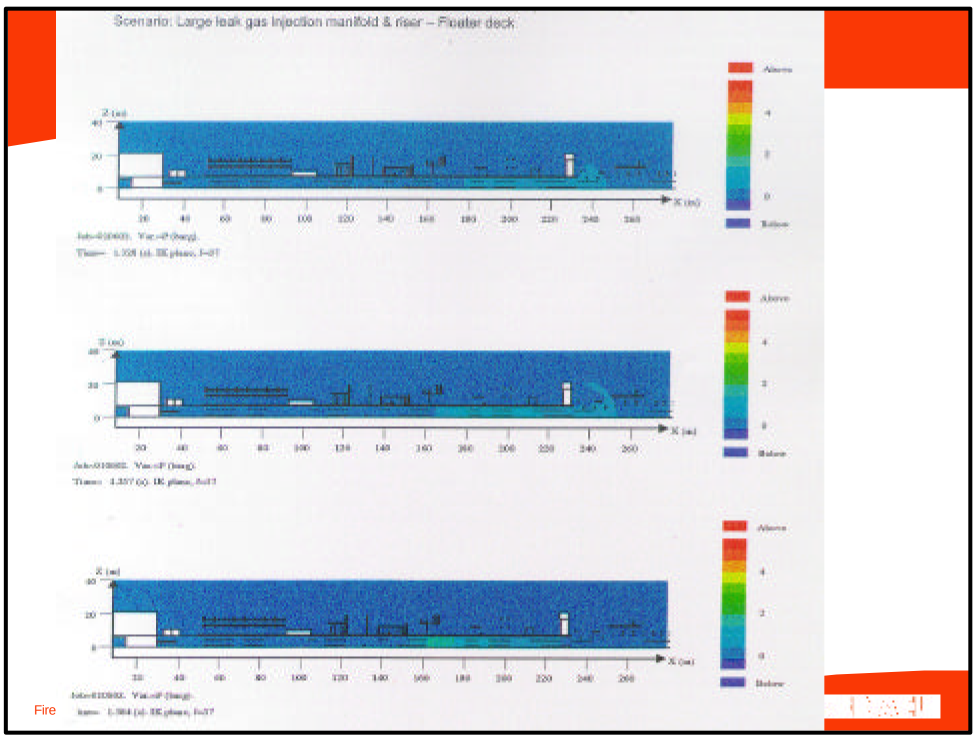

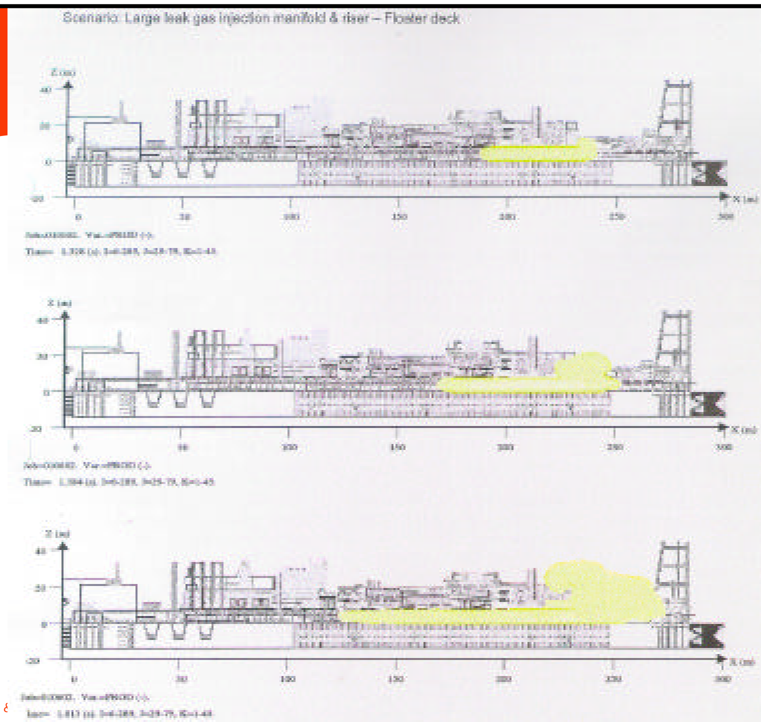

Fire &

Main results are presented in the table below. It represents the maximum overpressure [barg] measured for each area.

Area affected	Gas in the floater deck				Gas on topside
	Gas injection riser		Gas lift jumper		All scenarios
	Base case	Mitigation by deluge	Base case	Mitigation by deluge	Base case
Accommodation (North-facing wall)	8.8	3.8	0.7	0.3	< 0.01
Accommodation (other walls)	3.0	1.4	0.4	0.3	< 0.01
E/I building (base)	1.2	0.4	0.7	0.3	0.01
E/I building (walls)	0.6	0.25	0.3	0.2	0.02
Hull	7.7	2.4	3.4	1.5	0.02
Maximum overpressure	15.7	9.3	7.8	2.7	0.05

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Explosion risks:

CONCLUSION:

All gas clouds that have frequency > ALARP catastrophic
if they explode,
do not damage
- LQ
- nor Hull Deck
- nor large oil process vessels if some supports are renforceded

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Pool fire simulation: criteria

On the escape way the fire may be harmeful if:

- **smoke content > 1%**
- **CO content > 1500 mg/m3 during 30 mn**
- **CO2 content> 100 000 mg/m3**
- **air temperature> 150°**
- **radiation level > 6.3 kw/m2**

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Pool fire simulation: scenario

Simulation with Kameleon :

*** most probable:**

- 42 m2 (14*3 m) pool filled with 2147 kg (initial thickness 0.06) of stabilised oil

*** worst conditions**

- wind speed 5 m/s perpendicular to hull coming from sea
- full plated top-side deck
- without any equipment on any of the 2 decks
- fpso freboard mini = 7 m (maxi 23 m)

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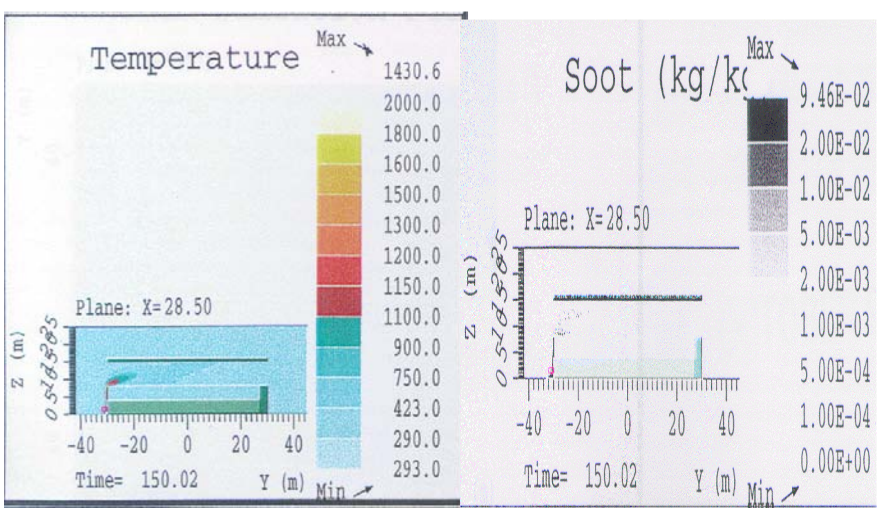
Kameleon: pool fire



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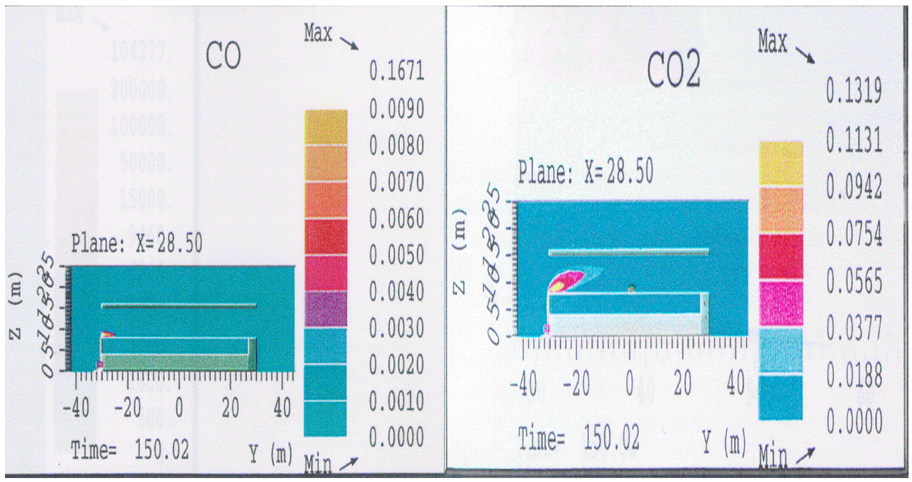
Kameleon: pool fire



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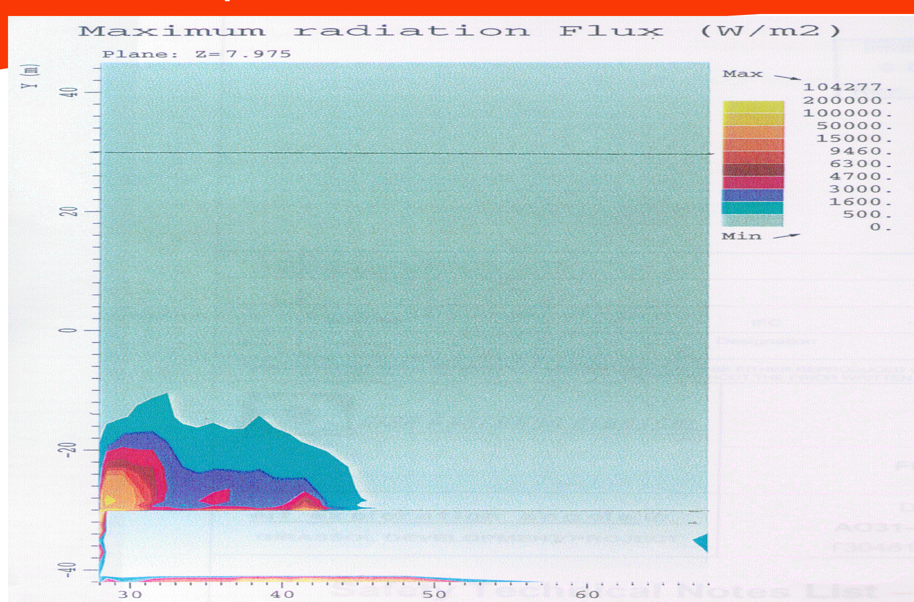
Kameleon: pool fire



Fire & Blast 2002 Houston

Special Interest Presentation by Ricardo Rios de Campos Rosa on Petrobras P36 Investigation

Mr. Rios presented an overview of the investigation into the fire and explosion abroad Petrobras P36, which led to the sinking of the semi submersible in Campos Basin's Roncador field in Brazil.

The rig was converted to increase processing capability of 180,000 bbl of oil per day. At the time of the accident, the rig was producing around 84,000 bbl of oil and 1.3 million m^3 of gas per day.

The enquiry commission concluded that the most probable sequence of events leading to the sinking of P36 were (a) mechanical explosion caused by excessive pressure in the starboard emergency drain tank due to a mixture of water, oil and gas rupturing the tank, and (b) the rupture of the drain tank ruptured the sea water service pipe initiating flooding of the compartment and release of sufficient gas to fill the entire void space on the 4th level and other areas and caused a very large explosion.

The explosion killed 11 people, besides inflicting serious physical damage to the platform. All attempts to stabilize the unit failed and the platform sank after increasingly listing for a period of 5 days. The accident also spilled $350m^3$ of oil at sea.

Mr. Rios in conclusion called for:

1. Establishing a regulatory regime for operational safety in exploration and production activities in Brazilian waters.
2. Establishing procedures for inspections and auditing concerning the structural integrity of the production installations
3. Improvement of the operational safety management system
4. Review of classification of risk areas, specially in major conversions /modifications
5. Comprehensive staff training program in maintenance operations and accident response.

Twenty-six slides as presented are attached.

P-36 accident considerations

anp

OVERVIEW AND COMMENTS ABOUT "PETROBRAS 36" HER HISTORY AND THE ACCIDENT

Fire & Blast Considerations, June 2002
Ricardo Rios de Campos Rosa
rrios@anp.gov.br

P-36 accident considerations

anp

HISTORY

- **Originally the rig was built for Drilling and Producing operations.**
- **The rig conversion into a Producing Unit capable for processing 180,000 bbl of oil per day, required large structural and naval modifications.**

P-36 accident considerations

HISTORY

- Equipment changes was made to match the new purposes.
- The unit arrives in Brazil under "dry tow" with some equipment waiting to be commissioned.
- The accident happens with the rig anchored in Campos Basin's Roncador Field, producing around 84000 bbl of oil and 1.3 million m³ of gas a day.

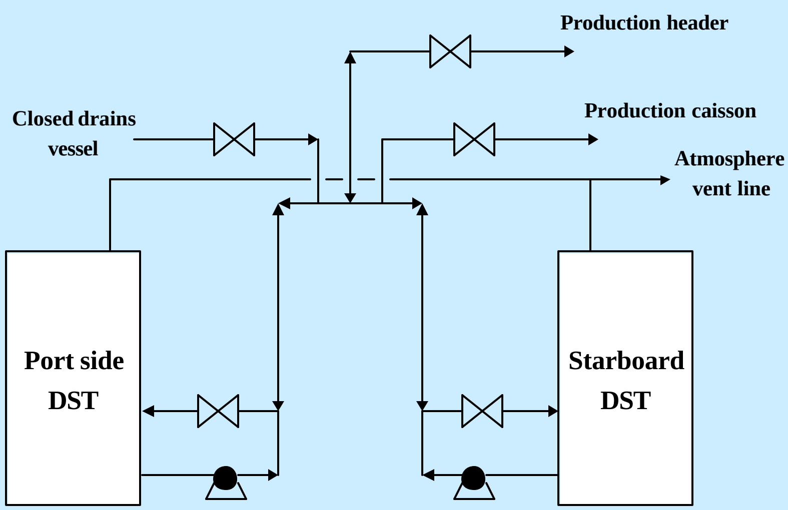
P-36 accident considerations

P-36 accident considerations

ACCIDENT CRITICAL EVENT

- Drainage operation of the **Drains Storage Tank** in the aft port side column

P-36 accident considerations

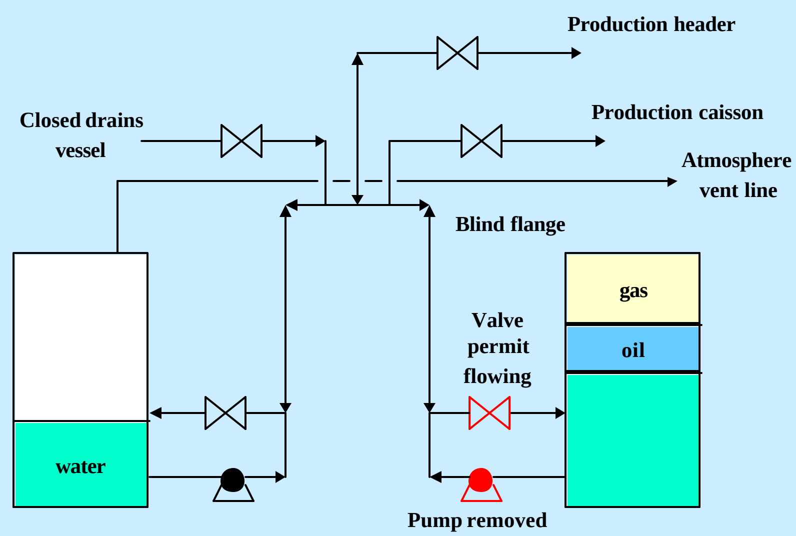


P-36 accident considerations

ANALYSIS OF THE OPERATIONS

- **Frequent water movements in the Drains Storage Tanks**
- **Maintenance of the starboard side Drains Storage Tank Pump**
- **Vent line blind flange**

P-36 accident considerations



P-36 accident considerations

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ANALYSIS OF THE OPERATIONS

- **Operation to empty the port side Drains Storage Tank**
- Operation undertaken without straight supervision
- Pumping water through production header
- Mechanical failure or incomplete closure of the starboard tank intake valve
- No redundancy for valve simple failure, concerning the tank intake line

P-36 accident considerations

ANALYSIS OF THE EXPLOSIONS

- **First explosion -** mechanical explosion caused by the rupture of the tank
- **Second explosion** – very large chemical explosion killing eleven members of the fire brigade

P-36 accident considerations

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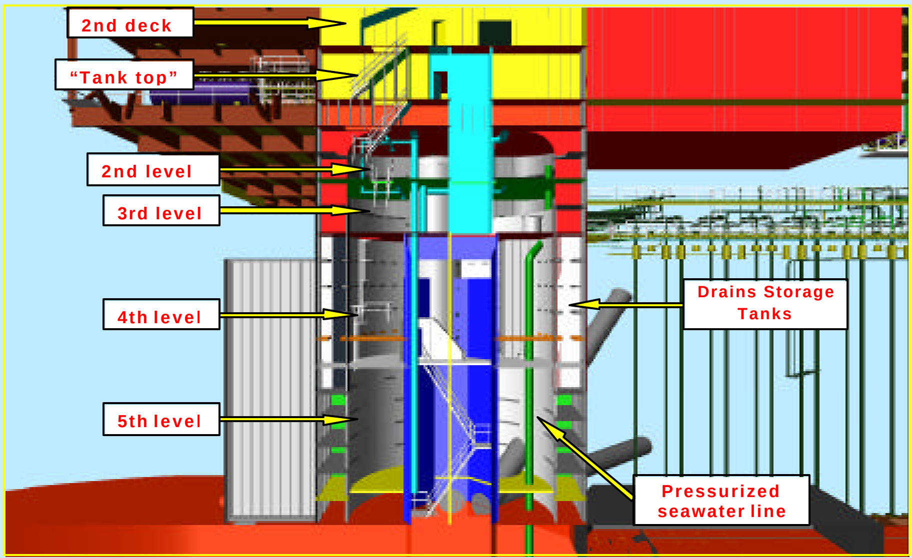
P-36 accident considerations



P-36 accident considerations

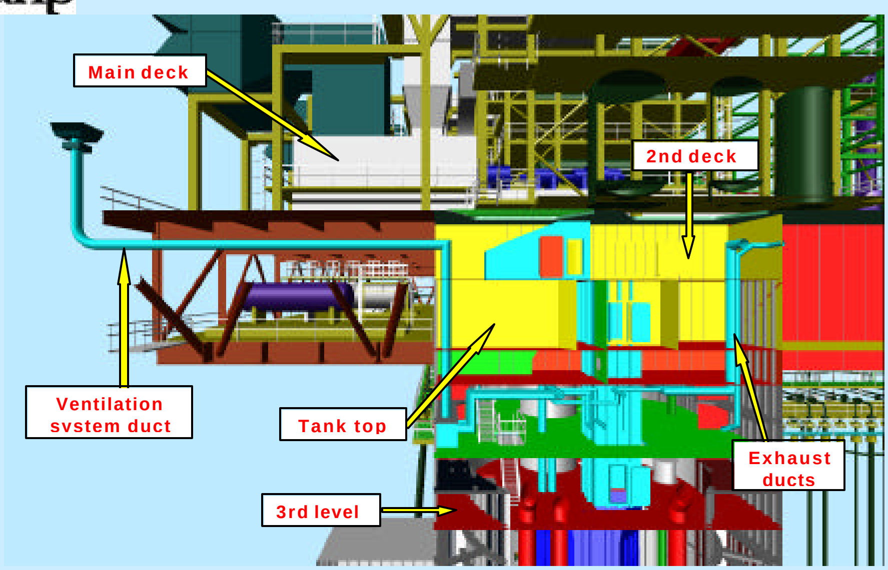
ANALYSIS OF THE EXPLOSIONS

- **First explosion** - mechanical explosion caused by the rupture of the tank
- **Second explosion** – very large chemical explosion killing eleven members of the fire brigade

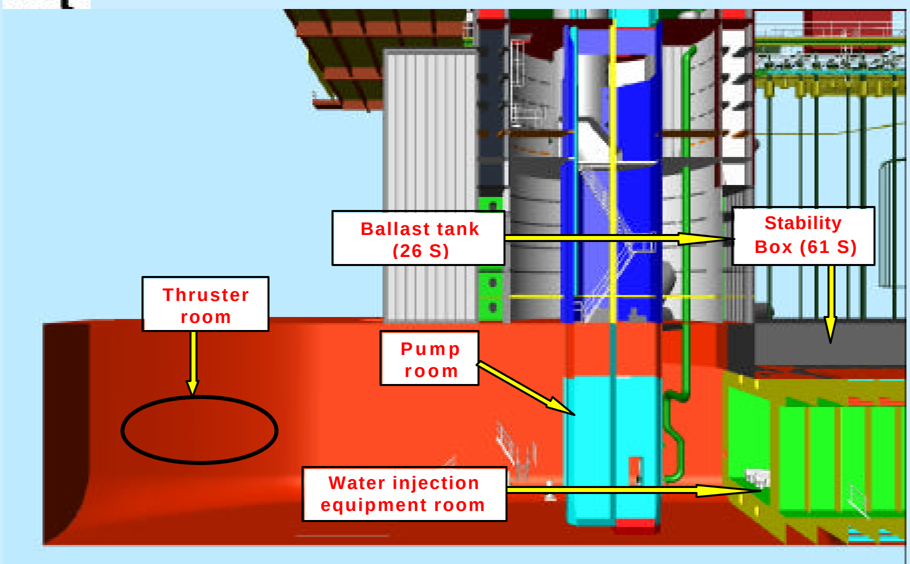
P-36 accident considerations

ANALYSIS AND RESULT OF THE DAMAGE

- **Flooding of column and pontoon**
- **Admission of ballast water at port bow**
- **Continuous submersion of the platform**



P-36 accident considerations



P-36 accident considerations

EVACUATION AND ABANDONMENT OF THE PLATFORM

- From the total of 175 people on board, 138 considered non essential for the emergence operations were evacuated, by crane, beginning at 1:44 a.m. and finishing up at 4:20 a.m., on March 15 of 2001.

- Final abandonment carried out by helicopters at 6:03 a.m., with the rig listing at 6°, on the same morning.

P-36 accident considerations

anp

ANALYSIS OF THE SINKING

ATTEMPT TO SALVAGE THE PLATFORM

- Progressive flooding of the platform started at 8:15 a.m. on March 15 of 2001
- Nitrogen injection through the stability box vent line next to the damaged column
- Slow increase in draft and list
- Platform completely submerged around 11:40 a.m. on March 20 of 2001

P-36 accident considerations

P-36 accident considerations

P-36 accident considerations

ENVIRONMENTAL IMPACT

- Around 350 m^3 of oil emerged during the first 24 hr after the sinking at about 150 km from the coast
- Oil spill treated by mechanical recovery and chemical dispersion

P-36 accident considerations

P-36 accident considerations

CONCLUSIONS AND RECOMMENDATIONS

- Improvement to the Operational Safety Management System
- Review of Project Design Criteria
- Review the Classification of Risk Areas, specially in majors modifications of the installations
- Simultaneous commissioning, maintenance and operation actions
- Staff dimensioning, capabilities and training program
- Management of unit conversion projects

P-36 accident considerations

ANP ACTIONS FOR OPERATIONAL SAFETY

- Establishing a Regulatory Regime for Offshore Operational Safety in Brazilian waters
- Establishing Procedures for Inspections and Auditing, concerning the Structural Integrity of the Production Installations (onshore and offshore)
- Accident Investigations Team

P-36 accident considerations

REGULATORY REGIME FOR OFFSHORE OPERATIONAL SAFETY

- Objective - Establish Regulations and Procedures to Assure the Operational Safety on E&P Activities
- **Obligations to the Concessionaire**
  Installation Description; Formal Risk Assessment; Safety Critical Elements Identification;Internal Auditing and Independent Verification; Incident Investigations
- **Obligations to ANP**
  Inspection and Auditing; Documentation Analysis; Authorisation to the Operation; Accident Investigations

P-36 accident considerations

FUTURE ACTIONS

- **Development of Agreements with the Brazilian Maritime Authority and the Ministry of Work, to perform integrated Inspections and Auditing**

Theme Papers

Where available, the written version of the paper is reproduced. For the papers for which the written versions were not available, a short abstract of the speech prepared from written notes taken during the workshop is presented along with the copies of the slides used for illustrations.

Design Philosophy and Management Processes

Graham Dalzell
Senior Fire and Safety Engineering Consultant
BP Upstream Technology Group in Aberdeen

Why are we here?

This is one of the most potentially hazardous industries in the world. It balances an airport, a power station, a marine terminal and a hydrocarbon processing plant on top of an elevated structure, way out at sea, while drilling into a virtually infinite source of high pressure fuel and then adds a hotel with up to 200 people on it, all in the space of a football field. The primary reason that we are here is that we, both corporately and individually, care deeply about the safety of those people. Managing all of those risks is difficult and, while individual aspects can be managed with ease, addressing the totality of the problem poses immense challenges. Unquestionably, the greatest opportunities, and difficulties, exist during the design process.

There is a growing public intolerance of disasters. What was done yesterday will not be good enough today. The television networks relish a spectacle and, rest assured, if they can get cameras to the scene, pictures will appear throughout the world in minutes and, if this isn't possible, graphic interviews with survivors will be broadcast. This brings pressure for retribution both individual and corporate and the penalties are becoming harsher. We must not, however, let the fear of prosecution lurk in the back of our minds. It may cause the design processes to be more aligned with avoiding the personal consequences of the hazards, than with avoiding the hazards themselves. Hazard management cannot be effective without fully acknowledging the hazards, understanding them and openly communicating that knowledge. This does increase the exposure to litigation and it is a problem that we must all address.

Perhaps we should all approach the next three days with a very open mind, recognising that none of us in perfect and that we have a lot to learn from each other. We should aim to develop a common process which can help not just Europe and America, but all parts of the world with a developing offshore industry. How can we get the smallest and most infrequent "bang for our buck" and what is the answer to that knotty problem; "how good is good enough?"

Different cultures:

Offshore engineering is a mature discipline, with experience gained over 50 years and in many countries, much of it in the United States, Canada, Australasia and Europe. Each country has invested considerable time, investment in research, and engineering expertise, in the study of fire and explosion hazards. Sadly, each has also experienced these hazards, in some cases with catastrophic results. This history has caused divergence in the ways that the hazards are addressed but we still have common aims; not to kill people or damage the environment, and to avoid losing our assets or corporate reputations.

There are fundamental differences between the two main influences; the United States and the North Sea. Its not that one is better than the other, they are simply different as a result of their history and the types of hazardous situations which each one faces. In the North Sea, with the exception of the gas fields, the predominant facilities are massive integrated drilling and production facilities with up to 200 people on board in a seriously hostile marine environment. There scale of the operations is such that escalation from a smaller incident can occur before people can muster and effective emergency response initiated. There is the potential for total loss off life with no easy means of escape. The Gulf of Mexico and many other parts of the world have inherently simpler, lower risk, low manning, smaller installations with evacuation and survival in the water, awaiting rescue, is practical. However, things are changing with the Deep Water projects developing some of the largest and most complex installations in the world.

In the UK, Piper Alpha was a defining moment, leading to the Cullen Inquiry and subsequent change from prescription to the “Safety Case” legislation. This was the change from government regulations, which defined the provision and standard of safety systems, to a regime in which the operator was required to demonstrate that risks had been assessed, and reduced to “ as low as reasonably practical” – the dreaded demonstration of ALARP. In short, total freedom and total responsibility. From the outside, this is seen as a complex, burdensome theoretical exercise and, in the beginning, it was. However, things have moved on since then. The introduction of the Prevention of Fire and Explosion, and Emergency Response Regulations in 1995 heralded a change from the predominantly QRA based approach to a more pragmatic approach to hazard management, in which an effective system is required for managing the specific causes and consequences. There is increasing interest in inherent safety, but achieving it is making us question the fundamental approach to safety in design. These are the three major contributions that the UK can offer to the process; expertise, research and techniques for risk and consequence risk analysis; a structured approach to managing hazards; and a radical approach to inherently safer design.

As an outsider looking at the US, several aspects are impressive. The first is the continuing effort to establish, maintain and improve effective codes and standards. API is seen as providing the core engineering standards worldwide. They give the basic standards whereby structural, well and process integrity are established. It the plant doesn’t leak, and the structure doesn’t collapse, the facilities are safe from fires and explosions. Without these standards, we would be facing an order of magnitude increase in the number of fires and explosions. The second is the way these codes and standards are implemented. There is a rigour to your design process and verification that ensures that every drawing and calculation is carried out and verified by a state registered professional engineer. The third is the simplicity of your facilities, and the consequent low levels of activity and manning. Such facilities are inherently safer. What you don’t have, we might not need.

Balance:

Effective hazard management depends upon many components and the skill lies in ensuring that every aspect is covered to the extent necessary. This requires balancing the resources and in putting appropriate and sufficient emphasis on each one. There are at least five areas where a balance is required:

The first is the balance between prevention and cure; between minimising the likelihood, and protecting against the consequences. It is all too easy to equate hazard management with consequence management alone but prevention is, by far, superior. Sadly, it is difficult to measure and therefore not valued as the primary risk reduction measure, particularly when responding to quantitative risk assessment. It is easier to sell a bigger fire pump, or a stronger firewall, than it is to sell the accident that doesn't happen. There seems to be reluctance to make that absolute commitment to prevention, so protection is provided anyway, just in case. It is not only the balance between what we provide, but also the balance of effort in the study of causes versus the analysis of severity and consequence. There has been explosion in consequence models but is the effort balanced and justified unless equivalent or greater effort is also applied to the examination of the causes?

The second balance is between the relative dependence on people and on plant to manage hazards. Both are needed, and a failure to provide competent people or to maintain the plant will result in an accident even on the best designs. Most accidents can be traced back to people - human error - but it is the designers that create the tasks and determine their frequency. They also determine the potential for plant deterioration and failure. The designers therefore determine what needs to be done in operations to keep the facilities safe.

The third balance is between the demands and investment in different hazards. Immediately after Piper Alpha, there were calls for all platforms to be unmanned with operations personnel shuttled in by helicopters from drilling rigs which could be converted into accommodation barges and moored a couple of miles away. They had forgotten the other two North Sea disasters; the overturning of the Alexander Kielland accommodation barge and the crash of the Chinook helicopter close to Shetland, with over 100 deaths between them. Just because we have eloquent experts in fire and blast and a diverse range of assessment and protection methods does not necessarily mean that these hazards make the greatest contribution to the risks. They may not warrant a disproportionate allocation of resources over structural, marine or well hazards. There must also be a balance between investment in major accident hazards and those more frequent occupational risks. Killing 1 person every year for 100 years is just as serious as killing 100 people once every 100 years. However, our concern over litigation and public outrage over larger incidents may influence this focus; the concept of being risk averse.

The fourth balance is in the relative effort to reduce risk during conceptual design versus the detail. Everyone acknowledges that front end loading has immense value in delivering an optimised design and exactly the same principle applies to hazard management. Unfortunately, the hazard management machine can be a slow starter and reveal many "if onlys" just as we are about to start cutting steel.

The fifth balance is the relative dependence on the " givens" - the default provision of design codes, safety systems and management practices – and the provision of features or systems specifically to manage the cause or consequences of identified hazards. The higher the minimum basic standards; design safety factors, default ESD and protection systems, blast wall ratings, as implemented as a default minimum, the less the need for additional features or even for detailed hazard analysis. However, these higher minimum standards come at a cost, not only capital but also in risk. The more there is, the more maintenance it requires, and the more chance of an accident and casualties.

If we do not actively manage our hazards, we will simply provide a kit of parts in the hope that the kit is complete and that all of the parts are the correct ones. If our luck holds out, they might be the right ones or the deficient ones may never be called on in the life of the facility. If not …..? If we only provide the kit of parts with the balances driven by perception, custom and practice, we will never provide the optimum capital and operational solution to managing the hazards.

Inherent safety:

There have been many attempts to capture the essence of inherent safety. The onshore chemical industry has introduced concepts of substitution, intensification, simplification, and attenuation. These are fine for process hazards and are well understood by chemical engineers but the offshore industry needs to consider a broader and possibly simpler concept. In looking at later generation North Sea platforms, particularly those designed after Piper Alpha, there was not quite the step change in risk that might have been expected. One of the underlying reasons has been the increasing complexity and amount of plant, particularly safety systems. While they may be addressing the consequences of hazards, they are also significantly increasing the maintenance burden and the exposure of people to hazards through their occupancy of the platform and the hazardous areas within it. Is the real key to offshore inherent safety the minimisation of plant and activity offshore? If we examine everything we provide and challenge the need for it and every man-hour of maintenance during the platform life, then we might make that step change. Consider the hazards associated with repainting the process areas and the reduction in risk that a 40 year paint system would provide? Do we think of this as safety investment and judge it on those merits? While classical inherent safety involves eliminating and minimising process hazards, there is an equivalent risk reduction from having an inherently reliable, robust, long lived and maintenance free plant. In other words, make it big, thick and simple!

Another two aspects of inherent safety are total involvement and proactivity. The search for a safer design must involve everyone in the design team asking the simple questions; ***what is dangerous, why is it dangerous and is there a safer way?*** Inherent safety is an attitude of mind which should be instilled in every engineer on the day that they enter college and reinforced throughout their working lives. These questions must be asked about every aspect of the design from the choice of concept, to the location of an instrument. They should be asked as an integral part of the design process, not a retrospective afterthought when there is no leeway to change the design. If we leave the search for a safer design to a handful of experts, then the big decisions such as the concept and layout might be addressed, but all of the lesser opportunities will be missed. It's better to have four hundred brains identifying and working the opportunities than four. The cumulative benefit of all of the small changes could be as much as the few critical decisions. However, realising this opportunity needs real leadership and a commitment to allow people time to think and to invest in their ideas.

Evolution of the design process; 1 - Design Codes:

The building blocks of design safety are our codes and standards. They are full of mistakes - our mistakes. Every time we blow up a plant, we revise our codes to take account of the lessons we have learned. The problem is that many odes tell us what to do, but not why so it is not always possible to confirm that a particular code is appropriate for our circumstances. As we have progressed, codes have been revised and created to take account of our engineering expertise and research, often addressing conditions or hazards that are anticipated; i.e. what might occur rather than what has happened. They will include the most robust feature of inherent safety; the design safety factor. This accounts for a multitude of potential errors from poor manufacture, through use, misuse, overload and long tern deterioration. There needs to be great care not to erode these design safety factors through our greater ability to design "closer to the limit". They are there to address our human imperfections and I challenge any engineer to predict those accurately.

The latest generation of codes are genuinely risk or hazard based. It is reflection of the maturity of the management of particular groups of hazards that their codes take accidental events as the basis of design, and it is the designer's responsibility to identify and characterise the loadings. Structural engineering is a case in point, where boat impact and seismic loadings are design inputs. In the case of seismic, for events of a frequency of 10^{-3}/year, the structure most remain intact and for events of 10^{-4}/year, plastic deformation may occur but the structure should retain its ability to support the people and plant. This is genuinely risk based. It would be reflection of effective fire and explosion hazard management that protection could be based on a design case determined from an analysis of the hazards on the facilities. It would not be right to base man made hazards on a generic frequency, as in the structural seismic case beacuse that likelihood is up to Mother Nature. In the case of fires and explosions we introduce the causes and consequent likelihood. We should therefore be able to determine the bounding design case, in terms of the failure (a range of hole sizes) based on what could realistically occur, and a severity (arising from the release pressure, release rate and duration). However, if we do take that approach then all of the codes must integrate to form one effective hazard management strategy, including; layout, process plant design and integrity, fire and gas detection, ESD, depressurisation, drainage, fire protection and structural strength. If any one of these codes is developed in isolation, then the process will not work.

Evolution of the design process; 2 –Process Safety Management

Although developed for the onshore industry in the US, the guiding principles of PSM; to apply management systems and analytical techniques to understand and control process hazards in order to prevent of minimise the consequence of a release of hazardous chemicals; are widely applied by operating companies in the offshore industry. It provides a very solid foundation on which to base hazard management, by ensuring that the basic requirements for people, plant and business processes are established and maintained from cradle to grave. It also requires rigorous hazard analysis with a concentration on examining causes, through the HAZOP process. Note; there may be differences between the US and UK in the application and breadth of HAZOP. In the UK, it concentrates primarily on process deviation and what goes on inside the pipes and vessels. In the US, it appears to be broader and more holistic, also addressing what goes on outside, particularly the actions of people. The effectiveness of PSM depends very much on the way it is implemented. It is possible to address each element in isolation - the " kit of parts" - but with a good operator, it can create effective hazard management, providing that the requirements arising from the HAZOPs are actions and embedded into the management systems.

Evolution of the design process; 3 - The Safety Case

The European requirement for the Safety Case did not originate with Piper Alpha but with an earlier onshore disaster, Flixborough and with the European requirements arising from Seveso. The main principle of the Safety Case, is that the duty holders must demonstrate a "Case for Safety" and show that all hazards have been identified and that everything "Reasonably Practical" has been done to minimise the risks to people. In principle, this is a laudable aim. Unfortunately, it is a highly indeterminate standard, if it can be called a standard at all, and quite difficult to regulate. It created an approach to compliance which overly concentrated on the numerical calculation of individual and societal risk. It also focussed upon those measures which had been added to further reduce the risks, the icing on the risk management cake, rather than the core ingredients of integrity and competences management. There is implied criticism here of the Safety Case. This is not so; it is the way that we have complied with it that has failed to bring out the full richness and value of the process. With the knowledge that we now have, we would have done it better.

Evolution of the design process; 4 – Integrated Hazard Management

For several years, various parties in the offshore industry have sought to bring together the best of the preceding three steps; codes, management processes and risk assessment; into an integrated and pragmatic process for hazard management, both in design and operation. This workshop is part of that integration process. One of the key steps in the UK was the introduction of PFEER – the Prevention of Fire, Explosion and Emergency Response regulations. This had a very simple core regulation - no 5 - that required that all major accident hazards should be identified, analysed, that suitable and effective prevention, detection, control and mitigation measures should be provided, and that they should have minimum measurable performance standards. In short it required that hazards should be understood and effectively managed. Although the PFEER regulations were high level and goal setting, comprehensive supporting guidelines on Fire and Explosion Hazard Management were produced through a mutual effort by the regulators, design contractors, consultants and operating companies. These give a framework for integrated hazard management and attempt to address the balances mentioned above.

The key is hazard understanding. If everyone, from pipe-fitter and piping draftsman to corporate executives know what is dangerous, why it is dangerous and what they have to do to make it safe, then hazards can be managed effectively. Perhaps, what was needed was not a Safety Case, but a Dangerousness Case; a book of hazards, which explicitly spelt out what could happen, how it could happen and what it would be like. As responsible parents, we don't assure our children that they live in a safe house, that all the furniture complies with the latest fire proof codes and that we are competent to bring them up; we graphically describe the burns that they will suffer if they upset a saucepan or put their hands in the fire. Unfortunately, the explicit description of hazards exposes the operator to litigation should an accident occur. Is it better to have the smoking gun and no murder, or the body? That is one dilemma that faces us, particularly in the US.

The second, essential, element is a sound infrastructure of codes and standards to ensure the fundamental integrity of the process plant and structure. They may also be used to provide a basic level of safety systems, such as ESD. These must be complemented by effective management systems to assure their compliance in design and their upkeep in operation.

With that real understanding of cause and consequence, in a form which the whole design team can appreciate, it is much easier to take a pragmatic and structured approach to hazard management. It is possible to decide which events will be design cases and which must be prevented at all costs, based on the practicality of either strategy. The choice of systems to manage the hazards can be matched to the requirements; for example, the use of passive fire protection to counteract jet fires as it is the only practical solution. The performance of the systems can then be specified so that it achieves a specific role required by that hazard. Having made these decisions, the default code provision can be examined to determine what, if anything, extra is required, and what may be deleted.

Lastly, this must be agreed with, and communicated to the future operators, so that they can embed the requirements into their management processes and implement them for the life of the facility.

What is "Good Enough" and how is it measured?

Our society seems to be fascinated with measurement; to determine our performance in every aspect of our lives, and safety seems to have the greatest scrutiny. It governs both business and government. It is all too easy to concentrate on what is measurable, rather than what is truly important. Measuring compliance with default codes and standards is simple but how is the choice and adequacy of these codes assured? If the real key to effective hazard management is the understanding and management of the hazards by the design team, how could that be gauged and demonstrated to the regulator, if required? Possibly, there are six areas to be considered:

1. Are the basic minimum standards reasonable and suitable for the types of hazards and operating conditions?
2. Have all of the hazards been identified and analysed to the extent necessary to manage them effectively?
3. Has there been a real attempt to minimise risks at source.?
4. Are the management decisions arising from the analysis of the hazards reasonable and practical?
5. Are the systems provided to prevent and control the hazards suitable, effective and reliable, and will they remain so for the life of the facility?
6. Have the process and hazards been documented, implemented effectively through the design and operating management systems, and communicated to the operator?

There is one last question that is for this workshop to debate: What is acceptable and how do we judge that everything reasonable been done to minimise the risks from the hazards; i.e. are risks ALARP? The UKOOA risk based decision-making framework suggested a hierarchy whereby different risks may be judged. These will use progressively more opinion-based criteria for the higher risks and, particularly, those hazards that are novel, poorly understood, likely to induce public outrage and endanger corporate reputations.

- **Codes, standards and prescriptive requirements:** For moderate risk hazards, where the causes, severity and consequences of hazards are well understood relatively uniform and predictable, and it is practical to address them effectively, then sole dependence on prescriptive codes and standards is acceptable. For example, the design of the internal fabric and divisions within accommodation blocks.

- **Engineering judgement:** With hazards that are variable but the causes and consequences are predictable using accepted methods, then engineering judgement based on those predictions is viable as the primary decision method. This process is already embodied within some codes, such as those for structures and corrosion protection. It is applicable for major accidents and high risks but only with well-understood hazards. Offshore process fires and explosions are not quite there yet as there is not common agreement on the criteria for selection of the design cases but this is close. Note, however, that engineering judgement without real hazard understanding and input is guesswork!
- **Qualitative risk assessment:** The use of risk matrices with clearly defined bands of likelihood and consequence, together with regions of tolerability, improvement, and unacceptability are an excellent assessment method, providing that those who are exposed to the risks and have responsibility for managing them in operations participate in the ranking. This is a simple and highly effective method of stakeholder involvement, (below).
- **Quantitative risk assessment:** This is the accepted European method of determining acceptability and ALARP. It has fallen into some disrepute through its misuse. This particularly relates to the dependence on historical, questionably relevant data, hypothesis, and the inability to fully value the effectiveness of good prevention measures. It is a specialised activity and the output needs careful presentation if it is to be used effectively by a wider audience. Used correctly, it is a highly valuable tool for strategic decision making in high-risk areas.
- **Internal stakeholder consultation:** Where decisions will affect the risks to which the workforce is exposed, and they have a key role in managing them, it is reasonable that they should be consulted on aspects that are radically different, and higher risk, compared with those which they normally experience. This should be done informally through the early appointment of the core operations team to work in the design office. However, on controversial aspects, formal consultation and recording with others may be prudent. At the opposite end of the corporation, the controversial and high-risk decisions must also be considered at board level. However, it is essential that the requirements to manage the hazards, both in design and operation, are explicitly presented, so that their obligations for safety over the lifecycle are appreciated and accepted.
- **External stakeholder consultation:** This is less appropriate for offshore safety risks than onshore or environmental concerns, simply because it normally only affects the workforce.

Sadly after almost all disasters, these following words are all too common. ***I didn't think that could happen, I didn't know that was important or I didn't realise it would be like that***. In future, ignorance of the hazards and a failure to put in place effective measures to prevent or control them will not be acceptable.

Fire: The State-of-the-Art

Ben Poblete
Risk Management Specialist
Lloyd's Register North America, Inc.

STATE OF FIRE LOADING IN DESIGN TODAY

Ben Poblete
Risk Management Specialist
Lloyd's Register North Anerica Inc.

INTRODUCTION

To understand the state of fire loading in engineering design today it is critical to first understand the history of fire loading on offshore installations. The information obtained from the historic background determined the approach that has been taken by most of the exploration and producing companies today. It is also critical that to understand the reasoning behind the current and potential future approach to fire loading thus, a short discussion on the elements of risk management should also be introduced as well as how these elements are used in engineering design of offshore facilities. It is through the understanding of risk management principles that will supplement the engineering decisions made for new offshore developments.

It must be emphasized that no matter what the benefits are with a performance-based approach the decision will still be based on the understanding and communications of the fire hazard to the engineering design management team. The operators will base their engineering decisions or options on their understanding of the complexity of their facility and with the size of their fire hazard. Other factors such as cost, engineering schedule and weight constraints of the fire protection solution will also be an essential factor in the decision to accept or reject a performance-based proposal.

HISTORY

Before 1988 most offshore facilities, internationally, relied on both prescriptive local / national regulations and certificate of fitness requirements issued by the certifying authorities such as LR / ABS / DNV. These regulations / requirements were developed by the regulatory bodies based on experience from previous accidents and near misses from the marine industry. The Safety of Life at Seas (SOLAS) regulations was the major document referenced by the regulatory bodies as well as industry guidelines such as API RP (Recommended Practice) series. It must be noted that the regulations, in the 1980's, were mostly reactive rather than proactive due to the creation of guidelines as a means of capturing "lessons learnt" by the industry. During this time period most of the major offshore operators were developing and upgrading their Loss Prevention guidelines to create a more proactive approach in the application of fire protection systems for their installations. These guidelines were more stringent than the regulatory requirements and imposed more specific requirements based on company experience. Companies, such as Mobil Corporation, developed a hydrocarbon fire curve, to ensure that the fire protection systems, such as passive fire protection (PFP), could withstand the more credible fire scenarios that could occur on an offshore platform. The regulatory requirements at that time only recognized cellulose fire curves as the minimum requirements for PFP on an offshore installation. The application of PFP was also based on the approved certified thickness for standard structural configurations.

CATALYST FOR CHANGE

As with most regulation, such as the Safety Case legislation in the UK, a major industrial accidental event is normally the catalyst that instigates a review and subsequent modification or development of new rules and regulations that governs the safety of the industry. Unfortunately with the offshore industry, the catalyst for change was the Piper Alpha incident on the 6th of July 1988. The lessons learned after the public and technical inquiry changed how the regulatory bodies approached the life cycle Health, Safety and Environmental (HSE) aspects of an offshore installation. This change in the UK legislation also instigated changes, worldwide, in the development of new regulations that would govern offshore development in other countries. The focus, in most legislations and classification rules, was to move from a prescriptive to a more goal-oriented type of regulation. This type of legislation focused more on the safety management systems of an operator and also corresponded to the current business model that is used by industry. Since the focus of the new Safety Case Regulations was on the duty holder and their formal safety approach to life cycle management of offshore installations more work were performed to identify and manage fire and explosion hazards. This goal setting approach provided a more holistic attempt to focus on major hazards and provide an inherent safe approach to offshore design and operations. After Piper the offshore industry instigated a significant amount of research effort, by both industry and regulatory bodies, were invested on the understanding jet fires and the improvements on fire protection systems for offshore facilities.

STATE OF FIRE LOADING IN DESIGN TODAY

Post Piper the offshore industry, especially in Europe, investigated quantitatively the potential and consequences of fire on installations. The resultant information and data from analysis and experimentation provided the industry with a better understanding of the fire hazard and what are the options available to prevent, reduce or eliminate the potential for fire. Fire protection vendors worldwide utilized this opportunity to upgrade and develop their products to cater to the diversified methods of fire protection that resulted from the analysis work performed by industry. This opportunity for development was not only restricted to the fire protection vendors but was equally beneficial for the offshore industry to develop better structural models that can accurately predict the effects of different types of fires on a facility structure. The new legislations, especially in the UK, no only provided the industry with a more risk based approach towards fire hazards but also provided an opportunity to develop a more cost effective solution to the fire concerns identified.

Meanwhile, internationally, most of the regulatory bodies maintained the prescriptive aspects of their offshore legislations but provided an opportunity, in their regulations, to demonstrate an equivalent level of safety. This mix of prescriptive and goal setting regulations are readily apparent with the classification societies that classify and verify installation all over the world. They provide facility owners with the opportunity to comply with regulations or to cost-effectively find equivalent-level-of-safety solutions to their facilities design or modifications. This is especially important when dealing with fire protection systems on the classed installations.

In the design, fabrication and construction, of an offshore installation worldwide one of the key components of a development project is the quality of the engineering design team tasked to design the facility. The success of a performance-based approach is highly dependent on the skill and experience of the loss prevention or HSE engineering team on the project. The lack of qualified manpower has forced most engineering houses to focus on compliance with regulations rather than attempting to invest engineering manpower and cost on cost-effective equivalent-level-of-safety engineering solutions. Engineering teams are now attempting to adopt a more risk-based approach with regards to the fire loading of structures. The approach also involves more interdisciplinary participation and discussions that have improved the understanding of the fire hazards that will affect their engineering design. The performance-based approach has also initiated industry to update their engineering design guidelines for offshore facilities especially when dealing with structural integrity during an accidental fire event.

RISK MANAGEMENT

The focus on performance-based approach in engineering design has necessitated the need for offshore operators and engineering designers to obtain a better understanding of the aspects or elements of risk management. The key aspect of risk management is the identification and the understanding of the mechanisms of the undesirable events. The identified credible fire scenario is the key elements in determining whether an engineering team should pursue a cost-effective scenario-based fire protection scenario. The wrongful identification of a credible fire scenario could result in either the underestimation of the fire protection requirement that could result in a potentially high consequential result in an accidental event or the overestimation of fire protection requirement that could force engineering teams to forgo this approach and solution and revert to compliance based approach. The success of the performance-based approach is the proper identification of the credible fire hazard and the management and communication of the fire hazard to the engineering design team.

FUTURE OF FIRE LOADING IN OFFSHORE INSTALLATION DESIGN

The future of fire loading in offshore installation design will be based on a combination of both prescriptive and performance based fire protection system application (see Figure 1). Performance based fire protection solutions provides opportunities to apply innovative and cost-effective optimization of fire protection systems, obtain a better understanding and clarity of the loss potential in a fire scenario on the facility, and create some international harmonization in the application of these loss control solutions based on the formal safety assessment process.

It must be emphasized that no matter what the benefits are with a performance-based approach the decision will still be based on the understanding and communications of the fire hazard to the engineering design management team. The operators will base their engineering decisions or options on their understanding of the complexity of their facility and with the size of their fire hazard. Other factors such as cost, engineering schedule and weight constraints of the fire protection solution will also be an essential factor in the decision to accept or reject a performance-based proposal.

CONCLUSION

The international progression from a prescriptive, regulatory responsibility for fire hazard control to a performance-based, operator responsible, fire hazard management strategy and plan was instigated by the lessons learned from the severe Piper Alpha incident in 1988. The future of fire loading in engineering design f offshore facilities will be based on a combination of prescriptive and performance based fire protection solutions. No matter which engineering solution is chosen it is critical that the credible fire scenarios are identified early in an engineering design. The magnitude, type and potential of the fire scenarios will determine the type of engineering solutions to isolate, reduce or eliminate the fire consequence in an engineering design. Other factors such as engineering schedule, cost and weight penalties of the fire protection solutions would be integral in the decision-making process of an engineering management team.

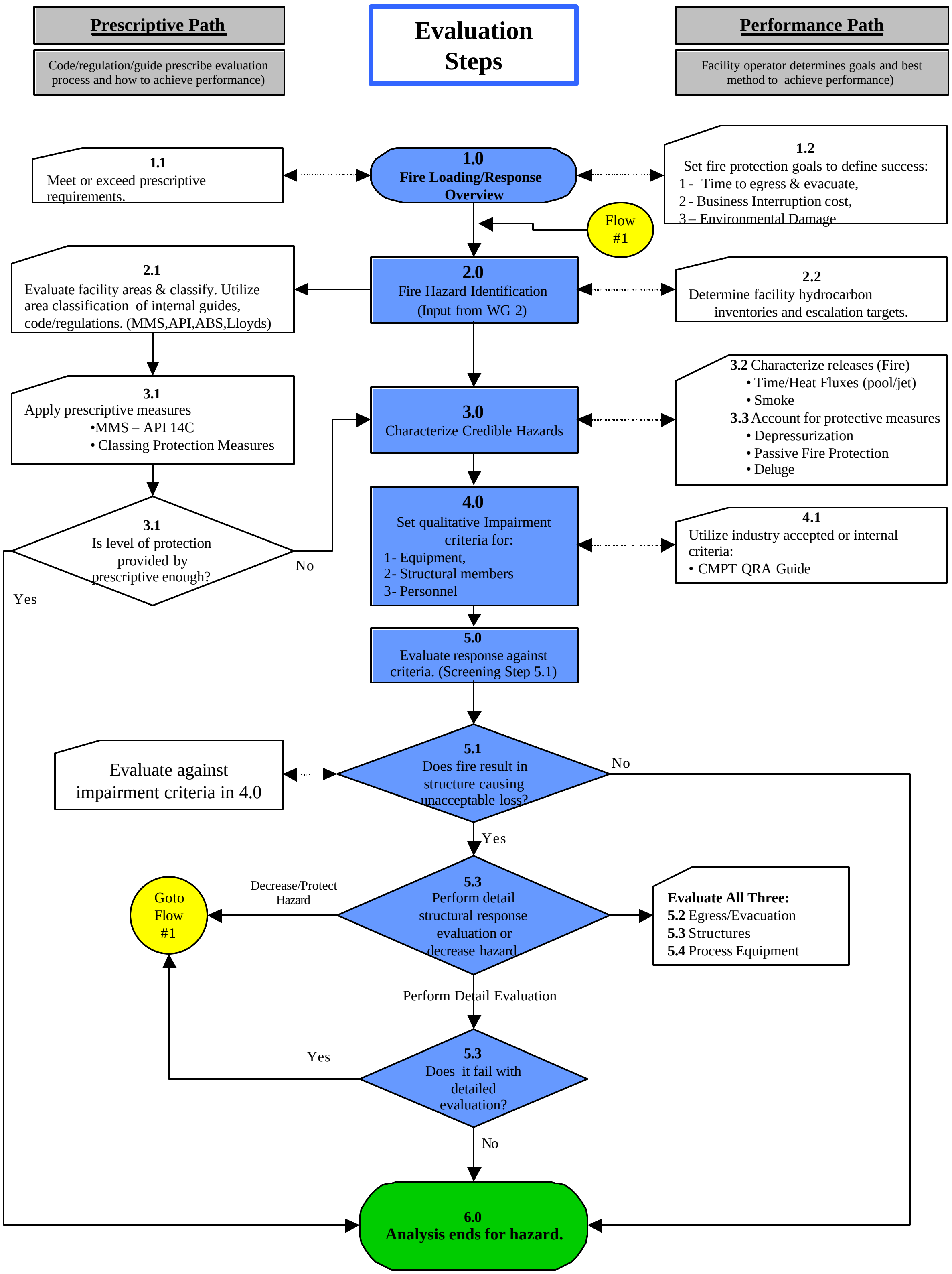


Figure 1: Decision Tree for Fire Loading on Offshore Installation Design

Blast: The State-of-the-Art

Vincent Tam, BP Amoco Corporation, UK

Blast: The State-of-the-Art

Vincent Tam
BP Corporation, UK

Vincent Tam presented the theme paper entitled " Blast: The State of the Art". After discussing explosion fundamentals which lead to release, dispersion, ignition, explosion, loading and response, he outlined the factors characterizing explosion and the resulting loading, i.e., fuel type and concentration, ignition source and confinement.

Narrating the development of small and medium scale testing and model development in 1970s and 80s after Flixborough accident of 1974, and large scale testing and model validation efforts after Piper Alfa incident, Vincent Tam provided a list of the JIPs which generated specific information on the various subjects relating to Blast issues:

- Blast and Fire Engineering – Phase 2 (1994-97)
- Explosion Model Evaluation Projects MEGGE and EME (1994-98)
- Blast and Fire Engineering – Phase 3a (1997-98)
- Gas Dispersion Project (1999-2000)
- Blast and Fire Engineering – Phase 3b (2000-2002)

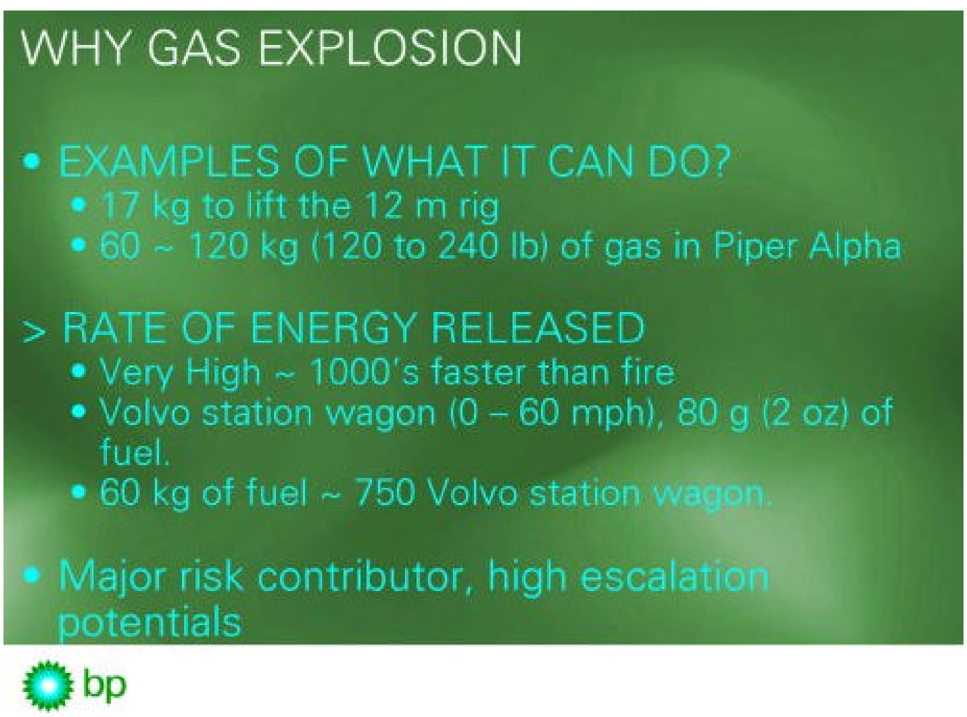
Vincent Tam stressed the need for collating and consolidating the knowledge base developed in the studies to be used in a comprehensive design guide.

Thirty-three slides presented are attached.

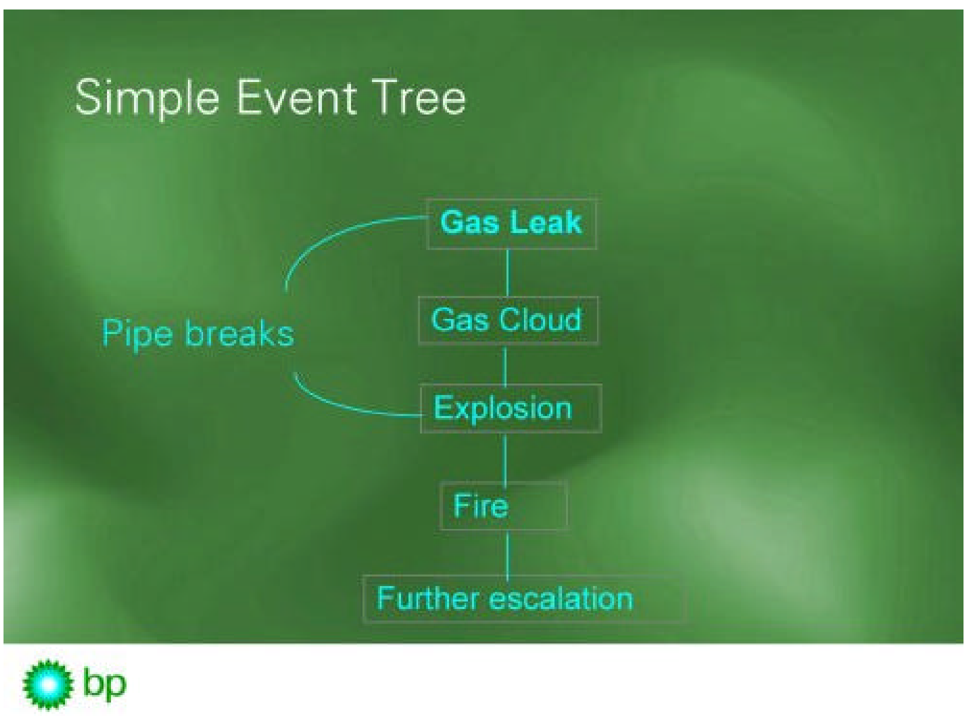

Gas Explosion Hazard:
A Review - Explosion Loading
Vincent Tam, 12 June 2002
bp

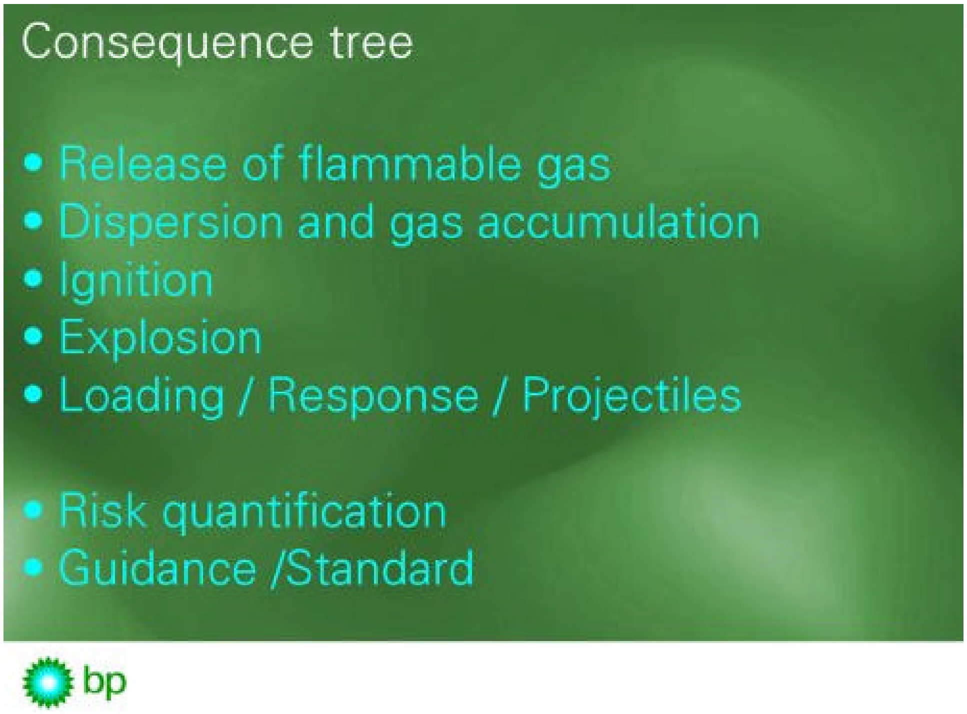

CONTENTS
•Gas Explosion
Factors that influence severity
•JIP & Tools
•E.g. Phase 2 & 3b
•Consolidation
Risk quantification
Guidance

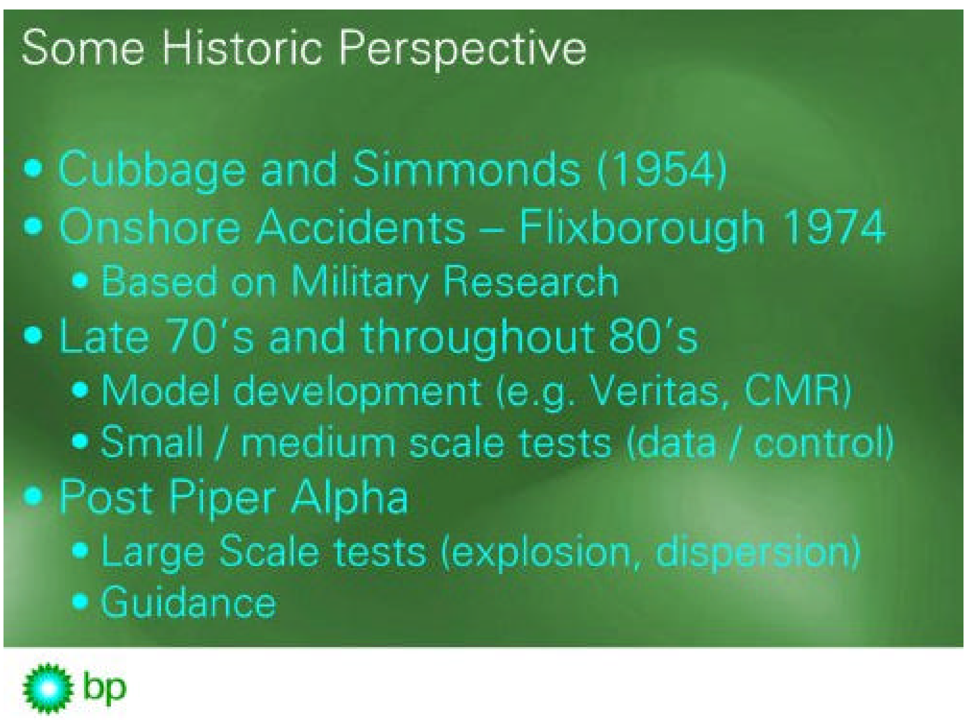

WHAT IS A GAS EXPLOSION?
• COMBUSTION OF A FLAMMABLE GAS
• Damaging pressures, act on large surfaces
• Wind – drag forces, missiles
• TYPES OF EXPLOSION
• Deflagration (few mb to a few bar)
• Detonation (very high overpressure >~18 bar)
bp


WHY GAS EXPLOSION
• EXAMPLES OF WHAT IT CAN DO?
• 17 kg to lift the 12 m rig
• 60 ~ 120 kg (120 to 240 lb) of gas in Piper Alpha
> RATE OF ENERGY RELEASED
• Very High ~ 1000's faster than fire
• Volvo station wagon (0 – 60 mph), 80 g (2 oz) of fuel.
• 60 kg of fuel ~ 750 Volvo station wagon.
• Major risk contributor, high escalation potentials
bp


Explosion Damage
Window Breaking .... 20 mb
Collapse of walls ....100 mb
Floating roof tank lifted .... 200 mb
Pressure vessel overturned .... 600 mb
Large tank sphere break free ...... ~ 1 bar
bp


Simple Event Tree
Gas Leak
Gas Cloud
Explosion
Fire
Further escalation
Pipe breaks
bp


Consequence tree
• Release of flammable gas
• Dispersion and gas accumulation
• Ignition
• Explosion
• Loading / Response / Projectiles
• Risk quantification
• Guidance /Standard
bp

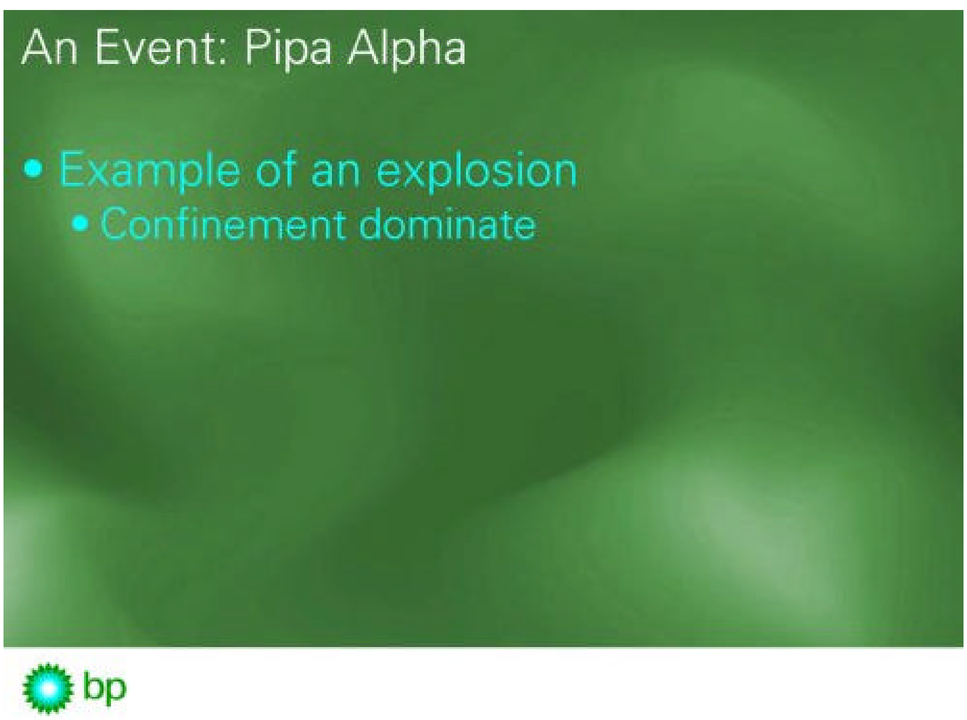

Some Historic Perspective
• Cubbage and Simmonds (1954)
• Onshore Accidents – Flixborough 1974
• Based on Military Research
• Late 70's and throughout 80's
• Model development (e.g. Veritas, CMR)
• Small / medium scale tests (data / control)
• Post Piper Alpha
• Large Scale tests (explosion, dispersion)
• Guidance
bp

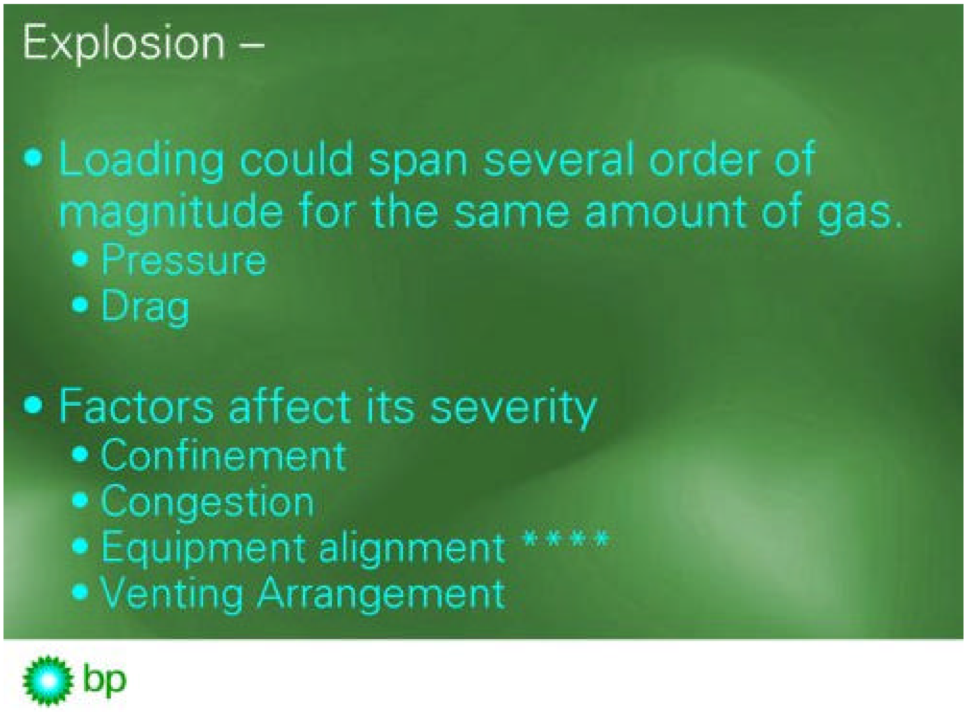
Explosion –

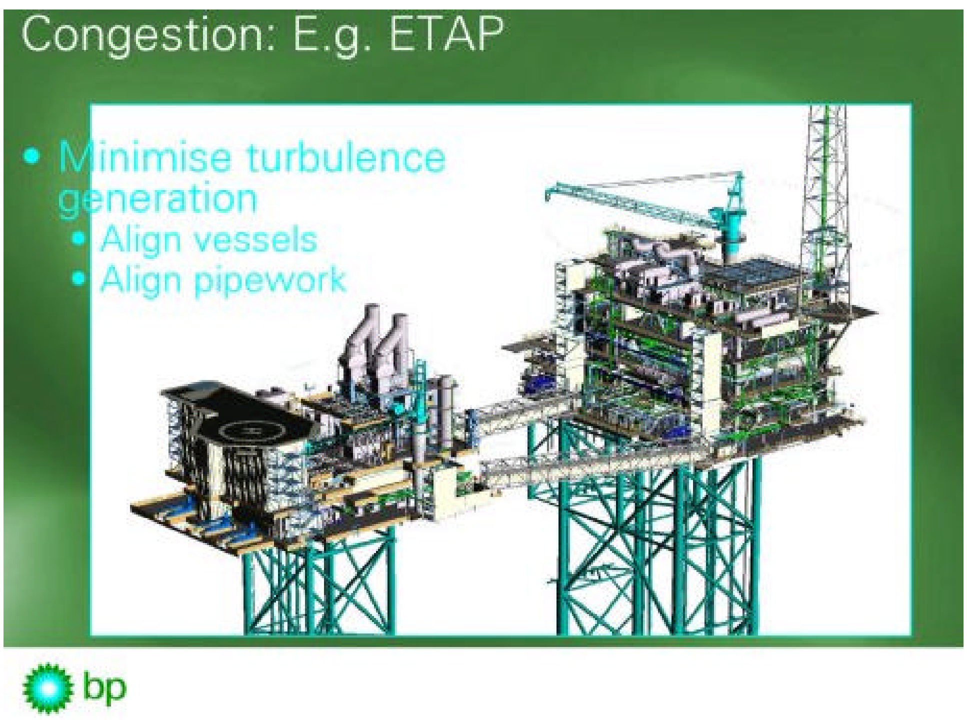
- Loading could span several order of magnitude for the same amount of gas.
  - Pressure
  - Drag
- Factors affect its severity
  - Confinement ****
  - Congestion
  - Equipment alignment
  - Venting Arrangement

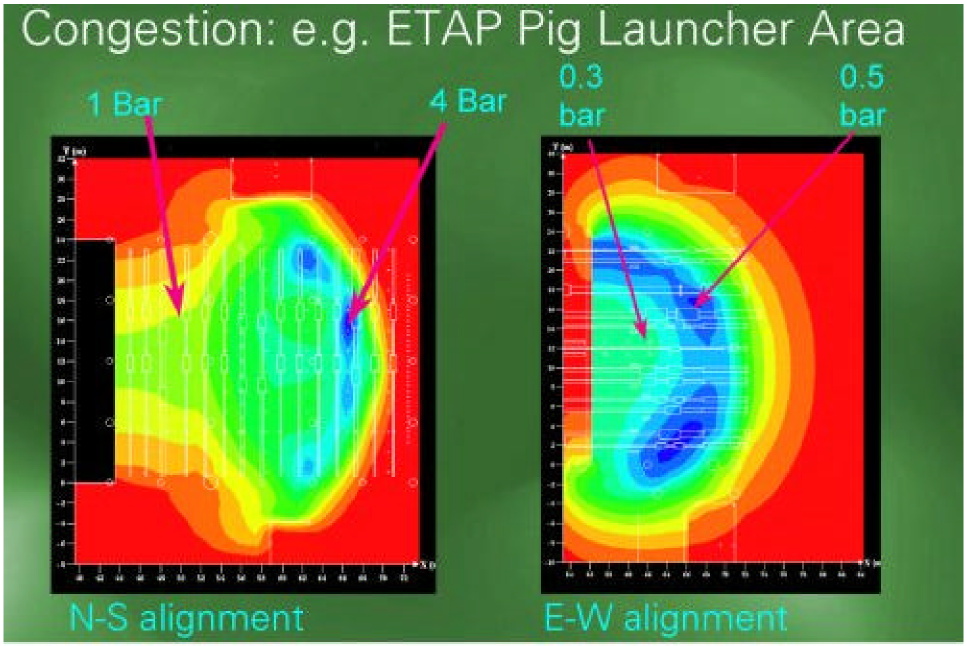
bp


Gas Explosion Confinement
• Explosion in a Box
bp

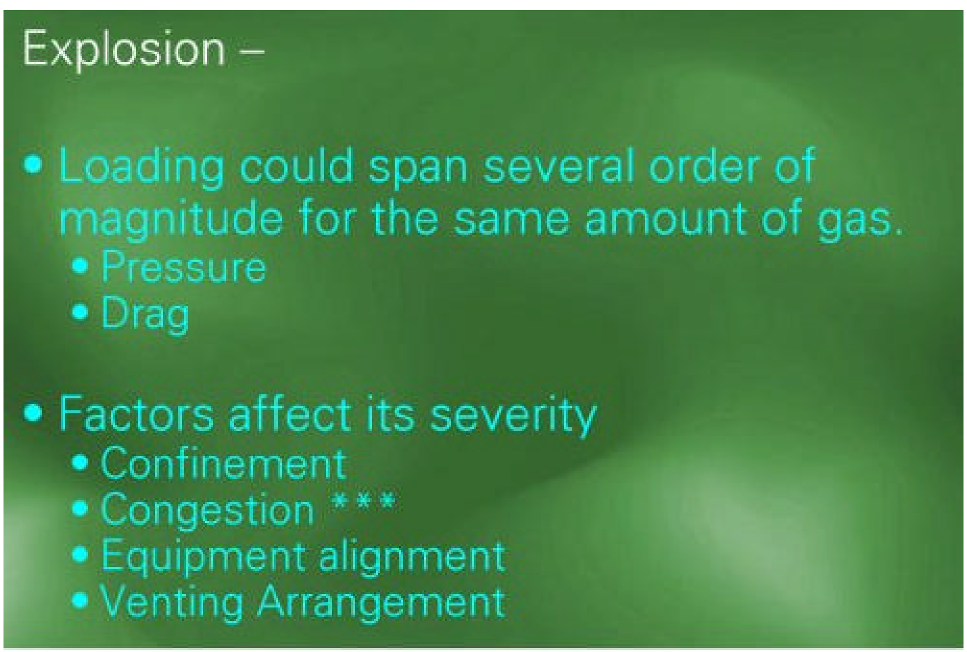

An Event: Pipa Alpha
• Example of an explosion
• Confinement dominate
bp


Explosion –
• Loading could span several order of magnitude for the same amount of gas.
• Pressure
• Drag
• Factors affect its severity
• Confinement
• Congestion
• Equipment alignment ****
• Venting Arrangement
bp


Congestion: E.g. ETAP
• Minimise turbulence generation
• Align vessels
• Align pipework
bp

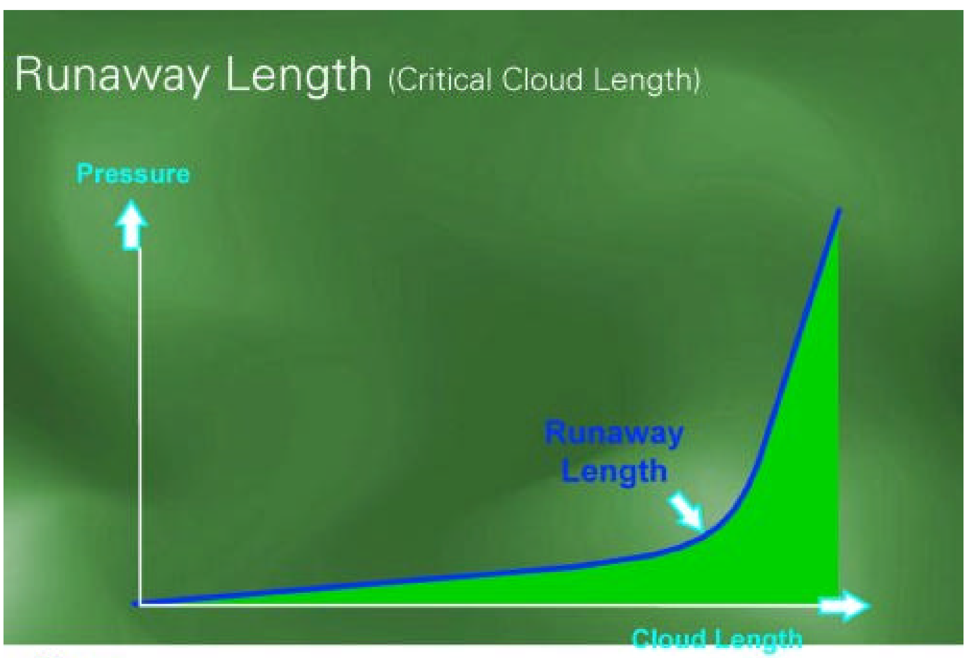

Congestion: e.g. ETAP Pig Launcher Area
1 Bar
4 Bar
0.3 bar
0.5 bar
N-S alignment
E-W alignment

bp


Explosion –
• Loading could span several order of magnitude for the same amount of gas.
• Pressure
• Drag
• Factors affect its severity
• Confinement
• Congestion ***
• Equipment alignment
• Venting Arrangement

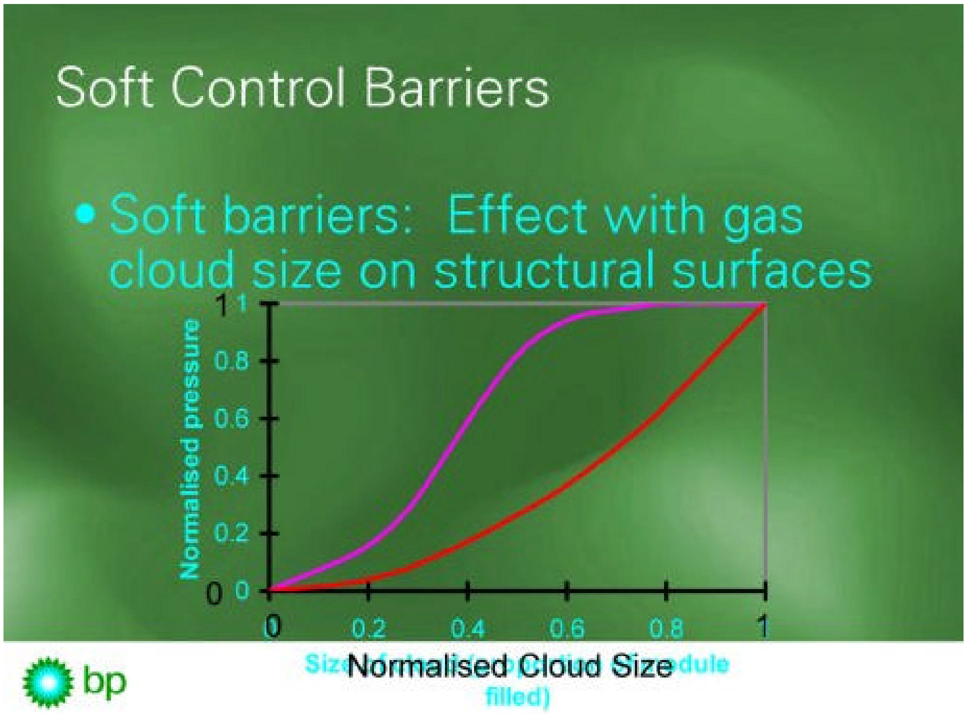
bp

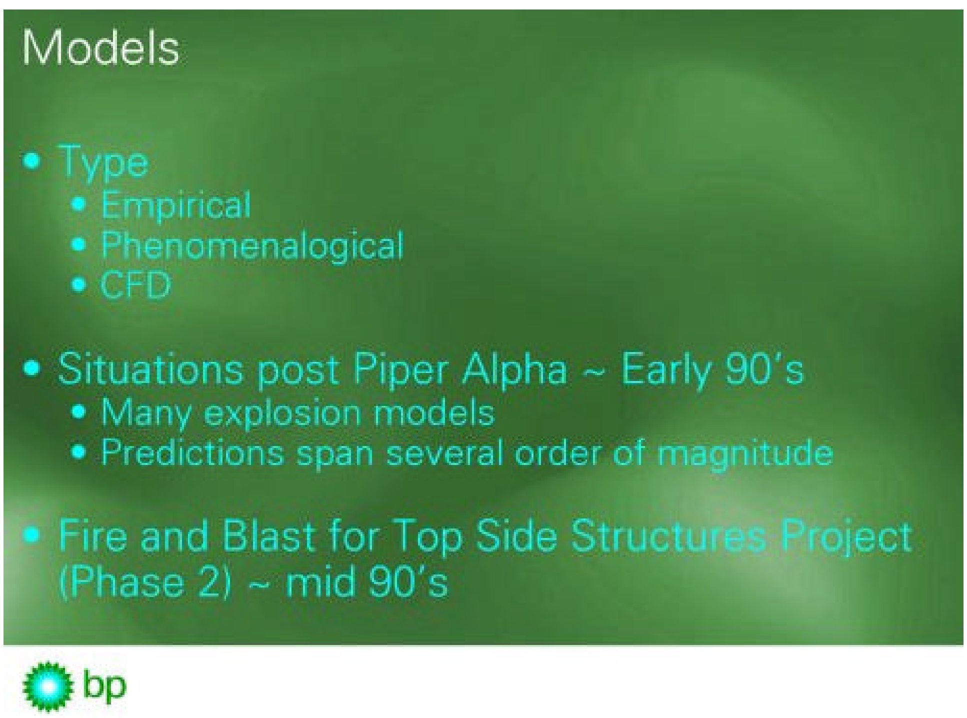

Congestion: Flixborough

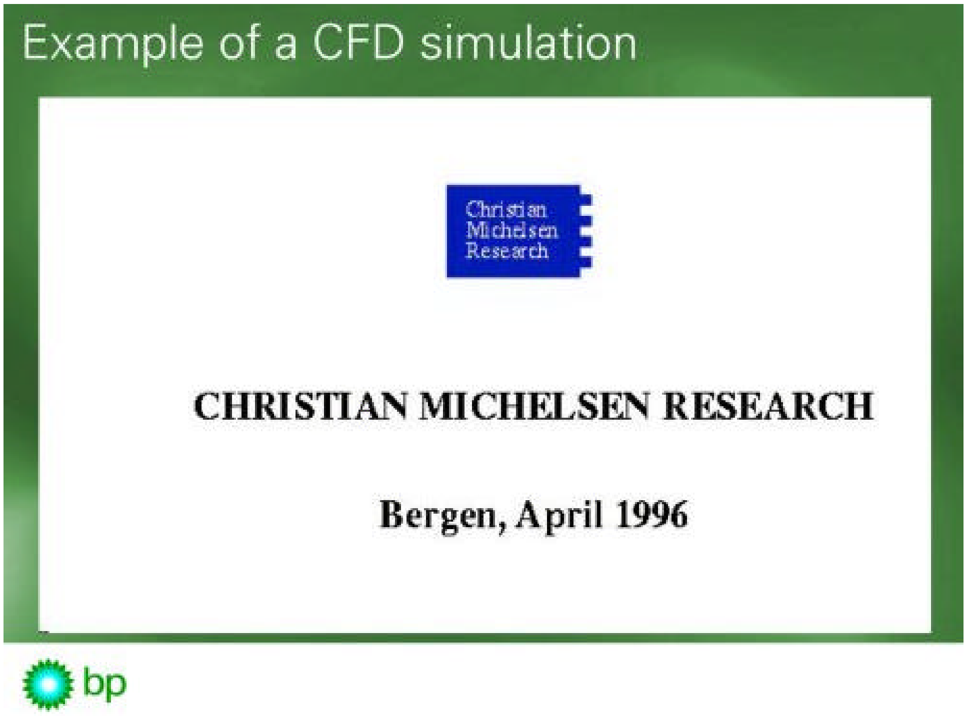

Runaway Length (Critical Cloud Length)
Pressure
Runaway Length
Cloud Length

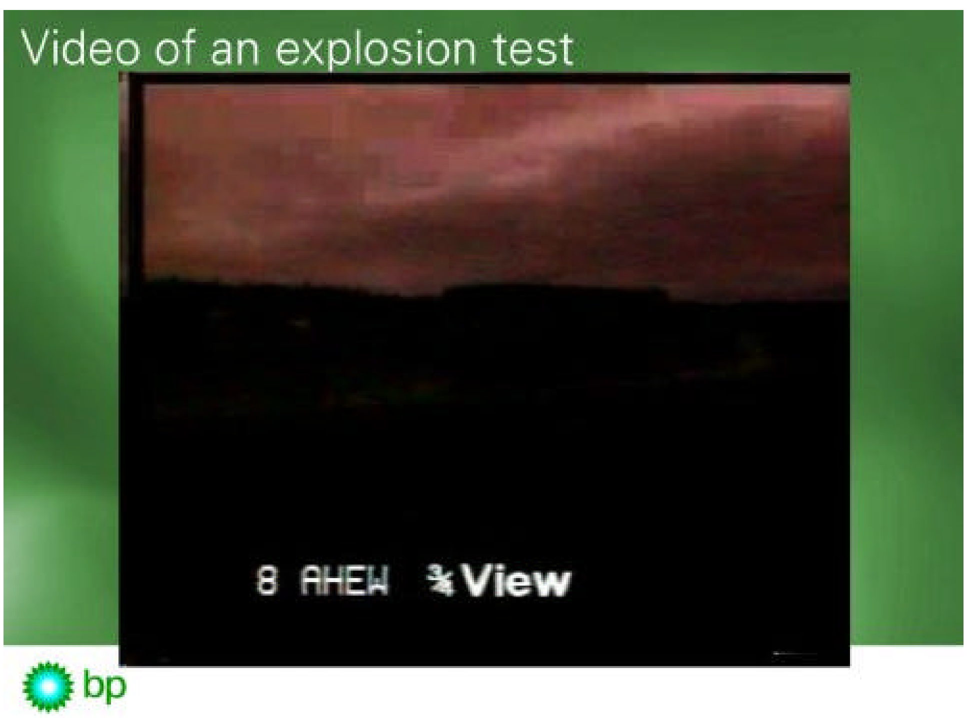

Mitigation/control measures
• Water deluge
• Work since 80's
• Droplet diameter
• Active control measures
• Micromist
• Passive control measures
• E.g. gas barriers.
• Equipment layout
• Venting arrangement
• Aspect ratio of hazardous areas
bp


Suppression test A: Time = 120 ms
bp


Soft Control Barriers
• Soft barriers: Effect with gas cloud size on structural surfaces
Normalised pressure
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1
Normalised Cloud Size
filled)
bp


Models
• Type
• Empirical
• Phenomenalogical
• CFD
• Situations post Piper Alpha ~ Early 90's
• Many explosion models
• Predictions span several order of magnitude
• Fire and Blast for Top Side Structures Project (Phase 2) ~ mid 90's
bp


Example of a CFD simulation
Christian
Michelsen
Research
CHRISTIAN MICHELSEN RESEARCH
Bergen, April 1996
bp


Video of an explosion test
View
bp

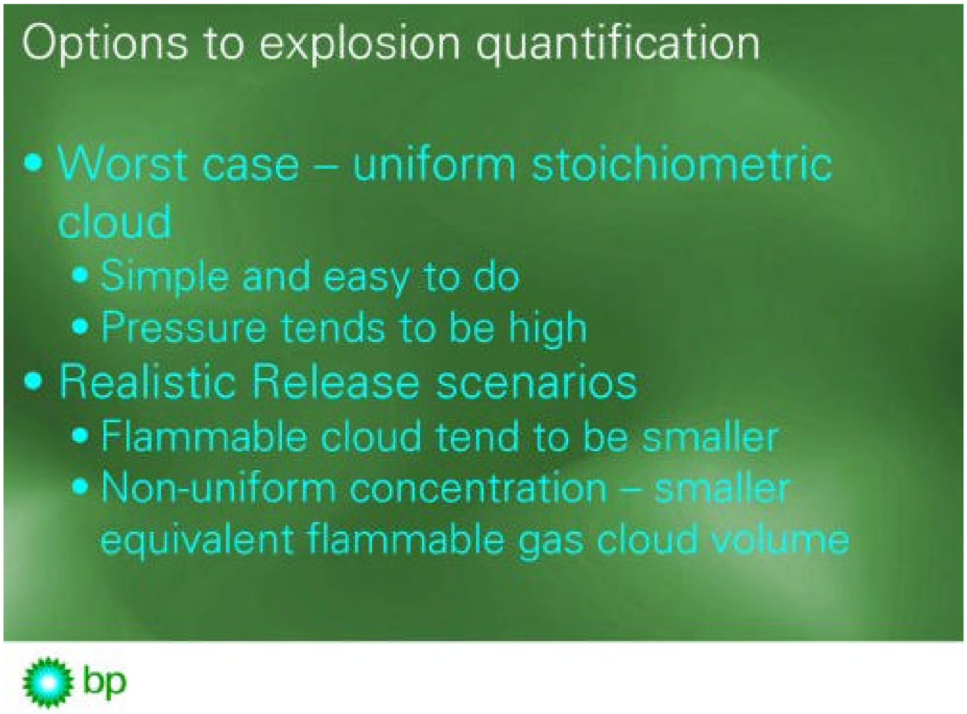
Large Scale Explosion Tests

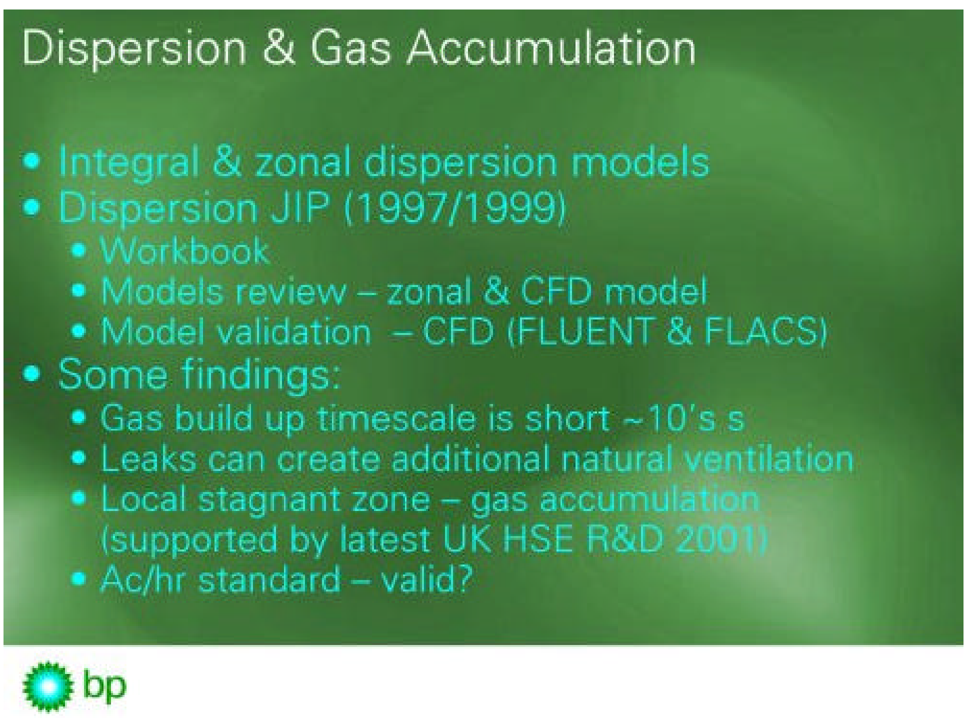
- BFFTS Phase 2
  - High loading measured
  - Model Evaluation
  - Some findings (geometric details, v high p)
  - MEGGE initiated
  - Few models remain (Scope, FLACS, AutoReagas, CHAOS, Exsim)
- Phase 3a
  - Control measures – venting & deluge
- Dispersion JIP
- Phase 3b
  - Realistic scenarios / blast impact on panels

bp

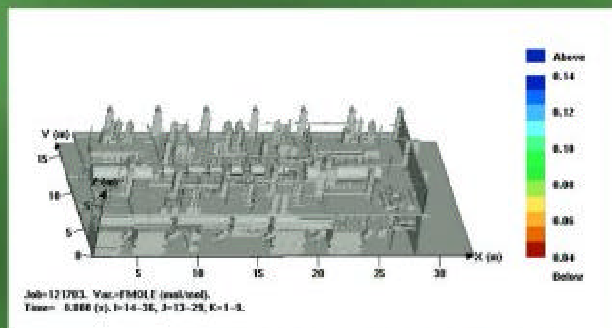
SCI 2 TEST 7

bp


Options to explosion quantification
• Worst case – uniform stoichiometric cloud
• Simple and easy to do
• Pressure tends to be high
• Realistic Release scenarios
• Flammable cloud tend to be smaller
• Non-uniform concentration – smaller equivalent flammable gas cloud volume
bp


Dispersion & Gas Accumulation
• Integral & zonal dispersion models
• Dispersion JIP (1997/1999)
• Workbook
• Models review – zonal & CFD model
• Model validation – CFD (FLUENT & FLACS)
• Some findings:
• Gas build up timescale is short ~10's s
• Leaks can create additional natural ventilation
• Local stagnant zone – gas accumulation (supported by latest UK HSE R&D 2001)
• Ac/hr standard – valid?
bp

Example of dispersion test

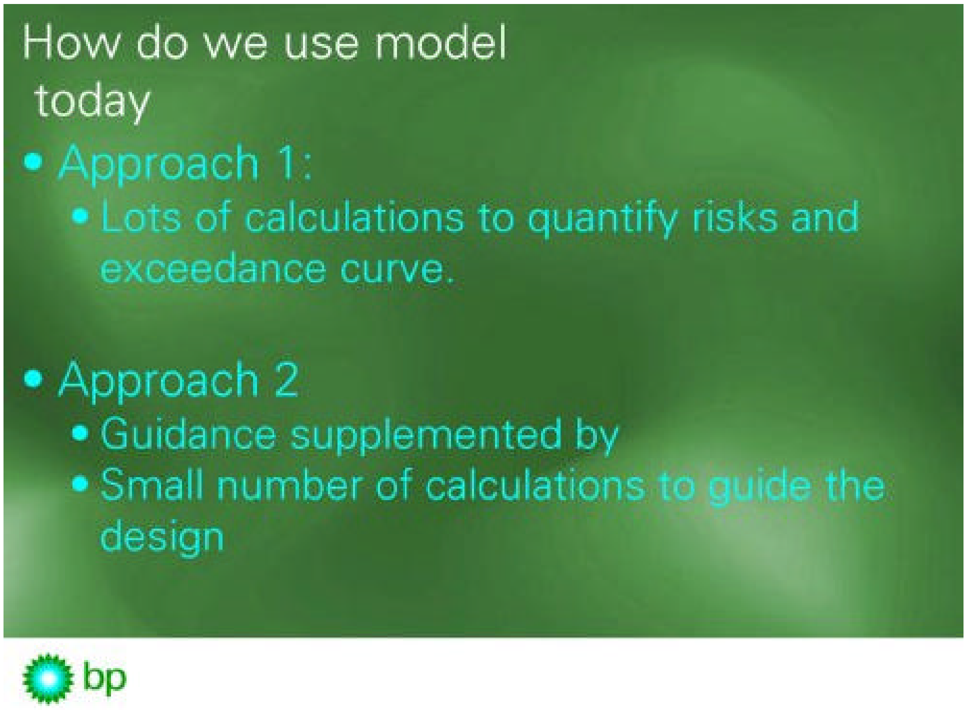


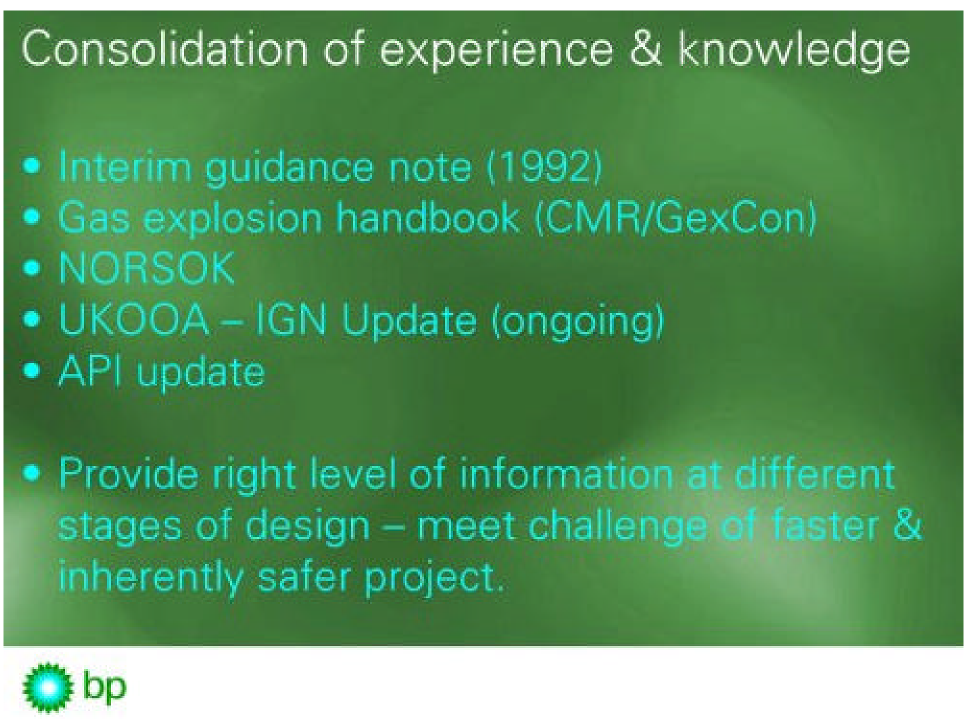
bp

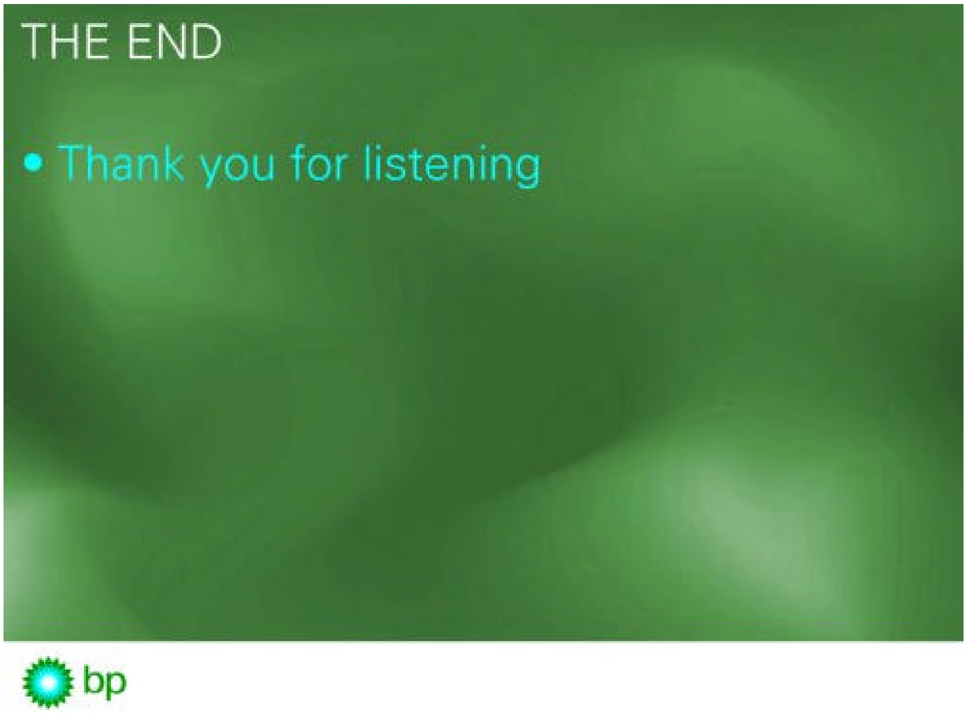
Ignition – mechanism and probability

- Mechanism
  - E.g. Friction: CMR tests (e.g. grinding tools)
- Probability
  - Volume based methods
  - Ignition probability JIP led by DnV

bp


How do we use model today
Approach 1:
Lots of calculations to quantify risks and exceedance curve.
Approach 2
Guidance supplemented by
Small number of calculations to guide the design
bp


Consolidation of experience & knowledge
Interim guidance note (1992)
Gas explosion handbook (CMR/GexCon)
NORSOK
UKOOA – IGN Update (ongoing)
API update
Provide right level of information at different stages of design – meet challenge of faster & inherently safer project.
bp


THE END
• Thank you for listening
bp

Fire and Blast: International Perspective

David Galbraith, Health and Safety Executive, UK

Fire and Blast: International Perspective

David Galbraith,
Health and Safety Executive, UK

David Galbraith provided an international perspective on the development of Fire & Blast guidance and standards initiatives, and outlined the recent initiatives such as:

- Norsok Standards Z-013 and N-003
- UKOOA/HSE explosion and fire guidance
- API Task Group on Fire and Blast
- Current MMS workshop
- Revision to CSA S471

David indicated that Norsok standards follow rigorous probabilistic approach. They require establishment of leak scenarios, cloud size distribution, CFD simulation of explosion loads, consequences and a risk report. Usually a large number of analyses are required.

On the other hand, UKOOA/HSE initiative would call for codified design guidance. The new guidance would introduce bounding overpressures for typical installations, which could be used during concept and FEED stage. With factors (affecting specific installations), such bounding overpressures may also be modified to suit any specific physical condition of the installation.

Canadian standard is currently being updated to reflect changes being proposed by UKOOA/HSE.

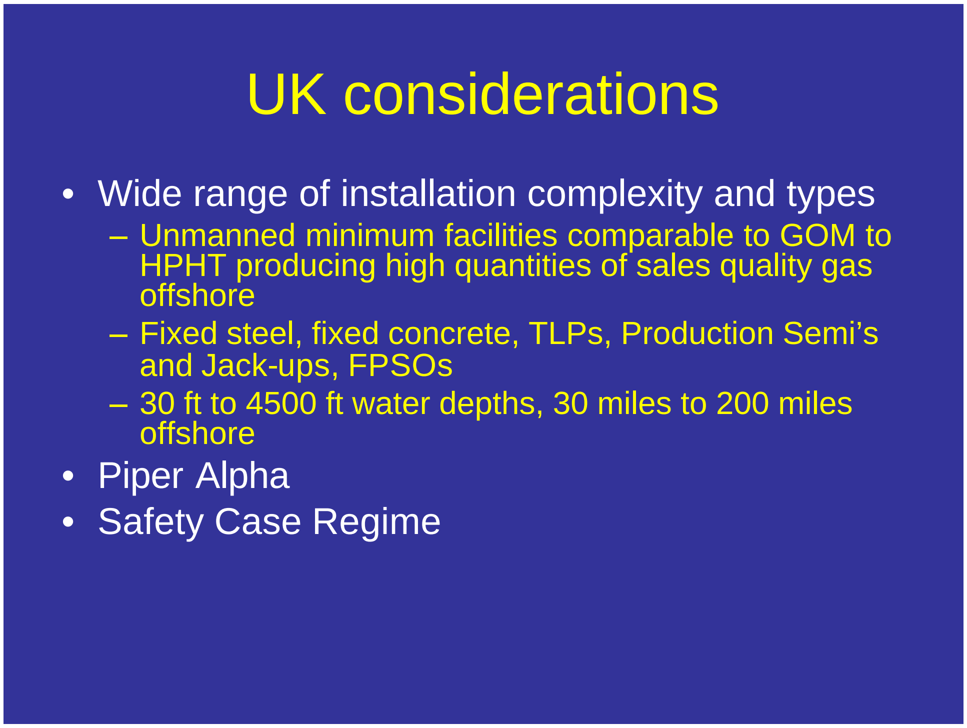
Twenty-one slides presented are attached.

Fire and Blast
International Perspective

David Galbraith
Galbraith Consulting Ltd
fireandblast.com ltd

International perspective
Current initiatives

- USA
  - API – Task group for fire and blast
  - MMS – Workshop
- UK
  - UKOOA / HSE Interim Guidance Notes revision
- Canada
  - Revision to CSA S471
- Norway
  - Norsok Standards Z-013, N-003 (both published)


UK considerations
• Wide range of installation complexity and types
– Unmanned minimum facilities comparable to GOM to HPHT producing high quantities of sales quality gas offshore
– Fixed steel, fixed concrete, TLPs, Production Semi's and Jack-ups, FPSOs
– 30 ft to 4500 ft water depths, 30 miles to 200 miles offshore
• Piper Alpha
• Safety Case Regime

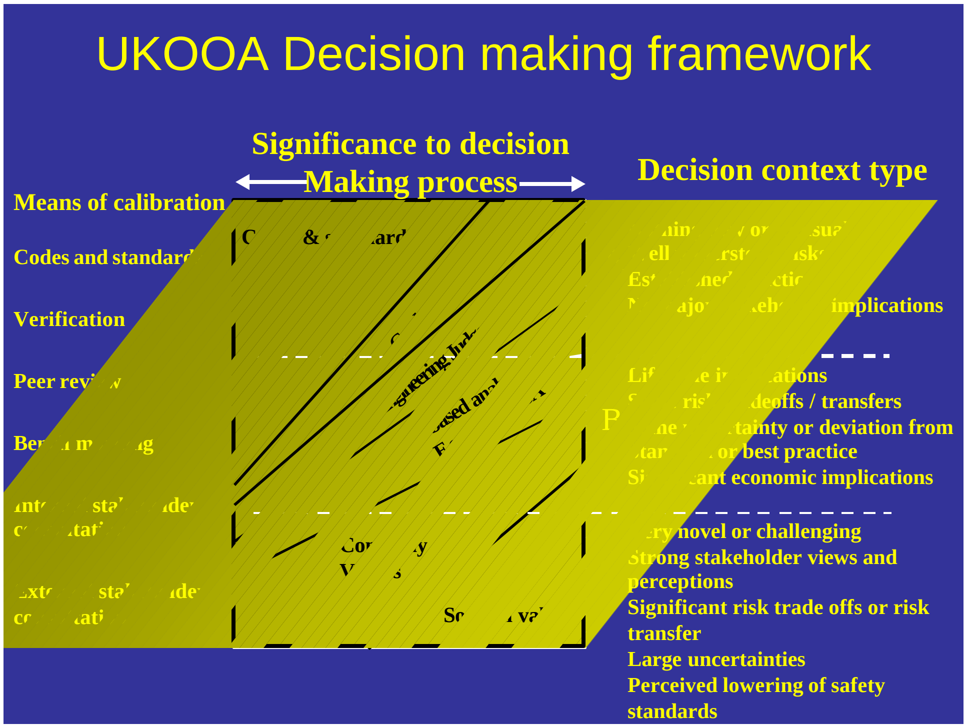

UK Approach
• Safety case regime
– "Duty holder" has to make the case for safety
– 300 + safety cases have been prepared
Most used CFD and QRA
– Independent verification of operations
– Safety cases resubmitted every 3 years (assessment to current knowledge)
• Moving from QRA to inherent safety approaches
• Lot of detailed interaction with regulator

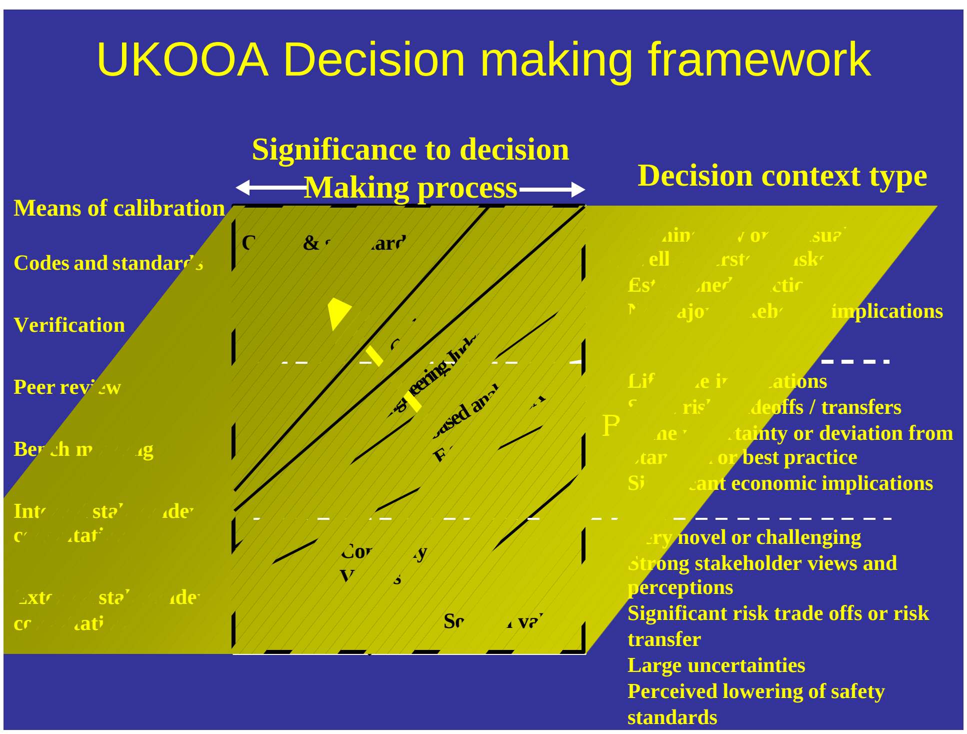
UK Considerations

- $43 millions of fire and blast research
- Good "academic" understanding of effects of parameters
  - Layout, concentration, cloud size, venting, ignition, dispersion
- Poor design application of "academic" knowledge

Recent UK experience

- Two recent major installations
  - HPHT
  - Major disruption during project
  - Blast wall design criteria doubled – after fabrication
  - Now know what a 4-bar blast wall looks like
  - Unproven need for wall strengthening


UKOOA Decision making framework
Significance to decision Making process
Decision context type
Means of calibration
Verification
implications
or best practice
Significant risk trade offs or risk transfer
Large uncertainties
Perceived lowering of safety standards


UKOOA Decision making framework
Significance to decision Making process
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implications
or best practice
Significant risk trade offs or risk transfer
Large uncertainties
Perceived lowering of safety standards

IGN Update project

- To translate the academic knowledge gained over last 10 years and $43 millions to usable design guidance
  - Part 1 - explosion issues, loads and response
  - Part 2 - fire issues, loads and response
  - Part 3 - design guidance derived from parts 1 and 2
- Intent / desire to simplify selection of design requirements early in project

UKOOA / HSE initiative

- Work in progress
  - Development of bounding cases
  - Concept and FEED
  - Overpressure from Type of installation & area of installation
  - Apply multipliers for

Production Rate	Module footprint
Compression Pressure	Confinement
Gas Composition	Module aspect ratio
Number of production trains	

Technical input to project

- Contract consortium
- Sponsors' technical representatives
- Consortium's advisory panel
  - UK, Norway and US representation
- Peer review
  - Selected by fireandblast.com and sponsors
- Open review:-

http://fireandblast.com/ign-update

UKOOA / HSE IGN Update

- Part 2 – next year?
- Part 3 – thereafter
- Currently solely UK funded
- Scope for other organisations to participate
  - Other operator associations
  - Other regulators


Norway
• Very large fields and large platforms
• Wealthy country
• Can therefore invest to CFD and QRA for all installations
• Have prepared numerous NORSOK standards
– Z-013 Risk and emergency preparedness analysis
– N-003 Actions and action effects (Loadings)
• NORSOK standards generally followed very closely
• "Design of Offshore Facilities to Resist Gas Explosion Hazard Engineering Handbook"


Norwegian Procedure NORSOK Z-013
• Procedure for calculation
– Establish leak scenarios
– Establish cloud size distribution
– Establish explosion loads
CFD simulations
FLACS specifically noted
– Establish consequences
– Present risk picture (report)
• Requires large number of analyses

Canada

- Offshore activity in severe environments
- 5 platforms - Fixed steel, concrete, FPSO
- 100 – 150 miles offshore
- Some unmanned
- Manned platforms usually not evacuated in severe weather (some hurricane activity)

Canada

- Petroleum board regulations
  - i.e. CNSOPB and CNOPB
  - Refer to CSA standard S-471
  - Boards definition of "fit for purpose"
    - Meets regulatory requirements
    - Reflects good practice
    - All risks assessed and measures implemented to make ALARP
- Certification regime
  - COF issued by Certifying Authorities
  - CA has to satisfy itself of "fitness for purpose"

Canada

- CSA S471
  - Section on accidental loads being updated
  - Currently references NORSOK N-003 + Z-013 / ISO for loadings and other NORSOK documents
  - Revisions will take account of API and UKOOA / HSE initiatives

Other areas

- Generally follow API
- A few follow UK standards
- Russians influenced by Norwegian practice
- ISO standards being supported

International standards

- Supported by many countries,
  - US, Canada, Argentina, Brazil
  - All European countries with Offshore hydrocarbons
  - Australia, Indonesia, China, Russian Federation, Japan, Korea
  - Egypt, Saudi Arabia

International Standards

- ISO 13702 Control and mitigation of fires and explosions – requirements and guidelines
- Structural
  - ISO 19900 series

ISO 19900	General Requirements
ISO 19901 3	Topsides structure
ISO 19902	Fixed Steel Structures
ISO 19904	Floating structures


Observations
• Current active initiatives
– Acknowledgement of possibilities of large blasts
– Usable procedures for designers
Avoid knock on effects on fabrication
• Trend for internationalisation
• Awareness of each others initiatives
• Approaches seem to be converging
• Lets keep talking across the pond

Large Scale Fire Tests Applicable to the Design of Offshore Facilities

Alex B. Wenzel
Department of Fire Technology, Southwest Research Institute
San Antonio, Texas

ABSTRACT

A review is presented of large-scale fire test protocols that are used to evaluate materials, systems and structures in offshore facilities. Each of the tests addresses one of the major fire threats on offshore oil platforms, i.e., compartment fires, fuel spill pool fires, and jet fires from a ruptured pressurized fuel pipe. The catastrophic consequences of jet fires on offshore platforms were tragically realized after the Piper Alpha disaster in July 1988. This disaster sharply focused attention on the need to ensure that equipment and facilities on offshore installation are adequately protected against major fire threats. Laboratory test facilities and the associated instrumentation operational at Southwest Research Institute are discussed. These facilities are capable of generating the thermal and radiative profiles, as well as erosive effects, experienced in full-scale fire environments.

INTRODUCTION

A set of experimental methods is available to evaluate the fire performance of materials, systems and structures when exposed to the major fire threats, which may be encountered in offshore facilities. Some methods evaluate the behavior in and contributions to enclosure fires. Other methods are used to determine the ability of structural members to maintain their load-bearing capacity and the ability of enclosure separations to contain the fire to the compartment of origin and to prevent fire spread to other parts of the structure. Test methods have been developed to evaluate the performance of structural members that are exposed to jet fires from ruptured pressurized fuel pipes, or that are subjected to fuel spill pool fires.

The various intermediate to large-scale laboratory test methods are discussed in the sections that follow:

COMPARTMENT FIRE TESTS

The test methods that are discussed in this section are intended to evaluate products for their contribution to a compartment fire and to assess the performance of products and systems in terms of flame spread from the fire compartment to other parts of a structure.

REACTION-TO-FIRE TESTS

The first step to evaluate fire performance of materials and/or assemblies is to determine how they react when exposed to the heat from a compartment fire. Tests developed for this purpose measure propensity for ignition; surface flame spread characteristics; and the rate of heat, smoke, and toxic gas release. The laboratory test protocols available to measure reaction-to-fire may be grouped in two categories, small-scale and intermediate- to large-scale tests. In both instances, the most important reaction-to-fire material characteristic is heat release rate. Since oxygen consumption calorimetry is the most widely used and accurate experimental technique to measure rate of heat release, a brief discussion of this technique is presented first.

OXYGEN CONSUMPTION CALORIMETRY

In 1917, Thornton [1] showed that for a large number of organic liquids and gases, a nearly constant net amount of heat is released per unit mass of oxygen consumed for complete combustion. Sixty years later, researchers at the National Bureau of Standards (currently the National Institute of Standards and Technology, or NIST) in Gaithersburg, Maryland, found this to also be true for organic solids, and obtained an average value of 13.1 MJ/kg of O_2 for this constant [2]. This value may be used for practical applications and is accurate with very few exceptions to within ±5%. Thornton's rule implies that it is sufficient to measure the oxygen consumed in a combustion system in order to determine the net heat released. This technique, generally referred to as the "oxygen consumption calorimetry technique," is currently the most widely used and accurate method for measuring heat release rate in experimental fires.

INTERMEDIATE- TO LARGE-SCALE REACTION-TO-FIRE TESTS

The most widely used intermediate-scale reaction-to-fire test method in North America is the tunnel test, ASTM E 84. The apparatus consists of a long tunnel-like enclosure measuring 7.6 x 0.46 x 0.31 m (Figure 1). The 7.3 x 0.51-m test specimen is mounted in the ceiling position, and exposed at one end to a 79-kW gas burner for 10 minutes. There is a forced draft through the tunnel from the burner end with an average air velocity of 1.2 m/s. The measurements consist of flame spread over the specimen surface and smoke obscuration. A flame spread index (FSI) is calculated on the basis of the area under the curve of flame front location versus time. A smoke developed index (SDI) is obtained from the area under the curve of absorption versus time. Both the FSI and SDI are 0 for a non-combustible board, and are normalized to 100 for red oak flooring. The U.S. Coast Guard has requirements for interior finish materials on merchant vessels that are based on ASTM E 84 test performance. These requirements are published in 46 CFR 164.012, and call for an FSI of 20 or less and an SDI not exceeding 10. Resins of composite materials for use on T-class ships are qualified as "fire retardant," if the FSI in the tunnel test is 100 or less.

The International Maritime Organization (IMO) specifies that a room test be conducted according to the ISO 9705 standard to qualify a lining material as fire restricting. The apparatus described in ISO 9705 consists of a room measuring 3.6 m deep by 2.4 m wide by 2.4 m high, with a single ventilation opening measuring 0.8 m wide by 2 m high in the front narrow wall. All walls, except the front wall, and the ceiling are covered with a combustible lining material that is exposed to a propane burner ignition source. The burner is 0.17 m wide, has a square surface that is 0.17 m above the floor of the room, and is located in the corner of the back wall and one of the side walls. The propane burner is operated at a heat release rate of 100 kW for 10 minutes, followed by 300 kW for 10 minutes. Heat release rate is measured on the basis of oxygen consumption. Instrumentation for measuring rate of heat release and smoke production is installed in the exhaust duct. A schematic of the test apparatus is shown in Figure 2. To qualify a material as fire restricting, the following requirements listed in IMO Resolution MSC.40(64) [3] must be met:

1. Test-average heat release rate over the entire test time shall not exceed 100 kW;

2. Maximum 30-s average heat release rate shall not exceed 500 kW;
3. Test-average smoke production rate shall not exceed 1.4 m^2/s;
4. Maximum 60-s average smoke production rate shall not exceed 8.3 m^2/s;
5. No flame spread to area below 0.5 m from the floor at distance greater than 1.2 m from corner; and
6. No flaming droplets or debris may reach the floor, except in an area within 1.2 m from the corner.

Intermediate- to large-scale tests have the advantage in that they account for the effect of scale on fire performance of products and systems. However, the intermediate- to large-scale tests are significantly more expensive than small-scale tests, and obtain an evaluation of performance for a particular fire scenario and set of conditions. A complete, relevant evaluation for all fire scenarios would require multiple tests, and would quickly become cost prohibitive. It is recommended that intermediate- to large-scale tests be used primarily to evaluate the uncertainty and accuracy of computer models or correlations that predict fire performance in real fires on the basis of material characteristics measured in small-scale tests. In addition, intermediate- to large-scale tests are also needed to evaluate performance of special materials for which model predictions are not reliable.

FIRE RESISTANCE/ENDURANCE TESTS

In the course of a compartment fire, when the exposed surfaces of all the combustible items in the room are burning and the rate of heat release develops to a maximum, producing temperatures as high as 1200EC, an event known as flashover has occurred. Fire resistance tests assume that a fire goes to flashover, and simulates post-flashover fire conditions. The term fire resistance is associated with the ability of an element of a structure or component to continue to perform its function as a barrier or structural component during the course of a fire for a specified period of time. The length of time the element will continue to serve as a barrier is conventionally determined by testing a representative full-scale sample (under load if appropriate) to failure subjected to a standard fire as defined by a standard time-temperature curve within a large furnace. A standard fire is one whose temperatures can be as high as 1200EC with a total heat flux up to 220 kW/m^2 within 5 minutes, and sustained for the desired resistance period [4]. The furnaces can be assembled either horizontally or vertically for testing structures such as walls, bulkheads, decks, ceilings, floors, linings, and other common structures or components used in offshore and marine applications. Figure 3 shows a motor operated valve system tested in a horizontal furnace.

The current standard furnace tests are referenced in IMO Resolution A.754, ASTM E119, USCG 46 CFR 164, NFPA 263, ISO 834, UBC 7-1, and UL 1709. All of these standards are basically the same and delineate the dimensions of the test specimen, the instrumentation to be used, as well as the time-temperature curve and rate of heat release to be developed by the furnace as shown in Figure 4. Note that the UL 1709 curve shows a higher rise time and temperature curve than ASTM E119. This is because this test is designed to simulate the effects of a hydrocarbon pool fire as compared to a standard room fire.

For fire endurance testing of composite piping, a burner assembly as shown in Figure 5 is used. Basically, the fire source consists of two to three rows of five burners. The burner arrangement depends on the diameter of the piping system. A constant heat flux averaging

113.6 kW/m^2 (∀10%) is maintained 12.5 ∀ 1 cm above the centerline of the array. Depending on whether the piping systems are designed for wet or dry applications, the endurance test is conducted for a time ranging from 30 to 60 min. The test procedure and its acceptance criteria are described in IMO Resolution A. 753 [5].

In summary, the furnace tests adequately represent the temperature and heat flux conditions of most compartment fire conditions. Although accidental fires may exhibit higher temperatures, they generally have shorter durations. However, other fire variables such as the balance of radiative and convective heating, pressure fluctuations due to turbulence of high gas velocities, thermal shock, and differential heating are not included or controlled in the furnace tests. These conditions are presented in fire environments emanating from accidental releases of hydrocarbon liquids or the rupture of high-pressure pipelines containing hydrocarbons, and can affect the response and performance of composites in a real fire. This is also true for the fire endurance tests for plastic or composite piping, as the fire environment defined by the IMO Resolution A.753 is not representative of the above mentioned more severe environments.

HYDROCARBON FUEL SPILLS

Hydrocarbon spills normally result in pooling of the fuel which, if ignited, will result in a pool fire. A pool fire is defined as a turbulent diffusion fire burning above a horizontal pool of vaporizing fuel under conditions where the fuel vapor has zero or very low initial momentum. A key feature of this type of fire is the degree of feedback between the fire and the fuel. The heat transfer back from the fire to the pool controls the rate of evaporation and, hence, the size, duration, and other characteristics of the fire [6]. More generally, the pool fire test is conducted to simulate accidents originating in the overfilling of a storage tank, rupture of a pipe or tank, and/or a spill during transport of hazardous materials. A typical pool fire is illustrated in Figure 6. The most common test procedure used in the United States is outlined in Title 10, Chapter 1, Section 71 of the US Code of Federal Regulations. This procedure defines the fuel to be used and describes how to prepare, instrument, and mount the test sample above the fuel. Normally the size of the pool fire is at least three times greater than the size of the test sample. The time-temperature curve which can be developed by this type of test is similar to the high rise curve specified in UL 1709, which has a peak temperature of 1100 ∀ 100EC within 5 minutes and which is sustained for the desired test period, as illustrated in Figure 7. This type of fire will develop a heat release of approximately 160 ∀ 80 kW/m^2 with typical hydrocarbon fuels such as gasoline, diesel and aviation fuels.

Bear in mind, however, pool fires are events of major importance in many environments where a variety of materials, assemblies, and systems are used, and in accidents, the fuel is uncontrollable and may burn for a long period of time. Depending on the fuel, the ventilation (if in a confined condition), and the wind conditions, a wide range of heat flux densities can be produced. Systems exposed to pool fires can, therefore, experience changes in the heat loads and thermally induced stresses.

RUPTURE OF HIGH PRESSURE PIPE LINES

The accidental release of contents from high-pressure pipe lines, transfer facilities, or a high-pressure gas riser can result in jet fires, pool fires, and explosions. The escalation of such events was the major factor in the development of the Piper Alpha disaster in the North Sea in July 1988, which resulted in the loss of 167 lives and massive structural damage to the offshore platform. The subsequent inquiry by Lord Cullen [7] stated the need to develop tests to find ways to protect offshore installations against jet fires by means of current available materials.

A jet fire is a turbulent diffusion flame emanating from the combustion of a hydrocarbon fuel, which is continuously released with significant momentum in a particular direction [6]. Source momentum and directionality distinguish jet fires from pool fires. Jet fires have negligible inertia, meaning that they reach maximum intensity almost instantaneously.

In the sections that follow, a discussion of the characterization of jet fires, large-scale jet fire tests, the laboratory-scale jet fire procedure, and a high intensity jet fire apparatus are presented.

JET FIRE CHARACTERIZATION

In direct response to the Lord Cullen investigation findings, in March 1992, the Health and Safety Executive (HSE) in the United Kingdom, in conjunction with the Norwegian Petroleum Directorate (NPD), convened a working group with members from UK Offshore Operator's Association (UKOOA), Shell Research Ltd., British Gas R&T, and SINTEF-NBL. In 1993, Southwest Research Institute (SwRI) in the USA and Lloyd's Register in London joined the working group. The mission of this Jet Fire Testing Working Group (JFTWG) was to develop laboratory-scale test procedures that would reproduce the jet fire conditions likely to be encountered in an accidental rupture of a high-pressure pipeline [8]. In a research program undertaken by British Gas and Shell Research Ltd. at Spadeadam in the early 1990's, 170 experiments were conducted and a large number of measurements were taken, including size, shape, emission spectra, total heat flux, and convective and radiative heat fluxes using two fuels [7, 9]. The fuels were a single-phase release of natural gas at flow rates from 3 to 10 kg/s (140 to 460 MW) and a two-phase release of liquid propane gas (LPG) at flow rates from 1.5 to 22 kg/s (70 to 1020 MW). The releases were made horizontally at 1.5 or 3 m above the ground. Heat fluxes of up to 250 kW/m^2 were obtained from a sonic horizontal release of natural gas at 3 kg/s from an orifice 20 mm in diameter with a pressure of 6 Mpa (gauge). The release was directed perpendicularly at a 0.94-m diameter pipe placed 9 m from the release at 3 m above the ground. The flame from this release was approximately 2.5 m wide by 20 m long and was 2.5 m across the location of the pipe. The two-phase LPG had low initial velocity and was buoyant, with flame trajectories strongly influenced by the wind. The maximum heat fluxes engulfing the target were in the order of 300 kW/m^2, with the thermal and convective radiations about evenly divided. The gas temperature distribution across the flame was symmetrical about the flame axis, with a maximum-recorded value of 1435EC, 13 m from the discharge point. The gas temperature decreased with distance and was 964EC at a point 20 m from the discharge. The average emissive power measured varied from 240 to 350 kW/m^2 [9].

LARGE-SCALE JET FIRE TEST

The first large-scale tests of passive fire protection (pfp) materials in natural gas jet fires were conducted at Spadeadam in 1989 [9]. The purpose of these tests was to demonstrate the survivability and performance of a pfp material protecting the test specimen from an impinging jet of ignited natural gas. The response of full-size unprotected and passively fire protected structural steel members to impingement by a representative, large jet flame for one hour was determined. Tubular and I-beam sections were tested under total incident heat fluxes up to 300 kW/m^2, with substantial convective and radiative components, high gas velocities, and fire environment temperatures. More than 30 jet fire tests on pfp materials have been undertaken at Spadeadam. A detailed description of the large-scale jet fire test is given in references [9] and [10].

LABORATORY-SCALE JET FIRE PROCEDURES

Following the large-scale test program, SINTEF-NBL and NPD conducted an experimental program using a laboratory-scale jet fire test setup. The test was based on a sonic release of propane (0.3 kg/s or less), producing a jet flame that impinges into a 1.5-m square box with 0.5-m sides. Measurements made by Shell Research Ltd. and SINTEF-NBL indicated that this laboratory-scale jet fire test could reproduce the conditions measured in the large-scale jet fires. Therefore, the JFTWG decided to adopt this test procedure as the basis for evaluating the effectiveness of planar pfp test specimens. Subsequently, a variation to this procedure was developed to cover up to three different test specimen configurations: coatings applied to flat substrates, coatings on edges, and pfp materials applied over panels.

In December 1993, an Interim Jet Fire Test Procedure (IJFTP) was developed by the working group and published by the HSE. The limitation of the IJFTP was that it was restricted to planar and I-beam configurations. Other geometries such as tubular sections needed to be explored. To address this, a research program conducted by SwRI in 1995-1996, investigated the parameters necessary to simulate the large-scale jet fire environment enveloping tubular sections [11].

Based on this work, it is now possible to define four different versions of the laboratory-scale jet fire test procedure. These versions, illustrated in Figures 8, 9 and 10, include a panel test, a planar steelwork test, a structural steelwork test, and a tubular section test [8, 12]. Pass/fail criteria are usually determined by the end-user or the authority having jurisdiction.

For all versions of the test, the jet flame is issued from a tapered, converging nozzle 200 mm in length with an inlet diameter of 52 mm and outlet diameter of 17.8 mm. The fuel used during the test is commercial grade propane, which is delivered as a vapor without a liquid fraction at a rate of 0.30 ∀ 0.05 kg/s (14 ∀ 2.3 MW). The mass flow rate is recorded continuously throughout the test along with the temperature and pressure at the nozzle.

HIGH INTENSITY JET FIRE APPARATUS

In 1996, SwRI developed a test apparatus to simulate the radiative, convective, and erosive effects for a number of situations where the fire environment is not adequately reproduced by the above-mentioned jet fire test procedures and/or where the costs of the tests are a factor. The apparatus, known as the "High Intensity Jet Fire Apparatus," consists of a moveable premixed fuel and air nozzle, which can be set up to handle a wide variety of liquid and gaseous hydrocarbon fuels. When higher temperatures and heat fluxes are desired, pure oxygen (in addition to air) is injected into the premixed nozzle. In its current configuration, the apparatus is capable of producing consistent, sustained heat flux levels in excess of 550 kW/m^2 and temperatures up to 1600EC. Figure 11 illustrates the apparatus in operation.

Critical parameters such as fuel/air/oxygen pressures, flow rates, heat flux, temperature, impingement velocity, and nozzle standoff distance are measured to correctly simulate specific fire environments [13]. Currently, there are no standard test procedures for the use of this apparatus.

The advantages of the high intensity jet fire apparatus over the laboratory-scale jet fire test apparatus are that by its use, one can tailor the fire exposure to meet specific fire environments, it is less expensive to operate, can use different fuels, can develop higher impingement velocities, and can be enriched with oxygen to achieve higher temperatures and heat fluxes. The high intensity apparatus is limited to testing 1 x 1-m test specimens with an impingement diameter of 460 mm, where the maximum heat flux and temperatures are developed.

In summary, from the work conducted to date, the following observations are made concerning the jet fire test procedures discussed:

(1) The application procedure of the pfp material protection system is the most important step affecting the performance of the system against the impingement of jet fire.
(2) The heat fluxes generated in laboratory-scale tests are comparable to the large-scale tests and have been shown to reproduce key conditions of thermal and mechanical loads of large-scale jet fires. However, the procedure cannot guarantee a specific degree if protection from the myriad of possible jet fire. Therefore, this test procedure cannot be used to confer a universal fire resistance rating for specified period of time in the way the furnace test confers a hydrocarbon rating.
(3) The results of this test do not guarantee safety, but may be used as elements of a fire risk assessment.
(4) The test offers no assessment of other properties of the passive fire protection material such as weathering, aging, shock resistance, impact or explosion resistance, or smoke production.
(5) There are three test laboratories now capable of undertaking testing accordance with this test procedure. They are Southwest Research Institute in San Antonio, Texas; the UK HSE's laboratory in Buxton, Derbyshire, United Kingdom; and SINTEF-NBL in Trondheim, Norway. Round Robin tests between the three test laboratories have been conducted. The results showed that the test was reproducible. Reference [14] describes the results of these uniformity tests.
(6) The high intensity jet fire apparatus can be used to reproduce more intense fires than those currently reproduced using the laboratory-scale jet-fire setup. However, it is limited as to its ability to test large specimens or assemblies.
(7) The procedure is currently going through the process of becoming an ISO standard.

MODELING

Laboratory-scale tests are relatively inexpensive, but have limitations due to the fact that they do not account for scale effects. Real-scale tests address this problem, but are much more complicated and expensive. Furthermore, real-scale tests only provide information about performance of the material or system for the fire scenario and exposure conditions of the test. To obtain a sufficient amount of data to characterize performance over the entire range of fire scenarios and exposure conditions of interest, would require a very large number of tests that would be cost prohibitive. The most efficient approach consists of a combination of laboratory- and real-scale tests with computer fire modeling techniques. Two types of models are needed: models to predict the exposure conditions created by the fire (temperatures, heat fluxes, etc.) and models to predict the response of structural members to these conditions. A large number of the two categories of models are available [15, 16]. The laboratory-scale tests are used to obtain material properties, thus providing input data for the model. A small number of well instrumented real-scale tests are performed to obtain data to assess the uncertainty and accuracy of the model, i.e., to validate the model. The model can then be used with confidence to predict fire performance of the material for fire conditions that are different from those in the real-scale tests. Thus, the model is used as a tool to extend the experimental data. With this approach, optimum use is made of all the information that is available concerning the fire performance of the materials, components, assemblies, and/or systems.

SUMMARY

As discussed in this paper, the major fire threats to marine and offshore installations and facilities can be categorized as those originating in a room or compartment, accidental spillage of fuels both indoors and outdoors, and the rupture of high-pressure pipe lines.

The test procedures that have been developed to simulate the effects of these potentially catastrophic major fire threat events range from those that evaluate the behavior of materials and/or components to flame and fire spread, fire growth, and fire resistance to tests that are designed to evaluate the behavior of a structure and/or structural components or the effectiveness of paint, coatings, or passive fire protection materials to the conditions likely to be encountered in the field. Tests designed to determine the flame and fire spread and fire growth are conducted under controlled conditions specified by a standard requiring small test sample sizes, and are relatively less expensive than the larger scale fire resistance, pool, and jet fire tests. Experience with the intermediate-scale calorimeter apparatus is limited, and some additional research is needed to determine whether it is suitable to evaluate composite materials.

With respect to pool and jet fire test protocols, there are no consensus standards, although currently it is being evaluated to become an ISO Standard. The test protocol prepared by the JFTWG for testing of pfp materials is a guide for conducting laboratory-scale tests on pfp materials, but it is not a standard. This protocol is for testing materials, not assemblies. Jet fire tests cannot be used to confer a universal fire resistance rating for a specified period of time as done in the furnace tests. Although the current jet fire tests have been designed to simulate some of the conditions, which can occur in an actual jet fire, exact reproductions cannot be achieved. The results do not guarantee safety, but may be used as elements of a fire risk assessment for structures or assemblies. The high intensity jet fire apparatus can be used to reproduce more intense fires than those currently reproduced under the laboratory-scale jet fire setup. However, it is limited as to its ability to test large specimens or assemblies.

Models can account for scale effects and can use data from laboratory and real-scale tests to predict performance under time-varying conditions. The most efficient approach to characterizing materials and system performance over the entire range of fire scenarios and explosive conditions of interest is to combine laboratory and real-scale tests with computer fire modeling techniques. With this approach, optimum use is made of all the data available concerning the fire performance of materials, components, and/or systems.

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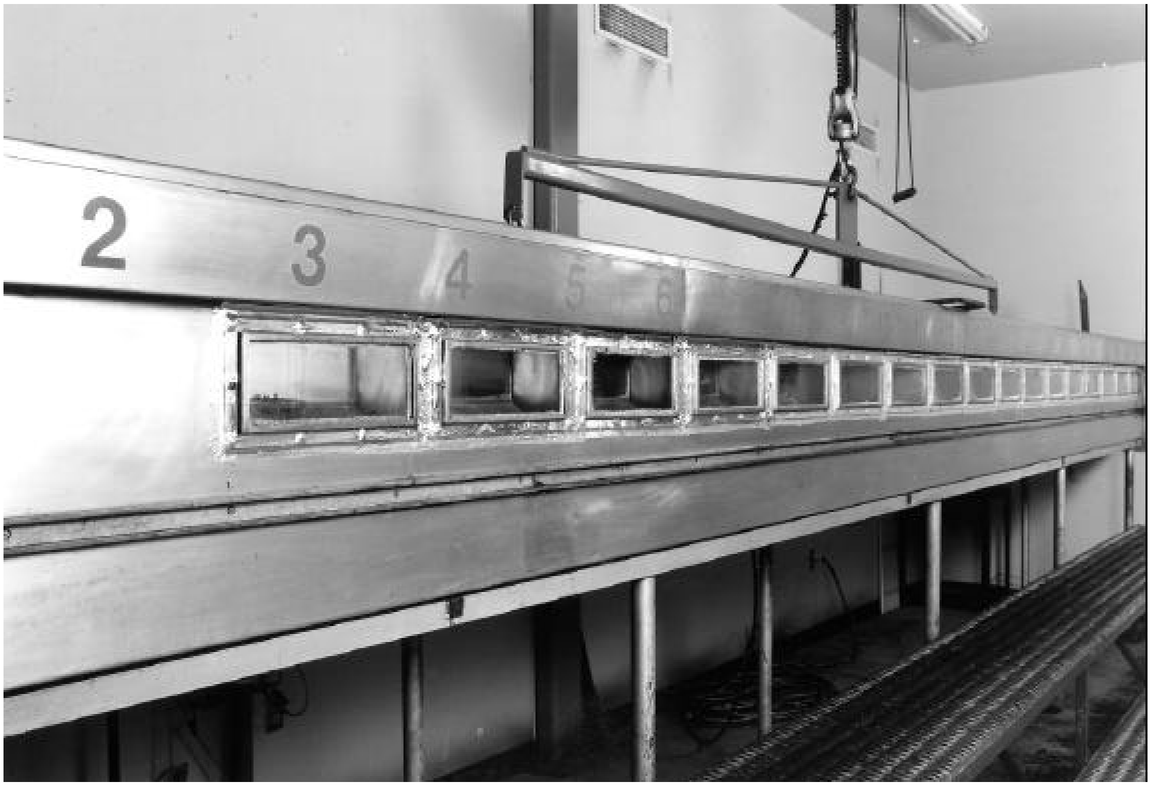


Figure 1: ASTM E 84 Tunnel Test Apparatus

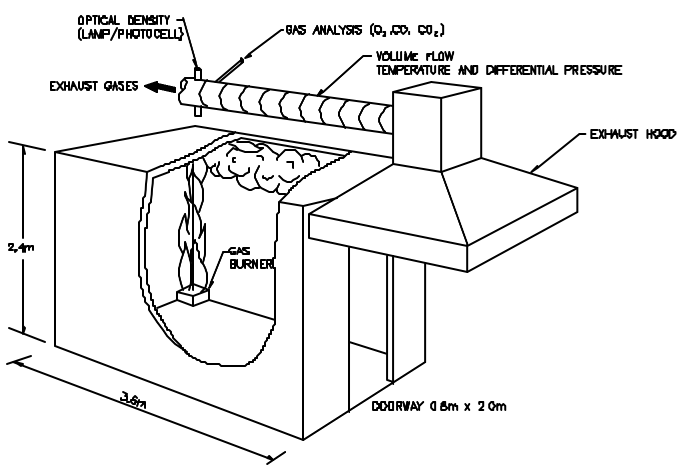


Figure 2: ISO 9705 Room Test Apparatus

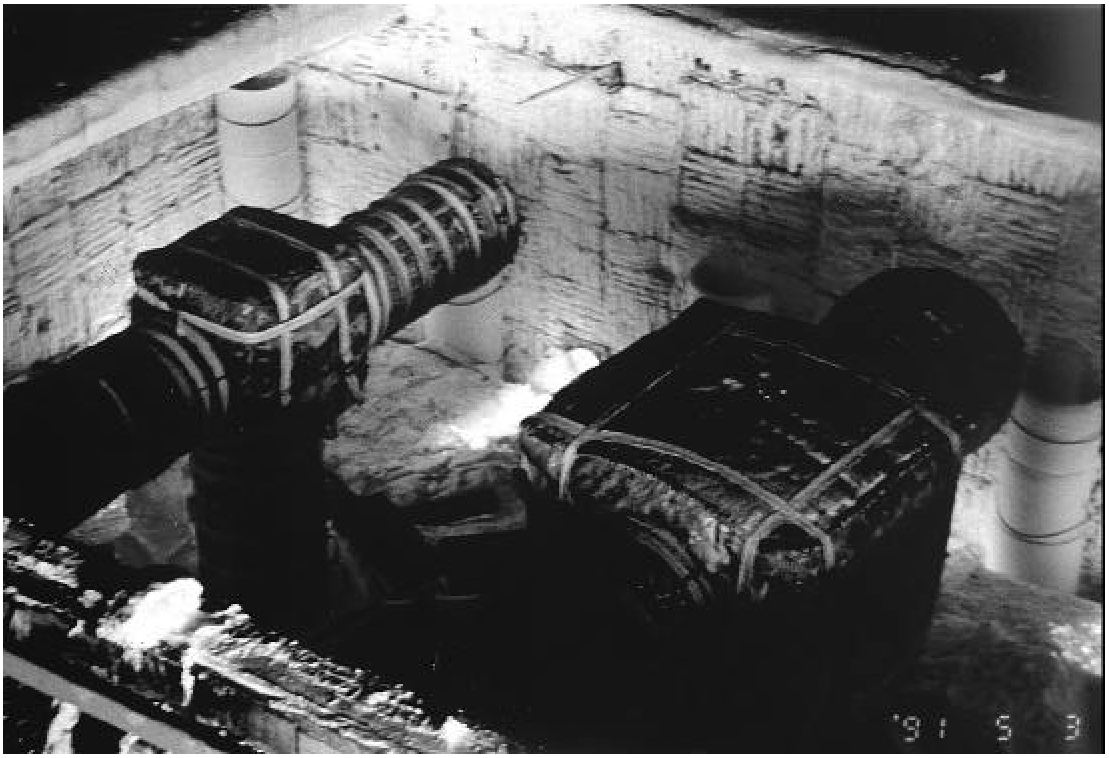


Figure 3. Motor Operated Valve (MOV) in Horizontal Test Furnace.

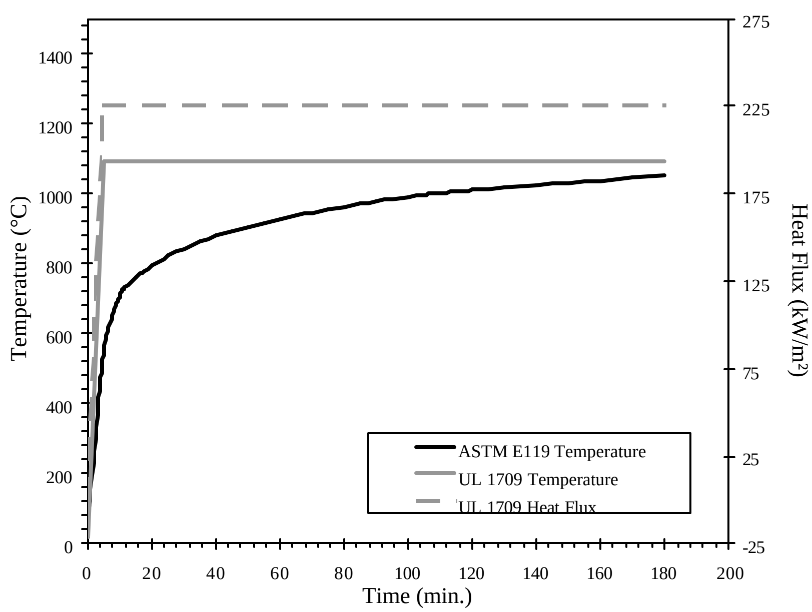


Figure 4: Typical Temp.and Heat Flux Profiles for "High Rise" and Standard Exposures

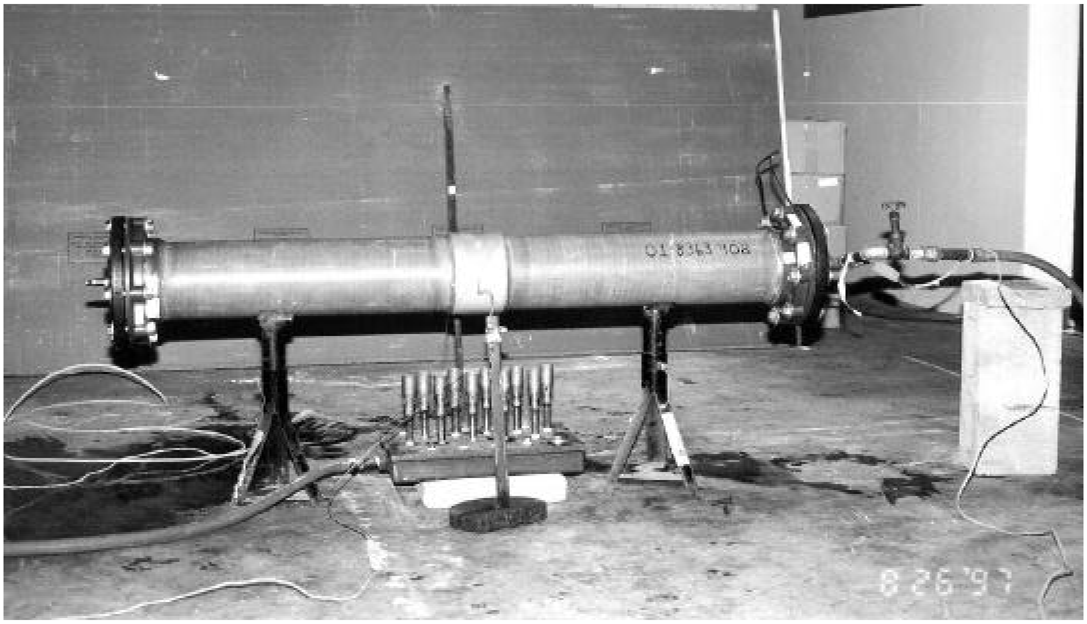


Figure 5: Burner Assembly for Fire Endurance Testing of Composite Pipes

Figure 6: Typical Hydrocarbon Pool Fire Test

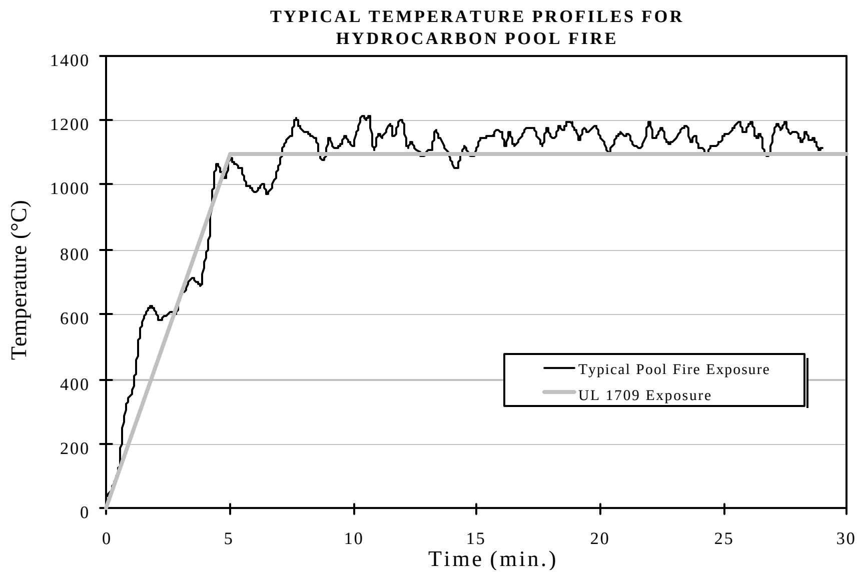


Figure 7: Typical Temperature Profiles for Hydrocarbon Pool Fires

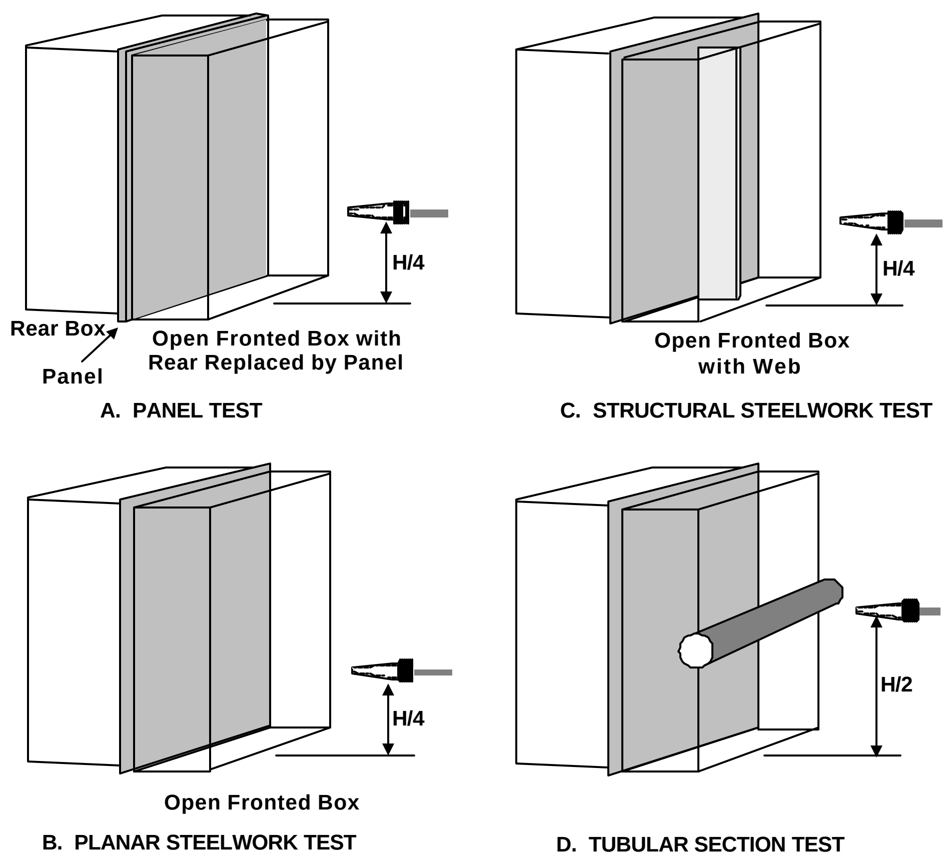


Figure 8: General View of the Different Versions of the IJFTP

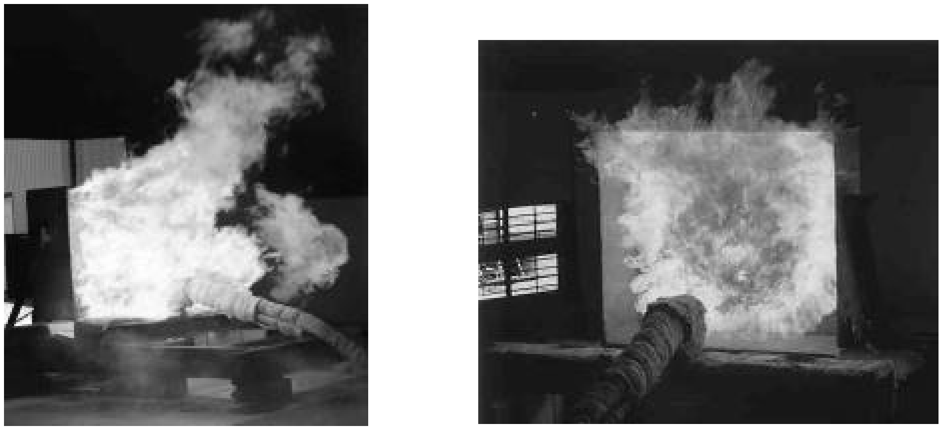


Figure 9: Panel and Planar Test Procedure

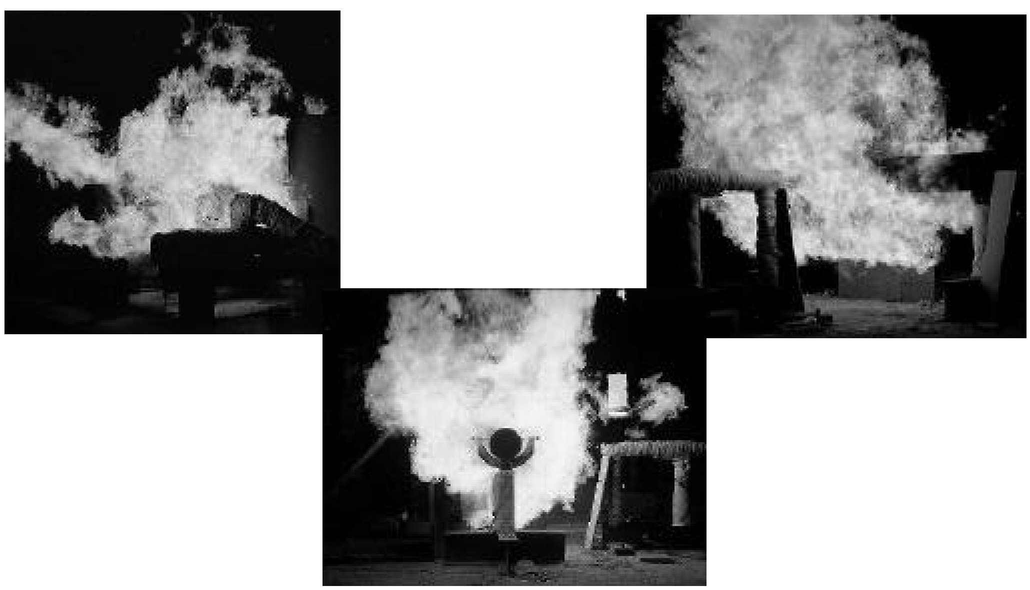


Figure 10. Tubular Test Procedure

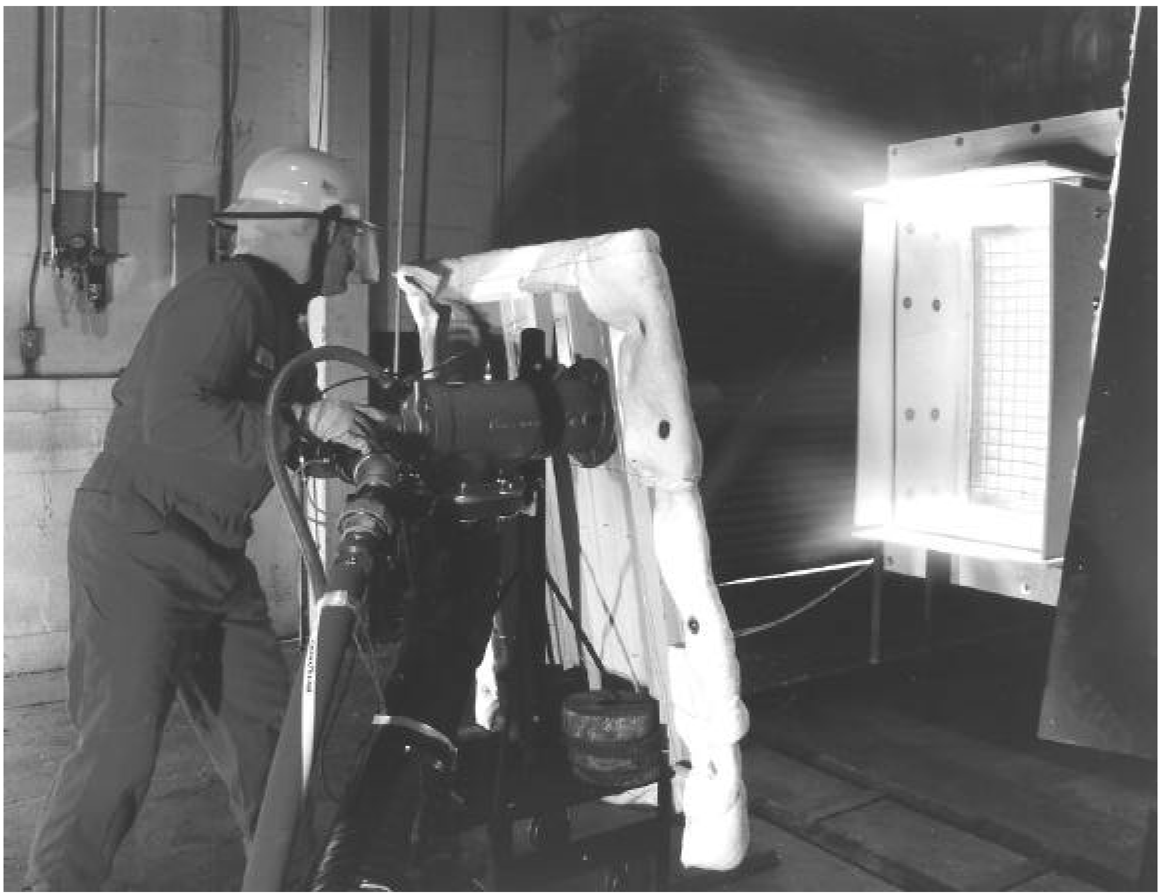


Figure 11: High Intensity Jet Fire Apparatus

Large Scale Testing – Blasts

Gary Shale, Advantica Technologies Limited, UK

Large Scale Testing – Blasts

Gary Shale
Advantica Technologies Limited, UK

Gary Shale discussed the advent of large scale blast testings after the Flixborough incident. After the Piper Alfa disaster, 1/3 scale tests were carried out using oxygen enrichment techniques to account for the scale effects. Joint industry projects also carried out large scale tests

The JIP, Blast and Fire Engineering Phase 2 & Phase 3a showed that very high overpressures could be generated if the entire volume was filled with stoichiometric air-gas mixture. Phase 3b of the JIP included large scale tests with partial fill and realistic releases. Under these scenarios, it was found that overpressures could be significantly reduced.

Gary concluded after detailing the role of large scale testings in product performance demonstrations.

Thirty-one slides presented are attached.

ADVANTICA TECHNOLOGY

International Workshop – Fire & Blast Considerations in the Future Design of Offshore Facilities

Large Scale Testing – Explosions

Advantica Technology, UK

Gary Shale
June 13, 2002

ADVANTICA TECHNOLOGY

Overview

- Advantica Technology
- Spadeadam Test Site
- Explosions Research
- Modeling/Risk Assessment
- Performance Testing
- Fire Studies
- Summary

About Advantica

ADVANTICA TECHNOLOGY

- Originates from the UK state-owned gas company, British Gas
- Following privatisation and de-merger was part of BG plc.
- Now part of the Lattice Group which also owns Transco the operator of the UK gas transmission and distribution company
- Operates in the United States as Advantica Technology North America (ATNA)

About Spadeadam

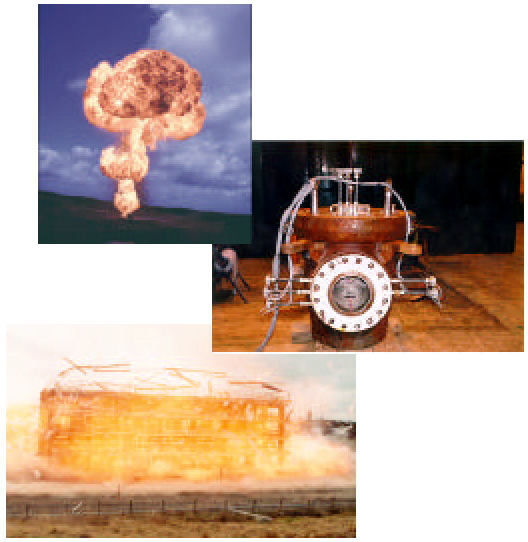
ADVANTICA TECHNOLOGY

- Located in North of England near border with Scotland
- Within forested region away from public
- Developed over last 25 years to provide capability to study major hazards at full scale

Spadeadam Services

ADVANTICA TECHNOLOGY

- **Understanding Hazards**
  - fire, explosion
- **Assessing Performance**
  - equipment and product testing under operating or extreme conditions
- **Validating Design**
  - demonstrating compliance, conformity and fitness-for-purpose



Flixborough

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Effect of Repeated Obstacles

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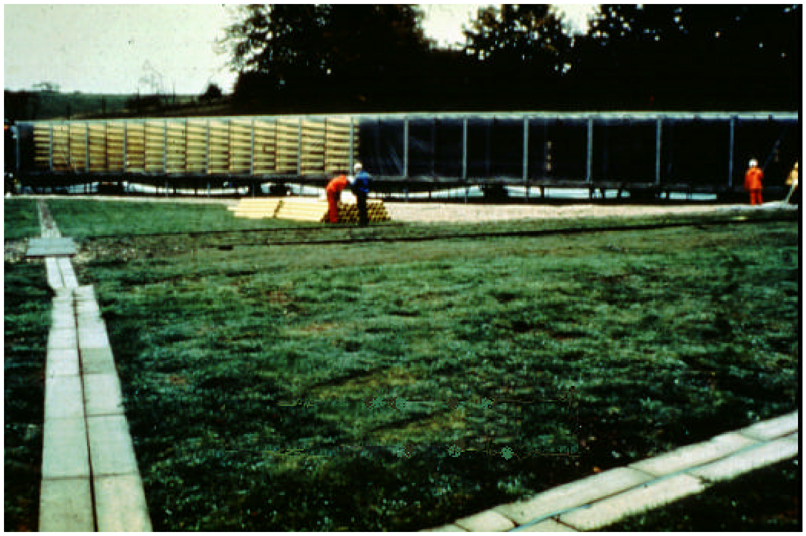

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Important Parameters

- Fuel Reactivity
- Level of Congestion
- Level of Confinement
- Cloud Size

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Piper Alpha Disaster

Led to:

- Changes in Regulations
- Preparation of Safety Cases
- Need for understanding of fire and blast hazards in offshore conditions

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Joint Industry Projects

ADVANTICA TECHNOLOGY

- **Blast & Fire Engineering Project – Phase 1**
  - Collate current understanding of fire and blast
  - Provide guidance
  - Identified:
    - Effects are scale dependent
    - Lack of large scale data
    - Lack of model validation
- **Blast & Fire Engineering Project – Phase 2**
  - Full scale fire and explosion experiments
    - Spadeadam (Explosions & Jet Fires), SINTEF (Confined Fires)
  - Model evaluation

Phase 2 - Explosions

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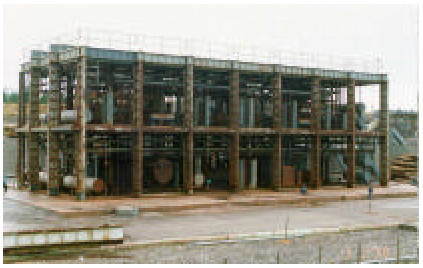
- **Full scale test rig**
- **27 experiments**
- **Uniform clouds, mostly stoichiometric**
- **High overpressures possible**
- **Mitigated by water deluge**
- **Model predictions had large variability**



Phase 3A - Explosions

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- **Sponsored by UK Health & Safety Executive**
- **Objectives:**
  - Design and modification
  - Mitigation measures
  - Model evaluation and development

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Phase 2 and 3a Conclusions

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- **Experiments showed high overpressures possible**
  - Mostly stoichiometric mixtures
  - Uniform gas clouds
- **Often not possible to design against worst case**
- **Risk based approach**
- **Need to understand:**
  - Gas dispersion from high pressure releases
  - Realistic explosions - Phase 3B

Phase 3B

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- **Laboratory Experiments (Shell Global Solutions)**
  - Fuel turbulent combustion characterisation
- **Medium Scale Experiments (CMR)**
  - Partial Gas Clouds
  - Realistic Releases
- **Full Scale Experiments (Advantica)**
  - Partial Gas Clouds
  - Realistic Releases

Phase 3B – Full Scale Explosions

ADVANTICA TECHNOLOGY

- **29 experiments in all**
- **Base Case tests**
  - Stoichiometric, 100% fill
- **Partial Fill Tests**
  - Stoichiometric, quiescent
  - 10%,19% and 43% of total volume
- **Realistic Releases**
  - Rates between 2 and 12 kg/s
  - Varying release position and orientation

Phase 3B – Key Results

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- **Lower overpressures for smaller gas clouds**
- **Generally, the realistic releases produced varying gas concentrations and cloud sizes and lower overpressures**
- **During certain conditions, realistic releases could give rise to large regions of near-stoichiometric mixtures and result in overpressures similar to Base Case**
- **Rich gas regions tended to be trapped by walls and did not appear to contribute to the explosion**
- **Jet releases with varying concentrations were less easy to ignite than more uniform clouds**

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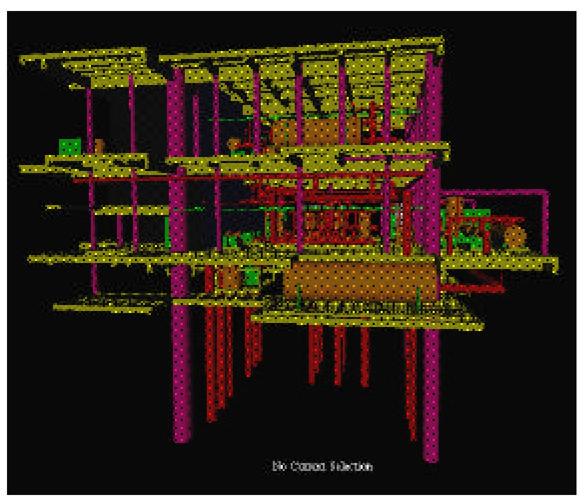
Modeling/Risk Assessment

- Models included in ARAMAS risk assessment package
- Large number of transient scenarios
- Escape, evacuation and rescue
- Effect of safety system performance standards



Safety System Performance

ADVANTICA TECHNOLOGY

- **Safety systems**
  - Gas detection
  - Emergency shut down (ESD)
  - Blowdown
  - Deluge
- **For each system:**
  - Potential for failure to operate
  - Delay time for activation
- **ARAMAS enables effect of performance on risk reduction to be assessed**

Performance Testing - Spadeadam

ADVANTICA TECHNOLOGY

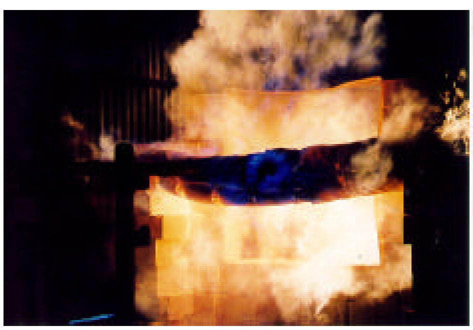
- **Testing of safety critical equipment**
- **Demonstration of performance under fire and blast loading**
- **Examples:**
  - Explosion survivability of water deluge pipework (Sable, Canada)
  - Explosion relief by Louvers (Marathon, UK)
  - Performance of PFP following blast loading (Cape Industries, UK)

Explosion test of PFP Jacket

ADVANTICA TECHNOLOGY

Fire Test of PFP in Certified Facility

ADVANTICA TECHNOLOGY



- During Test

- After Test

Fire Studies

ADVANTICA TECHNOLOGY

- **Jet Fires of Natural gas, Propane, Butane, Kerosene, Oil, Gas/Oil mixtures, Gas/Oil/Water mixtures**
  - Heat loads to objects
  - Effect of deluge
  - Flame stability

Fire Studies

ADVANTICA TECHNOLOGY

- **Pool fires of LNG, LPG, Butane, Methanol, Naphtha, Kerosene, Condensate, Oil**
  - Effect of Water Deluge
  - Object engulfment

Fire Studies

ADVANTICA TECHNOLOGY

- **Pipeline Fires**
  - Steady state and transient
  - Fracture propagation testing of pipe material

Summary

ADVANTICA TECHNOLOGY

- **History of large scale experimental research into explosion and fire at full scale undertaken at Spadeadam**
- **Important to reduce to a minimum the key contributors to an explosion:**
  - Potential release locations
  - Potential ignition sources
  - Confinement
  - Congestion
- **Use the information and knowledge from large scale experimental work in preparation of safety cases, QRAs and performance standards studies**

And Finally….

WORKING GROUP 1

PHILOSOPHY AND MANAGEMENT STRATEGY

Contributors:

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Donnie Carter, BP America

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FIRE AND EXPLOSION PHILOSOPHY AND MANAGEMENT STRATEGY

1.0 INTRODUCTION

This paper outlines a basic fire and explosion management strategy for offshore facilities. The objectives of this paper are to:

- Provide an understanding of Hazard Management Systems
- Discuss key elements for successful implementation of a Hazard Management System
- Provide an understanding of a fire and explosion design strategy
- Provide details on developing a fire and explosion design strategy

This paper focuses on fire and explosion strategies during the design phase, however, many of the concepts can be carried forward to the operation of the offshore facility.

The approach developed in this paper leads to a proactive design culture where all fire and explosion risks are eliminated or minimized. It will enable projects to deliver an optimal result, taking into account project specific conditions, such as the scope of the operation, local environment, local/regional legislation, public perception and partner buy-in.

If the design team takes ownership of the proactive hazard management process, the resulting facility will be significantly nearer to the *"no accidents, no harm to people, no environmental damage"* goal. In most cases, the lifecycle cost of the facility will be significantly less than following the previous prescriptive approach, and in many cases the capital cost as well as the operating cost will be reduced, so the process will be value improving in every possible sense of the word.

2.0 HAZARD MANAGEMENT SYSTEM

Management of risk is a fundamental activity of all companies in the offshore industry. Most companies have developed a formal policy of how risks will be managed. These policies reflect relevant corporate beliefs and values.

The way these policies are implemented may vary from company to company, but come under the classification of a Hazard Management System (HMS), which is the nomenclature used in this paper. An HMS provides a framework of guidance to allow consistent and methodical evaluation and management of hazards and risk.

A Fire and Explosion Strategy is considered an integral part of an HMS. There are many ways to approach the development of an HMS, however key decisions must be made and policies established. Figure 1 illustrates an example of an HMS and how a fire and explosion strategy fits within an HMS.

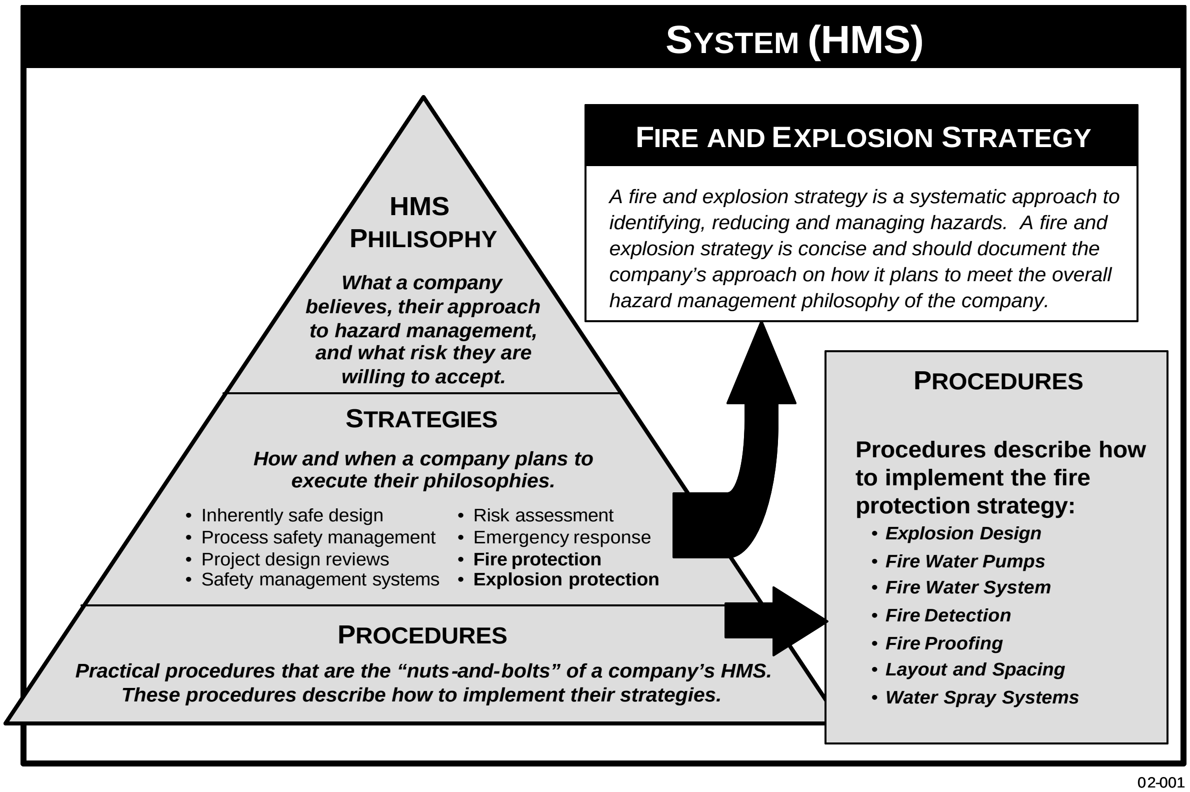


Figure 1. Integration of Fire and Explosion into a Hazard Management System

The Hazard Management System (HMS) should be applied to every design decision from the type of hydrocarbon processing and support structure to the need for, choice and location of a component during the design. The process must be applied before the decision is taken so that every opportunity to minimize hazards is identified and considered while it can still be implemented.

The HMS applies to all elements of the project, including topsides, hull systems, well systems, drilling, pipelines, etc. The HMS can be applied to all phases of the project: installation, commissioning, start-up, and operation of the facilities.

2.1 Understanding the Mechanics of Risk Reduction

In order to understand the HMS, it is necessary that all participants in risk reduction understand the three concepts illustrated in Figure 2.

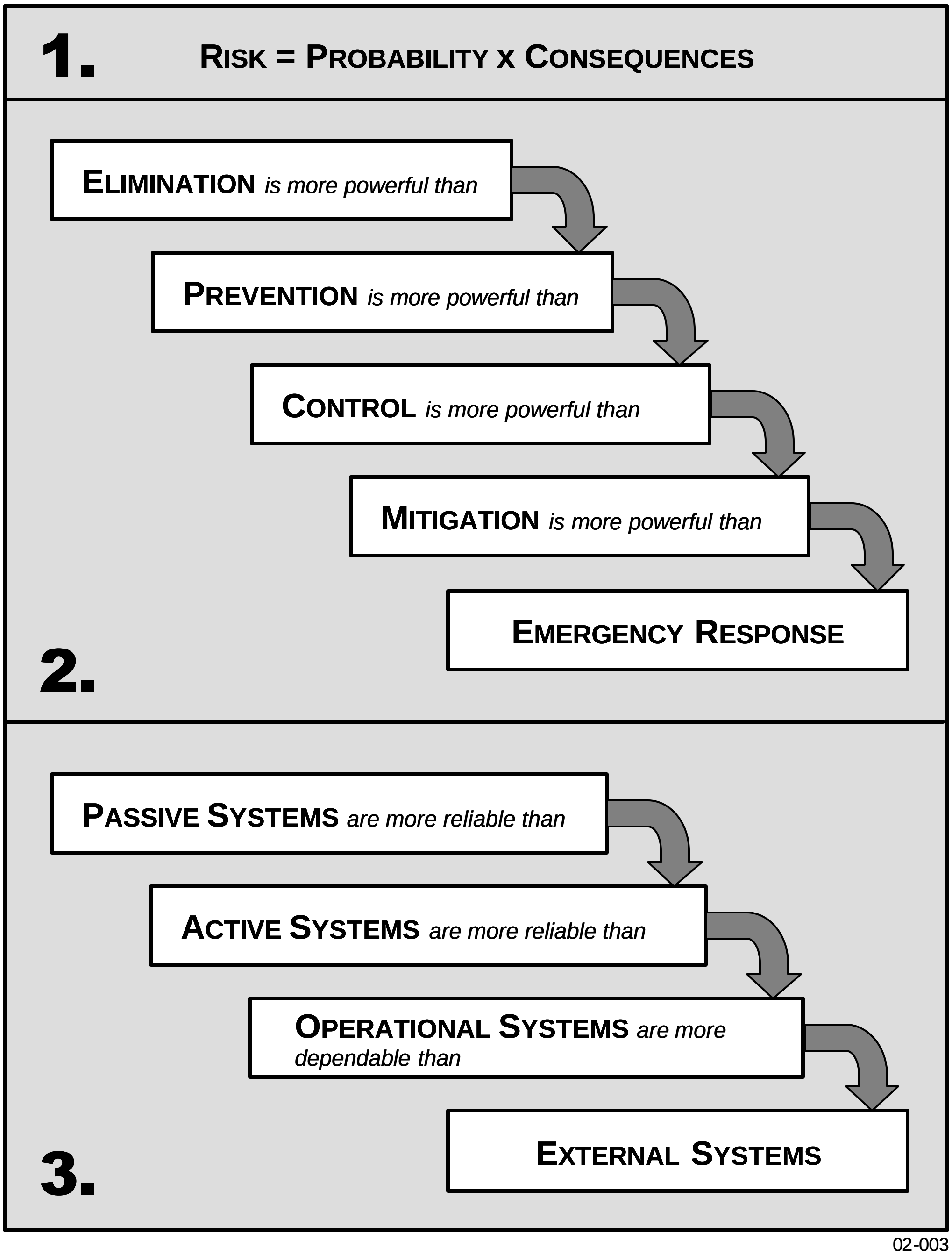


Figure 2. Risk Reduction Concepts

Ideal hazard management relies primarily on minimization at the source and passive prevention. This minimizes the causes arising from human error and the consequences of injury and death.

Figure 3 illustrates the sequence of actions to be taken in order of their effectiveness in reducing risk.

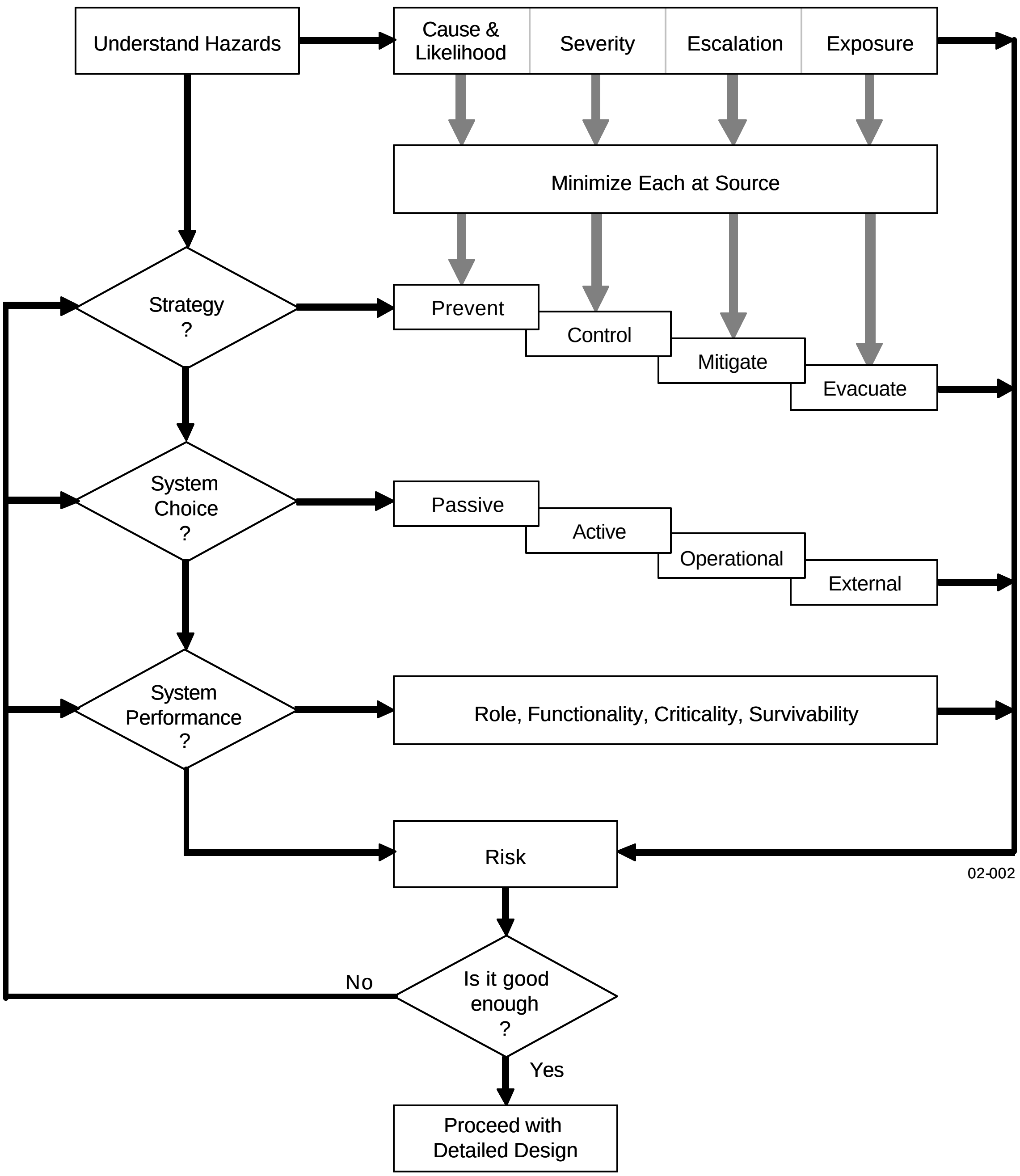


Figure 3. Risk Reduction Flowchart

2.2 Implementing the HMS Process

An initial documentation of the fire and explosion hazards should be captured in the hazard registry for the project and should list the primary risk drivers, causes and consequences. This is a living document that should be continuously updated through the design stages. It enables major changes to be assessed and documented as part of the Management of Change process.

2.2.1 Understanding the Hazards

A progressively deeper understanding of the fire and explosion hazards should be developed in the design phase. This is core information that can be used to base fire and explosion hazard management decisions and subsequent designs. Hazard analysis is carried out as a design input, for example the effects of fires and explosions. This knowledge will help to define each hazard strategy, select or confirm the systems to prevent, detect and set their performance.

The awareness of hazards, their causes and effects, is the greatest risk reducer for an operating facility. The understanding derived from this systematic examination must be shared with the whole design team, summarized and handed over to the future operator either within, or as a supplement to, the hazard register.

2.2.1.1 Causes and Likelihood

There should be a widespread understanding of the types of causes, both procedural and engineered, and of the propensity for those causes on the facility. There should be a formal process, such as a Hazard Identification (HAZID) or a Hazard and Operability Study (HAZOP) to confirm that all causes have been identified. A formal process must be applied to all major hazards arising from any facility or structures. For example, all fire and explosion hazards in a floating marine structure should be rigorously examined.

2.2.1.2 Severity

Since fire and explosion hazards have the potential to cause a major accident, the severity should be quantified in relevant terms such as the type of hazardous event, the energy, the size, intensity, location and duration.

2.2.1.3 Immediate Consequence

Since fire and explosion hazards have the potential to result in a major accident, the consequences of the initial event should be determined, both to people and to the facility, structure or safety systems that may fail leading to further escalation.

2.2.1.4 Escalation and Major Accident Effects

Since fire and explosion hazards have the potential to escalate to a major accident, all of the routes to that escalation should be identified and mapped. The sequence, timing and characteristics of the event progression should be determined.

2.2.1.5 Risk

A picture of the relative risks to the overall facility from individual hazards should progressively develop as the design progresses. This is essential information for the decisions in the hazard management system. Major accident hazards may each be subjected to a qualitative risk matrix analysis that covers both the initial event and its potential for escalation. Where specific hazards make a dominant contribution to the overall risk, or the overall risks cannot easily be reduced to tolerable levels, a more formal process of Quantitative Risk Assessment (QRA) may be applied.

2.2.2 Eliminating or Minimizing Hazards

A systematic process should continue using the outputs of the HAZIDs and safety studies as triggers to eliminate or minimize hazards:

- For every identified hazard or hazardous activity, determine if it can be designed out
- For every cause, examine ways to make failure inherently less likely to occur through the inherent strength, reliability, longevity and simplicity of the design
- Examine the severity for opportunities to minimize it at source and to limit its damage potential
- Study the immediate impact of the event on the facility and people to see if changes to the layout or the way people operate it can reduce their exposure
- Examine the routes to escalation and the exposure of the muster and evacuation routes. Challenge the layout in order to eliminate these chains of events and minimize exposure of the wider community

2.2.3 Adopting a Strategy to Manage Each Hazard

In simple terms, this is the decision of the route to take, *to prevent, protect or evacuate.* The strategy should determine the appropriate relative investment of finite resources between prevention and cure. It is not acceptable to simply provide a default array of prevention measures and safety systems and then to retrospectively attempt to justify their adequacy. There must be active management of what is provided in the knowledge of the hazards and their associated risks.

The following four strategies are the options, listed in descending order of preference. They should be applied sequentially until adequate layers of protection have been provided. The choice of each strategy must be taken in conjunction with the future operator, who will have to implement what has been decided, and live with the risks and potential legal consequences.

2.2.3.1 Prevent

Where total *elimination* of a hazard is not possible, then every practical means should be used to reduce the likelihood of the event; i.e. *Prevention*. Choosing prevention, as the sole means to manage a hazard, is only viable if there is an absolute assurance that every cause has been identified, is fully understood, and that wholly effective prevention measures will be in place for the lifecycle of the facility.

A typical strategy that would rely solely on prevention would be a catastrophic explosion within the storage tanks of a Floating Production and Storage Operation (FPSO), which would split the vessel in half. The severity is such that it is impractical to counteract the effects and the maintenance of a non-flammable atmosphere should be practically achievable under all circumstances.

2.2.3.2 Control (the Severity)

Having done all that can be done to eliminate or prevent the occurrence, and realizing that it is still foreseeable that some events may occur, the next most powerful strategic option is to control, or limit the magnitude of the event. The addition of further systems to detect and then control the event should, where possible, reduce that severity so that it is unlikely to result in fatality or cause escalation. If this is not practical, then, at least, it should limit the severity to that which can realistically be contained by the mitigation systems without endangering the overall facility.

2.2.3.3 Mitigate Effects/ Reduce Escalation

When everything that is practical has been done to control the severity of these foreseeable, but controlled events, the assessment of the immediate consequences will identify the people and facility that may be exposed to the effects. After optimizing the design to minimize this exposure, a mitigation strategy should be adopted to protect the people. Protection should also be provided for the facility if it is likely to fail leading to critical escalation, such as:

- Major loss of life
- Catastrophic failure, such as vessel rupture
- Major loss of hydrocarbon inventory
- Loss of critical safety systems needed to control the hazard
- Loss of primary structure or buoyancy
- Loss of secondary structure leading to the above

A typical strategy that would rely on a combination of prevention, detection, control and mitigation would be the management of the separator oil fires on a well-designed offshore platform. With corrosion, instrument connections and maintenance activity, a leak is foreseeable, but the prevention measures would minimize the likelihood. A combination of fire detection, isolation, depressurization and drainage would limit the size and duration so that exposure of the accommodation was not threatening. Passive protection, firewalls and deluge would prevent further escalation, giving a fully integrated set of measures without the need to evacuate.

2.2.3.4 Emergency Response, Evacuation and Recovery

When everything practical has be done by design to control the escalation and mitigate the consequences of an unwanted event, consider if anything else is needed to limit the exposure of people to a particular event and protect their evacuation. This is the defense in depth, in case of an extreme initial event or the failure of the strategies listed above. Facilities to muster and evacuate will always be provided but the choice of strategies should aim to reduce dependence on them to an absolute minimum. Where they are critical, it must be practical to muster, make decisions and use the equipment within the timescale and effects of the event. Emergency response and recovery plans should be developed for each critical scenario.

An example of a strategy, which may depend on muster and evacuation, is the recovery of personnel from a fixed installation following structural damage and well leakage caused by a severe earthquake or large vessel collision.

2.2.4 Systems Choice

Many systems, particularly those to prevent incidents, will be provided, initially, through the use of the baseline codes and standards. In choosing further systems to complete the strategies, the emphasis should be on effectiveness and minimizing the potential for failure, particularly through human error. The choice should also seek to minimize maintenance with the associated exposure of people to the risks that the systems are in place to minimize; fewer tasks in which to make mistakes and fewer people exposed. To assist in this optimal selection, systems have been classified from passive to external, in descending order of preference is shown in Table 1.

Table 1. System to Prevent Incidents

Type	Description
Passive	These are systems that act upon the hazard simply by their presence. They do not need to react to the hazard or need operator input at the time of occurrence in order to be effective. The only modes of failure are long-term deterioration, physical damage or removal. They are preferred because they are inherently the most reliable, requiring only inspection and maintenance, thereby reducing the need for people to be in hazardous locations. *Typical examples are corrosion allowances, bunds to limit the spread of oil leaks, and blast walls.*
Active	These are systems that may require mechanical or electrical facility, or control signals in order to work. They are susceptible to failure and downtime of these systems. As such, they are less reliable, particularly where their failures may be un-revealed. They require inspection, testing and maintenance, and are thus susceptible to human error or omission. They also cause increased numbers and activity on the facility. *Typical examples are; HIPS systems, depressurization systems, fire and gas detection and active fire and blast.*
Operational	These are systems that depend primarily upon people, either to initiate the system, or to carry out the whole function. As such they can be the least reliable and require sufficient trained people to be on the facility in order to ensure their operation, with associated minimum competences and procedures. Their effectiveness is wholly dependent upon the future operator, who should agree to the dependence on these measures. *Typical examples are; manual setting of choke valves to prevent sand erosion, visual detection of oil leaks and the manual initiation of ESD.*
External	These are systems that depend on the correct reaction of people beyond the company itself, and its direct workforce. There is clearly further room for error due to the longer communication lines and frequent changes of the people involved. Effectiveness is dependent upon effective contracts and audit. *Typical examples are; the dependence on the competence of a supply boat master to avoid riser impact, and isolation of a third party feeder pipelines.*

2.2.5 Setting System Performance Standards

Performance standards should be set for all fire and explosion safety systems and procedures. They should be endorsed by the future operator and be documented for the operations group. The standards reflect the minimum level of performance that must be achieved over the lifecycle of the facility.

In setting standards for people, through procedures and competencies, there should be realism about what is achievable, given the number of times the activity would have to be performed in the operating lifecycle, the working conditions and the types of people who may be undertaking the work.

The standards should address the role, functionality, criticality (quality, availability, reliability) and survivability, with respect to the hazards to which they are assigned. In some countries, the minimum standards are set in the regulations and in others; it is a requirement to clearly define the minimum standards.

2.2.5.1 Role

The exact role that a system will play must be defined before any of the other parameters can be defined. That role must be defined with respect to the particular hazards.

For example, the role of a depressurization system is not simply to meet a particular depressurization rate in a code, it could be the prevention of vessel rupture in a high pressure condensate fire or the reduction of the duration of a gas fire so that it cannot cause critical escalation.

2.2.5.2 Functionality

The functional standards define the minimum performance necessary to fulfill the role but do not define *how* that performance should be achieved. Failure to achieve it will require repair or replacement. Codes and standards will often give or infer default standards and the means to achieve them. If these are the start point, the code suitability should be verified against the specific hazard requirements to confirm its effectiveness. For engineered systems, typical examples of *functional* performance standards are:

- Sensitivity and response time of gas detectors
- Weather limitations and response time of rescue systems
- Application rate of fire water to keep vessel temperature down to a specified temperature

For example, the functional performance standard of a fire pump may be defined by the response time, its run time, and a flow and pressure curve which can meet the different, and multiple demands of each of the major accident hazard scenarios where water is critical to their mitigation. [Note that these are not the "as new" criteria, but the change out criteria during operations].

2.2.5.3 Reliability and Availability

The criticality of a system will determine how reliable and available it must be. In the case of *prevention* measures, it will indicate the goal in terms of reducing the likelihood of the event. For *all other systems*, it will determine the target success rate for the system, should a cause be realized or an incident occur. This success rate has two components; reliability and availability. These affect the probability that the functional performance, or the emergency response will be achieved. The reliability will be verified by functional testing at predetermined intervals. The availability is defined by the maximum allowable downtime in a fixed period.

For example; a fire and gas detection system may have an 85% probability of detection of small events and a 99% probability of detection of incidents with the potential to escalate or kill. This is achieved through the assurance of adequate coverage, testing of the panel and detectors at predetermined intervals, clear definition of tolerable failure rates and the limits for the duration of lockouts and obstructions such as scaffolding, which may impair effectiveness.

2.2.5.4 Survivability

Finally if a system has to operate or maintain its integrity during or after an event, it must have sufficient strength, protection or redundancy so that it can fulfill its role and meet the functional standards. This will be defined by the standards for survivability**.** These will be expressed in terms of the severity of the event that it should survive. These standards are only required if the system is critical to managing the event to which it is exposed.

For example, a fire and gas detection system does not need to survive a fire or explosion, as it should already have fulfilled its role in the incipient stages of the event. A separator and connected piping and instruments may have to maintain its integrity when exposed to a 7 psi explosion overpressure, an ESD valve actuator and power supplies may have to be fail safe or protected from a jet fire until it has closed, or a lifeboat may have to be launched with a 15^o *heel on a floating installation.*

2.2.6 Is it Good Enough?

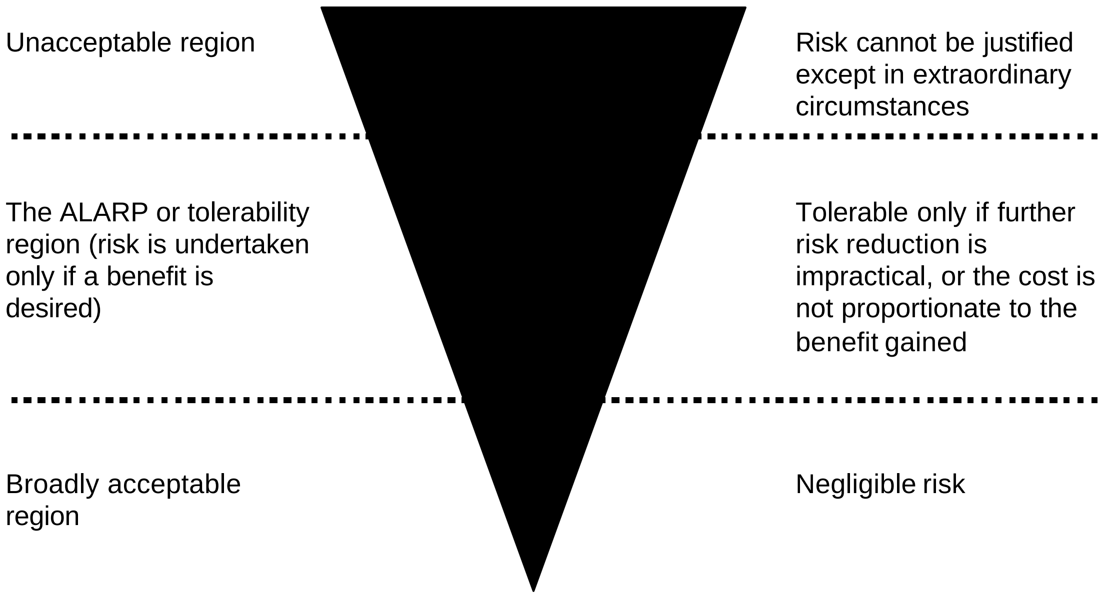
Every project must demonstrate a process that has minimized risks and has effective and practical proposals to manage the hazards that remain. The purpose of this demonstration of adequacy is to show that the design is "Good Enough", i.e.:

- The Project Goals are met
- The Company's Risk Acceptability Criteria are satisfied and that the risks are reduced to As Low as Reasonably Practical (ALARP)

2.2.6.1 ALARP Concept

A concept that was developed in the United Kingdom, is accepted by regulatory bodies and has gained a wide acceptance with industry is called as low as reasonably practical (ALARP). This concept is illustrated in Figure 4. The figure shows three regions. The top area is where the risk is clearly not acceptable and action must be taken to reduce the risk. The bottom region is where the risk is clearly acceptable and not further action is required. The middle region is the ALARP area where a company must demonstrate that all practical mitigation has been applied and additional mitigation is not reasonable to precede with additional mitigation.

There have been attempts by companies to assign numbers to these regions. There would be different values used for workers and for the public near the facility. Each company must establish their own risk tolerance values.



As the risk is reduced, the less it is necessary to spend to reduce it further. The concept diminishing proportional return is shown by the triangle.

Figure 4. ALARP Concept

2.2.7 Demonstration of Adequacy

The demonstration of adequacy should comprise the following:

- The project has chosen a concept in which the risks from fire and explosion hazards can be minimized and managed effectively
- The overall process to identify, understand and manage fire and explosion hazards is complete
- The project has made a comprehensive attempt to identify and actively consider all practicable means of minimizing the risks from the residual hazards at source
- The three primary decisions on each of the major accident hazards have been documented together with all potentially better options and the reason for their non selection namely:
- The selection of the strategy for the management of each major fire and explosion hazard
- The choice of the systems to implement that strategy
- The setting of realistically achievable performance standards for each system

2.2.8 Documentation

The hazard register, started during concept, should be progressively developed to document the complete residual hazard management system. It is a core document for design and future operation and must be accepted by the future operator. It should cross reference the hazards to the decisions and the systems needed to implement them. It should directly record, or provide links to the following information:

- The hazards
- The causes, severity, consequences, routes to escalation
- The overall risk picture for the facilities
- The operating limits
- The chosen strategies for each hazard
- The prevention, detection, control, mitigation and evacuation systems for each hazard strategy
- The minimum performance standards for the systems

The system should handle and record any changes so that changes in the above are assessed in the Management of Change procedures.

3.0 KEY ELEMENTS FOR SUCCESSFUL HMS IMPLEMENTATION

This section discusses the key elements for successful implementation of a company's HMS.

3.1 Leadership

This is the key element in achieving a company's defined set of goals. At all levels, it should be an absolute expectation that all seek to understand the fire and explosion hazards, to minimize them and to make sure that the hazard elimination and management systems are in place, practical and effective.

3.2 Setting Goals

The goals should be set at an early stage of the project, when the generic hazards associated with the development are known. This will allow specific focus to be placed on reducing the risks from particular hazards may specifically exclude certain types of development or activity.

Goals may be divided into categories - the first four below relate to inherent safety, and the fifth to effective residual hazard management. The expectation would be that several goals are set in each category:

- Fewer hazards
- Fewer causes
- Reduced severity
- Fewer consequences
- More effective residual hazard management

3.3 Resources

A safer design and effective hazard management cannot be achieved without sufficient time, people and capital investment. As a minimum the following resources will be required:

- Management time and commitment to leadership
- Time to develop, and resources to fund, a contractual strategy which rewards the search for a safer design
- Sufficient time for all to participate fully in the processes of risk identification and evaluation
- Time for discharge of individual responsibilities for design safety
- Appointment and time allocation of the primary operations representative
- Full time specialist safety engineering and hazard analysis support
- Time and funds for external specialist studies and support

3.4 Capital versus Operations Expense Philosophy

The safer solution may require an increase in capital expenditures to reduce operating or maintenance man-hours. It may require investment in facility, which has a longer life, is more reliable, and requires less maintenance or less hazardous operation. It should be clear that operational expenditure will almost certainly involve hazardous activities and personnel exposure, which could be minimized or avoided altogether, and Capex vs. Opex equations should be solved in the light of this knowledge and with a weighting factor for risk reduction.

3.5 Fire and Explosion Design Plan

The fire and explosion design plan should outline all the resources, activities, timings and deliverables for the project. It should cover, but not be restricted to the following, which are described in detail later and in supporting references:

- The leadership and development of the attitudes necessary to deliver a safer design
- An agreed set of criteria by which the achievement of the goals may be assessed
- The resources and organization to achieve the goals including people, knowledge and time
- A suitable set of design codes and standards
- An operation and maintenance philosophy which is based on an understanding of the hazards
- A systematic process for the identification, assessment and management of hazards
- The adoption of lessons learned from existing operations, concurrent and previous projects
- A schedule of all activities such that the necessary knowledge and deliverables are available in time to implement the hazard management process
- A documentation and communication strategy to ensure that everyone in design, construction and the future operation is aware of the hazards and their role in managing them

3.5.1 Operations Input

A safer design cannot be achieved without experienced operator input. The future operator must provide these resources via full time personnel on the project, for example experienced installations managers, and by access to discipline engineers and facility operators with facility specific experience.

3.5.2 Specialist Support

Sufficient specialist support should be provided to assist with the hazard management process. This applies particularly to the analysis of fire and explosion hazards and to any installation specific aspects, eg design of a marine structure. This support should be provided in a timely and pragmatic manner so that the hazards may be minimized through the inherent design of the process, layout, structure and facility, rather than the retrospective analysis and management of the hazards in a fixed design.

3.6 Risk Drivers

Understanding the fire and explosion hazards, and the risks that they pose to people, to the environment, and to reputation, is key to achieving the goal of "*no harm or accidents*". At the earliest stages in the project, the major risk drivers associated with each of the development options should be identified by a structured process, (preliminary HAZID), and the elimination, prevention, control and mitigation of these hazards, in that order of preference, should govern the future course of the development.

Both the likelihood and the possible effects should be examined. This information should be collated so that everyone can have a full understanding of the potential risks, which will have to be faced, whatever concept is chosen.

3.7 Selecting and Justifying the Preferred Design

The project should be prepared to justify to management, and others as appropriate, the choice of a particular design. To aid this process, the Environmental, Health and Safety (EHS) team should prepare the EHS aspect of the justification for sanction and justification for any derogation from the project Safety Goals. The project should be prepared to verify that it is practical to manage the residual hazards through the life of the facility.

3.8 Reduce Residual Risks in Design

Once the preferred concept is chosen and justified, the focus should turn to reduction of residual risks. A reasonable understanding of the residual hazards of the chosen design should now exist. The next step is to engage in deepening that understanding and laying down strategies for the progressive reduction and management of the residual risks.

The discipline should be applied to every decision from the choice of overall process to the need for, choice and location of a component during the design. The process must be applied before the decision is taken so that every opportunity to minimize risks is identified and considered while it can still be implemented.

3.9 Risk Acceptability

The final project plans should contain a demonstrable process of risk reduction that started with a goal of "*no accidents or harm to people or the environment*" for the lifecycle of the offshore facility and of the subsequent operational phase. Every project that goes to management for approval must demonstrate a process that has minimized these risks at source and has effective and practical proposals to manage the hazards that remain.

3.10 Design and Construction

This phase requires that the facility and associated systems are designed and constructed so that they will achieve their intent for the lifecycle of the development. It requires that all necessary information on the hazards, and performance of systems for their management, is provided to, and fully understood by, the contractors, constructors and the future operators to enable hazard management plans to be fully implemented and the goals to be achieved. The process must be revisited if changes impair the ability to achieve the goals or the ability to manage residual hazards effectively.

3.11 Operating to Meet the Intent of the Strategy

Operations must provide the people, practices and levels of competence needed to meet the intent of the hazard management plans so that the goals may be achieved. They should also operate within any limitations determined during development. These limitations should have been developed in agreement with the operator. Any significant changes to the facilities or their operation, which may lead to a variation in the hazards, should cause the process to be revisited.

4.0 FIRE AND EXPLOSION DESIGN STRATEGY

Key factors that should be reviewed holistically by a company in determining their fire and explosion strategy are discussed in this section. These factors will assist company management in determining their approach to fire and explosion. Determining an appropriate fire and explosion strategy involves considering and balancing a number of technical and economic factors, including:

- Protection of personnel
- Value of a business
- Nature and cost of major incidents that could potentially occur
- Potential business interruption
- Amount of loss acceptable to company

These factors can be highly interrelated and should not be considered individually.

4.1 Acceptable Loss

One approach in beginning the development of a fire and explosion strategy is to define the level of risk that the company is able or willing to accept. Acceptable loss is defined as the cost of a loss event (repair/replacement plus business interruption) that is within the capability of the company, business unit or division to absorb financially. This loss can be retained within the company or transferred to others through insurance.

4.1.1 Cost of Fires and Explosions

The costs associated with a fire can be accounted for in a number of ways. These vary depending on the corporate culture and can include the following components (F.P. Lees, 1996):

- Impact to personnel
- Damage to plant assets
- Delay in plant startup
- Plant downtime
- Business interruption
- Loss of markets
- Loss of public reputation
- Fines
- Legal actions

It is important that all companies maintain a consistent philosophy for estimating potential fire and explosion losses in their facilities to establish fire and explosion strategies. There are different approaches for estimating fire loss, but most fall into insurance or industry approaches:

These estimates are prepared for different reasons. The insurance estimates are intended to guide insurers in establishing the amount of liability they are willing to accept and the premium they will charge for that coverage. The industry estimates are intended to inform management of the potential fire and explosion loss and liability. The results of these two approaches should not necessarily be compared. However, both are useful to management in determining a fire and explosion strategy.

4.1.2 Insurance Approaches

The insurance industry looks at various levels of potential losses:

- A fire and explosion loss that occurs with all fire and explosion systems in service, often described as the Normal Loss Estimate (NLE)
- A fire and explosion loss that occurs with one active fire and explosion system out of service, often described as the Probable Maximum Loss (PML)
- A fire and explosion loss that occurs with all active fire and explosion systems out of service, often described as the Maximum Foreseeable Loss (MFL)
- A fire and explosion loss that occurs from a worst-credible incident

The steps in estimating the fire and explosion losses are:

- Determine the value of the company's process facilities that produce its major product(s). This is usually the replacement cost or, if reasonably recent, the construction costs of the offshore facility and its equipment
- Identify the fire and explosion scenario for the level of potential loss
- Estimate the cost of repair or re-building the facility after a fire and explosion and the amount of lost production downtime from the incident until it is re-started
- Estimate the lost income from the affected production due to business interruption (BI). The typical way to do this is to assume standard production rate, sales price, but not take credit for utilities, maintenance and similar costs that may not be incurred during the downtime.

4.1.2.1 Industry Approaches

Industry approaches to estimating fire and explosion loss generally fall into two key areas:

- Calculations to determine loss, such as Fire Hazard Analysis and consequence modeling, etc.
- Company design standards based upon industry and company experience

These approaches essentially identify fire scenarios for all units and the consequences of those fires. If escalation is deemed possible, then additional damage is determined. Once the total damage is determined, a cost for replacement can be calculated.

The estimated fire loss estimate establishes an upper limit of cost which can be tested against company, division or business unit management criteria to determine whether additional fire and explosion design features or insurance may be warranted.

4.1.2.2 Business Interruption (BI)

The cost to repair or rebuild after a fire or explosion is often small compared to the cost of business interruption. Generally, business interruption can range from 3 to 10 times the cost of repairs. There are a number of ways to calculate business interruption. Some factors to consider when determining the cost of business interruption include:

- Daily interruption cost – the cost associated with lost production. This could include contract penalties and fixed costs (salary, maintenance, taxes) for the plant
- Impact on upstream or downstream facilities – a significant impact on cost is when the facility that had the fire or explosion is either a supply to a downstream unit or the receiver of a production stream. In either case, both facilities are impacted and the cost for total loss of production needs to be considered

4.1.3 Prescriptive vs. Performanced Based Design

Prescriptive fire and explosion design is standardized guidance or requirements without recognition of site-specific factors. For example, providing two 2,000 gpm fire pumps per facility is one company's approach to fire water systems. The size of the facility, hazards posed or specific water demand is not considered. Prescriptive approaches to fire and explosion design generally are a result of compliance with regulations, insurance requirements, industry practices, or company procedures. Table 2 illustrates examples of prescriptive approaches to fire and explosion. These are generalized approaches based on past incidents.

Table 2. Examples of Prescriptive Requirements

Source	Requirement
Regulation	State and local codes
	USCG, MMS
Insurance	Active fire protection
	Passive fire protection
	Safety systems
	Specific equipment requirements for compressors and heaters
Industry Practice	American Petroleum Institute (API) API 500 - Electrical Classification API 2030 - Water Spray API 2018 – Fireproofing API 2031 - Gas Detection
	National Fire Protection Association (NFPA) NFPA 10 - Fire Extinguishers NFPA 12 - Carbon Dioxide Systems NFPA 13 - Sprinkler Systems NFPA 15 - Water Spray Systems NFPA 20 - Fire Water Pumps
Company Requirements	Standards or procedures for: Equipment spacing Electrical area classification Water spray and sprinklers Fireproofing Safety shutdown systems Isolation and blow down Relief and flare design Pressurization systems Drainage

Performanced-based design adopts an objective-based approach to provide a desired level of fire and explosion performance. The performanced-based approach presents a more specific prediction of potential fire hazards for a given system or process. This approach provides solutions based on performance measured against established goals rather than on prescriptive requirements with implied goals. Solutions are supported by a Fire Hazard Analysis (FHA) or, in some cases, a fire risk assessment.

A fire risk assessment takes account of more than just the consequences, and includes the likelihood of the fire and explosion scenarios occurring. A performanced-based approach looks at determining the need for fire and explosion design on a holistic basis.

Performance objectives and metrics allow the designer of fire and explosion systems more flexibility in meeting requirements and can result in significant cost-savings as compared to the prescriptive approach. Conversely, for small projects, the cost of performance-based design may not be cost-effective.

5.0 DEVELOPING A FIRE AND EXPLOSION DESIGN STRATEGY

A fire and explosion design strategy is a systematic approach to identifying, reducing and managing hazards. The objective of a fire and explosion design strategy is to ensure that:

- Protection of personnel is considered in the design of fire and explosion systems
- Credible hazards have been identified, assessed, understood and documented
- Every opportunity to minimize the hazards has been identified, considered and, where practical, implemented
- The capital investment is optimized with a view to minimizing hazards
- Corporate goals can be met for the facility's lifetime
- Adverse effects on neighbors, community and environment are controlled

Each company should develop a fire and explosion design strategy. The fire and explosion design strategy should be given to and used by a project team. A fire and explosion design strategy should be developed for new projects, if one does not already exist.

A fire and explosion design strategy should be concise and generally ranges in length from two to five pages. A fire and explosion design strategy should document the company's approach on how to meet their overall risk management philosophy.

WORKING GROUP 2

SAFE DESIGN PRACTICE

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1st Session: Wednesday 3:30 – 5:00

Introduction / Objective / Common Theme

Introduction

Work Group 2 will consider the implementation of hazard management systems for fire and blast on a particular project on facility, including the selection / design of process layout, safety systems and operational procedures and the definition of credible release scenarios for consideration in design.

Objective

Objective of this Work Group – Safe Design Practice is to discuss the:

- *Impact of design on fire and blast likelihood and severity*
- *Design processes and techniques that could be applied*
- *Methods and strategies for managing fire and blasts*
- *Methods for developing design credible fire and blast scenarios*

During this Work Group's sessions, guidelines, recommended practices, codes and specifications will be discussed for their applicability, effectiveness, and opportunities for improvement.

This Work Group's discussion areas are:

1. *Implementing Philosophy & Management Processes (WG #2) for a Project*
2. *General Fire and Blast Design Processes*
3. *Layout Design Guidelines*
4. *Developing Design Credible Release, Fire, & Blast Scenarios*
5. *Design Prevention Features*
6. *Ignition Prevention Features*
7. *Detection of Releases and Fires*
8. *Fire Size and Duration Limiting Design Features*
9. *Consequence Limiting Design Features (WG #3 and WG #4)*
10. *Response and Recovery Features*
11. *Summary*

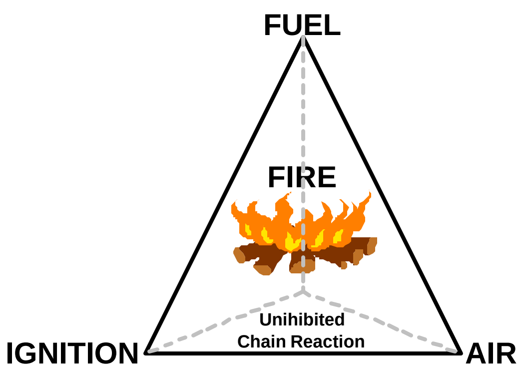
Deliverable is a "white paper" representing the consensus or options of the participants on Safe Design Practices as relating to Fire and Blast Considerations in the Future Design of Offshore Facilities.

Common Theme

Common themes throughout this session are that fire and blast safe design practices involve an understanding of the basics of Fire & Blast, application of an Inherent Safety Hierarchy, and the Belief that ALL Accidents are Preventable:

Basics of Fires & Blasts

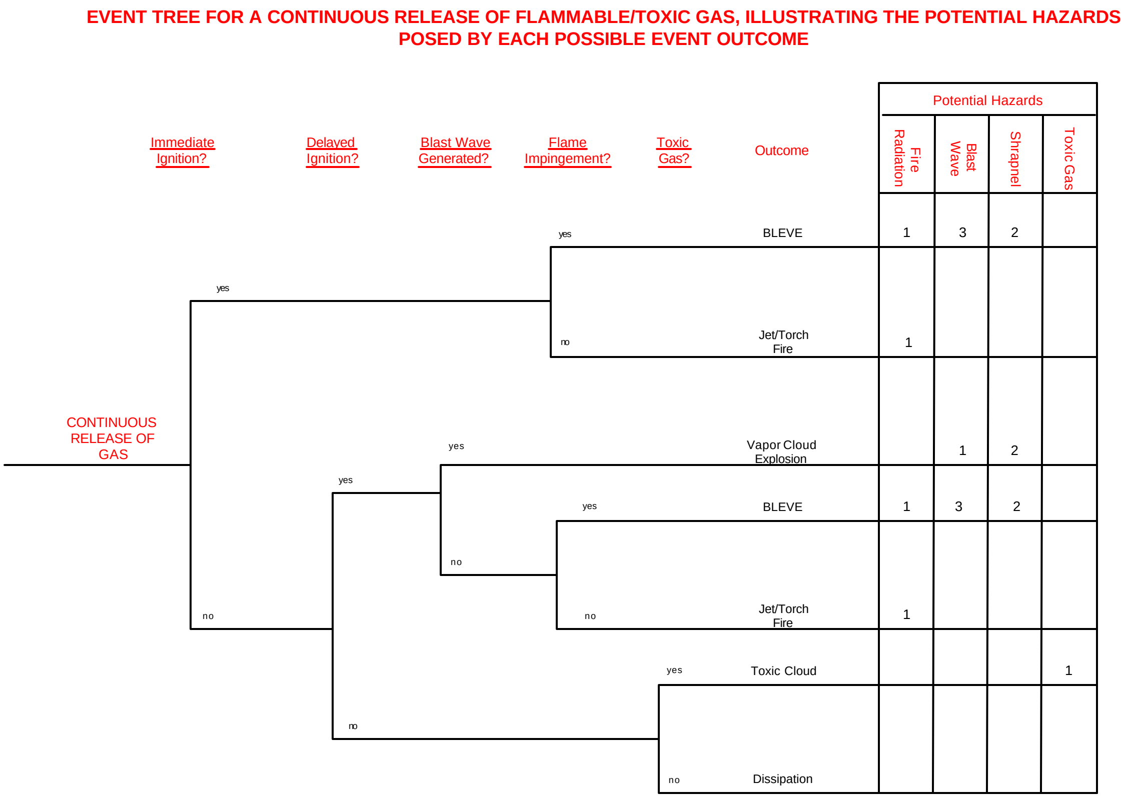
While simplistic, the fire tetrahedron (formerly a triangle) illustrates the requirements for a fire: fuel, air, an ignition source, and an uncontrolled chain reaction. The base of the tetrahedron is the chain reaction is meant to highlight that some firefighting agents (e.g., Halon & dry chemical) act by interrupting the chain reaction but do not secure the scene from possible reignition.



Gas / fuel from a possible loss of containment has the following possible outcomes. Toxic can be H_2S from a sour well.

The factors influencing whether a blast wave is generated is discussed in WG #3 but is generally summarized as a function of:

- Flame speed of the burning open-air fuel release often referred to as reactivity.
- Freedom of the flame front to expand in all dimensions without restrictions (3-D), within an open frame structure (2-D), or between decks / plates (1-D).
- Turbulence created by the flame front passing over / around obstacles such as equipment, piping, and structural members and the spacing / pattern of such obstacles (i.e., closely spaced, multiple layers).



Inherent Safety Hierarchy:

- Eliminate – that is, removing all potential of a fire or blast hazard (e.g., no release)
- Prevent – that is, disrupting a fire or blast from occurring by eliminating the possibility of ignition / air or blast factors.
- Detect / Control – that is sensing a release, fire, or blast and implementing executive actions such as facility shutdown, etc.
- Mitigate – minimizing the effects of the fire / blast such as by deluge water spray systems, fireproofing (PFP), robust structural design (WG #3 and WG #4)
- Establish Contingency Measures (emergency response, evacuation, etc.)

Belief that ALL Accidents are Preventable

All accidents, especially releases, fires, and blasts are preventable by application of:

- safe design practices and operating procedures
- use of proper equipment
- training and education

- motivation to work safely
- total reporting of all near misses and hazard concerns

1. Implementing Philosophy & Management Processes (WG #1) for a Project

The Work Group will attempt to identify and define simple guidelines for how a project will translate the philosophies and management processes (Work Group #1) with a focus on fire and blast into specific deliverables, actions, or requirements by a project – that is, an HSE (Health, Safety & Environmental) in Design Plan. Points for the Work Group to consider are:

1.A. HSE in Design Plan

The deliverables, actions, and requirements (DARs) should be defined for the proposed project consistent with the project phase. Resources, responsibility, and delivery date for each DAR needs to be budgeted and scheduled.

Deliverables, actions, and requirements include the studies, multi-discipline reviews (e.g., hazard analysis for identification, design guidance, and confirmation), action tracking systems, hazard concern tracking systems and documentation of resolution, and engineering deliverables (e.g., calculations, designs, and drawings). See also Life Cycle Management sketch on the next page.

The resources, time and material, should be budgeted as well as delivery responsibility assigned and scheduled considering the available project information and the need for timely project input. Blast inputs are especially critical and require early assumptions based on experience with confirmation studies.

Life Cycle Hazard Management

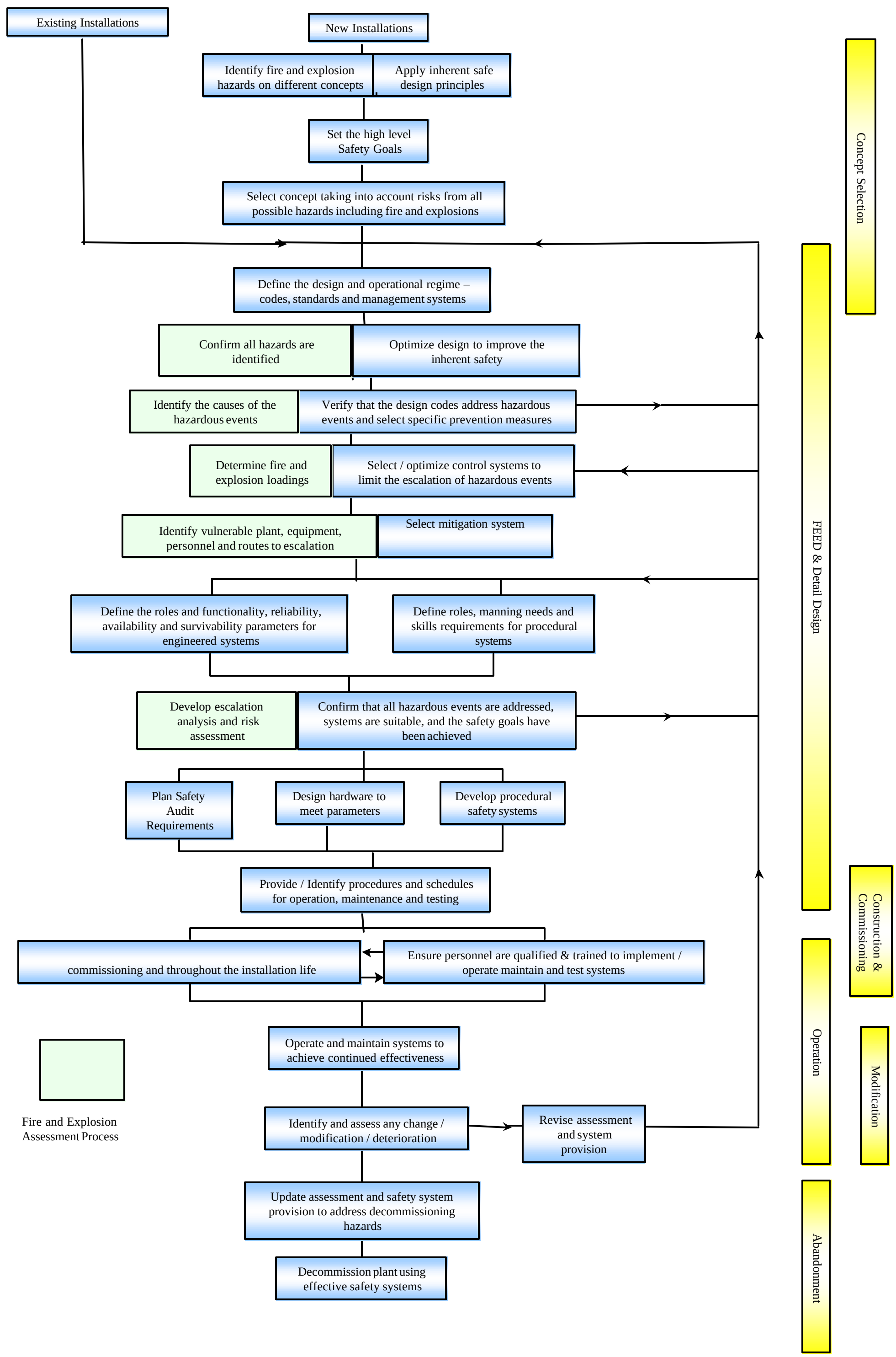
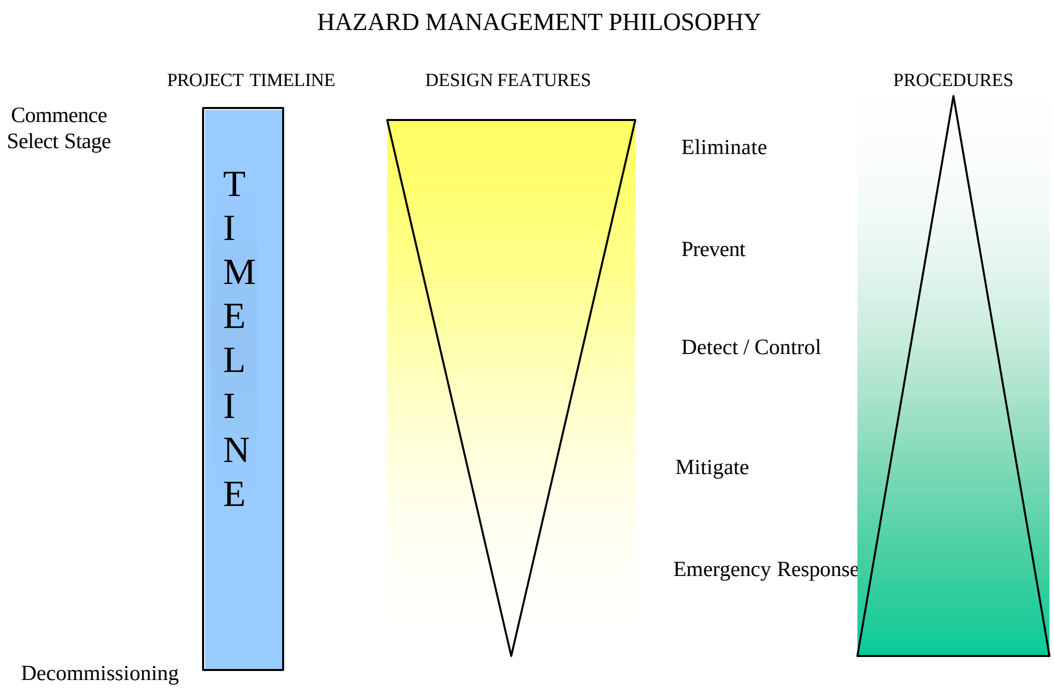


FIGURE 1.2

1.B. Typical Project Phase Goals

Following are typical project and HSE phase goals as well as possible fire and blast deliverables. Key to remember is to have the input earlier enough to influence the fire and blast features of the design.



Select Phase:

Typical high-level project goals for the Select Phase are to identify, evaluate, and rank technically feasible options selecting one development strategy for the Define/Feed Phase and their major risks, both business and HSE. Costs and schedule will be developed for the execution of the Define/Feed Phase and sometimes for the project to determine if the project is a capital budget priority.

The HSE goals during the Select Phase could be to:

- provide input at the earliest phases of the development
- ensure major risks associated with the concepts being considered for the development are evaluated, including questioning fundamental decisions
- generate a comprehensive listing of major risk issues to be addressed in the Define/Feed Phase

Typical Select Phase fire and blast deliverables are:

- Understanding of fire and blast consequences for each feasible option
- High level fire and blast strategy / philosophy for Define/Feed implementation
- Understanding of the cost to implement the fire and blast strategy

Define/Feed Phase:

Typical high-level project goals for the Define/Feed Phase are to further define the selected development strategy to provide sufficient detail for project funding/sanction. The Define/Feed Phase may include developing and sending a bid package, evaluating bids as well as award of long-lead delivery items such as turbine generators and gas compressors.

The HSE goals during the Define/Feed Phase could be to:

- define all key HSE hazards and ensure these are addressed in the design process
- ensure engineering decisions are simple and robust from a HSE viewpoint
- optimize configuration and layout of the concept from the HSE viewpoint
- ensure that the cost estimate and schedule reflect all HSE hazard concerns as well as planned HSE deliverables and activities
- ensure operations are involved in HSE related decisions
- maximize opportunities to improve inherent HSE safety

Typical Define/Feed Phase fire and blast deliverables are:

- Coarse fire and blast risk analysis for definition of design features
- Appropriate quality estimate of fire and blast design features
- Completed fire and blast strategy / philosophy
- Coarse escape, egress, and rescue plan

Execute Phase:

Typical high-level project goals for the Execute Phase are to complete all Define/Feed Phase plans in accordance with the funding/sanction approval as well as HSE obligations until operations team acceptance. Intermediate Execute activities typically include detail design, procurement, fabrication, installation, hookup and commissioning, startup and possibly performance testing.

The HSE goals during Execute Phase should be to:

- ensure all HSE hazards have been identified and addressed

- minimize impact of HSE on Project costs and schedule
- confirm the facility is ready for start-up

Typical Execute Phase fire and blast deliverables are:

- Completion of all fire and blast engineering and basis of design documentation as well as confirmation studies (e.g., final fire and blast risk assessment)
- Confirmation and / or resolution that the provided fire and blast features are consistent with the project risk / hazard management goals
- Commissioning / acceptance testing of all provided fire and blast features prior to start-up

2. General Fire & Blast Safe Design Practices

The Work Group will attempt to define simple tools or mechanisms that allow us to evaluate our designs so that we can manage fire and blast hazards effectively and ensure we have implemented all reasonably achievable measures

2.A. Sample Fire & Blast Hazard Management Process

The objective of a fire and blast hazard management process is to reduce risks associated with potential hazards to a level that is deemed tolerable. Tolerable can be defined in many ways. It can be related to specific quantitative targets as is the case in some legislative regimes, it can be related in part to cost (risks being reduced to a level that do not incur excessive costs) and an array of other criteria defined by legislation and/or corporate goals as part of internal safety management systems.

An effective and simple approach to defining risk and hence identifying whether risk is tolerable is the use of risk matrices. These come in a wide variety of forms but provide a simple and effective means for design teams to assess the likelihood (probability of and event) and the outcome (consequence). Generic definitions for likelihood and outcome can be easily established. This enables the risks to be semi-quantitatively defined (positioned) and offers a mechanism for mitigating measures to be evaluated (i.e. is likelihood or outcome reduced, by how much and what is the residual risk level).

For the purposes of stimulating discussion and incorporating generally accepted industry practices a simple risk acceptance matrix is presented here. Risk is defined in three ways by the matrix:

A - risk is not normally tolerable – additional controls/design changes required

B - risk is tolerable with controls – evaluate additional controls/design changes

C - risk is tolerable.

Risk Acceptance Matrix – Frequency vs. Severity

	Frequent	Occasional	Infrequent	Unlikely	Rare
Severe	A	A	A	B	B
Critical	A	A	B	B	C
Substantial	A	B	B	C	C
Marginal	B	B	C	C	C
Negligible	B	C	C	C	C

FREQUENCY (Likelihood) RATING (FR): Each hazard scenario, taking into account existing controls, is ranked using a coarse system based on frequency of the cause. Frequency is assessed using the following as a guide:

Frequency Rating (FR) Criteria				
Category	Annual Probability of Occurrence [/yr]		Frequency 'Score'	Frequency Rating
Frequent	$> 10^{-1}$	More than once every 10 yrs	0	5
Occasional	$10^{-1} – 10^{-2}$	Once every 10 to 100 yrs	-1	4
Infrequent	$10^{-2} – 10^{-3}$	Once every 100 to 1,000 yrs	-2	3
Unlikely	$10^{-3} – 10^{-4}$	Once every 1,000 to 10,000 yrs	-3	2
Rare	$< 10^{-4}$	Less than once every 10,000 yrs	-4	1

The frequency 'score' is effectively the logarithm of the annual probability of occurrence. The frequency rating is a normalized representation of the frequency 'score' for use in the semi-quantitative hazard assessment.

SEVERITY (Consequence) RATING (SR): Each hazard scenario, taking into account existing controls, is ranked using a coarse system based on severity of the cause. Severity is assessed using the following guide.

Severity Rating (SR) Criteria			
Category	Severity (safety, environment, asset)	Severity 'Score'	Severity Rating
Severe	Large scale loss of life Large scale environmental impact Large scale loss of asset	+2	5
Critical	Loss of life of several persons Extensive environmental impact Major loss of asset	+1	4
Substantial	Loss of single life or serious injury to several persons Significant environmental impact Significant loss of asset	0	3
Marginal	Single serious injury or minor injuries to several persons Minor environmental impact Minor loss of asset	-1	2
Negligible	Single minor injury Little environmental impact Little loss of asset	-2	1

The frequency rating is a normalized representation of the severity score for use in the semi-quantitative hazard assessment.

RISK RATING (RR = FR + SR): Frequency and severity ratings are added together to give a risk rating. These are added rather than multiplied because they are logarithmic representations of the actual frequency and severity.

2.B. Mitigating and Controlling Identified Risks

Through use of the risk matrix it is possible to identify those hazards that need additional mitigation or control. In general, design teams should adopt a hierarchical approach to managing the hazards. This is summarized as follows:

- Eliminate
- Prevent
- Detect/Control
- Mitigate
- Establish contingency measures (emergency response, etc)

The ability of the team to implement mitigating measures in accordance with the hierarchical approach is constrained by the balance between risk reductions achieved and factors such as implementation cost, impact on schedule, practicality, etc.

The top two measures (eliminate and prevent) will clearly move the identified hazard into the tolerable region of the matrix. Other proposed measures need to be evaluated. These will include additional physical or procedural protection to offer additional mitigation against identified hazard.

The frequency of accident events can in some instances be reduced by procedural controls. For effective procedures such as line breaking and lock out, the frequency rating can be reduced by about 2 units. The assessment of the reduced frequency is based on the assumption that, if the procedure is effective against the perceived hazard, the probability of a trained operator not following it is approximately 1 x 10-2. This is an industry standard accepted figure for operators failing to follow procedures under stress and represents a pessimistic approach.

The severity of accident events can be reduced by physical controls (e.g. fire protection, deluge, water spray, blast protection, increased segregation, etc.). These measures are more difficult to assess from a risk reduction perspective and further judgement will need to be made on the reduction in severity rating. However, in practice, the reduction is likely to be 1 unit.

3. Fire & Blast Layout Design Guidelines

The Work Group will attempt to identify layout design guidelines that help improve "inherent safety" and define layout configurations that may help reduce the potential for or limit the impact of fire and blast.

3.A. Guidelines

Platform layouts can have a major impact on reducing the impact of hazards associated with Fire and Blast. Guidelines/practices can be applied to layout design to enhance safety (especially with regards to fire and blast).

The Work Group should try and define and categorize layout design guidelines. Mechanisms for defining and presenting these and guidelines and assessing what material benefits they offer should be considered.

In addition, simple methods that could be used to balance the application of these guidelines with other constraints imposed by aspects such as environmental issues, project economics, technical drivers, etc. should be discussed linking back to risk matrices.

Further, the Work Group should explore the applicability and benefit of current Recommended Practices and other industry guidelines.

Examples of commonly applied guidelines are presented below for consideration and with a view to promoting further suggestions:

- Location of highest pressure hydrocarbon systems as far away from designated safe areas as possible
- Locate wellbays as far away from accommodation as possible
- Location of the muster areas remote from major hydrocarbon inventories, in particular wellheads, risers
- Segregating or protecting key protection systems from the effects of fire and blast
- Physical separation of major components containing hydrocarbons (e.g. riser, wells, separators)
- Ensuring multiple escape/egress routes exist from affected areas
- Use of fire and blast walls to protect safe areas (accommodation) from the effects of fire and blast
- Locate compressor, pumps and other potential high leak frequency sources in well ventilated areas
- Control the areas where mechanical handling (lifting) operations need to be completed (i.e. reduction of releases as a result of dropped loads onto equipment/piping)
- Location of riser to avoid supply boat impacts
- Siting of high pressure gas, natural gas liquids and liquefied petroleum gas inventories in well ventilated areas and away from large inventories
- Provide extensive natural ventilation
- Avoid areas of high congestion/containment
- Ensuring there is sufficient diversity of supply of survivability systems (e.g. firewater, ESD/F&G, etc)
- Reduce likelihood for developing liquid pools (e.g. use grating, provide adequate drainage, etc.)
- Reduce hazardous inventories – endeavor to limit vessel capacities
- Large vessels should be located so that they do not prevent explosion venting
- Locate vessel axis along the line of explosion venting path

- Try and keep pipe and cable routings away from explosion venting areas
- Reduce leaks (flanges, drains, high point vents, etc) and ignition sources
- Ensuring appropriate types of equipment are used in hazardous areas ("intrinsically safe")

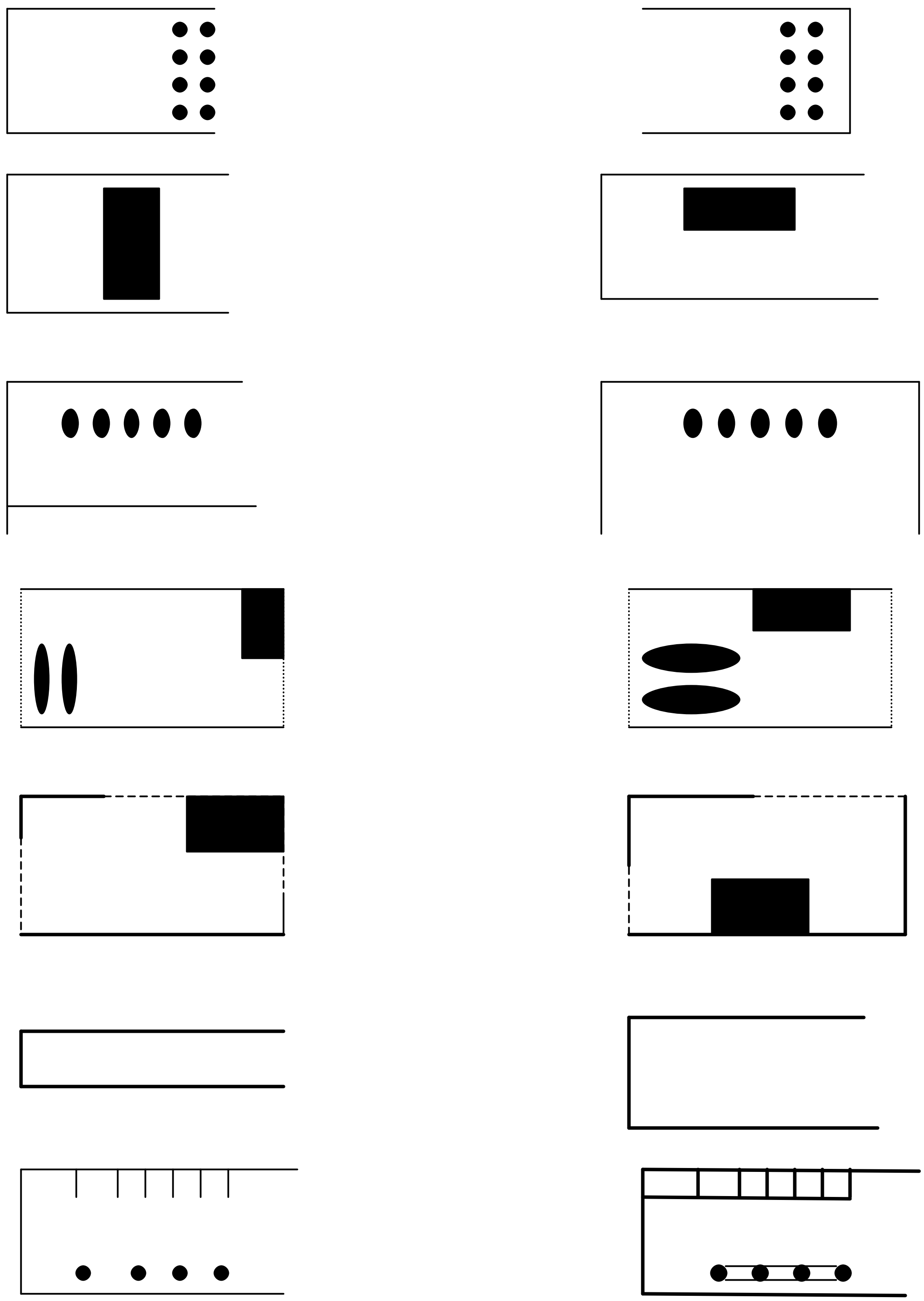
3.B. Generic layouts Linked to Fire and Blast Modeling

Much work has been done on explosion modeling and the various effects different vessel and module configurations can have on initiating blast or the effects of blast.

Can we establish generic "layouts" or 'layout configurations" that are linked to fire and explosion consequence analysis that in some way establish acceptable risk levels and prevent/limit the need for further fire and blast analysis.

Examples of generic configurations based around this type of work are presented in the following page.

Layout Considerations for Overpressure Reduction



3.C. Impact of Facility and Production Processing Types

There are a wide variety of Production Processes and Facility types. For example we have unmanned, minimum manning and manned (varying numbers small, medium, large) facilities. Clearly, the approach adopted on manning can affect the risk exposure of individuals and might adjust the view we need to take on fire and blast assessments. Accommodation can be remote from main processing (i.e. majority of platform personnel are segregated from risk). Again this may impact what we need to do from fire and blast design perspective.

Similarly we have oil developments with limited associated gas; gas developments with limited associated liquids and mixed developments. There are different types of operating pressure regimes, plant complexity, hydrocarbon inventories, etc. Again these all impact the likelihood of fire and blast or influence the consequences.

- *Can we define generic production facilities and types?*
- *Can generic "best practice" layouts be established for all or some of these? Can these be linked to levels of fire and explosion modeling that is required?*

3.D. Deep-Water vs. Shallow Water

Deep-Water developments present us with a number of challenges. Riser configurations, their motions and how we tie them back to the hull can impact the effects or likelihood of fire and blast at hull/topsides interfaces. The impact of fire on blast on Deep-Water hulls can have a more significant impact on escape, evacuation and rescue issues as the potential for "support structure" impairment could be increased.

In addition, provision of buoyancy for the support structure comes at a cost. This tends to drive design teams to optimize topsides so that the weights as light as possible. This can also lead to provision of smaller (more congested) layouts.

The Work Group should evaluate what impact deep-water developments have on established layout principles.

- *Are there generic criteria that can be established for dry tree risers, wet tree risers, export risers, etc?*
- *Can we define criteria that improve fire and blast response characteristics?*

2nd Session: Thursday 10:30 – 12:00

4. Developing Design Credible Fire & Blast Scenarios

The Work Group will attempt to identify approaches to identifying design credible release scenarios including aspects that influence release orifice sizes. Discussion / comparison of design credible versus worst case scenarios.

4.A. Design Credible Fire & Blast Scenarios

A hypothetical release scenario which, by analysis or experience, has been judged by the team to meet the project / company HSE risk criteria and is the basis of design. All factors essential to determining the success of the outcome are included.

There will probably be several design credible scenarios of differing severity to use as the basis of design for different fire and blast performance goals (e.g., asset protection, emergency egress / escape).

The minimum fire and blast performance goal of any facility should be that of survival. Survival can be defined as at least one escape route and the temporary refuge / muster area are maintained for the time required to complete a roll call and evacuate the platform. See also Section 10.

4.B. Possible Approaches to Identification

Consideration should be given to one or more of the possible approaches to identification of design credible release scenarios.

- Worst Case
- Industry, company, or similar experience.
- Release Analysis

4.B.1. Worst Case

Assume a worst case scenario such as the worst case scenario or alternately worst case outcome and then justify why that it is not a design credible. Worst case scenario could be a stoichiometric concentration of gas within the platform or area within the platform. Alternately, worst case outcome could be what would make the lifeboats inaccessible.

Methodology usually is to consider:

- What size release is necessary to fill the platform or area within the platform?
- What would need to fail and how could it fail to result in the worst case release?
- What atmospheric conditions (wind speed, solar heating, etc.) is necessary?
- What prevents the failure from occurring (regular metals thickness testing, preventative maintenance, etc.)?

Final result after several iterations is usually a design credible scenario.

4.B.2. Industry, company, or similar experience.
Evaluate experience of industry, company, and similar facilities for possible applicability to the considered facility. One source of data is the MMS:

OCS Events by Category: 1995-2002 YTD

	1995	1996	1997	1998	1999	2000	2001	2002 YTD
Loss of Well Control	**1**	**4**	**5**	**7**	**5**	**9**	**9**	**1**
Uncontrolled flows	1	4	2	5	3	9	8	0
Diverter events	0	0	3	2	2	0	1	0
Collisions	**6**	**5**	**10**	**5**	**10**	**9**	**17**	**4**
Explosions	**0**	**7**	**10**	**3**	**5**	**2**	**4**	**1**
Fires	**42**	**86**	**125**	**90**	**75**	**103**	**81**	**34**
Catastrophic	0	0	1	0	0	0	2	0
Major	0	3	1	2	3	1	2	0
Minor	3	11	11	7	4	5	0	0
Incidental	39	72	111	81	68	96	79	31
Unknown	0	0	1	0	0	1	2	3
Injuries	**31**	**62**	**83**	**66**	**47**	**64**	**60**	**11**
Fatalities	**8**	**10**	**11**	**14**	**5**	**5**	**7**	**0**

YTD = *Year to date.*

SOURCE: Tims database as of May 06, 2002.

Difficulties with non-company databases are determining the applicability to current review facility require evaluation of:

- Is the age, type of equipment, and specifications similar?
- Do they use the same or similar operating and maintenance philosophy and practices?
- Is the ambient environment similar (e.g., West Africa, North Sea, GoM)?

- Is the information provided sufficient to determine applicability?
- What biases or reporting thresholds, if any, are within the data collection?

Possible database sources include:

- MMS OCS Events by Category
- Worldwide Offshore Accident Database (WOAD) by DNV.
- HSE Offshore Technology Reports OTO 96-954 and OTO 97-950
- UKOOA Hydrocarbon Release Statistics Review by UKOOA, Jan. 1998

4.B.3. Generic Release Scenarios

Generic release scenarios are those that have historically have occurred. Following is a list from the most credible to least credible:

1. Pump Seal or Gasket Leak: Often represented as a ¼ inch orifice or the annular space between the flanges without a gasket or between the pump shaft and the caseless seal.
2. Small Fitting or Line: Often represented as a ¾ inch orifice or the typically installed diameter for an instrument connection, or sample/drain line.
3. Relief Valve or Overpressure Operation: Actual relief sizes if to atmosphere. May or may not be credible depending upon the operating pressure versus set pressure and the other levels of overpressure protection. API 521 offers some consideration on overpressure sources.
4. Medium Line or Partial Large Line: Often represented by a 2 inch orifice and evaluated as a possible credible release scenarios especially when considering dropped objects. Unlikely during the life of a process with an appropriately designed piping system and a complete preventative inspection program.
5. Large Transfer Line & Vessel Nozzle Failure: Full pipe diameter. Rarely considered as credible for design although frequently appears in loss databases. Evaluated usually for off-facility or facility separation distance determination and emergency response planning purposes.
6. Vessel Failure: Some suggestions by failure mode propagation or vessel deinventory within 10 minutes. Rarely considered as credible for design although occasionally appears in loss databases usually as a result of inappropriate vessel materials selection (e.g., hydrogen embrittlement, chloride/caustic stress corrosion cracking), improper relief sizing or relief plugging, mechanical impact as well as incomplete inspection.

4.B.4. Release Analysis / Studies

Evaluate possible release based upon analysis such as project Hazard Identification studies, hazard and operability studies, or hazard analysis. See also API RP 14J.

Possible Generic Event Initiating Causes to consider are:

1. Loss of Containment -- Open ended route (design relief, drain or vent, spurious relief)
2. Loss of Containment -- Under Design Operating Conditions due to Imperfections (Pre-Inspection & Test, Monitoring, Repair & Maintenance, coating)
3. Loss of Containment -- Due to Exceedance in Design Conditions (high Temp, low Temperature, Pressure, Vacuum, Forces, Stresses, Contamination., decompression)
4. External Forces (e.g., collision / impact, dropped objects, future installations, other installations)
5. Extreme Environmental Conditions -- Atmospheric (e.g., wind, wave, swell, storms, hurricanes, rain, ice)
6. Flow Assurance (e.g., hydrates, wax, asphaltenes, hydrocarbon liquid settleout, loss of insulation, slugging, plugging, fouling)
7. Service/Utility Failures (e.g., stuck pigs, closed valves, hydraulics, electric, communication, control leaking valves, SIS, DCS, local control systems, nitrogen)
8. Human Error (e.g., Inadequate design (overlooked, wrong method, missed interface) hot tapping, slugging, repair/replacement, startup, changing operating condition, shutdown, preparation for maintenance, valve operation) dropped or swinging loads (hoist failures, mechanical handling (size, weight, or frequency of lifts, drums, field transfers)), mis-/mal-operation (pressure, thermal, pH).

Alternate/Additional Loss of Containment Thoughts:

- Equipment Failures (e.g., thermal expansion, internal/external/galvanic. & splash zone corrosion, erosion, coating failure, bad welds, fatigue, cathodic protection, cyclic stress, brittle fracture, manufacture/construction. defects, overpressure, plugging or fouling, contaminates -- CO_2, H_2S, H_2, H_2O SALTS, SOLIDS, contaminate stress cracking, low temp embrittlement, shock/hammer)
- System Failures (e.g., inspection, operation, startup/shutdown, communication, maintenance, leak detection, emergency. temp repair, material specification spec & test, changes)

4.B.5. Mitigation Reduction Considerations

One method to evaluate initiating event frequency and the effects of independent layers of protection / mitigation is a layer of protection analysis (LOPA). LOPA is a simplified method of risk assessment between a qualitative process hazard analysis and a quantitative risk analysis. Beginning with an identified accident scenario, LOPA uses simplifying rules to evaluate initiating event frequency, independent layers of protection, and consequences to provide an order-of-magnitude estimate of risk.

5. Design Prevention Features

The Work Group will attempt to identify design prevention features to reduce or eliminate design credible release scenarios. Areas of discussion include application of SEMP, increased predictive maintenance and inspection including leak detection, dropped object, work permit / administrative controls, operating integrity.

API's SEMP is an MMS voluntary program for the GoM. It is similar in scope to other US performance regulations such as OSHAs Process Safety Management (PSM) and EPAs Risk Management Plan (RMP) as well as some operating companies Safety Management System.

MMS is currently proposing to adopt nine (9) industry standards for OCS fixed and floating platforms. These are:

1. API RP 2A – WSD, Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, 21st Edition, December 2000
2. API RP – RD, Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs), 1st Edition, June 1998
3. API RP 2SK, Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures, 2nd Edition, December 1996
4. API RP 2T, Recommended Practice for Planning, Designing, and Constructing Tension-Leg Platforms, 2nd Edition, August 1997
5. API RP 14J, Recommended Practice for Design and Hazard Analysis for Offshore Production Facilities, 1st Edition, September 1993
6. API Specification 17J, Specification for Unbonded Flexible Pipe, 2nd Edition, November 1999.
7. AWS D3.6M:1999, Specification for Underwater Welding
8. API RP 2FPS, Recommended Practice for Planning, Designing and Construction Floating Production Systems, 1st Edition, March 2001

9. API RP 2SM, Recommended Practice for Design Manufacture, Installation, and Maintenance of Synthetic Fiber Ropes for Offshore Mooring, 1st Edition, March 2001

WG2 can discuss impact of adoption of these industry standards on their current fire and blast design practices.

5.A. Safety and Environmental Management Plan (SEMP) (API 75)

Robust application of SEMPs eleven (11) management elements or other Safety Management System is one of the most cost effective and risk reducing fire and blast measures. One of the key aspects of a good design is that it is reflective of how the plant will be operated and maintained as well as designed to minimize human error.

Often quoted has been that causes of large losses are:

- 50% of ignition sources are unknown
- 40% due to mechanical failure usually failure to inspect of these:
  - 31% are piping systems
  - 17% tankage
  - 10% vessels
  - 1% heaters / boilers
- 20 to 30% due to operational error including failure to follow procedures
- 4 to 14% due to design error

The eleven (11) SEMP elements are:

Discussion can be on the prevention benefits / credits that can be taken for full implementation of SEMP on credible fire and blast scenario selection.

5.A.1. Safety and Environmental Information

Principally, this is the process design information and mechanical / facilities design information. Information should be complete but concise. Basis of design, that is, codes applied as well as design, operating, and maintenance assumptions should be apparent. Maintenance of this information is element 3 – management of change.

5.A.2. Hazards Analysis

API RP 14J and API 14C are the guiding documents. Principle is that:

- Identify and Evaluate Hazards for risk (frequency / likelihood and consequences) using a multi-discipline team. Includes application of human factors to minimize error.

- Implement Controls to acceptable risk (e.g., Apply Inherent Safety Hierarchy - eliminate, prevent, detect, control, mitigate, establish contingency measures)
- Document basis of design so that facility can be operated within controls
- Periodically reassess facility to maintain currency of hazard analysis and globally review changes since last hazard analysis

5.A.3. Management of Change

Applies to both permanent and temporary changes or deviations from the safety and environmental information as well as changes to personnel.

5.A.4. Operating Procedures

Should cover all that is necessary for the efficient, safe, and environmentally sound operation of the facility. Needs to include safe operating limits and consequences of deviation from those limits as well special precautions. Essential safety and environmental information assumptions and basis of design should be included.

5.A.5. Safe Work Practices

Key safety procedures of linebreaking, lockout/tagout, hot work, confined space, crane operations, and controls for contractors are all essential for preventing fire and blasts.

5.A.6. Training

New MMS training regulations (30 CFR Part 250 SubPart O) fully in force this October 2002 greatly expands previous prescriptive training requirements. All employees must be trained to competently perform their assigned well control and production safety duties. Procedures must be in place to assure competency.

5.A.7. Assurance of Quality and Mechanical Integrity

Assurance systems must be in place for maintaining equipment consistent with operating / service requirements, manufacturer recommendations, and industry standards. Should include design, procurement, fabrication, installation, and IRM (inspection, testing, repair, and maintenance).

5.A.8. Pre-Startup Review

Final check that all systems are installed according to design and that all SEMP elements are in place prior to the introduction of hydrocarbons.

5.A.9. Emergency Response and Control

Written plans should be developed for the last line of defense for protection of safety and the environment. Drills should be conducted to assure operational readiness.

5.A.10. Investigation of Incidents

Implementing lessons learned from investigation is key to preventing future accidents including those from similar facilities. Minimum expectation is to investigate all incidents with serious safety or environmental findings. However, total reporting of all near misses and hazard concerns is key to achieving no accidents.

Typical loss investigation root causes can be categorized as due to:

- safe design practices and operating procedures
- use of proper equipment
- training and education
- motivation to work safely

5.A.11. Audit of Safety and Environmental Management Program Elements

Auditing should determine if all SEMP systems are inplace and operational. Successful auditing answers the questions of:

- Has the facility identified and characterized their risks?
- If they do what they say they do, are the risks sufficiently managed?
- Are they doing what they say they are doing?
- Can they continually improve on what they are doing?

5.B. Other Design Prevention Features

Possible other design prevention features to minimize the likelihood of a possible release, fire, or blast are:

- Reducing the number of flanges, drains, and other connections
- Open ventilation reviews
- Increased wall thickness / schedule for piping, especially small diameter
- Minimize the number of high pressure / low pressure interfaces
- Design Safety Factor reviews to determine acceptability of inherent risk assumptions for this installation
- Material handling reviews to eliminate dropped object potential
- *Others?*

3rd Session: Thursday 1:00 -- 3:00

6. Ignition Prevention Features

The Work Group will attempt to address the ignition and fuel sources and their elimination, control, location, and/or confinement.

6.A. General

The prevention of ignition involves the control of the flammable and combustible materials as well as the control of the ignition sources, and the oxygen available to sustain combustion.

The goal of this activity is to provide information to prevent the ignition of flammable and combustible materials by separating the ignition sources from the fuels or by eliminating the oxygen required for ignition and fires.

The intent of this activity is to address the ignition and fuel sources and their elimination, control, location, and/or confinement. In areas where ignition or fuel sources can not be controlled, relocated or eliminated, the concentration of oxygen should be controlled to produce an atmosphere that is above the UFL or below the LFL. Where the oxygen also cannot be controlled, other means of mitigation must be applied.

These activities are generally based on industry standards and best practices, and sets goals for the design of safety and environmental measures.

6.B. Approach

Hierarchical approach to managing the hazard of ignition prevention is to:

- Eliminate
- Prevent
- Detect/Control
- Mitigate
- Establish contingency measures (emergency response, etc)

6.C. Eliminate or Prevent

The primary method of ignition prevention is:

- maintaining the hydrocarbons in the process systems
- keeping air out of the process systems

- controlling the pressures, flows and temperatures within the equipment operating envelope via the process design, instrumentation, and controls.

For those materials outside the process systems, such as in accommodations buildings, stores and workshops, ignition prevention is based on selecting materials with no or limited combustibility and restricting identified ignition sources to specifically controlled areas.

API 14C section 4.2.4 "Ignition Preventing Measures" includes the following Ignition Prevention Measures:

1. Ventilation
2. Application of electrical codes and recommended practice
3. Location of potential ignition sources
4. Protection of hot surfaces.

Full compliance with Ignition Preventing Measures of API 14C as well as other references, codes, standards, and specifications should be required. The Ignition Prevention Philosophy must have enhancements and additions to the requirements of API 14C to be commensurate with the specific needs of the project.

6.C.1. Layout

Certain processes on the facility inherently contain ignition sources, such as the direct fired heaters, turbine driven compressors and generators, and the flare. Those pieces of equipment that contain ignition sources, that cannot be removed, are identified and are located remotely from anticipated potential hydrocarbon release points.

The ignition potential from ignition sources that cannot be relocated remote from the potential fuel releases is reduced by other means such as with the turbine driven compressors. The high temperature of the exhaust cannot be located significantly remote from the compressor. Specially designed high velocity water spray systems are provided to dissipate releases in the case of turbine drive compressors.

Assurance review systems should address issues such as dropped objects such as control of the location of hydrocarbon piping and equipment, impact protection for those items that can not be relocated, and control of the movement of heavy materials in those areas.

API 14-C Recommended Practice for Analysis, Design, Installation, and Testing of Basic Safety Systems for Offshore Production Platforms should be adhered to for the identification of equipment and systems.

Complying with API 14J requires fired heaters, reciprocating engines, gas turbines and other ignition sources to be located as far a practicable form potential sources of flammable materials.

6.C.2. Materials

Materials utilized for the construction of the facilities should be selected to reduce combustibility. Interior finishes, furnishings, and furniture in an accommodations building should be non-combustible with the exception of the bedding and furniture pads. Ignition sources, such as smoking, must be restricted to areas of the facility where combustible materials are severely restricted. Fire protection systems are also generally provided in these areas such that small fires would be detected and extinguished before they could expose areas outside the accommodations.

6.D. Detect

6.D.1. Gas Detection

Point type combustible gas detection should be provided in areas where history has shown that releases occur such as around manifolds, pump seals and certain valves. Area (open path) type combustible gas detection should be provided to afford early warning of releases in areas where gas or vapor is normally contained in the process and releases are not generally anticipated. Additionally, detection can be applied to areas of concern such as air intakes, doorways, and possible accumulation due to minimum ventilation. Lastly, the previously located detectors should be reviewed for possible missing areas of coverage.

Two levels of detection should be provided. The lower alarm point is provided to allow personnel to intervene with and mitigate the release. The higher alarm point is provided to allow process controls to automatically intervene and mitigate the release. Voting of detectors is also provided to allow automatic control when multiple detectors sense hazardous concentrations.
Prompt detection of a release by the gas detection system and prompt mitigation by personnel, the fire protection systems, and the process control system reduces the probability of ignition.

API RP2G - Recommended Practice for Production Facilities on Offshore Structures, API RPI4G - Recommended Practice for Fire Prevention and Control on Open Type Offshore Production Platforms, and API RP14J - Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities as well as gas dispersion studies and explosion models required by the Safety Critical Elements should be used for the selection and placement as well as the function of the gas detection equipment.

6.D.2. Instrumentation

The process in a modern facility is fully instrumented. All critical actions are controlled from the control room or locally within the process. HAZOPs are performed on each system to verify that all critical processes are supervised and provided with secondary means of controlling the process.

6.D.3. People

Personnel will be monitoring the operations at all times. Personal rounds are generally conducted on a periodic basis. Radios, alarm call points and intercom communications are generally provided throughout the area for reporting anomalies. Personal rounds are critical to the detection concept as personnel are capable of detecting situations that fixed detection may not.

6.E. Control and Mitigate

6.E.1. Ventilation, Containment, and Drains

Ventilation is considered in two different areas, in the open and in enclosed spaces such as buildings and equipment,

The overriding design consideration for the topsides is to eliminate areas where gasses and vapors can collect. Walls, buildings and congestion should be held to a minimum to allow for free, natural ventilation. Decks should be constructed of grating where possible. Gas detection should be provided to monitor these areas for releases and for the provision of early warning for prompt shut in and blowdown.

Equipment and buildings that may normally contain various ignition sources such as control buildings and MCC buildings, are generally maintained under pressure and are ventilated at a rate designed to prevent an accumulation of hydrocarbon vapor or gases above the Lower Flammable Limit (LFL).

Ventilation intakes and entrances into spaces in all electrically unclassified areas, should be located as far as practical from classified areas, should have combustible gas detection, and should automatically shut off the flammable material source(s) and/or remove potential ignition source(s) before gas and vapors reach the LFL. Upon detection of gas at Electrical building fresh air intakes or doorways, all electrical power should be removed from the electrical building, except for emergency services and process control equipment rated for Zone 2 (Div. 2) Restoration of electrical power to electrical buildings must require reset of the gas detectors and a purge cycle of at least four complete air changes. NFPA Standard 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment, should be followed to assure the systems are designed and installed properly.

The process equipment and systems are designed to contain flammable materials (vessels, tanks, piping, pumps, compressors, etc.) and to maintain gas and vapor mixtures above the Upper Flammable Limit (UFL) at all times. Open and closed drains are normally provided to control releases and contain them in safe locations. Assurance systems should be provided to assure that the correct drains and containment are utilized for the particular area.

6.E.2. Lightning/Static Electricity

To prevent static accumulation and inadvertent discharge or ignition form lightning, all parts of the process must be electrically bonded to the structure. API 2003 – Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents should be rigidly followed to reduce the potential for ignition from lightning, static and stray currents. Operating procedures must require all tank and vessel openings, hatches, and man-ways be closed during lightning storms.

6.E.3. Electrical Isolation

Electrical isolation considers equipment used in hazardous areas as well as non-hazardous areas. In addition to complying with API 14F and API 505 (or 500) all electrical equipment should be at a minimum suitable for Zone 2 (Div 2) areas unless located indoors in a climate controlled (HVAC) area. In order to allow emergency systems to function in hazardous atmospheres all electrical equipment associated with Emergency Systems regardless of location must be designed as a minimum to be suitable for Zone 2 (Div.2) This includes equipment like (PLCs [PCS, ESS and general purpose], Public Address and Alarm Systems, emergency designated lighting, navigational signals, portable radios, etc.) a specific exception is the emergency switchgear. Detection of gas at the low point alarm should electrically isolate high risk ignition sources such as convenience and welding receptacles in hazardous areas. Operating procedures must include halting all hot work when gas is detected at the low alarm point.

6.E.4. Isolation

Process fluids can be isolated in a variety of ways. Fluids can be confined to operating units, modules, and systems. or individual pieces of equipment. This isolation can be performed locally at the equipment or from the control room. Isolation is critical to reducing the potential volume available to release. The Safety Critical Elements and Relief, Vent, Emergency Depressuring, and Flare Design address the volumes available, their control and the safe venting during upsets or emergencies. The reduction of the inventory released and the control of those releases reduces the likelihood for ignition of that inventory.

6.E.5. Loss of Containment

- Due to process upset or spurious relief is controlled by the relief, drain and vent systems.
- Under Design Operating Conditions due to Imperfections is controlled through Pre-Inspection & Test, Monitoring, Repair & Maintenance, and protective coatings.

- Due to exceeding the design conditions of high temperature, low temperature, high pressure, vacuum, contamination, and the like are controlled by process isolation and blowdown to a safe pressure.
- Due to human error such as inadequate design (overlooked, wrong method, missed interface) hot tapping, slugging, repair/replacement, startup, changing op conditions, shutdown, prep for maintenance, valve operation, and the like, are controlled by the process safety systems and safe work practices including hot work permits.
- Unanticipated equipment failures with resulting releases are controlled by the location of hydrocarbon containing equipment, the location of ignition sources, prompt detection with containment, isolation of the process and electrical systems and actuation of the appropriate fire protection systems.

6.F. Establish Contingency Methods

6.F.1. Fire Protection

Fire protection systems are generally provided to mitigate fires and releases. Hydrocarbon spills are often covered with foam reducing vaporization and reducing the potential for ignition. Fire protection systems on modern facilities can be provided to disperse vapors from hydrocarbon vapor or gas releases. These systems can be actuated manually from the control room as well as in the area protected by the system. Should ignition occur, these systems should function automatically. The referenced NFPA standards, the API standards, as well as the projects Fire Protection Philosophy are utilized in the selection, placement, and function of these systems.

6.F.2. Protection in Depth

Many levels of protection are provided to prevent the ignition of materials. They include

- Process design
- Basic controls of process alarms and operator supervision
- Operator training
- Critical alarms, operator supervision, and manual intervention
- Automatic ESD
- Physical protection such as relief valves
- Physical protection such as open construction to prevent vapor or gas containment
- Physical protection such as curbs and diking to control spills on the deck
- Automatic gas detection
- Fixed fire protection systems and equipment

- Emergency Response Team (ERT) response
- Trained ERT members

7. Detection of Fire and Blast

The Work Group will attempt to review the types of fire & gas detection (advantages and disadvantages), emergency response to fire / gas detection and confidence level and reliability factors.

7.A. Types of Fire Detection

The purpose of this discussion is to evaluate the different types of fire detectors that are available and to examine the advantages and disadvantages of each type in its application. Following are the types of fire detectors that are normally used offshore.

- Ionization Smoke Detectors
- Photo Electric Smoke Detectors
- Air Sampling Type Smoke Detectors
- Fixed Temperature Thermal Detectors
- Rate-of-Rise Thermal Detectors
- Rate Compensated Thermal Detectors
- Fusible Plug Thermal Detectors
- UV Flame Detectors
- IR Flame Detectors
- UV/IR Flame Detectors

7.B. Types of Gas Detection

The majority of gas detectors that are used offshore are of the following types.

The purpose of this discussion is to evaluate which type should be used in a particular application and to evaluate the advantages and disadvantages of each type.

- Toxic Gas Detectors
- Catalytic Bead Combustible Gas Detectors
- IR Diffusion Point Combustible Gas Detectors
- IR Line of Sight Combustible Gas Detectors

7.C. Emergency Response Associated with Fire and Gas Detection

The purpose of this discussion is to evaluate the purpose of the fire and gas detection system as it relates to the emergency response associated with the detection of an incident.

- Fire Alarm
- Establishing Fire Zones
- Cross Zones
- Asset Protection and Protection of Personnel
- Actuation of Fire Suppression Systems
- Starting Fire Water Pumps
- Coordination with Process and Facility Shutdown Logic
- Low Level Gas Detection
- High Level Gas Detection
- Combustible Gas Detection for Explosion Mitigation
  A) Concealed Spaces
  B) Vapor Clouds

7.D. Confidence Level and Reliability Factors

An important consideration in establishing a fire and gas detection system is the confidence level of the operators that the system will perform properly in case of an incident, and that the system is designed such that the incident will be adequately detected.

Point type combustible gas detection is typically provided where history has shown that releases occur such as around manifolds, pump seals and certain valves. Area (open path) type combustible gas detection can be provided to afford early warning of releases in areas where gas or vapor is normally contained in the process and releases are not generally anticipated. Additionally, detection can be applied to areas of concern such as air intakes, doorways, and possible accumulation due to minimum ventilation. Lastly, the previously located detectors should be reviewed for possible missing areas of coverage. The following discussion pertains to the accepted reliability of the system.

- Location of Detectors
  A) Buildings
  B) Air Intakes
  C) Deck Areas
  D) Process Areas
  E) Equipment

F) Enclosures
G) Arrangement of Detectors

- Fire Alarm Control Panel

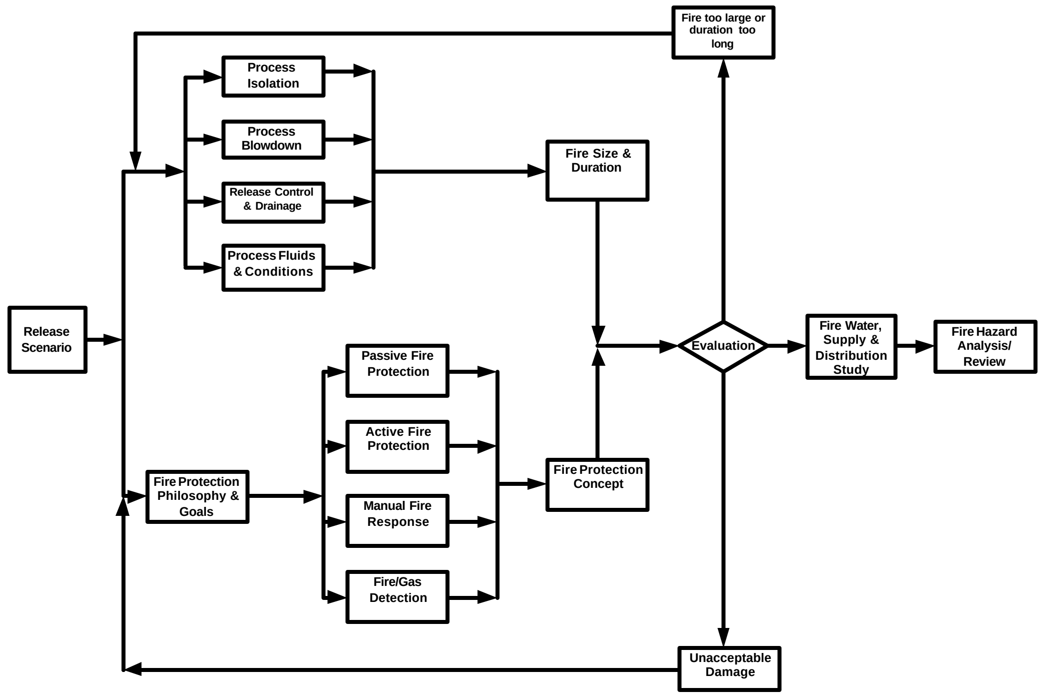
A) Hard Wired Modular Panels
B) PLC Based Control Panels
C) Master Fire Alarm Panel (MFAP)/ Local Fire Alarm Panel (LFAP)
D) Gas Alarm Panels
E) Smart Gas Detectors
F) NFPA 72 Considerations
G) Fire/Gas Alarm Response Logic
H) Redundancy
I) Back-up Power Supply
J) SIL

8. Fire & Blast Size and Duration Limiting Design Features

The Work Group will attempt to define the fire & Blast size and duration limiting design features such as process isolation, process emergency depressurizing, release control and drainage and reduction in process conditions.

8.A. Relationship Between Design Limiting Features

The following flowchart shows the relationship between systems that limit the fire size and duration and those that limit the consequences. A balance is needed between the two for an acceptable design consistent with the risk acceptance procedure.



8.B. Process Isolation

Typical GoM practice is to have boarding and off-boarding isolation valves (API 14C) as well as compressor isolation valves as part of the seal protection.

Larger process systems can accumulate substantial volumes of hydrocarbons and intermediate process isolations (emergency isolation valves) can greatly reduce the fire intensity and duration.

One possible approach is to evaluate by inventories (e.g., 5000 pounds gas or 15,000 pounds liquid) or by conditions (e.g., 500 psig or release rate of greater than 1000 pounds per minute is possible). Consideration should be given to the time to detect and actuate the process isolation system as well as the impact on fire size and duration given the design credible release scenario release rate.

Other considerations are:

- Automation or Operator Initiation. Automation can be with a time delay to allow the operator time to determine if it is a spurious trip. See also Section 10 – Operator Response.
- Protection of Valve and Actuator. See Section 9 – Passive Fire Protection.
- Fail position and spurious trip consequences

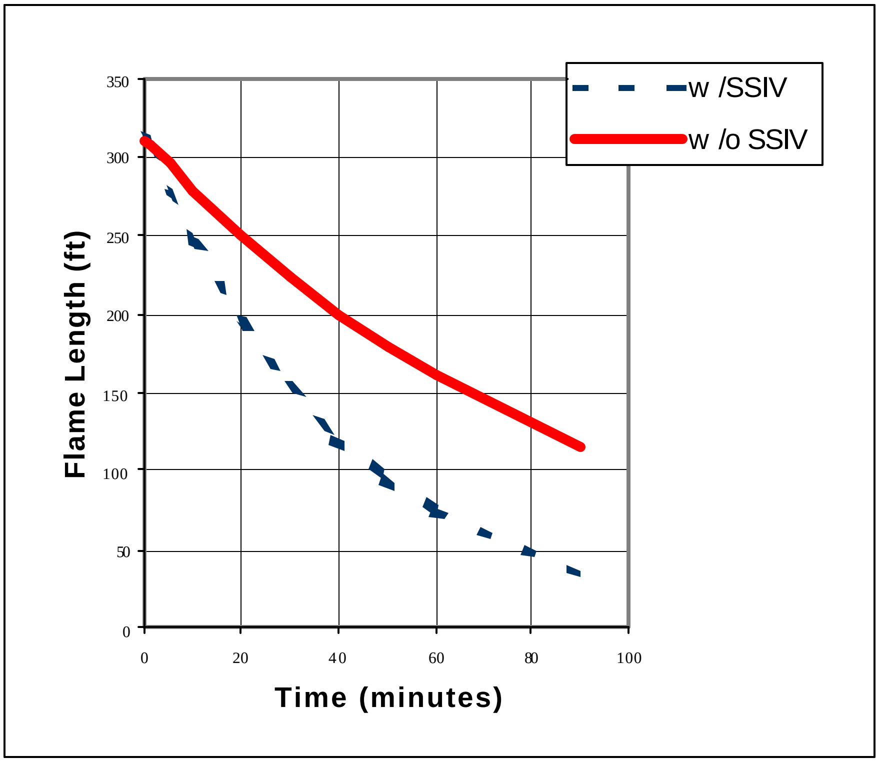
8.C. Process Blowdown

The process blowdown or emergency depressurization is to safely dispose of hydrocarbons, usually through a vent or flare, from the process during a possible loss of containment scenario. The purpose of this blowdown is to:

- Deinventory pressurized hydrocarbons to minimize the possibility of a stress rupture or BLEVE.
- Reduce the fire size and duration of a possible fire or release from loss of containment.
- Protect equipment such as compressor seals usually at a rate agreed to by the seal and compressor manufacturers.

API 521 is the principal consensus recommended good practice design document. However, API 521 offers options for process blowdown:

- None
- Depressurization to 50% of the vessel design pressure or other level where stress rupture is not an immediate concern within 15 minutes.
- Depressurization of vessels over 250 psig to 100 psig within 15 minutes



Other considerations are:

- Automation or Operator Initiation. Automation can be with a time delay to allow the operator time to determine if it is a spurious trip. See also Section 10 – Operator Response.
- Depressurization Regimes and extents. For example; vessels over ANSI 150 and interconnecting piping over ANSI 1500.
- Protection of Valve and Actuator. See Section 9 – Passive Fire Protection.
- Low temperature induced brittle failure from flashing fluids. Evaluation often begins at 32 deg. F.

8.D. Release Control & Drainage

Generally addressed by limiting the areas that could pool liquid hydrocarbons.

8.E. Process Fluids & Conditions

A difficult fire protection option is to reduce the operating pressures and the piping / vessel sizes. Lower pressures and lower volumes can reduce fire size and duration but are often at odds with the necessary production rate to be profitable.

4th Session: Thursday 3:30 – 5:00

9. Consequence Limiting Design Features (WG #3 and WG #4)

The Work Group will attempt to highlight some of the fire and blast consequence limiting design features that will be discussed in more detail in Work Groups #3 - Blast Load and Response and #4 – Fire Load and Response. Consequence limiting features include passive fire protection and active fire protection.

9.A. Passive Fire Protection (PFP)

PFP, also known as fireproofing. Generally considered for structures but can also be achieved by using structural mass or special high temperature steel.

Generally rated for type of fire such as ordinary wood, paper, etc. or hydrocarbon. Ordinary ratings are IMO A-, ASTM E-119. Hydrocarbon ratings are IMO H- and J- as well as UL 1709.

Areas other than structural steel and barrier walls to consider using PFP are:

- Individual Critical Electrical Power and Instrument Lines can be accomplished using mineral insulated (MI), silicon insulated (SI), or mica insulated (IEC 331). Typical application would be for navigational aides, alarm notification systems, power to large turbine / generators auxiliary lube oil pumps, select emergency power users and select instrumentation (e.g., valve position indicator for boarding / offloading valves).

- Grouping of Critical Electrical Power and Instrument Lines can be accomplished either as a passive only system of fireproofing boxes / wraps (requiring power de-rating) or flame exposure barrier and active water spray.
- Critical Pneumatic and Hydraulic Lines using seamless stainless steel (Type 304, 316, or 321) in accordance with API 2218.
- Emergency Isolation Valves & Actuators are generally API fire safe but the design credible fire scenario may exceed the API standard test and need supplemental protection. Use of delays or other than fail-safe position may require that actuators be fireproofed. See also critical instrument lines. Valve and actuator fireproofing can be wrapped, boxed, or directly applied.
- Vessels can be fireproofed or insulation such as foam glass with stainless steel cladding and banding can be qualified as fireproofing.

9.B. Active Fire Protection

Typically water based systems such as automatic sprinklers for shops and quarters, deluge sprinkler systems for areas, water spray systems for equipment, and foam-water systems for pool fire areas. Occasionally there may be dry chemical or dual-agent (dry chemical and foam) systems.

9.B.1. Active Fire Protection Goal Selection

First consideration is what is the goal of the active fire protection system.

- <u>Fire Extinguishment</u> – The goal of firefighting is to extinguish all fires. However, it is isolation of the fuel is the method of extinguish for appropriate to process gas fires or pressurized liquid fires. Extinguishment is appropriate for ordinary combustible materials such as found in shops and quarters. Foam-water systems (NFPA 11 and NFPA 16).
- <u>Fire Control</u> – Application of water to the fire and its immediate surrounding area to absorb the heat produced. Typically used when the fuel release cannot be stopped and there are no important equipment or other exposures requiring protection. Automatic sprinklers (NFPA 13) and deluge sprinkler systems (NFPA 13, NFPA 15, and API 2030) generally assume fire control.
- <u>Fire Exposure Protection</u> – Application of water to equipment and other surfaces to minimize the damaging effects of heat. Typically used when the fuel release cannot be stopped and there are important equipment or

other exposures requiring protection. Water spray systems (NFPA 15 & API 2030) generally assume radiant heat fire exposure protection.

- Release Control – Application of water spray for the dissipation or as a barrier between a release source and an ignition source. Typically used when a gaseous fuel release cannot be stopped and ignition prevention is desired.

9.B.2. Application Rate Selection

Application rates vary depending on the type of fuel, the type of incident anticipated and the intended use of the water spray system.

Water Spray

API 2030 suggests application rates that range from 0.1 gpm/sq.ft. to 0.25 gpm/sq. ft. and above.

NFPA 15 (Water Spray) also recommends various application rates. The protection of:

- cables utilizes the minimum application rate of 0.15 gpm/sq.ft.
- fire source protection the minimum application rate is 0.5 gpm/sq.ft.
- Area coverage utilizes a minimum application rate of 0.25 gpm/sq.ft.

These are minimum application rates based upon radiant heat exposure from pool fires – not flame impingement. Hundreds of gallons per minute are necessary for cooling of flame impingement. The size of the fire and the quantity of protection needed for the particular protected area should be assessed to determine if these minimums are appropriate for the fire exposure.

In some cases significantly higher flows are required to provide the protection desired. Single large high pressure equipment such as valves may demand flows of 1,000 to 4,000 gpm and more to provide the desired results. The purpose of these special water spray systems is to control the rate of burning and provide for exposure protection to the equipment, piping and the exposed structure. The nozzles are designed to push a release and fire from the area of the equipment off to the side. If there is no ignition, the action of these water spray systems is to push the vapors and liquids away from the equipment and disperse the vapors by ingesting air into the release. The nozzles are selected, aimed, and located to provide strong ventilation to the area, fire control, and exposure protection.

Foam

Foam can be provided topside or through sub surface injection as well as through spray nozzles and monitors and hose. The application rates vary considerably depending on the fuel, fuel depth, fuel array, foam concentrate and means of application. Application rates vary from 0.1gpm/sq.ft to over 0.5 gpm/sqft. Application rates of 0.1 gpm/sqft. are generally reserved for the gentle application to liquid pool incidents. Manual application is generally made at .016 gpm/sqft. through monitors and hand hose lines.

Application through fixed systems such as a foam water spray range from 0.1 gpm/sqft to 0.5 gpm/sqft. In these systems the foam is used to extinguish the forming pool fires while the spray simulates the protection provided by a water spray system. Foam water spray systems are provided to control the rate of burning, extinguish fires, and/or provide for exposure protection. Foam water spray systems are not intended nor designed to extinguish gas fires. Foam water spray systems will protect the exposures and control the rate of burning until the flow of fuel can be stopped. Once the flow of fuel is stopped the foam will cover the spill and extinguish the fire. These systems can also be used to cover liquid spills that are not ignited to reduce the probability of them becoming ignited.

Alcohol and polar fuels require special foam concentrates. Regular foam concentrates will not work on polar solvents. Fuel in depths greater than 1 inch require the gentle application of foam to be effective. Three dimensional fuel arrays require greater application rates than do pool incidents. Some alcohol and polar solvents also require higher application rates that listed in the standards.

These standards recommend MINIMUM application rates. Each situation should be analyzed to assess if the minimum applications are appropriate. In many cases once assessed it is determined that higher application rates are required to provide the desired results.

9.C. Manual Fire Fighting Response

Discussed in upcoming Section 10.

9.D. Gas / Fire Detection

Previously discussed in Section 7.

10. Response and Recovery Features

The Work Group will attempt to discuss the possible response and recovery features such as operator response, emergency response teams, egress and escape, etc.

10.A. Operator Response Considerations

Factors to evaluate when considering operator response are:

- Time for the operator to become aware of the need for a response
- Time to evaluate the incident and recognize an appropriate response once aware of the incident.
- Time to alert others or take appropriate action.

These steps usually take 3 to 5 minutes if there is automatic detection or continual area attendance. Without automatic detection or non-continual area attendance response times can be 10 minutes or longer. Larger incidents are usually shorter response times and smaller incidents longer response times.

10.B. Emergency Response Teams

While fire emergency response teams is not typical for GoM facilities, rescue response teams are more common. Once aware of an incident 10 to 15 minutes is the typical emergency response team assembly time in addition to the previous operator response time (3 to 5 or 10 minutes).

An additional 5 to 15 minutes is required to start of response implementation once the team has observed, assessed, and formulated an action plan.

Often overlooked is accommodations / quarters. Larger platforms especially those with drilling have substantial occupancy. Application rates for automatic sprinkler protection from NFPA 13 is for fire control only and assumes that final extinguishment is provided by an emergency fire response team. Interior firefighting is often more difficult than process firefighting because of smoke accumulation, darkness, can lead to confusion.

10.C. Egress and Escape / Assemble

The minimum fire and blast survival goal is for the safe egress, muster and evacuation of personnel from the platform. As such, it is essential that egress and escape capability be demonstrated during process and non-process design credible fire and blast scenarios. Demonstration would be to:

- identify the primary and secondary muster locations
- confirm or define primary and secondary evacuation and/or escape routes for the layout
- evaluate impact on escape routes and muster locations during the design credible fire and blast scenarios
- evaluate the ability to safely recover injured personnel or personnel who have escaped from the production facility
- confirm risk acceptability of those fire and blast that threaten safe egress, muster, and evacuation. Conversely, this would imply the risk acceptance of a non-orderly escape from the facility.

10.C.1. Radiant Heat Threshold Considerations

API 521 offers some suggestions on the radiant heat criteria (without solar) for egress and escape beginning with an emergency reaction time of 8 to 10 seconds before the average individual would seek cover or depart from the area. Radiant Heat Criteria:

- 1500 btu/hr/sqft. heat intensity in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing
- 2000 btu/hr/sqft. heat intensity in areas where emergency actions lasting up to 1 minute may be required by personnel without shielding but with appropriate clothing
- 3000 btu/hr/sqft. value of K (permissible design level) at design flare release at any location to which people have access … exposure should be limited to a few seconds, sufficient for escape only.

Exposure Times Necessary to Reach the Pain Threshold (API 521)

Radiation Intensity		
BTU/hr/sq.ft. (total)	**KW/m^2**	**Time to Pain Threshold (seconds)**
550	1.74	60
740	2.33	40
920	2.90	30
1500	4.73	16
2200	6.94	9
3000	9.46	6*
3700	11.67	4
6300	19.87	2

World Bank data notes time to pain threshold as 8 seconds with second degree burns at 20 seconds.

10.C.2. Egress, Muster & Escape Considerations

NFPA 101 "The Life Safety Code" offers significant information on the behavior and response of people in fires. Offshore operators are a select and trained for work offshore but when off duty have will have a different response than on duty. Another source is the SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings.

NFPA 101 suggests that the following characteristics be considered for response and occupant when determining emergency egress.

Response Characteristics

(a) Sensibility - to physical cues. Ability to sense the sounding of an alarm; can also include discernment and discrimination of visual and olfactory cues in addition to auditory emanations from the fire itself.

(b) Reactivity - ability to interpret correctly cues and take appropriate action. can be function of cognitive capacity, speed of instinctive reaction, or group dynamics; might need to consider reliability or likelihood of a wrong decision, as in situations where familiarity with the premises influences way finding.

(c) Mobility - speed of movement. determined by individual capabilities as well as crowding phenomena such as arching at doorways.

(d) Susceptibility - to products of combustion. Metabolism, lung capacity, pulmonary disease, allergies, or other physical limitations that affect survivability in a fire environment.

Occupant Characteristics

Alertness	Awake/asleep, can depend on time of day
Responsiveness	Ability to sense cues and react
Commitment	Degree to which occupant is committed to an activity underway before the alarm
Focal point	Point at which an occupant’s attention is focused, for example, to front of classroom, stage, or server in business environment
Physical and mental	
capabilities	Can affect ability to sense, respond, and react to cues; might be related to age or disability
Role	Can determine whether occupant will lead or follow others
Familiarity	Can depend on time spent in building or participation in emergency training
Social affiliation	Extent to which an occupant will act/react as an individual or as a member of a group
Condition	Over the course of the fire, the effects — both physiological and psychological — of the fire and its combustion products on each occupant

Large population accommodations / quarters egress, muster and escape features may be developed considering the Life Safety Code requirements for dormitory / hotels.

10.C.3. Travel Rates

The NFPA Handbook summarizes much of the research that has been conducted on the behavior of people when confronted with fires as well as travel rates on different types of surfaces, up and down stairs, duration of travel time (i.e., fatigue) as well as flow congestion.

- 3.5 ft/sec Unimpeded flow (about 25 sqft/person)
- 2.3 ft/sec Impeded flow (about 7 sqft/person)
- 2.3 ft/sec Upstairs (about 9 sqft/person)
- 2.6 ft/sec Downstairs (about 9 sqft/person)

Additional factors to consider are:

- Flow congestion points
- Visibility (smoke, lighting, water spray, etc)
- Facility motions if floating production facility

Total evacuation time needs to consider time for roll call and assembly, time to decide on whether to man the lifeboats, and time to lower the lifeboats.

11. Summary

The Work Group will attempt to highlight the findings of this WG as well as discuss topics or lessons learned for possible future workshops.

Lessons learned:

- Lack of definition between work groups
- Human Factors started off with a short presentation and the work group then focused on topics of interest / concern.
- Earlier delivery of material.
- Smaller / narrower focus of work group. For example, new technology could be a work group, layout could be a work group, possibly demonstration of how / what other people are doing.

Summary of findings:

- Clear management of design process and acceptance criteria. Including philosophies and guidelines.
  - Demonstration of acceptability whether ALARP or other acceptance criteria. Qualitative or Quantitative.
  - Fire and Blast Goals – people, environment, asset

- Discussion of fire and blast deliverables by design phase was helpful.
- There was a definite technology / understanding to provide good blast specifications by the end of Define / FEED.
- GoM concern that North Sea blast testing had limited relevance to current and future GoM platforms. Possibility for a rig to research.
- North Sea was more analysis and quantitative driven than typical GoM fire and blast design. North Sea
- Design Credible Release Scenarios for fire and blast:
    - Norwegian North Sea is using probabilistic blast analysis (up to 5000 scenarios per module)
    - UK North Sea is using scenarios and limited probabilistic fire and blast analysis.
    - Limited meaningful data collection even when implementing SEMP for selection of design credible release scenarios.
    - GoM had no consensus on blast. Range was:
        - One operator did blast on all platforms (small, large, shelf, or offshore).
        - Generally operators are doing blast on the larger more complex platforms (not necessary shelf vs offshore). However, blast on any GoM platforms is not performed by all operators.
- Thursday lunch video would be helpful as a tool for educating work force from field to engineers and designers.
- A quick survey of the participants in this session found that:
- ~50% were with oil companies
- ~50% were with engineering firms
- a few were consultants
- ~50% were HSE specialists, about ½ this group were fire and blast specialists
- ~50% were facility engineers
- Good discussion between experienced GoM and North Sea personnel

WORKING GROUP 3
BLAST LOADING AND RESPONSE

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1 INTRODUCTION

Design of offshore structures to resist the effects of blast loads has been the subject of intense study in recent years, primarily in the North Sea (NS) environment. These structures are often enclosed to some degree offering regions of confinement and congestion which present potentially hazardous blast loads for the structure. Design of NS structures have developed as the result of research and applied engineering. Gulf of Mexico (GOM) offshore structures have typically been of a different configuration which presents less damaging overpressures than North Sea type structures. As GOM development expands to deep water, structures begin to look more like the confined, congested environment of NS structures.

The resulting changes in blast environment present important changes in the design of structures. Blast loads become more important at each stage of design. To deal with this reality, operating companies and designers must find cost economical ways to design for these explosion hazards. This white paper starts by describing the ways a design project is executed and some of the associated difficulties. The paper also examines blast load prediction and structural response in terms of the available approaches and their implementation. UK Interim Guidance for the Design and Protection of Topsides Structures Against Explosions and Fires, issued by FABIG in 1992 details the current state of the practice in NS. This paper will serve to stimulate discussion of these methods and application in GOM to promote information sharing and consensus, to the extent possible, on approach design approaches.

2 DESIGN PROCESS AND INTERFACES

When evaluating the major hazards associated with the design and operation of offshore oil and gas platforms explosions must be considered. Explosion hazard assessment activities occur throughout the selection and design phases of the project. The assessment process involves interactions with several disciplines and impacts many of the design activities. Different levels of analysis are appropriate for different levels of complexity in design. Simple, approximate estimates are applied to the initial project concept. The analysis complexity develops with the project.

Early explosion hazard assessment can affect concept selection. Assessment in the design phases often has significant impact on the process design, the topsides layout, the structural design, and the emergency response systems. The process of explosion hazard assessment and design modification is done in an iterative fashion. The design feeds the analysis and the analysis results affect the design.

3 INITIATING EXPLOSION HAZARD ASSESSMENTS

Explosion hazard assessments are undertaken to evaluate several concerns including life safety, investment/asset risk, and for design optimization. Protection of life safety is a primary design issue and explosion studies focused on life safety will typically evaluate effects on emergency shutdown systems, occupied buildings, temporary safe refuges, and means of egress and evacuation systems. Studies that analyze asset risk will also include damage to platform systems that are required for control and shutdown (beyond those needed for safe evacuation), evaluation of the potential for progressive collapse, and structural and equipment damage levels that could cause significant down time. Explosion studies have also been used to optimize the platform layout and the design of the structures.

The assessment is often initiated as a result of an early project hazard identification exercise. At project conceptual stage the assessment will be simple and typically based on the experience and expertise of the project team. Important issues in the concept selection phase include:

- Choice of manned or unmanned operations,
- Type of production: gas, oil or gas and oil
- Type of installation (e.g. Fixed, FPSO, SPAR, Semi Submersible)

As the design progresses the analysis becomes more complex and requires more detailed input. When design safety and structural integrity are being analyzed the inputs typically include:

- Process Flow Diagrams & P&IDs
- Proposed platform layouts
- Structural steel drawings
- Flammable material release scenarios
- Emergency Response, Shutdown, Blowdown and Isolation information

3.1 EXPLOSION ASSESSMENT INTERACTIONS

The explosion requires input from several disciplines and affects many design activities. Developing the assessment will require information on the process design, the structural and equipment layout and an understanding of the platform emergency response. The results of the explosion analysis need to be evaluated with structural expertise to understand the response of the structure and the equipment. If the structural response exceed the design criteria (for safety, equipment or structural response) several options are available:

- Concept change (e.g. reduce occupancy, use subsea tiebacks),
- Modify process to reduce inventory,
- Change the layout to improve natural ventilation, reduce gas cloud size or improve explosion venting
- Strengthened the structure to resist blast,
- Improve the emergency response systems
- If the design is modified the explosion may be re-run to check the explosion hazards on the new design.
- Project Phases

Most design engineering projects follow three phases of execution. Explosion Hazard management activities are integrated with design activities in each phase as noted below:

Select The explosion hazards associated with all the development options under consideration are identified and categorized and are an integral part of the concept selection decision making process. The major hazards of the selected option will be defined for subsequent design and/or evaluation

Define Develop strategy for managing explosion hazards while optimizing the concept. Specifically, decide how to manage the hazard, identify what is needed to implement the decision, and set the performance standards for the safety systems

Execute Design to the strategy and achieve the required performance criteria and validate that hazards have been identified and managed in accordance with this explosion hazard management strategy.

The most cost-effective phase, to manage major explosions hazards, in a project life cycle, is during the Select and/or Define activities of a development project (see Figure 1). Figure 1 demonstrates that:

The Select and/or Design phase is when there is the most cost-effective time for explosion hazard management.

The cost effectiveness and impact on project schedule, of hazard management effort expended during the Select/Define phases are significantly better earlier rather than later in these phases.

There are more opportunities to implement explosion hazard management strategies earlier in the Select and / or Define phase. There is also more room for recoverable error in hazard management decisions during the early phases than later in the project schedule.

The unsuccessful implementation of a explosion hazard management strategy during the Select/Define phases may result in significant cost, weight and schedule penalties and at the same time result in the failure to maximize the inherent-safe design efforts of the project

3.2 DESIGN AND EXPLOSION OVERPRESSURE

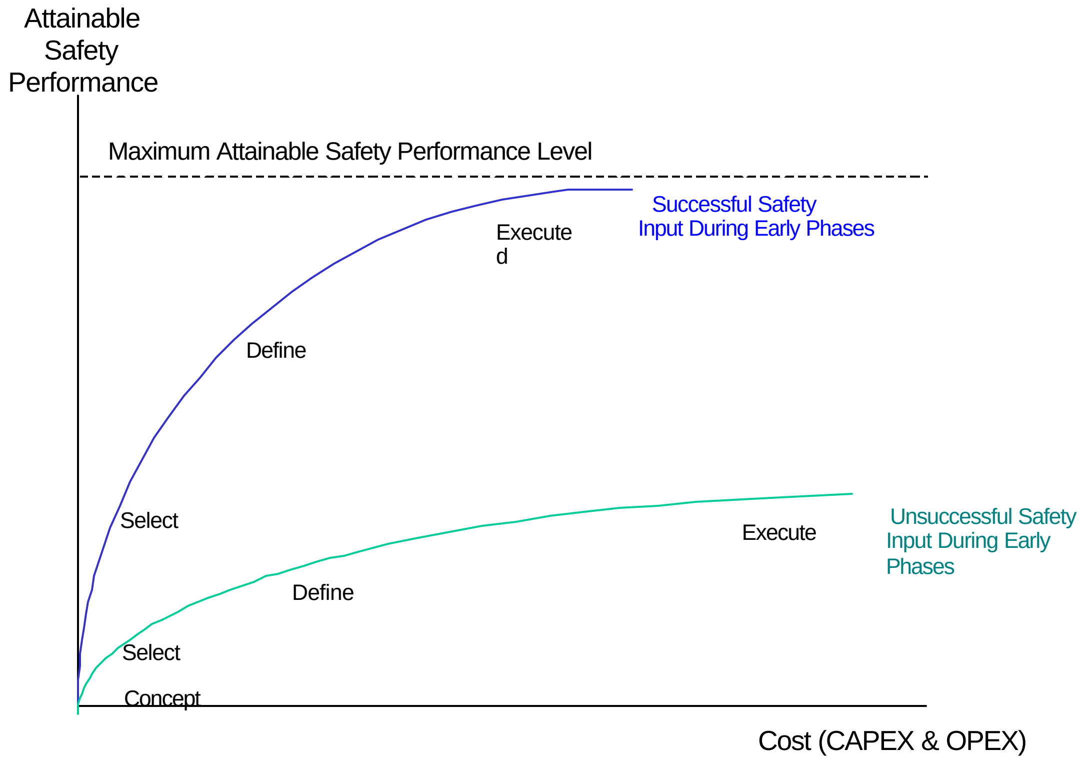
During the initial phases of an engineering design project the major drivers are normally:

- Codes / Regulations;
- Cost;
- Schedule;
- Weight;
- Proven Technology

During the course of a project the above drivers could change in priority and thus any explosion risk management decision will have to maintain or consider these elements during the course of design development or management of change issues.

3.3 SELECT PHASE

Ideally during the select phase of a project each option is normally evaluated with regards to regulatory, code/standards or certification requirements regarding an explosion major hazard. Standards and codes contain guidelines and requirements developed from experienced industry practice and lessons learned from major accidents and near misses. Included with these requirements are company recommended practices based on the assimilation of industry codes and standards and worldwide engineering / analytical / management practices for common situations and appropriate solutions to the well-understood explosion hazards.



Explosion is not the only hazard that may affect the concept selection decision but this could be the most dominant concern for the selection process along with fire accidental events. Competent engineering judgment can be made at this phase of a project to assess the magnitude of the hazard and develop the strategies (prevention, control or mitigation systems) that could be implemented including an estimation of cost, schedule and weight impact for each option to be considered. It must be emphasized that the competency of the individual that will evaluate the explosion overpressure potential is very critical at this phase of the project. This is also the best phase to introduce any new technology that could be cost-effectively utilized to reduce the likelihood or consequence of an explosion overpressure accidental event.

At this phase of a project the type of information needed to evaluate the different types of explosion overpressure design would be:

- Global location of the facility and environmental conditions;
- General facilities layout including hull (floating) or base structures (fixed) design;
- Reservoir characteristic to obtain the type of hydrocarbon gas to be released;
- Intended structural design for each type of facility (size and space);
- Intended process design information.

The type of explosion analysis that could be performed depends on the duration of the select phase evaluation period. Company experience from previous and similar projects or facilities may be used as the first estimate of the explosion overpressure magnitude and the potential response of the structure. The focus, at this stage, is mainly on the structural integrity of the facility to provide safe egress, muster and evacuation of personnel. There is also the question of asset integrity after the explosion. The performance standards are critical to the assessment and development of prevention, control and mitigation solutions to each of the design development options.

If schedule permits, a coarse and quick explosion modeling is performed at this stage of the project. The results of this analysis will provide an estimate of the overpressure magnitude and the development of loss prevention solutions. There is normally a discussion between the loss prevention and structural specialist at this phase to discuss the magnitude and credibility of the explosion impact and the solutions that could be implemented to address the overpressure concerns. It is critical, at this phase to focus on the life cycle cost of the loss prevention solutions to be implemented.

3.4 DEFINE PHASE

During the define phase of a project the explosion loss prevention strategy, initially identified during the select phase will now be fully developed. At this part of the project the specifics, on how to manage the explosion hazard, will have to be identified and implemented. This is normally the time when specific performance standards, with regards to the safety systems, are developed. At this phase of the project cost and schedule (timing of explosion modeling versus the delivery dates of the structural steel and bulkheads) are parameters that concern the engineering design team. This is the most critical time to perform more detailed explosion modeling (CFD) with some what-if design scenarios to establish some design parameter for the engineering designers. The types of input information available at this stage of the project are:

- Reserved space and estimated weights of the process equipments;
- Structural design philosophy and primary steel concept;
- Construction and tow-out / installation philosophy or method to provide input to structural design;
- Proposed delivery schedule for primary steel to determine optimum explosion modeling duration;
- Process design philosophy to determine dispersion characteristic of hydrocarbon release (duration, size and gas characteristic).

The result of the explosion modeling along with the structural design and layout concept will determine the manageability of the explosion overpressure concerns. This is the ideal time to cost-effectively propose and implement inherently safe engineering design options that could minimize the extent of maintenance intensive explosion mitigation measures (e.g. detection, isolation, vent systems and water sprays). The outputs, in the form of pressure versus time curves and drag velocities will be inputs to the structural design model to determine the extent and magnitude of the primary steel, connection details and potential pipe supports philosophy. This phase is also when an explosion overpressure design philosophy will be developed and implemented. This philosophy will be the basis for the execute phase layout activities. Figure 2 provides an example of how the explosion management strategy would be addressed at this phase of the project.

3.5 EXECUTE PHASE:

During the execute phase of the project the explosion overpressure philosophy / strategy is implemented into an overpressure hazard management plan. This is when the project team will implement the explosion overpressure philosophy, achieve the required performance criteria and validate that hazards have been identified and managed in accordance with this explosion hazard management strategy.

At this stage of the project the loss prevention engineer or blast analyst will be interfacing with not only the structural discipline but also with the piping, architecture, controls/electrical/instrumentation, operations and safety groups to optimize the layout of the major piping and equipment on the facility. A more detailed model will be used towards the middle of this phase (usually after the detailed HAZOP or 60% model review) to verify the final blast overpressure numbers for the AFC design.

It is also during this phase of the project when quantitative risk analysis would be utilized to determine the most credible explosion overpressure if there are design concerns that could not be eliminated, isolated, controlled or mitigated. It must be emphasized that the results of this type of analysis is utilized for project or engineering decision-making purposes only not as design parameters to achieve.

3.5.1 Blast Load Prediction

Explosion load cases

In the UK Guidance, two levels of explosion loading are described analogous to earthquake analysis:

- Design level – elastic response of primary structure required. Return period 1 order of magnitude less than extreme (Ductility level) event.
- Ductility level – local deformation of the structure is allowed so long as escape to the temporary refuge/safe mustering area is possible.

To derive the Design level event overpressure use an exceedance diagram of overpressures against probability of being exceeded. The overpressure used is defined as a time averaged value (1.5 ms) of the representative peak overpressure.

It may not be possible to design structures/equipment to the worst credible event which itself needs to be defined. Current thinking in the UK is that this pressure should be derived using realistic release conditions with dispersion and credible ignition points and times. As opposed to assuming a fully filled stoichoimetric cloud containing the whole released inventory.

Screening Methods

General Description – This class of method does not perform any explosion analysis but defines acceptable design characteristics based on predetermined criteria. For instance, criteria of the spacing between process units and inhabited buildings may be used. Other examples are specified layout of equipment and venting patterns.

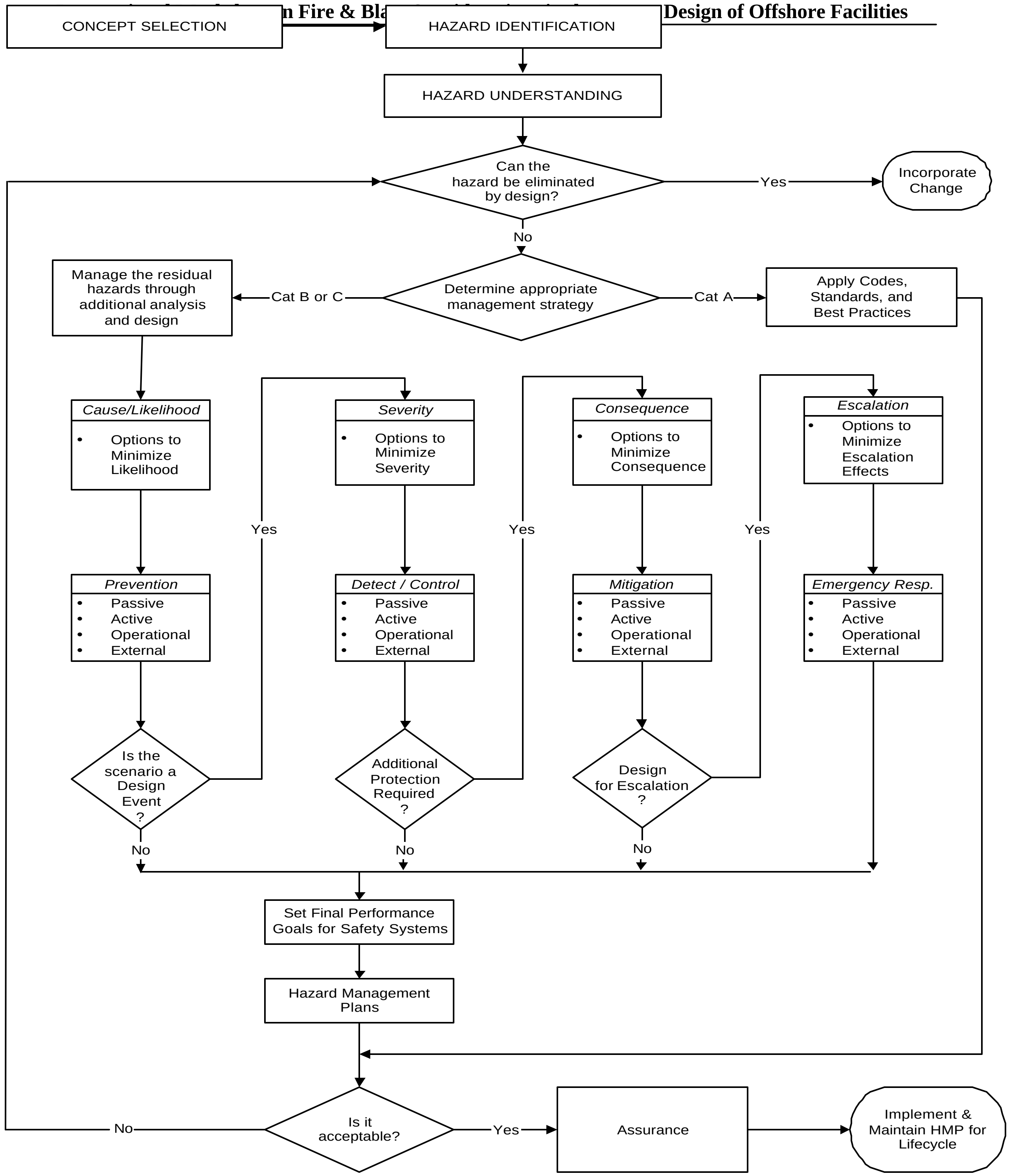


Figure 2 Implementation of Explosion Hazard Management Strategy

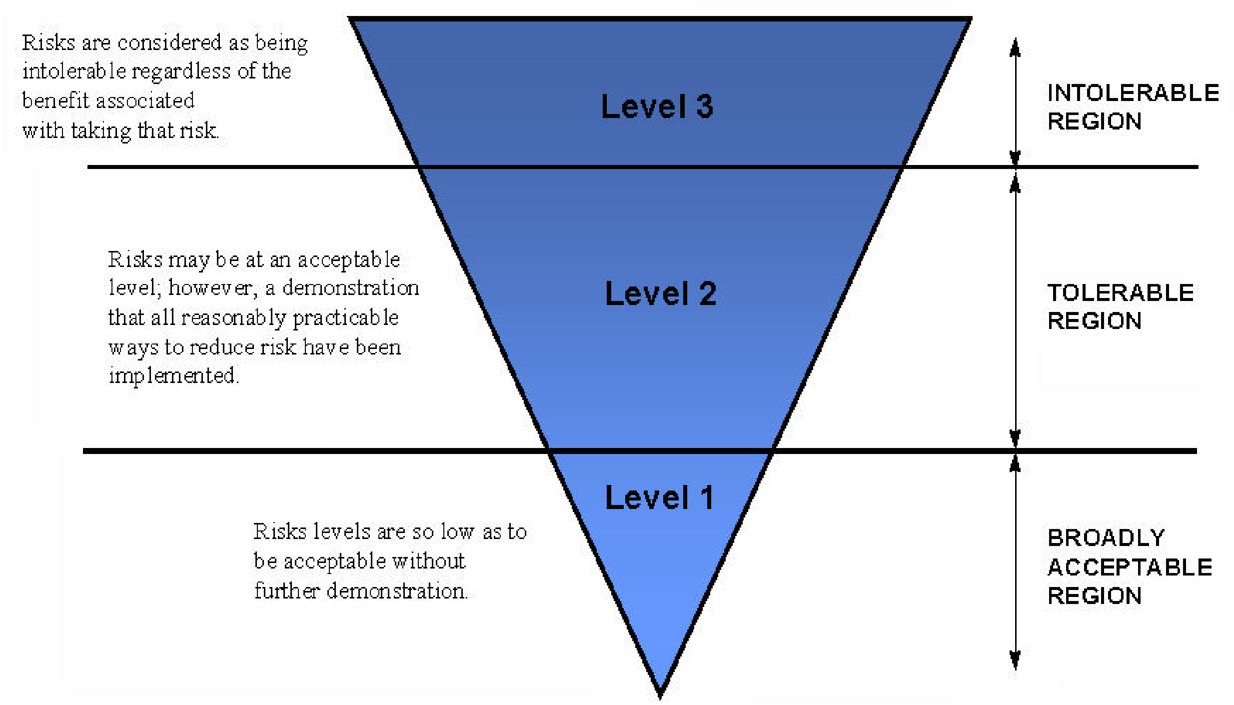


Figure 3: Acceptability Diagram

Level of Effort Required – This approach requires no extended blast analysis and therefore a very small level of effort.

Usefulness of Outputs – If the screening criteria is met the design is set.

Limitations – Such an approach provides no flexibility in the design process and is not useful in assessing existing facilities or unique designs.

Benefits – Minimal analysis time.

Pitfalls – No flexibility in design.

Conservatisms – If the design matches the specified layout and configuration the blast load produced by the explosion will match the existing database.

<u>Simplified Models</u>

General Description – These methods use data such as scaled distance curves.

Examples – TNO Multi-Energy, Baker-Strehlow, TNT Equivalence

Level of Effort Required – Model preparation can require little time. This is due in part to the fact the model does not incorporate scenario specifics in the load calculation. Post-processing can also be brief since the model provides limited output.

Usefulness of Outputs – For the offshore scenarios of interest here, it is not clear how useful the output would be. This is due in part to the fact that these models predict the same pressure for a given distance from the source and do not incorporate effects such as blast focusing or channeling. Reflected loads can be calculated but these are analogous to a blast wave in an open field rebounding off a plate.

Limitations – Can not accurately include design details of the facility.

Benefits – Can get an answer in a brief amount of time.

Rigor – Does not incorporate the exact scenario parameters within a first-principles type approach. It is not clear how such models can be used to provide accurate blast load predictions on offshore facilities. This is particularly true if the interest is in loads within the vapor cloud.

Input/output required – A general description of the facility and explosion source.

Pitfalls – Do have a limited range of applicability and uninformed users can transgress the bounds of applicability with little knowledge that they have violated the basic assumptions of the model.

Conservatisms – Most of these models assume a spherical vapor cloud is involved and that the entire mass of fuel in the congestions region contributes to the explosion. This does tend to produce conservative estimates unless there are channeling and focusing effects involved.

Misconceptions – There is a conception that the simplified methods require less overall man-hours for the analysis to be performed. However, since these tools are based on the analysis of ideal explosion scenarios, it can take large amounts of time to apply them to more complex scenarios.

Phenomenological Models

General Description – This class of method incorporates more of the actual scenario of interest than the simplified models. Some of these models use a first principles framework with some simplifications such as a reduced dimension definition of the domain. For instance, in an offshore module where venting occurs primarily at only one end, the global flow pattern is one-dimensional. Therefore, some of the features of the Explosion CFD models discussed below are applicable.

Examples – SCOPE, CHAOS

Level of Effort Required – A general description of the facility is needed. For instance, an overall vent area may need to be defined.

Usefulness of Outputs –

Limitations – If the explosion scenario is different from that assumed during the model formulation then the results may be inappropriate.

Benefits – Can get an answer in a brief amount of time.

Rigor – Can be very rigorous if the scenario of interest matches that assumed in model development.

Input/output required – General description of the facility and explosion source.

Pitfalls – Only applicable to facilities similar to those for which the model was developed.

Misconceptions – This class of model is not as universally applicable as some users think.

General Computational Fluid Dynamics (CFD) Models

General Description – Prediction models based on CFD technology solve the governing equations of fluid dynamics and combustion. The exact set of equations solved depends on the assumptions and framework of the particular CFD model used. Some analysis tools solve these equations in a reduced form such as only one or two spatial dimensions. Here only those models that solve the fully three-dimensional set of equations are referred to as CFD models.

In these codes other inputs may be required. For instance, the chemical reactions in the combustion process represented using a detailed kinetics scheme. This most be provided by the users. The equations are solved on a mesh or grid used to represent the actual facility in which the explosion occurs. This too must be constructed by the user.

Examples – Fluent, CFX, Pheonics, AutoReagas

Level of Effort Required – To use a general CFD code to model explosions first requires the user to have a high level of competence with the model. This is due in part to the grid construction process. Countless man-hours are required to define the facility and explosion scenario. Also, because there is much more data produced by the model, more time is needed to post-process data than that for the simplified methods.

Usefulness of Outputs – These codes can provide detailed data useful in design and assessments. Information such as load histories are a product of these simulations.

Limitations – This class of codes can simulate any facility or explosion source.

Benefits – Provides detailed time dependent load data useful for detailed structural analysis. Incorporates any unique features in the facility of interest.

Rigor – These models are both mathematical and geometrically rigorous in there representation of the explosion event. This is due to the fact that a set of first-principle equations are being solved on a virtual representation of the facility. This representation captures effects such as the migration and interaction of the vapor cloud and pressure waves with the structural elements.

Input/output required – Detailed description of the facility geometry. Detailed kinetics model of the combustion process involved.

Pitfalls – Explosion output is highly dependent on the accuracy of the chemical kinetics model. Also, since these codes are of a general nature, the user must stay very proficient with the model or excess time will be required to “relearn” the model each time.

Conservatisms – Conservatism will exist only if “worst case” type scenarios are used.

Misconceptions – There is an impression that the general CFD codes are more accurate than the explosion CFD models. This is not necessarily true since the explosion CFD models are solving the same equations but with some reductions where appropriate. For instance, most of the explosion CFD models use a one-step reaction path, which is sufficient for VCE analysis.

Explosion CFD Models

General Description – This group of CFD codes are those that have been tailored specifically to simulate the explosion problem. These codes solve the same set of equations as the general CFD models. They differ in how some of the processes such as chemical reactions are modeled. These models also use a computational mesh to represent the facility. However, they typically do not require the level of expertise in grid generation that the general CFD models require.

Examples – FLACS, EXSIM, CEBAM

Level of Effort Required – The man-hours required for this class of CFD models is less than that for the general codes. This is due in part to the grid construction process. The actual man-hours required will depend on the level of fidelity the user wishes to specify. Also, because there is much more data produced by the model, more time is needed to post-process data than that for the simplified methods.

Usefulness of Outputs – These codes can provide detailed data useful in design and assessments. Information such as load histories are a product of these simulations.

Limitations – This class of codes can simulate any facility or explosion source.

Benefits – Provides detailed time dependent load data useful for detailed structural analysis. Incorporates any unique features in the facility of interest.

Rigor – These models are both mathematical and geometrically rigorous in there representation of the explosion event. This is due to the fact that a set of first-principle equations are being solved on a virtual representation of the facility. This representation captures effects such as the migration and interaction of the vapor cloud and pressure waves with the structural elements.

Input/output required – Description of the facility geometry and explosion source.

Pitfalls – There can become a tendency to use the CFD model for all analysis. Many times simplified approaches can be used to screen out those scenarios that pose little or no danger. However, again it is less clear whether the simplified models suffice for offshore rigs for the reasons mentioned above.

Conservatisms – Conservatism will exist only if “worst case” type scenarios are used.

Misconceptions – The assumption that these models require much more time to apply than the simplified models is not always true. Here the time is associated with building the model. However, there is no time required to revisit the validity of the model for each new scenario. Also, detailed descriptions are not always needed. In early design, general layouts and projected process unit configurations can be used.

3.5.2 Structural Response

Blast Resistance

The ability of structural components to resist blast loads is primarily a function of resistance, stiffness and mass. Due to the relatively short duration of blast loads, structural components will respond dynamically to the suddenly applied blast pulse.

Certain components in offshore structures may be relatively strong and stiff due to functional requirements or conventional loads. These components tend to be stiff and respond primarily to the peak applied pressure. They are typically termed “pressure resistant” components and blast resistance is provided primarily through structural resistance.

Components which have a relatively lower resistance, are more flexible and have less mass, may be able to deform and absorb the blast load. In these cases, ductility is a key characteristic although mass may become an important tool to resist loads through inertial resistance. This latter approach, termed “impulse sensitive”, is typically more economical than a pressure sensitive design, but my not be feasible due to deflection limits and serviceability issues.

The structural analyst should approach design for blast with these concepts in mind when formulating a strategy to resist blast loads.

Performance Criteria

Establishing response limits is a key step in the design process. Response limits must consider the required level of protection for each class or type of component. Where a high degree of protection is required for equipment for personnel, peak dynamic response will be limited to ensure structural integrity following the design basis loads.

Response limits are typically described in terms of ductility ratio and member end rotation or a ratio of midspan deflection to component length. Ductility is determined by dividing the maximum deflection by the deflection at the elastic limit. This term is an indicator of the plasticity of the component at peak response and a measure of the reserve capacity. End rotations or deflection/span ratios are used to insure the geometry of the component is maintained to the degree necessary during response. Typically, both response limit types are used to determine adequacy of a component.

Other important considerations when selecting response limits are the interaction of loads within a component. For example, a column subjected to flexural loads from a blast may also receive axial loads due to the supported weight of the structure. This axial load may produce a secondary bending effect which reduces the component strength

Frequency of the event and consequence of damage are additional topics which must be considered when selecting response criteria. Explosion loads which produce high blast pressures resulting from a large flammable release are likely less frequent than small vapor release scenarios which produce lower loads and thus less response. A common approach is to analyze a structure for “design basis” and “maximum credible” load cases. A limited ductility is allowed for the design basis case whereas higher ductilities approaching the ultimate capacity of the structural components may be permitted for the maximum credible case.

Interface with other loads

Blast loads are typically higher than other design loads in terms of peak values. Because blast loads are typically short duration, a structural component can resist higher peak values under blast than for more conventional loads which are static or infinite duration. Higher response limits are also typical for blast loads thus it is not always clear which loads will control.

One approach to addressing multiple loads for a structure is to design members based on peak conventional loads followed by analysis of these components for blast loads. Changes required to meet blast load demand can then be specified.

Blast loads will not typically be combined with other conventional loads with the exception of dead load and operating loads from materials and equipment. The reason for this approach is that a blast is an extreme event and the probability of combined loading is very low and not appropriate for design.

3.6 ANALYSIS METHODS

The type of analysis performed will be dependent on several factors including:

- Stage of project design
- Information available in terms of structure configuration and equipment layout
- Occupancy
- Consequences of failure

Screening

In the initial stages of a project, structural configuration or equipment layout may not be well defined and a screening assessment may be appropriate to identify areas of concern with respect to blast response. This screening assessment may influence layout decision as the design proceeds and can be important in reducing potential explosion consequences thereby reducing structural costs. Screening assessments can evaluate multiple load cases to aid in decisions on configuration. Screening assessments may also be useful for determining whether additional analysis is required.

In the simplest form, comparing applied load to capacity based on tables of overpressure versus damage by component type is a screening assessment. These tables are based on test data, much of which come from nuclear weapon effects testing.

A significant weakness of the screening approach is that in many cases the structure or components listed in the tables are not representative of the structure in question. Care must be taken not to apply these tables in an unconservative manner. The obvious advantage is the speed with which a screening analysis can be done.

Application of previously conducted detailed analysis may be used for screening of similar construction. Response can be predicted given similar configuration and hazards using this experience-based approach. Care must be taken to insure that the structure and components of interest are represented by previous analysis.

Simplified Analysis

A simplified analysis relies on analysis of key components in a conservative manner to quickly analyze the effects of one or more load cases. This type of analysis may occur in early stages of the project. Layout changes can be readily addressed though the simplified analysis methods. This simplified approach may used to reduce analysis costs when the level of available structural information is not available to permit a more detailed analysis or if results of a simplified analysis can conservatively be shown to prove the adequacy of the design.

This method typically relies on an equivalent single-degree-of-freedom (SDOF) model to determine response of a component to a dynamic load or may involve use of a static equivalent approach. A simplified analysis approach does not directly address interaction between components and higher modes of response.

SDOF models

Structural components subjected to blast loads can often be modeled using a mathematical representation as a single spring-mass system. Response is quite often controlled by flexural modes which can be transformed into a single equation of motion for the simplified system. Response of the spring-mass system relates to the real response of a key point on the actual component. Transformation factors for load and mass are readily available to develop the equivalent SDOF system.

A transient blast load time-history can readily be applied to this model to determine dynamic response. A reaction time history can also be determined. Peak response is typically used to determine the maximum ductility of the structural component. Actual deflections and ductility are then compared with response criteria to determine adequacy for the design basis loads.

There are limitaiton with thei approach including difficulty dealing with complex structural element. The UK Interim Guidance Notes give a number of extensions of the method to deal with two way spans, stiffened plates and panels. These methods are only recommended for use in a Screening Assessment. Tension and membrane effects are not fully addressed.

The Biggs method may be used to obtain a better estimate the capacity of members in a Design Level analysis so long as the failure of these members does not have a critical effect on the primary frames of the structure.

The main problem with the Biggs method is that it tries to characterize the post yield resistance/displacement behavior by a single capacity. This is inappropriate for panels which often respond by deflecting substantially into the plastic region mobilizing tension effects in the panel. FABIG gives a method of including tension and membrane effects by including a third section to the resistance displacement function with non-zero slope to represent membrane action. Derivation of the slope of this third section of the curve is given in this reference.

Text book solutions of panel response are only available for a limited range of boundary conditions typically clamped and simply supported.

The Biggs method implicitly assumes that the deflected shape under blast loading is similar to the fundamental mode shape. Many multi-degree of freedom systems or systems with complex mass distributions do not respond in this way. This also applies to some stiffened plate blast walls.

The response of ductile structures using simplified methods needs extreme care in the construction of the resistance/displacement function. Construction of the resistance/displacement function using static finite element methods and Biggs method to model the dynamic response has however been successful for stiffened plate structures.

As the Biggs method does not explicitly give local stress information, the use of this method for the prediction of panel failure is not advised. For the same reason, the use of the method for the design of blast wall connections is not advised.

Pressure-impulse diagrams

Another useful tool for simplified dynamic response is the pressure-impulse (P-I) diagram. This graph of pressure vs. impulse contains one or more curves which represent a response level of a specific component. Multiple loads may be plotted on this graph to quickly determine response. The response level curve is determined from dynamic properties developed from the SDOF system.

Equivalent static models

A simple model of a structural component may be used in conjunction with a static load to determine response. The static load should be designed to produce a response in the static model that would be produced by the time-history blast load in a dynamic analysis model. The static equivalent load is a function of peak blast pressure and duration, allowable ductility, and natural period of the component. Understanding of this approach is critical because it requires iteration of the static equivalent with changes in the member properties. Additionally, a single static load is not appropriate for all components and must be based on individual properties. An additional consideration is that reactions developed in the static equivalent load model are not necessarily representative of the dynamic reactions. This potential problem can usually be addressed by designing connections to develop the full capacity of the member.

Conventional finite element analysis (FEA) models may be also used to analyze dynamic blast loads by applying an equivalent static load. An FEA model is a representation of the real structure using multiple components which are broken into discrete pieces to accurately predict response. An FEA model has the capability to predict interaction effects between members and to determine local deformations and stresses that are ignored by simplified models. FEA models are widely used for offshore facility design to analyze the effects of conventional and environmental loads.

Elastic response of components and can be predicted with conventional structural analysis tools. Static models are convenient because they are already in use in a typical project for analysis of conventional loads such as dead, live, and environmental loads.

The key to successful use is selection of the appropriate equivalent static load which must include the permitted ductility of the real member, blast load duration, and assumptions regarding the natural period of the components. This approach often is an iterative approach requiring adjustment of the load as member properties change. In simple terms, a static load is applied such that the static analysis produces member sizes which will perform adequately when subjected to the blast loads in a dynamic analysis model. The equivalent static load is referred to as a “design level” event in some guidelines.

A similar concept used in the UK is a dimensioning explosion overpressure may also be defined which is an overpressure which when applied to the primary structure gives member dimensions suitable for resisting the ductility level explosion. This is achieved by elastic analysis which may be static if the appropriate dynamic amplification factors are available.

This static load method has some potential for underestimation of non-flexural response and connection loads. A proper understanding of the limitations is important to avoid problems. This consideration is significant because of the widespread use of static models by those unfamiliar with dynamic response.

Dynamic analysis models

As project definition increases, more structural information is available to permit meaningful analysis with more detailed structural models. The advantage of a more complex model approach is the increased accuracy and reduced conservatism in response prediction.

Multi-degree-of-freedom

Some components or systems may accurately be represented by a simplified model utilizing multi degrees of freedom (MDOF) as opposed to the SODF model. An example would be a framing system subjected to out-of-plane loads. Primary components could be modeled as a separate degree of freedom but provide analysis of the interaction of these components under dynamic loads.

Finite element analysis (FEA)

A more typical approach to dynamic analysis utilizes a FEA model. The structure is modeled using shell, solid, or beam elements to represent the real structure with particular attention to dynamic properties. Boundary conditions are used to properly represent supports or connected member and are especially important where one way elements or gap/contact conditions may exist. A dynamic model is significantly more complex than a static model in most cases. Sufficient resources should be planned for this type of analysis.

In practice, FEA models typically utilize static loads with elastic response. Analysis using inelastic (plastic) response with transient loads is considerably more complex and potentially significantly more expensive than static, elastic analysis.

Elastic

An elastic model can be utilized when the response will be limited and the response will be linear. Stresses and deflections will be linear with respect to the applied load. This type of model can also be used for static equivalent approaches wherein the load is modified to compensate for the use of an elastic model such as a design basis load case.

Non-linear

Models which incorporate non-linear response permit prediction of structural response as materials are deformed beyond the elastic limit. Plastic hinging and other non-linear response can be modeled to more accurately determine deflections than permitted by elastic models. This is important for loads which produce significant response. This type of analysis can model absorption of blast energy through deformation and theoretically produces the most accurate response prediction.

Additional Considerations

Comments from Steve Walker MSL Engineering

Define Phase _ last line on page 6

Reference is made to the outputs of a CFD analysis using the computer model available at the time. It is unlikely that the fine detail of the small bore piping between 3 and 8 inches in diameter will be available at this stage.

Work (HSE report by Brewerton) has been done which indicates that it is possible to project values obtained at an early stage to avoid surprises later. For example it is stated that if all piping and congestion above 8 inches in diameter is present in the model then the calculated overpressure peak will be about 80% of the final value.

Explosion load cases

Reference is made to the UK guidance. The Interim Guidance Notes do not talk about the two levels of explosion loading. This does however appear in the BP Guidance document

(Walker, Corr, Bucknell, O_Connor, 'Guidance for the protection of Offshore Structures against fires and explosions', MSL Services Inc./BP Corporation, Document Reference CH152R002 API Draft 0, September 2001) and is expected to appear in the new Guidance being prepared in the UK sponsored by UKOOA/HSE.

General computational fluid dynamics (CFD) models

Please move AutoReagas to the next section under 3.2.5 Explosion CFD models as it is a code of this type.

Blast resistance

The term pressure resistant is not a term used in the UK, maybe it is in the US.

Inertial resistance is not in itself able to resist the load as the kinetic energy imparted to the structure is later converted to potential (stress) energy at peak response. A long natural period (high inertia/low stiffness) however will alleviate the effect of the load through a dynamic amplification factor less than 1.

Impulse sensitive is not a common term, this term implies that the natural period of the target structure is greater than the load duration, which may not be the case.

SDOF methods

The Biggs method is best for one way spanning barriers and members which are not under static loads or do not have masses attached. I.e. the members may be considered to respond in isolation.

The Design level analysis is essentially an elastic analysis. Although Biggs is an elastic-plastic model it may be used to check stand alone barriers within such a model so long as the support reactions are properly represented.

FABIG a reference to this should be included (there are a number of references to this which pre-date the FABIG reference of 2002).

Equivalent static models

This section does not say how this is done.

Usually the shock spectra figure from Clough and Penzien, _Dynamics of structures_, McGraw-Hill gives the dynamic magnification factor as a function of load duration/natural period ratio which is then applied to the peak load to give an equivalent static load. This is limited to structures which respond predominantly in their fundamental mode.

The design level event is not necessarily static.

Additional Considerations

This section identifies additional items that need to be discussed to get industry current practice and to determine what are regarded as "best practices". These topics will be discussed during the workshop. Attendees are encouraged to discuss their company's design practice.

Performance of non-structural items

Hanging items - anything not tied down may become hazardous debris. Designers should be aware of this and included proper tiedowns.

Other items – are there any other non-structural items that need to be addressed in the design process?

Ancillary areas (non-occupied) like switchgear buildings...depend on the consequences. Need to ensure that escape routes should not be blocked after the event in question and/or that this does not cause secondary collapse of occupied areas.

Capsule response - What are the performance requirements for capsules in the event of a blast? What criterion is used to ensure that the capsules are able to function as an escape route?

Impact of structural response on systems – What systems are checked for the anticipated structural response caused by an explosion. Is it limited to the hydrocarbon lines and/or safety critical systems?

Projectiles – Are projectiles typically included in the explosion analysis? If so, how is this analysis performed? What items are considered?

Knock-on effects – This could include a secondary explosion into an adjacent module after the failure of a firewall and could change the initial conditions of the structural analysis. Is this type of analysis done?

Fire and Blast Interaction – Barriers are a good way to confine fires but this surface will now need to be designed as a blast wall. Large open areas minimize explosion pressures but make it very difficult to control fires. Both Fire and Blast need to be evaluated on a topsides design.

Proposed API flow chart/risk matrix – API is in the process of revising the Fire and Blast section in RP 2A. If available, the proposed flowchart and risk matrix will be presented.

Recommended design loads – The industry is considering giving design blast loads for offshore facilities that would be based on a number of parameters such as size, confinement, hydrocarbon type, etc. The design blast loads would need to be conservative but would give a minimum design load that could be used for topsides design. This, along with good connection details would increase considerably the resistance of the facility to blast loads.

Dimensioning Blast - The concept is to use a factor on the design explosion such that the members would be sized to withstand the "ductility" event. This analysis method is intended to be a design tool and would use a linear analysis program.

Dimensioning blast loads are of such a magnitude that when they are applied to a simple elastic analysis model with conventional code checks for an accidental load case, result in members dimensioned to resist the worst case credible event or 'Ductility Level' blast.

The definition of Dimensioning-blast overpressure Q_{dim} is based on a simulated overpressure for the Ductility Level explosion Q_{duct}. This overpressure should represent those values generally indicated by simulation to be applied to a substantial proportion of the structure.

Considering the limit state equation for a Ductility level event with no safety factors and the elastic limit state under the dimensioning blast overpressure:

$Q_{dim} = Q_{duct}$/(Ductility factor x Strain rate factor x Scale factor)

Appropriate values for the Strain rate factor are 1.1 to 1.27 from Reference 1.

The Ductility factor may be read from Figure 2 and the Scale factor from Figure 1.

The Ductility factor used here is strictly only applicable to members and structures which can be represented as one degree of freedom systems. This restriction may be relaxed. The inherent redundancy in the structure is not represented but would be partially represented in the elastic frame analysis used to determine response. Factors representing uncertainty are not included but may be applied to Q_{dim} directly as in the LRFD approach.

Data already exists to 'benchmark' the above approach by direct comparison of the results of a Design Level analysis using the Dimensioning Blast with an Ultimate Strength analysis using the Ductility Level explosion overpressure for a real topside design. This may put into context some of the theoretical objections, which could be raised to discourage the application of the dimensioning blast loads.

REFERENCE

R.L. Bruce, 'Blast overpressure prediction - modeling the uncertainties', ERA Conference, 'Offshore Structural Design – Hazards, Safety and Engineering', November 1994, ISBN 0 7008 0587 7.

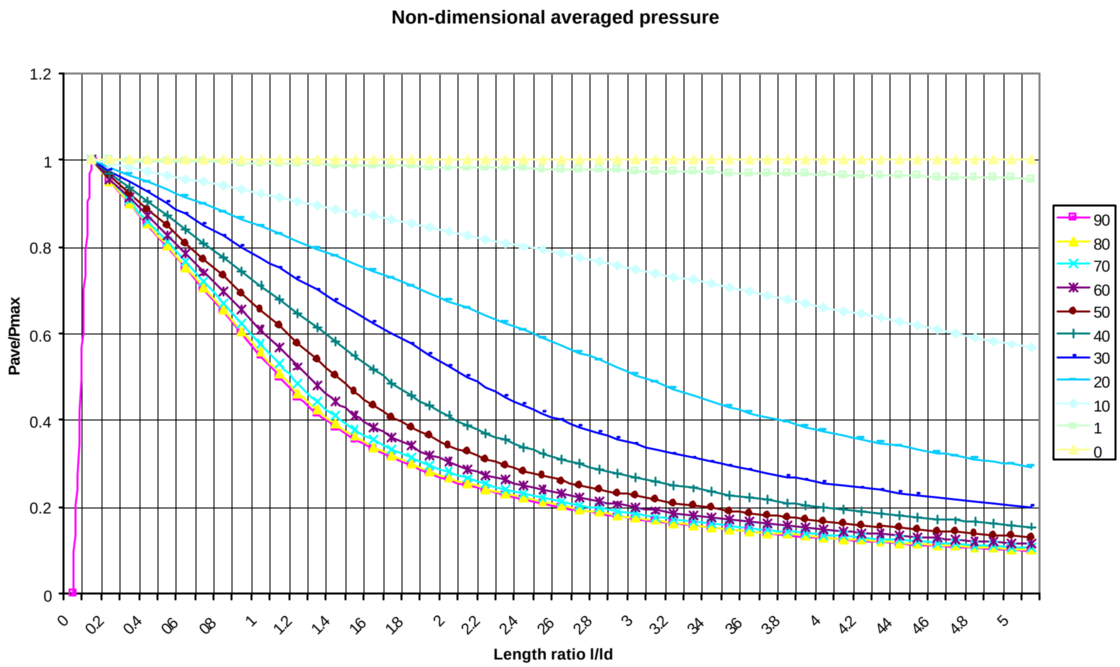


Figure 1: Variation of Scale Factor with load to target length ratio

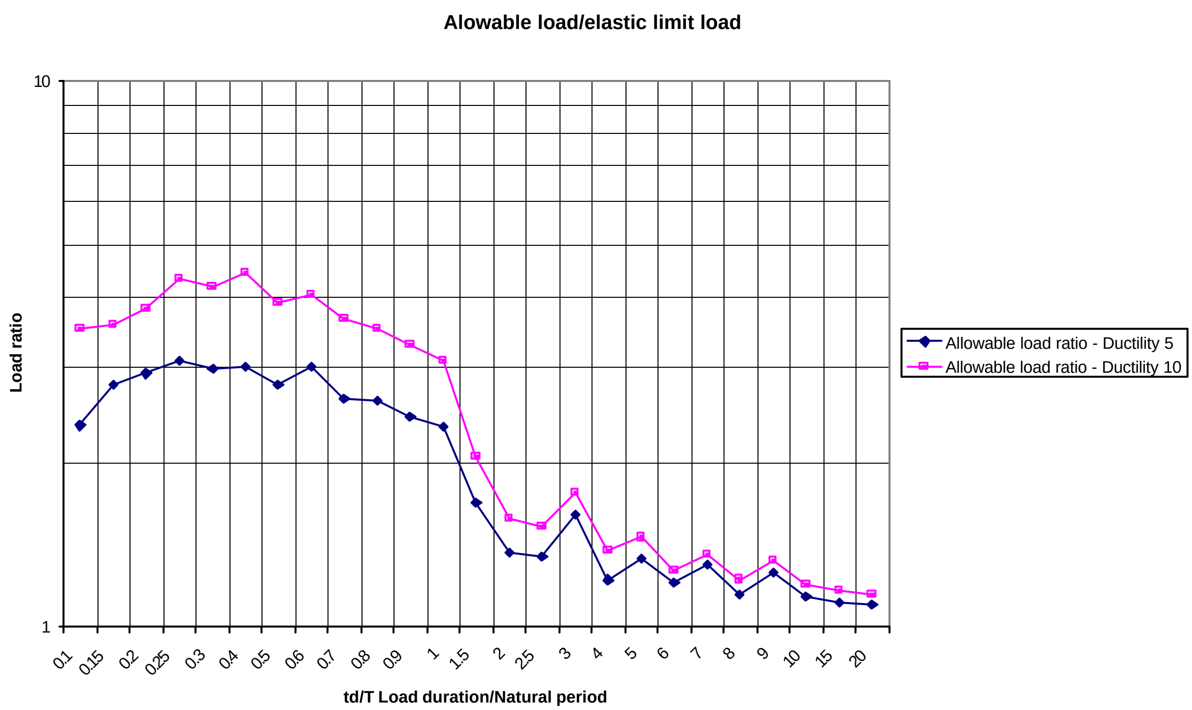


Figure 2: Capacity Ratio Curves (Ductility Factors)

WORK GROUP 4

FIRE LOADING AND RESPONSE

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1.0 Fire Loading and Response Introduction

This Working Group's objective, during the Workshop, was to generate discussion concerning the different types of fire loads that could affect the design of an offshore facility and how to effectively design the facility to manage the effects of fire. It was recognize that there is wide range of approaches still being used to identify fire hazards and account for their effects in facility design. The range goes from code compliance through a goal setting approach which aims to meet performance objectives. The discussion will include but is not limited to:

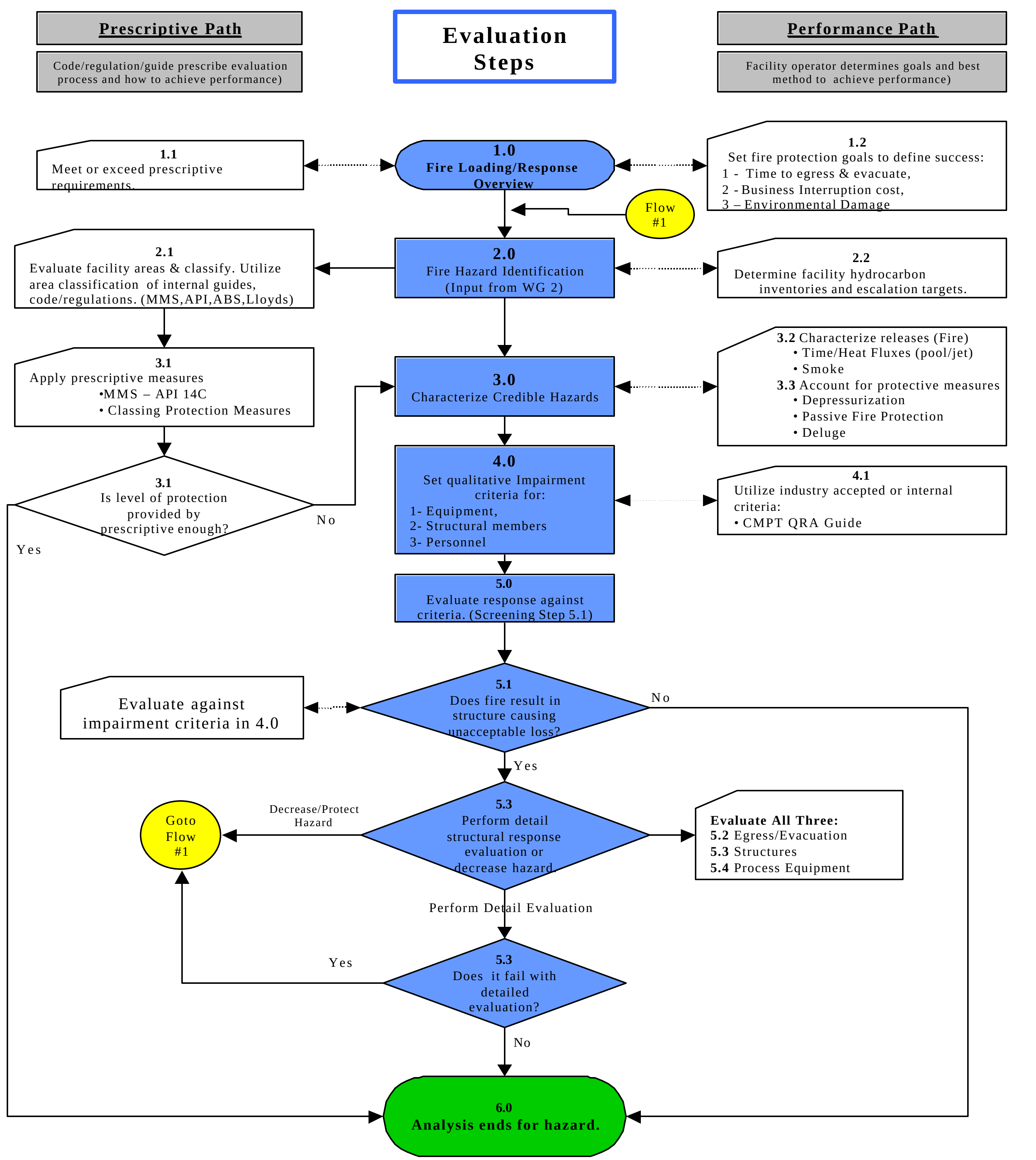
- Fire protection strategies, deciding the most effective approach to follow: prescriptive, performance or both. (Global approach or varies by hazard);
- At which stages of the design, should the fire hazard identification/characterization activities take place;
- How to characterize credible fire hazards (Heat/Smoke);
- Setting personnel, Structural, and Equipment impairment (failure) criteria;
- How to screen the different types of fire hazard scenarios and to determine what structural members, vessel & piping supports are critical;
- The qualifications and responsibilities of those executing the fire scenario identification and fire loading analysis.

The fire scenarios discussed in this workgroup will be the result of the efforts of Workgroup #2 who will provide the most credible scenario after the application of an inherent safe approach to process and layout design of an offshore installation. The approach to this workgroup was to utilize the decision making tree ,Figure 1 to help with flow of the session's discussion. Types of Installations considered include:

- New Design/Retrofits or Redeployment
- Linked Facilities
- Subsea Well Tie-Back
- Floating/Fixed (marine)
- Pipelines
- Unattended/Attended

The discussion included such topics as Emergency Response/Capability, movement of companies to minimize the use of active fire fighting systems and equipment on new offshore designs and focusing more on providing personnel protection, safe egress & evacuation from fire scenarios. Todays facilities design is often focused towards an inherent safe design strategy and awareness of life-cycle facility costs of fire fighting equipment and systems.

Figure 1: Fire Loading and Response Decision Tree



1.1 Prescriptive Path

This route is taken when the project or company requirements or specifications dictate that the engineering design is to comply, as a minimum, with the prescriptive requirements. The prescriptive requirements can be dictated by the legislation, regulations, classification, Industry practices, company guides/practices.

1.2 Performance Based Path

This route is taken when the designer or operator has successfully identified their credible fire hazards and mechanism, analyzed the likelihood and consequence of the event and assessed that the prescriptive requirements do not match the fire consequence hazard it was to mitigate against. The performance approach emphasizes flexibility in designing to manage hazards. The purpose of the path is to provide documentation and justification for an equivalent-level-of-safety engineering proposal that will meet the intent of the prescriptive requirement. Decisions on whether to adopt a performance based approach depends on the design project team willingness and technical capability of adopting this approach. The performance approach should be based on sound engineering principals and not opinions.

To help with the decision-making process, whether to comply with industry standards/regulations or to utilize a risk-based method, a simple list of questions could be used to guide project management on the approach to fire protection. The typical questions, for a capital project, would be:

- Will this be a simple/standard or novel/complex offshore facility?
- What are the regulations/guidelines to be used in the design?
- Will the type of personnel involvement or the philosophies related to the operation and/or maintenance of the new facility or equipment differ substantially from what is currently practiced by the company (manpower can affect the maintenance of the passive fire protection system)?
- Will the new facility, equipment, instrumentation, etc. introduce new technology to the designers and operators (schedule will be affected by first time risk-based engineering designers)?
- Is one of the objectives of the new project to optimize staffing levels in the new facility (less PFP will mean less maintenance)?
- Will a different user population use the new facility than is intended in the design standards and specifications? Will a U.S. engineering contractor using U.S. design standards design the facility, for use in another country and operated by local or third-country nationals? If so, the design will require some simplification in the design to cater to the user population.
- Is the project team willing to spend more time in working with a risk-based approach?
- Credible Leaks (Corrosion, Erosion, Maintenance, Dropped Object, etc)

The answers to these and many other questions helps determine the appropriate level of risk management involvement in the design of the new project. The fire hazard identification work is performed at different phases of an engineering design project. As the engineering project progresses the level of details available provides input to more accurate analysis and assessment of the mechanism of the fire scenarios and its consequential effect to an installation structure. The different project phases, where fire hazard identification will occur are represented in the diagram below.

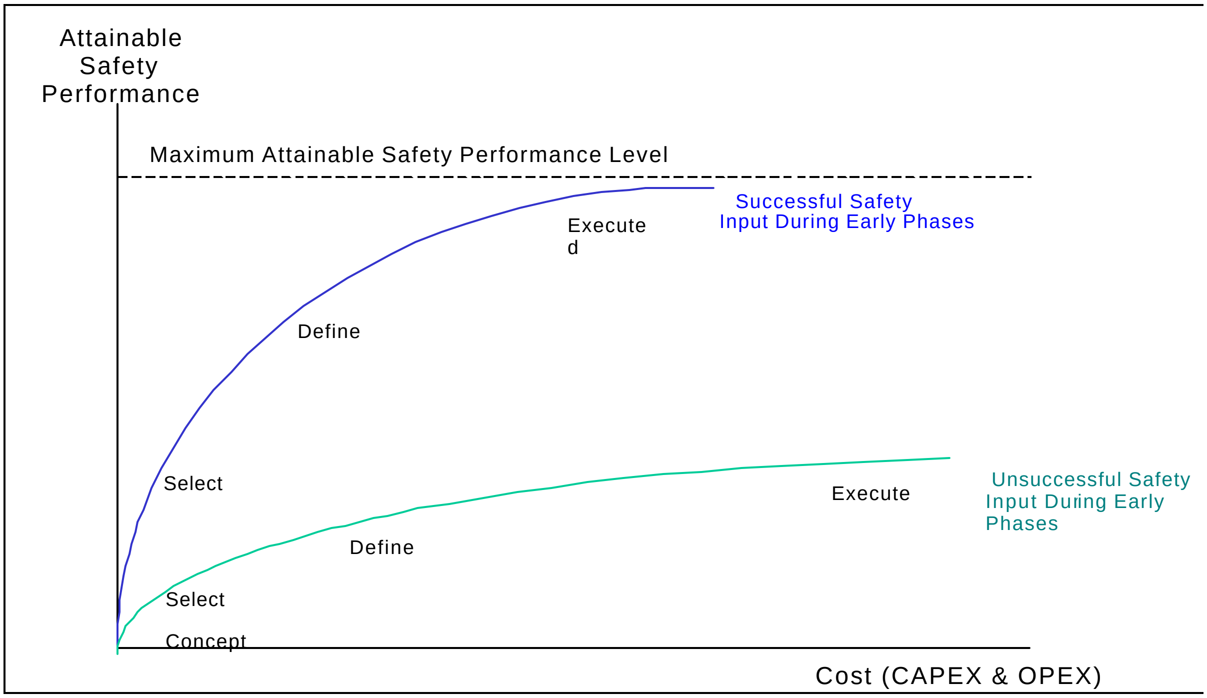


Figure 1: Attainable Safety Performance versus Cost during the different phases of a Capital Project

It is critical that engineering designer understand the advantages or benefits of a performance-based approach during the different phases of an engineering project. Also, the most difficult part of this approach is the determination of the operational performance standard, early on in an engineering design, which would accurately reflect the true operations of the facility. There is always discussions on whether to protect assess or personnel/environment and credits taken on the fire protection strategy and the type of structural assessment that will have to be performed.

1.2.1 <u>Influencing Design Safety and Project Phases</u>

Most design engineering projects follow three phases of execution. Hazard management activities are integrated with design activities in each phase as noted below:

- **Select (Conceptual):** The fire hazards associated with all the development options under consideration are identified and categorized and will be and integral part of the concept selection decision-making process. The major hazards of the selected option will be defined for subsequent design and/or evaluation

- **Define (FEED):** Develop strategy for managing fire hazards while optimizing the concept. Specifically, decide how to manage the hazard, identify what is needed to implement the decision, and set the performance standards for the safety systems
- **Execute (Detailed):** Design to the strategy and achieve the required performance criteria and validate that hazards have been identified and managed in accordance with this fire hazard management strategy.

The most cost-effective phase, to manage major fire hazards, in a project life cycle, is during the Select and/or Define activities of a development project (see Figure 1). During the course of a project the above drivers could change in priority and thus any fire risk management decision will have to maintain or consider these elements during the course of design development or management of change issues.

1.2.2 Setting Performance Goals

One of the most difficult aspects of working with a performance-based design is the establishment of realistic goals for the design team. The performance goals are normally categorized by:

- Time to egress & evacuate:
- Business Interruption Cost:
- Environmental Damage:
- Damage to reputation.

These goals define the expected performance of the safety systems. It will normally have the following criteria for the safety systems:

- Role or purpose of the system;
- Minimum functional performance standards to ensure effectiveness;
- The Probability of success, or system availability;
- Survivability.

These performance goals are specific for the fire hazards and the safeguards for the designed facility. It is critical to ensure that when setting these goals there is a clear definition of success,

1.2.3 Structural Assessment Process (API 2A)

The structural assessment process, used during the engineering design of an installation, for a performance-based fire loading approach can vary depending on the experience of the project team (operators, contractors and regulators/certification agents). Experienced project team are more focused with the approach resulting in a more cost-effective fire protection design. During the engineering design process there are constant interactions between the structural and loss prevention/safety engineering disciplines. The interactions are focused on providing a realistic and cost-effective solution to the fire hazard concerns on the facility design.

An example overview of an assessment process is presented in Figure 2 and 3 (See Figure 10.1 in Appendix A). It was primarily used during the conceptual phase of a project to screen those platforms considered to be at low risk, thereby not requiring detailed structural assessment.

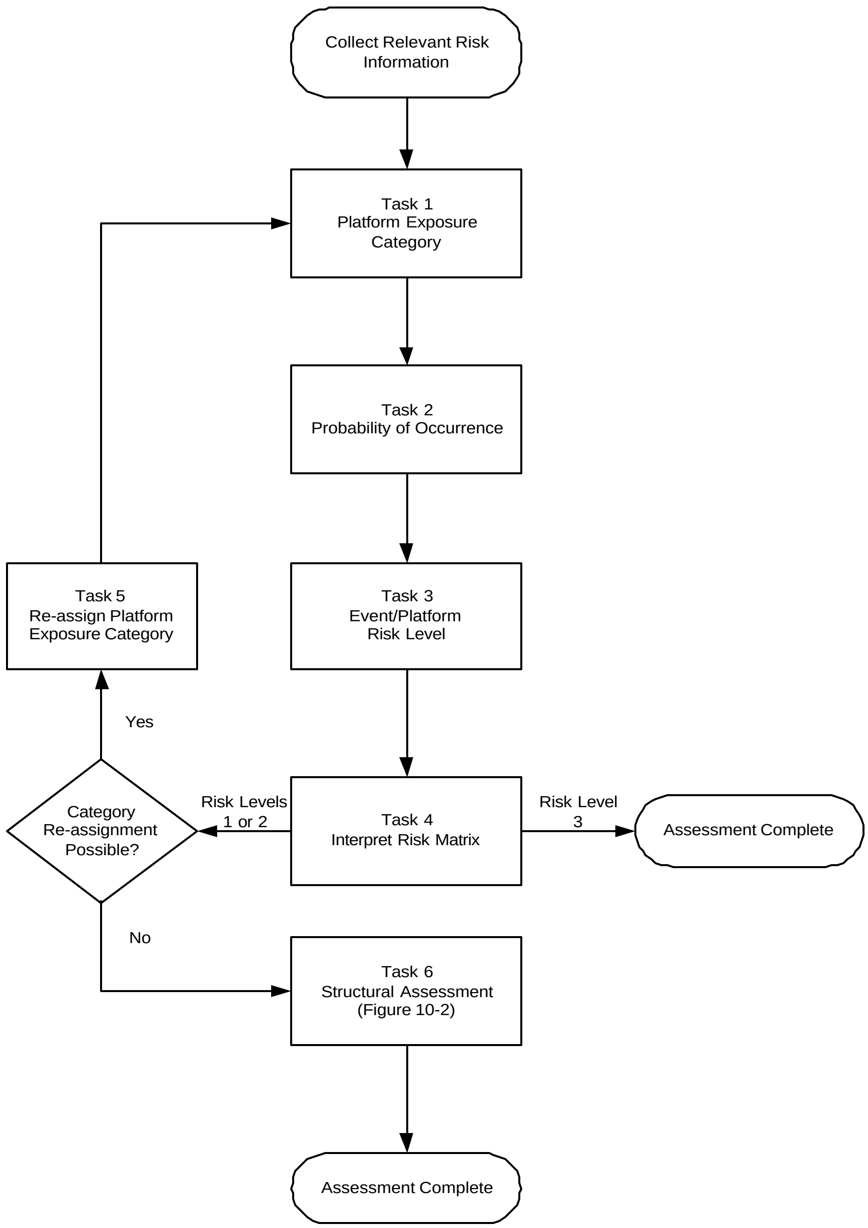


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Figure 2: Example of Structural Assessment Process

The assessment tasks listed below should be read in conjunction with Figure 2 and Figure 3 below. The tasks are as follows:

- Task 1: For the selected platform, assign a platform exposure category.
- Task 2: For a given event, determine probability of occurrence of the event and assign level L, M or H.
- Task 3: From Figure 3, determine appropriate risk level for the selected platform and event.
- Task 4: Interpret risk level to conduct further studies or analyses to review risk, consequence, and cost of mitigation.
- Task 5: If necessary, reassign platform exposure category and/or mitigate the risk or the consequence of the event.
- Task 6: For those platforms considered at high risk for a defined event, complete detailed structural integrity assessment for fire or blast loading.

Probability of Occurrence	**Platform Exposure Category**		
	E-1	**E-2**	**E-3**
High	Risk Level 1	Risk Level 1	Risk Level 2
Medium	Risk Level 1	Risk Level 2	Risk Level 3
Low	Risk Level 2	Risk Level 3	Risk Level 3

Figure 3: Risk Matrix

1.2.4 Fire Protection Strategy

During the project inter-discipline (primarily Loss Prevention/Safety and Structural) discussions one of the most effective method of minimizing the magnitude or potential of an identified credible fire hazard scenarios is to develop a Fire Protection Strategy, Philosophy and/or Plan). The Fire Protection Strategy provides directions to project management in the identification of the major fire hazards that would exist in the life-cycle phases of the development. The strategy will also include the measures in the management process, including design that will eliminate the hazard or will minimize the consequence or likelihood of the major fire scenarios. The Fire Protection Philosophy will provide the project team with the design priorities in the management of fire on a facility. This will normally follow the order of:

- Elimination;
- Prevention;
- Detection and Control;
- Mitigation;

- Emergency Response.

The order of preference to manage a fire hazard, during engineering design, is passive, active, operational and external systems. The objective is minimal personnel intervention. The final hierarchy of documents that would manage a credible fire hazard is a Fire Hazard Management Plan. The objective of a plan is to communicate the credible fire hazards that have been identified, during engineering design development, and the prevention, control and mitigation systems that have been implemented to reduce the likelihood and consequence of these hazards to an acceptable level of risk. The plan normally provides a list of credible fire accidental events, derived from a Fire Hazard Analysis, at different locations within the installation. The plan will provide for each credible fire scenario;

- The major consequences of the event and the potential consequences;
- The safeguards that have been included in the design to prevent, mitigate or control the hazards and resultant consequences;
- A ranking that will demonstrate the level of risk for each fire scenario;
- A statement of performance goals for the associated prevention, mitigation and control systems that will be implemented in the design.

The plan documents the identified credible fire hazards and the design strategy implemented by the project engineering team to address these hazards

The management of fire hazards will be addressed in the Safe Design Practices - Workgroup 2.

2.0 Fire Hazard Identification

The identification of the credible fire hazards is derived from the Safe Design Practices - Workgroup 2. During an engineering design process this hazard identification would include, but not restricted to, techniques such as:

- Hazard Identification (HAZID);
- Checklists;
- Failure Modes and Effect Analysis (FMEA);
- Fault Trees;
- Hazard and Operability (HAZOP) studies.

Further analysis and assessments are required, after identification, to obtain a better understanding of the mechanism or nature of the fire hazards involved.

2.1 Prescriptive Hazard Identification (Codes, Regulations, Guides)

The easiest method to be adopted by an engineering design team is more of a compliance based risk management approach where the designer/operators will adhere to applicable codes and regulations for the installation. This is most familiar with the majority of the operators and engineering designers and it involves little demand in engineering innovations and eliminates the risk of non-compliance. One deficiency with this approach is based on generic concerns in design of an offshore unit; it must be noted that the establishment of these generic concerns were based on historic facts, incidents and lessons learned from the offshore industry. Another concern with adhering to codes/regulations is that there is no potential opportunity to save money on weight, CAPEX/OPEX costs (installation / maintenance costs) or project schedule. The prescriptive approach is the standard for most intra-company engineering guides.

2.1.1 Changes in Prescriptive Codes, Regulations and Guides

The use of established codes, rules and regulations to dictate the design and layout of an offshore facility, represents the traditional prescriptive design approach. A practical example of such a prescriptive regulation is the IMO MODU Code that requires that a bulkhead with an A-0 level of fire integrity be provided to separate an accommodation space from a galley. Since such prescriptive rules apply to a wide range of potential design scenarios, they are generic in nature, typically providing overlapping layers of protection with associated redundancy.

2.1.2 Applicability of Prescriptive Measures

Many traditional prescriptive codes, such as the International Maritime Organization's *Convention on the Safety of Life at Sea* (SOLAS) and those generated by classification societies, such as the *ABS Rules for Building and Classing Facilities on Offshore Installations*, are now incorporating provisions to permit performance based alternatives. Performance-based rules are typically based on the functional requirements of each space, establishing a target level of safety, while providing the designer the freedom to achieve the goals. As an example, a performance based regulation, may state that the objective is to safeguard occupants from the effects of fire while they are evacuating a vessel. Proponents of a performance-based system provide the following justification for the application of such an approach:

Innovation

Performance-based regulations allow a design team to select materials and arrangements outside the boundaries formed by prescriptive codes and standards. As a result, the vessel design is no longer restricted to the predefined conditions within the regulations; instead, the fire safety measures can be chosen to address the specific hazards present in each vessel.

Clarity

The overall fire safety objectives of the regulations as outlined in the above example, regarding occupant egress from a vessel, are explicitly defined and can be easily understood by all parties.

Potential for financial savings

Since prescriptive codes apply to a wide range of potential design scenarios, they are generic in nature. As a result, prescriptive regulations can be conservative, providing layers of protection with associated redundancy. In comparison, in a performance-based approach, the fire safety measures are designed for a particular vessel with pre-defined occupancy and operational characteristics. The fire safety system can therefore be designed without the need for duplicated or overlapping safety measures, reducing the vessel's construction and life cycle costs.

International harmonization

Many prescriptive regulations are developed by individual Administrations as a result of previous fire incidents within their area of jurisdiction. As a result they are only applicable to specific geographic locations. Performance-based codes have the potential to remove these regional barriers, allowing for the global communication and acceptance of fire safety standards.

Improved knowledge of loss potential

Since a performance-based design approach requires the fire safety of each vessel to be independently considered, an improved knowledge of the loss potential may be developed.

2.2 Performance Base Hazard Identification

To move towards a risk-based approach, the project team would have to categorize the hazards involved in the design. The following is an example of a hazard management framework utilized to ensure that the appropriate emphasis and consistency in the implementation of a fire hazard management throughout all capital engineering projects. This framework entails categorizing the hazards, at any phase of a project, based on the understanding of the fire hazard and the potential consequences and then applying the appropriate management approach(es); see Figure 2. The hazard categorization (See Figure 3) will aid in:

- Providing the guidance on management or engineering decision making on how the fire hazards will be managed and the fire protection systems that will be utilized;
- Providing the guidance on establishing the level of verification required to show that the design is acceptable and that the fire risks have been minimized
- Prioritizing the utilization of key specialist resources

2.2.1 Structural Hazard Assessment (API 2A)

The platforms with assigned risk level 3 do not warrant structural assessment. The platforms with assigned risk levels 1 or 2 may trigger structural assessment as determined from Overview of the Assessment Process shown in Appendix A - Figure 10-1. If required, structural assessment must be performed for a representative range of fire or blast scenarios for the 'survival' of the platform. The structural assessment process is shown in Appendix A - Figure 10-2.

For platforms with risk level 2, a structural assessment may start with performing a screening analysis. Should a structure fail in screening analysis, then a design level analysis should be carried out.

Probability of Occurrence	Platform Exposure Category		
	E-1	E-2	E-3
High	Risk Level 1	Risk Level 1	Risk Level 2
Medium	Risk Level 1	Risk Level 2	Risk Level 3
Low	Risk Level 2	Risk Level 3	Risk Level 3

Figure 3: Risk Matrix

For platforms with risk level 1, a structural assessment may start with a design level analysis. If the structure fails in design level analysis, then an ultimate strength analysis should be performed. If the ultimate strength analysis fails to meet the performance criteria, then mitigation measures should be considered. This may include measures for elimination of the initiating event, reduction of the severity of the event, and/or structural modification. If none of the mitigation options is feasible, fire protection measures should be considered to satisfy the performance criteria.

2.2.2 Hydrocarbon Inventories and Critical Equipment

If a more detailed fire hazard analysis is performed then the design team must try to rationalize which systems are deemed critical from a safe production perspective. This is where the major safety functions are identified and defined as well as performance standards are needed to demonstrate acceptability. The goal of the major structural members is focused on ensuring safe egress, structural integrity, temporary refuge and safe evacuation. The type of escalating scenarios is also defined at this step such as:

- fire preceding an explosion,
- an explosion then a fire (jet or pool),
- a jet fire then pool fire;
- a pool fire resulting in a jet fire;

It is normally at this stage where the design team will ask the risk or loss prevention analyst about the credibility of the scenarios but the certainty cannot be defined due to the uncertainty in the amount of potential leak path at the early phases of a design project. The key is to identify the critical escalation targets (prioritizing the consequential effect may be a means of screening what is critical) and the duration of the heat load due to the hydrocarbon inventory and other factors such as:

1. The fire event parameters;
2. The fuel types to be considered;
3. The types of storage and releases to be considered;
4. The inventory on the installation;

5. The fire hazard location.

The amount of fuel available for a release is a good indication of its damage potential. The fuel quantity thresholds below were taken from an operators internal guides. The fire must be large enough to have a reasonable chance of engulfing one or more critical items and it must last for a sufficient duration to cause failure. Depending on the release hole area, a small inventory could give a small fire for a long time or a huge fireball for a few seconds. Notwithstanding the effect of hole size, the damage potential can be summarized as follows:

- Up to 1000 lb: Escalation is most unlikely. Fires will be small or only last a few minutes
- 1000 to 5000 lb: Potential for local escalation within a module or in the immediate processing area. Moderate fires will last up to 30 minutes
- 5,000 to 20,000 lb: Potential for total engulfment of a module or process unit. Potential for structural failure and process escalation unless there is effective protection. External flaming from offshore modules and flame impingement on adjacent processing areas may also occur. Fires could last for more than an hour.
- 20,000 lb plus; Potential for simultaneous engulfment of several process areas total module engulfment. Potential for external flaming and partial or total topsides engulfment which could last for several hours.

3.0 Characterizing Credible Hazards

At this stage of the stem process there is the determination of the minor, major, design and residual accidental events. The project team will determine what is considered to be the credible fire releases and scenarios. At this point of the process the duration, length and potential direction of the fire scenarios have been identified. The critical structural members, resulting from the fire model, will also be identified.

At this point of an engineering project, it must be emphasized that there is normally different project groups working on the development; especially for a floating production system. On a typical deepwater offshore project this could be divided into the:

- Topsides group;
- Hull group;
- Drilling group;
- Well Systems and / or Turret group;
- Risers and flowline group;
- Mooring group.

Therefore it is critical that Simultaneous Activities or Operations (SIMOPS) be addressed after or during the fire modeling work. There are considerable project (schedule / weight / cost) pitfalls when the fire loads are treated in isolation by a project group; communications of the fire modeling work to all the development group is essential to accurately identify the consequential effects or events to the facility.

The other item to be addressed when the credible events are established is the full understanding of the barriers and safeguards that are either part of the design specification or philosophy or will be incorporated into the design to mitigate the fire accidental event. This information is critical in determining the likelihood for the event.

3.1 Prescriptive Path Hazard Characterization

Codes/Regulations/Standards

Evaluate facility areas and classify according to contents. Utilize area classification of internal guide, codes, and regulations. (MMS, API, ABS, Lloyds)

Does judgment/experience help determine that the level of protection provided by the prescriptive requirements is enough? If not then go to performance based hazard characterization (Qualitative/Quantitative) and determine further protective measures. The subtlety of code or regulatory interpretation is dependent on the experience of the certification surveyor.

3.1.1 <u>Applicability of Prescriptive Measures</u>

(API / NORSOK / IP / SOLAS/ ISO / MARPOL / NFPA /ABS Rules / LR Rules / DNV Rules, etc… as well as NPD / MMS / USCG / UK HSE / CNOPB-CNSOPB / Australian, etc.. Regulations)

When working with the project group the relevant regulations have a combination of both prescriptive and risk based or objective types of rules or guidelines. As mentioned above most regulations have an "Equivalency" clause in which an operator/designer could deviate from the legislation as long as there is a demonstration of "an equivalent level of safety". The demonstration document is in a form of hazard analysis and assessment that will show that the alternative design option has not jeopardized the facility safety performance; in comparison to what is the design norm. There are even instances where some of the regulations or rules may increase the level of risk on an installation. The key aspect here is that there will be a deviation from what is normally imposed on the facility structure and thus it is critical that the critical heat loads are accurately identified to evaluate structural performance.

The key portion here is also a standardization of A-class and hydrocarbon class fires (H-class) but still no standard jet fire test and passive fire protection classification. The optimization of PFP, when applied to primary structures, has matured as methodology for the last 12 years. There is now more fire test data on the different type of PFP available that it is easier to custom make the required amount of PFP for a structure and have a certificate to back up the optimization results.

3.2 Performance Path Hazard Characterization

The heat flux is normally provided to the structural modeling to determine conduction / convection / radiation heat transfer. This portion also will deal with the potential smoke effects of the fire. The impairment of escape or egress routes will be important from a consequential perspective. During this part of the project some aspects that would have to also be considered would be;

- Resolution of fire hazard characterization
- The effects of diking/bunding and drainage on the release scenario duration.
- Decision Making Process and Screening Criteria
- Assessing the impacts of fires
- Methods of modeling
- Competency of screeners
- Lifecycle (Fit for Life or Fit for Purpose?) criteria

3.2.1 Resolution of Hazard Characterization

One of the first and foremost aspects to resolve in a performance based fire loading strategy is the determination of the amount of fire hazard detail, characteristic or resolution needed to make a decision. It is critical to first get a thorough understanding of the fire hazard before making fire protection recommendations that could potentially affect the cost, weight or schedule of a development project. Significant conservatism (corresponding to weight, cost and schedule impacts) in fire protection strategy could be encountered with poor understanding of the fire hazard involved.

The use of a screening approach (categorizing design fire events and residual accidental event or major accidents) is one method to focus on the most critical design aspects. Utilizing a screening approach involves developing an inventory of credible release cases. Once the release cases are determined then initial characterization is completed for all of the cases. The results of the empirical modeling against conservative impact rule sets. The release cases which do not cause failure when held against the impact rules are put aside and considered addressed. At this stage conservative recommendations can be made which will likely be more than adequate to address the hazards. There is usually incentive to further refine the recommendations when implementing their cost is comprehensively evaluated. To address this, the evaluator will evaluate the remaining credible cases and increase the accuracy of the release characterization and impact assessment. The detail of either the release characterization or impact assessment should be increased in a step fashion to manage engineering costs.

3.2.2 Heat Loading

The calculation of heat flux from each type of fire scenario will be described below. The environmental and layout conditions are critical in understanding the heat flux received by the target structure or vessel. The are no industry recognized standard heat flux rates, this requires the assessor to develop reasonable heat flux loads. The two types of fires that are normally considered are:

- Jet Fires (Liquid & Gas);
- Pool Fires.

3.2.3 Accounting For Objects In Release Path

It is likely that pressurized releases will impact other process equipment (vessel/piping) and structural members. If the objects impacted are of significant size they will cause the released material to lose it's velocity and change directions. The resulting flame will have a larger volume and shorter length resembling a fireball rather than a defined cone shaped jet. This should be accounted for when evaluating flame characteristic calculation results. These changes will affect radiant heat load contours. Due to unpredictable factors (release direction/size, object location, etc) required to definitively account for objects in the release path some practical judgment may be required. Models based on Computational Fluid Dynamics (CFD) can be employed to characterize fires and account for objects response to heat loading. There is a range of practices utilized to determine how object respond to heat loading from the empirical calculations to CFD modeling. Some companies believed CFD modeling is not necessary to make decisions on minimizing and protecting against process releases.

It was noted that one operator has long experience in using a CFD code (Kameleon) for practical fire safety work. When using it in realistic platform modules they often get maximum heat loads ,typically limited regions, the are considerably higher than the industry accepted standards. This means results in relatively short duration on the same point for the highest heat loads. This results in uneven heating which normally it helps for both structure and equipment to survive. This approach sometimes results in conclusions and measures different compared to using simple and more static methods.

3.2.4 Methods to Characterize Fires

Some of the general factors that affect the characteristic of a fire are:

- Shutdown System – Blowdown
- Detection (Availability/Reliability/Response Time)
- Automatic /Manual Response
- Active/Passive Fire Protection
- Understanding Effects of Adding Barriers/Layers of Protection (CCPS/SHELL)
- Isolation/Reduction/Mitigation/Segmentation of Inventories
- Ideas on how to perform modeling
- Effect of Fire Confinement (Enclosed versus Open)

There are always discussions on the fire protection credit given to active systems.

3.2.5 Example Assumptions

Below are examples of general assumptions used to model the release scenarios. When conflicts arise between the general assumptions and the scenario specific assumptions the scenario specific assumptions govern.

Facility Evacuation

1) Estimated time to fully evacuate the facility 60 minutes

General Release Modeling

2) Pipe work (volumes) in model are roughly accurate due to current design detail.

3) fires on the Production and Cellar deck are considered partially confined
4) All process control valves continue to operate as normal during PSD & ESD alarm situations.
5) For gas releases a discharge coefficient of 0.85 is applicable.
6) For liquid releases discharge coefficient of 0.62 is applicable.
7) Jet fire and liquid pool fires on the topsides are modeled as unconfined fires with respect to radiant heat, smoke and carbon monoxide levels.
8) When a jet fire has decayed to a pressure of 10 psig it has effectively ceased.
9) 2-phase vessels are generally assumed to be 50% full
10) Non-process hydrocarbon inventories will be equipped with containment and drainage.

<u>ESD, Isolation, Blowdown, & Fire Rated PSV's</u>

Note: ESD time estimates include the following elements: Time from initial release to detection + Time to full stroke of SDV's & BDV's. Base case is estimated on using fusible plugs as the detection device.

11) After shutdown valves (SDV) close, the gas pressure in the isolatable gas section quickly equalizes reaching the settling pressure in a short period.
12) The blowdown system was sized so that when there is no leak in the isolatable gas section, the pressure will reduce to 100 psig in 10 minutes.
13) ESD is manually activated or automatically activated from detection of fire.
14) ESD closes all process/riser/well SDV's and opens BDV's.
15) All isolation and blow down valves are 100% reliable and function per design,
16) It takes 90 seconds for surface SDV/BDV full movement (45 second for detection & 45 seconds for valve movement)
17) Blow down is initiated immediately upon confirmed fire detection.
18) FSV on BDV's will not leak into isolatable gas inventories.
19) No credit is given for fire sized PSV's which will release mass out of the vessels.
20) Fire sized PSV's protect vessels from overpressure with flame impingement for 10mins.

3.2.6 Gas Releases Consequence Modeling

The following section describes the information required to perform a simple spreadsheet fire hazard characterization.

<u>Data Needed to Characterize Fires</u>

- Leaks Data – Databases to find the information (OREPA/PARLOC/WOAD/E&P FORUM/UK HSE)
- Meteorological Data

- Inventory (Liquid/Gas/Two Phase/Three Phase
-

Release Rates

The initial release rate of hydrocarbon gas through a hole to the atmosphere depends on the pressure inside the equipment, the hole shape/size, and the molecular weight of the gas. For a small hole in the containment, there are two possible release conditions: Adiabatic if the pressure drop across the orifice is large. Isothermal if the pressure drop is small. The adiabatic case is the most common for accident conditions and is described below The process is treated as an isentropic free expansion of an ideal gas using the equation of state:

$$Pv^k = \text{constant} \qquad \text{Equation 1}$$

Where:

V = the specific volume of the gas

K = the isentropic expansion factor which is equal to γ the ratio of specific heats for pure isentropy; but in practice pure isentropy is not achieved, hence k is less than γ

Equation 1 is combined with Bernoulli's equation. Assuming flow on a horizontal axis and using a coefficient of discharge to account for friction at the orifice, the mass flow rate of an ideal gas through a thin hole in the containment wall is:

$$M = C_d \times r_{ambient} \times A_h \sqrt{\frac{2 \times P_{process}}{r_{process}} \times \frac{k}{(k-1)} \times \left[1 - \frac{P_{ambient}}{P_{process}}^{\frac{(k-1)}{k}}\right]} \qquad \text{Equation 2}$$

Where:

M = Mass flow rate (kg/s)

P = Pressure (Pa)

C_d = Coefficient of discharge , typically 0.85 for gas releases

A_h = Area of hole (m^2)

ρ = Density of the gas (kg/m^3)

If the pressure ratio is above a critical value given below, the exiting mass flow is limited to a critical maximum value. This is sonic or choked flow:

$$\left(\frac{P_{process}}{P_{anbient}}\right)_{critical} = \left(\frac{2}{k+1}\right)^{-\frac{k}{(k-1)}} \qquad \text{Equation 3}$$

and

$$M_{\max} = C_d \times A_h \times \sqrt{P_{process} \times r_{process} \times k \times \left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}} \qquad \text{Equation 4}$$

3.2.7 Unconfined gas jet fire Flame Length and Radiant heat

Gas jet fires have a high forward flame velocity and will exhibit an erosive effect on impinged materials due to the momentum of the hot gas flame. Gas jet fires can have high heat transfer rates and have the potential for rapid failure of unprotected equipment.

For quantification purposes, jet fires are approximated by a cone. The base of the cone will be "lifted-off" from the release point and the cone can be deflected by an ambient wind.

The following equations [1] were used to give an approximate size of the flame

Jet Length (ft) ~ 22.8(m)0.46 Equation 5

Flame vol (ft^3) ~ const. x $(m)^{1.35}$ Equation 6

Where: m = release rate (lb/s), constant values are as follows:

Methane = 1100

Propane = 1200

The flame volume is appropriate for the case when the jet flame impacts onto an object and is deflected into a diffuse fireball. The extent of the fire ball is calculated assuming the flame volume is spherical. Gas jet flames are also buoyant and exhibit a strong lifting behavior. This further causes the flame to have more spherical proportions.

The calculation of the flame volume can also be used to assess the shape and dimensions of a fire that might be partially confined by a roof or walls.

When a jet fire has decayed to a pressure of 10 psig the fire is assumed to have effectively ceased. This pressure is close to the transition pressure from sonic to subsonic flow.

When a jet fire event has decayed to this level, its magnitude and exposure potential are considered to have reached a threshold level below which no significant damage can occur (i.e., no escalation potential) and active fire fighting measures can effectively bring the fire under control.

To calculate the radiant heat contours for gas or liquid jet fire, approximated multiplying factors have been developed and are widely accepted [6]. The factors do not account for the affects of objects on radiant heat. The multiplying factor for each heat contour is applied to the flame length. Since the flame length is assumed to be cone in shape, interpretation of a specific release the contours should account for this. The multiplying factors are as follows [6]:

Radiation Level BTU/hr/ft2	**Multiplying Factor Estimate Distance to Radiation Level**
79,200 **(250 kw/m2)**	1.0 **(Objects impinged by flame)**
11,900 **(37.5 kw/m2)**	1.2
4000 **(12.5 kw/m2)**	1.45
1500 **(4.7 kw/m2)**	1.75

3.2.8 <u>Liquid Release Consequence Modeling</u>

Pressurized liquid releases will initially burn as a liquid spray fire, which is similar to a gas jet fire. The higher the pressure, the higher the portion of liquid which is burnt in the spray. As the liquid pressure reduces, the fraction of liquid that burns in the spray will decrease and eventually all the liquid will fall to the ground and form a liquid pool fire.

The transition pressure for liquid spray fire to pool fire depends on the type on the type of liquid. The lighter the liquid the lower the transition pressure.

The transition pressures below which all the liquid will burn as a pool is approximately 60 psi for heavy crude oil, 30 psi for light oil and 15 psi or lower for condensate. At pressures higher than the transition pressure, an increasing portion will burn as a liquid spray. This analysis conservatively assumes that all the liquid burns in the spray above the transition pressure. Below the transition pressure all the liquid will burn as a pool fire.

<u>Release rates</u>

The outflow rate of liquid is determined using a spread sheet that uses the following expression:

$$m = C_d A r_o \sqrt{2gh + \frac{2(P_i - P_a)}{r_o}} \qquad \text{Equation 7}$$

Where: m = Liquid mass release rate (kg/s)

C_d = Coefficient of discharge

A = Release hole area (m^2)

r_o = Density of liquid (kg/m^3)

h = Static head (m)

P_i = Inventory pressure (Pa)

P_a = Atmospheric pressure (Pa)

<u>Unconfined Liquid Spray Fires</u>

For quantification purposes, spray fires are often approximated by a cone. The base of the cone will be "lifted-off" from the release point and the cone can be deflected by an ambient wind. In cases where there is limited spraying or no immediate vaporization, the cone will be narrow but will terminate in a large rising plume. This plume can have the shape and characteristics of a pool fire of the same liquid.

The following equations [1] were used to give an approximate size of the flame. Fire ball size is pertinent to cases where the jet is deflected by local obstructions to the extent that the fire burns as a fire ball rather than a well defined jet.

Spray Fire Length (ft) ~ 39*(m)0.46* Equation 8

Flame vol (ft^3) ~ const x $m^{1.35}$ Equation 9

Where m = release rate (lb/s), constant values are as follows;

crude oil 2100

condensate 1350

The flame volume and fireball diameter are appropriate for the case when the jet flame impacts onto an object and is deflected into a diffuse fireball.

The flame volume is appropriate for the case when the spray flame impacts onto an object and is deflected into a diffuse fireball. The extent of the fireball is calculated assuming the flame volume is spherical.

The calculation of the flame volume can also be used to assess the shape and dimensions of a fire which might be partially confined by a roof or walls.

To calculate the radiant heat contours for gas or liquid jet fire, approximated multiplying factors have been developed and widely accepted [6]. The factors do not account for the affects of objects on radiant heat. The multiplying factor for each heat contour is applied to the flame length. Since the flame length is assumed to be cone in shape, interpretation of a specific release the contours should account for this. The multiplying factors are as follows [6]:

Radiation Level BTU/hr/ft2	**Multiplying Factor** **Estimate Distance to Radiation Level**
79,200 **(250 kw/m2)**	2.0 **(Objects impinged by flame)**
11,900 **(37.5 kw/m2)**	1.2
4000 **(12.5 kw/m2)**	1.45
1500 **(4.7 kw/m2)**	1.75

3.2.9 Pool Fires

Pool fire and jet fires have very different combustion characteristics. Pool fires do not impart a destructive erosive force on impinged materials. Pool fire heat fluxes while high near the burning pool surface, are typically only 60-70% as intense as jet fires.

When there is no wind, the flames from a burning pool will point straight up. However, the wind will cause the flames to tilt, increasing the downwind thermal radiation levels.

The angle of flame tilt is a function of the windspeed. The use of flame tilt greatly increases the complexity of flame and radiation modeling and requires the use of the use of a computer code such as PHAST for accurate results.

Flame modeling

In PHAST, the pool fire flame is represented by a sheared cylinder, with a shape determined according to Thomas's 1965 correlation taking into account the wind velocity. The radiation intensity at a point is determined from the equation below.

$$Radiation\ intensity = T_a \times F_g \times E_{rad}$$

Where:

T_a = is the transmissivity of the atmosphere

F_g = the view factor

E_{rad} = the emission intensity of the radiation source.

This is integrated over the surface of the flame. However, even a simple shape as a shared cylinder does not have an analytical expression for the view factor and numerical modeling is required. PHAST uses an approach based on a range of solutions from numerical modeling for some standard cases.

The smallest pool fire considered in this assessment is a 200-ft^2 fire. The equivalent diameter of the pool for this fire is 16 feet. This is roughly equivalent to the spacing of the primary topside structural supports. For a fire of this size on the production deck the flame height is below the height of the grated mezzanine deck. With flame tilt due to wind it is considered unlikely that a fire of this size will be able to impinge on more than a single primary column beam at maximum heat flux levels. Therefore, a 16-foot diameter fire is considered to be a localized event. A fire of this size can be effectively controlled by deluge, and fire fighting crews should be capable of converging on and containing the fire.

3.2.10 Smoke Modeling

As smoke travels downwind it is diluted by air entrainment and expansion of the smoke plume. The modeling of smoke in this assessment is based on dilution factors for the dispersion of smoke for 10 representative fire sizes. The dilution factors for these 10 representative fires are presented in terms of the burn rate and downwind distance in Table 1.

For fuel controlled fires a source CO level of 5,000 ppm or 0.5% has been used. For ventilation controlled fires 30,000 ppm or 3% has been used.

The applicable column from Table 2 is selected by selecting the representative fire with the nearest burn rate to the fire under consideration. The source level of smoke obscuration and Carbon monoxide is then multiplied by the dilution factor applicable to the distance downwind.

For gas jet fires and liquid spray fires the burn rate is simply the release rate. This is conservative, as the release pressure decreases the percentage of fuel burned will decrease. The unburned fuel will drop out onto the deck and burn as a pool fire at a lower rate

Table 1: Smoke Dilution Factors for Various Pool Fire.

Linear distance	Dilution factor for given burn/release rate (lb/min)									
(ft)	13.2	66	132	660	1,320	2,640	4,000	6,600	9,250	13,200
0	1	1	1	1	1	1	1	1	1	1
33	0.04	0.108	0.154	0.314	0.407	0.498	0.553	0.618	0.658	0.698
66	0.013	0.043	0.064	0.156	0.222	0.298	0.346	0.41	0.456	0.504
100	0.008	0.024	0.036	0.097	0.143	0.199	0.228	0.295	0.336	0.397
130	0.004	0.015	0.022	0.065	0.101	0.142	0.176	0.223	0.258	0.299
200	0.002	0.008	0.012	0.037	0.059	0.087	0.109	0.141	0.168	0.199
260	0.001	0.005	0.008	0.025	0.038	0.059	0.075	0.1	0.119	0.143
330	0	0.003	0.005	0.017	0.028	0.03	0.055	0.055	0.075	0.09

The source level obscuration of smoke for the fire type considered is given in Table 2.

Table 2: Source Obscuration by Smoke according to Fire

Type of Fire	Source Obscuration (/ft)	
	Fuel Controlled	Ventilation Controlled
Gas	49	95
Oil	154	230

For a pool fire the burn rate is a function of the material being burnt and the surface area of the pool fire. Typical values of the burn rate per unit area for the fuel types on the platform are given in Table 3. The burn rates in Table 3 have been used to match the fire being considered to one of the representative fires.

Table 3: Typical Burn rates for Hydrocarbon Fuels, Reference

FUEL	Burn Rate (lb/min/ft^2)
LNG	1.74
Gasoline/condensate	0.072 - 1.2
Kerosene/diesel	0.78
Crude oil	0.54 - 0.72

Ventilation or fuel controlled

Poorly ventilated fires have significantly higher CO concentrations and produce higher levels of smoke. Two correlation formulas were used to determine whether the fire is ventilation or fuel controlled as follows:

Jet Fires: $If\left(\frac{0.5\times A\sqrt{h}}{B}\right)\geq 160$, then fuel controlled otherwise ventilation controlled

Pool Fires: $If\left(\frac{0.5\times A\sqrt{h}}{D}\right)\geq 44$, then fuel controlled, otherwise ventilation controlled

Where A = overall wall opening area (m2)

h = height of opening (m)

B = Jet fire mass burning rate (kg/s)

D = Pool fire diameter (m)

Due to the generally open nature of the platform it is expected that fires in the process areas will be fuel controlled rather than ventilation controlled.

3.3 Accounting for Blowdown

Usually the assessment assumes that prior to full closure of the SDV and BDV, the gas leak continues at the initial rate. This is conservative for larger (2-inch) high pressure gas releases as the release rate is comparable or higher than the normal platform gas throughput rate. These release rates will not be sustainable and will start to drop off prior to operation of SDV and BDV valves.

Upon successful operation of all isolation valves for an isolatable gas volume with a leak, the pressure will start to fall as gas exits through the leak. On successful operation of the blowdown system, the rate of pressure loss will be greater as additional gas exits through the blowdown valve.

The blowdown of gas from the isolatable volume has two components. First the escape of gas through the leak site and second the release of gas to the blowdown system. The release of gas through the leak site is calculated as defined in section 3.2.6.

For liquid leaks, no pressure reduction is calculated for the loss of liquid volume during the release. All blowdown calculations account for gas evacuating through the blowdown system only.

The loss of pressure in the isolatable gas volume is calculated using a numeric procedure using an Excel Spreadsheet as follows:

The initial density of the gas is calculated using the non-ideal gas equation

PV = nZRT

Where:

n = number of moles

= m/M_w

m = mass of gas

Mw = Molecular weight

Z = compressibility

R = Ideal gas constant

$\rho = m/V$

Substituting for V and n.

$\rho = Z M_w P / RT$

The compressibility of the gas is taken from the PFD and simply adjusted for pressures away from those given on the PFD as described below:

$Z = 1 + PB/RT$

Where B is a constant determined for the compressibility given on the PFD.

For the period of the time step, the loss of mass is the loss through the leak and the loss to the blowdown system is calculated using the gas release equation. The gauge pressure to the blowdown system is the difference between process pressure and flare header backpressure. The mass loss to the system over the time step is calculated and the gas density is recalculated.

The temperature of the isolatable gas volume is assumed to remain constant. In reality as the gas expands the temperature would be reduce lowering the pressure, this would be balanced by the heat input from the fire.

$\rho = \{m_{strt}$ -Time step x (leak rate + blowdown rate)} / isoaltable volume

Using the recalculated density the new lower pressure is calculated using the equation below:

$P = \rho R T Z / T$

4.0 Impairment and Screening Criteria Process

It is critical at this phase of the stem process that we not only deal with structural impact but also equipment and personnel impact. The personnel impact will be on the heat load that would be imposed on an individual as they are escaping from the fire accidental event. Depending on the location of the facility will determine the extent of clothing that is utilized and thus determine the susceptibility of personnel to heat loads from a fire scenario.
This section will deal with:

a) Determination of component temperatures
b) Heat balance equations
c) Calculating heat balance equation;
d) PFP systems utilized.
e) Types of steel
f) Types of Concrete
g) Types of Aluminum
h) Types of FRP/GRP

The criteria will include performance standard of the different types of material that could be utilized against a specific type of fire (jet or pool, mass flowrate and directions) and duration.

4.1 Impact Criteria

The following criteria for were used to assess release impacts to personnel escape/evacuation, and equipment failure in fire. The source for each criteria is cited within the table 4.

Table 4: Impact Criteria

Hazard	Impact criteria	Effects
Convective and Radiant Heat[1]	95,000 BTU/hr/ft2 For 5 Minutes **(250kw/m2)**	Failure of small bore piping and other unprotected equipment and structural items. This level is typically experienced where there is direct flame exposure from a jet fire.[6]
	95,000 BTU/hr/ft2 For 10 minutes **(250kw/m2)**	Failure of unprotected large bore piping, vessel support and major structural elements. This level is typically experienced where there is direct flame exposure from a jet fire.[6]
	30,000 BTU/hr/ft2 For 10 minutes **(100kw/m2)**	Failure of small bore piping and other unprotected equipment and structural items. This level is typically experienced where there is direct flame exposure from a pool fire.[6] **Note:** No failure if protected by deluge.
	30,000 BTU/hr/ft2 For 15 minutes **(100kw/m2)**	Failure of unprotected large bore piping, vessel support and major structural elements. This level is typically experienced where there is direct flame exposure from a pool fire.[6] **Note:** No failure if protected by deluge
Radiant heat[1]	12,680 BTU/hr/ft2 **(37.5KW/m2)**	Personnel unable to escape initial release and passage through area is not feasible. No potential to damage lifeboats or other structural items for up to two hours.[5] **Note:** Approximately 265°C producing 2° Burns in 8 seconds[6].
	4000 BTU/hr/ft2 **(12.5KW/m2)**	Escape route to TSR considered blocked.[5] **Note:** 1-API 521 Maximum heat intensity radiant heat exposure where emergency actions lasting up to 1 minute may be required by personnel without shielding but with appropriate shielding. [7] 2-Approximately 205°C producing 2° Burns in 40 seconds[6].
	1500 BTU/hr/ft2 **(4.7KW/m2)**	Unable to man lifeboats. (Considered only after 10 minutes of release) [5] **Note:** 1- API 521 Maximum heat intensity where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate shielding.[7] 2- Approximately 165°C producing 2° Burns in 2 minute[6].
Smoke Visibility[2]	Less than 1 Meter	Unable to use escape routes.[5] **Note:** For offshore personnel who are trained in escape and evacuation in fires and are familiar with the escape route layout of the platform a 1-m visibility is considered reasonable, when personnel are equipped with smoke hoods.[6]
Carbon monoxide[2]	2,000 ppm	Unable to use escape routes or man lifeboats which equates to actions lasting several minutes. [5] **Note:** Equates to a headache in 10 minutes, collapse in 20 minutes & death in 45mins.[6]

1-Calculated as distance from release point.
2-Calculated as ½ the distance from release point to end of flame

5.0 Evaluating Response Against Criteria

5.1 Assessing Smoke Impacts to egress & evacuation

In addition to assessing the structural and equipment response to heat flux, it is often considered prudent to assess the impact to evacuation. The perform this type of assess adequate characterization of the combustion by-products must be obtained. Radiant heat, dense smoke, and CO may impact egress routes and the refuge area. The table above contains several impact thresholds against which the impairment of egress routes can be assessed.

5.2 Assessing Structural Response to Fire (API 2A)

5.2.1 Structural Screening Analysis

In screening analysis, the maximum allowable temperature that a steel member can sustain without reducing its yield strength below 60% of the yield strength (F_y) at ambient temperature, is determined from Table 10 -1. The fact that a fire is an accidental load the allowable stress may be increased to yield stress at maximum allowable steel temperature. In this method of assessment, also known as 'zone method', the stresses present in the member before the fire are ignored.

Using higher strain levels than 0.2% may give a proportionately higher decrease in Young's Modulus giving an unmatched reduction in yield stress. In that case, the zone method may not be applicable being unconservative locally for areas of higher strain.
For 0.2% strain limitation, structural members showing AISC [3] unity ratio of 1.5 with reduced yield stress derived from Table 10 -2 should be considered to have passed the screening analysis.

5.2.2 Structural Design Level Analysis

A design level analysis consists of a conventional linear elastic analysis. The platforms that do not pass the screening requirements may be evaluated using the design level procedures outlined here.

The maximum temperature attained by structural members during the duration of a fire should be computed. Depending on the maximum temperature attained by individual structural members during the duration of the fire, reduced stiffness of the member should be used in the structural analysis. The members attaining temperature greater than the maximum allowable steel temperature shown in Table 10 -1 for a desired strain level should be removed from the analysis.

The linearization of the non-linear stress strain relationship of steel at elevated temperatures can be achieved by the selection of a representative value of strain. A value of 0.2% is commonly used and has the benefit of resulting matched reduction in yield strength and Young's modulus, but has the disadvantage of limiting the allowable maximum steel temperature to 400°C. Using 0.2% strain criteria calls for reduction of yield stress to 0.6 of the ambient temperature value. As a fire is treated as an accidental load, the allowable stress may be increased to the yield stress. The reduced yield stress (0.6Fy) corresponding to 0.2% strain will then give an allowable stress the same as that for the structure before the fire.

Selection of a higher value of strain will result in a higher allowable temperature, but may well also result in an unmatched reduction in yield strength and Young's modulus.

The loads used in such an analysis should be in a form, which could be interpreted as a load case used in the design process.
In investigating the effect of a fire, the 'live' loads such as contained liquids and storage may be taken as 75% of their maximum values as is the case for the consideration of seismic effects. Alternatively, live loads may be taken as the values used in the fatigue analysis performed for the installation.

If the structure fails to meet the established performance standard, then ultimate strength analysis may be performed or mitigation measures may be taken.

Strain	Maximum Allowable Temperature of Steel	
%	°C	°F
0.2	400	752
0.5	508	946
1.5	554	1029
2.0	559	1038

Table 10 -1: Maximum Allowable Temperature of Steel

Maximum Member Temperature		Yield Stress	Member
°C	°F	Reduction Factor	Unity Ratio at 20°C
400	752	0.60	1.00
450	842	0.53	0.88
500	932	0.47	0.78
550	1022	0.37	0.62
600	1112	0.27	0.45

Table 10 -2: Yield Stress Reduction Factor with Maximum Member Temperature

Structural Ultimate Strength Analysis

The ultimate strength analysis allows redistribution of structural load from failed members and can indicate collapse of the structure after no further load distribution is possible. The platforms, which do not pass the design level analysis, may be evaluated using ultimate strength analysis. The temperature-time histories of the structural members subjected to the fire scenario are calculated. The most of the software used for the ultimate strength analysis may allow temperature-time history as input.

The linearization of non-linear stress strain relationship may not be necessary, as the most of the software used for ultimate strength analysis allows temperature dependent stress-strain curves as input. The software may also have the capacity to compute reduction in yield stress and Young's modulus at elevated temperature.
The live loads used in this analysis are the same as those used for design level analysis.
If the structure does not satisfy the established performance standard, then mitigation measures must be considered.

5.3 Assessing Protective Measures

This assessment of the effectiveness and criticality of the protective measures incorporated into the design is dependent on the experience and competency of the assessor. The critical interaction and balance between each of the proposed protective measures and the design engineering constraints (weight, cost and schedule) could only be fully appreciated by personnel that have successfully experienced this scenario in their design career. The measures which should be considered are:

- Active Fire Protection (F&G Detection Systems, Suppression, inerting, etc)
- Passive Fire Protection (Passive Fire Proofing, Diking/Drain, Facility Layout)
- Decision Making on Credits Provided by these Protection/Detection Systems
- Operational Response (Aggressive or Passive Fire Fighting Team response)

5.3.1 Competency of Screeners

As mentioned above the competency of the screeners or assessors (for the fire and structural loads) is very critical in the success of the performance-based fire loading approach. This issue would be addressed in Workgroups 1 & 2. This issue could also include the competency and experience of the certification or verification surveyor needed in the prescriptive approach.

5.3.2 Lifecycle (Fit for Life or Fit for Purpose?)

One of the issues, normally addressed in the design contracts of these offshore facilities is the definition of "Fit for Purpose" or "Fit for Life". The definition of these design requirements could be easily addressed with performance goals or standards. This will be addressed in Workgroups 1 & 2. "Fit for Life" normally includes more asset protection than a "Fit for Purpose" requirement.

6.0 Screening Results

If the loads are acceptable at this phase, then the analysis is complete. If not, then a more detailed look at the credible scenario or the response of the structure or equipment have to be reviewed.

It is very important to know when enough data has been produced to get a full understanding of the mechanism of a fire and sequence of the resultant consequences that could potentially occur.

7.0 Recycling & Presentation of Results

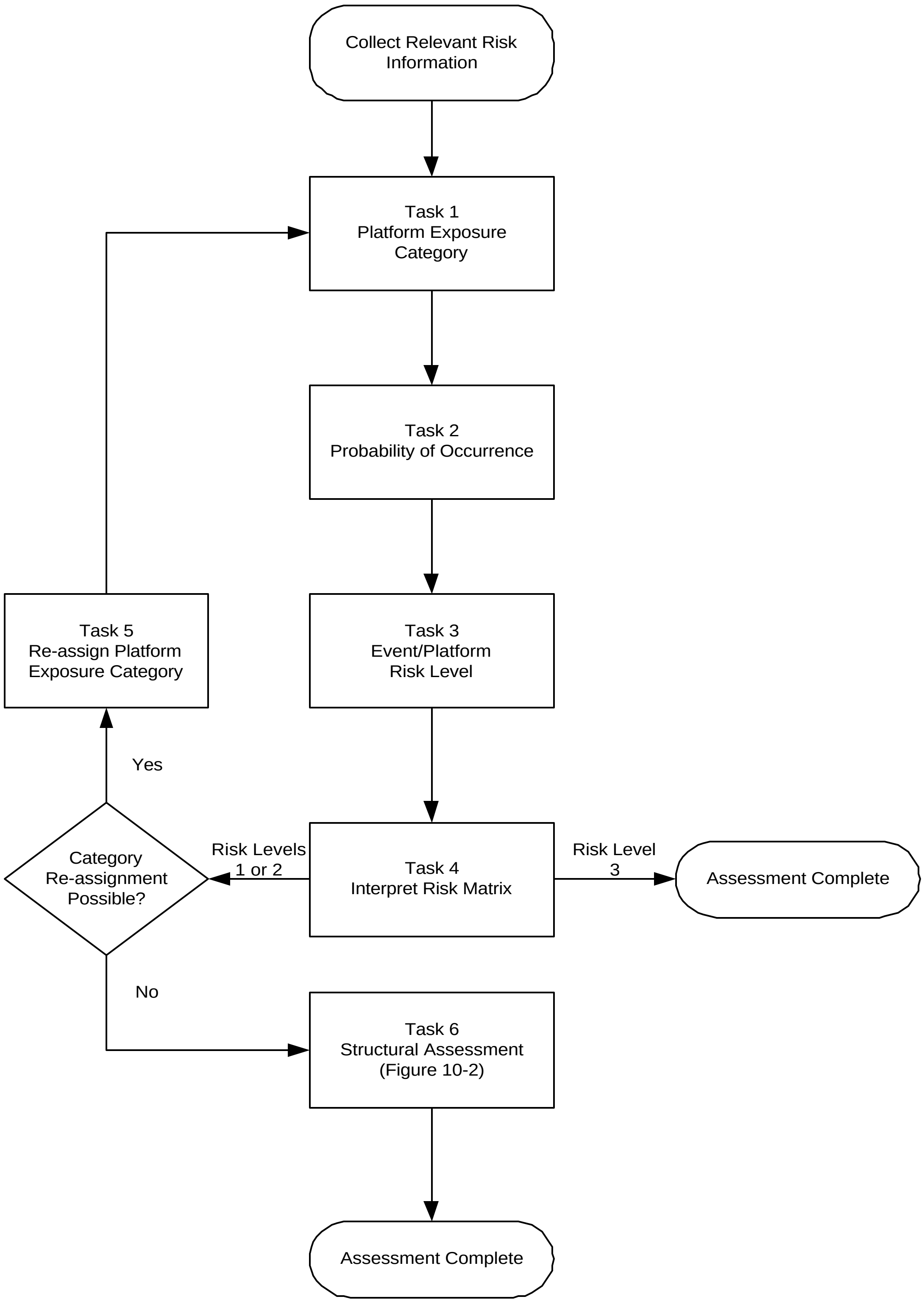
When presenting results from these analyses and assessment work, it is critical to understand who the final audience will be. The information provided to the project decision-makers should be presented and focused so as to capture the attention of the readers. Informed decisions could only be made with informed data that could be easily assessed. Some issues would include:

- Styles – Audiences
- Interpretations
- CADS/Spreadsheets/Layouts
- Hazard Management Plans – Direction
- Implementation
- Verification / Validation
- Variations in Implementation Strategy – What to do to changes?
- ** Decision Making on Whether or Not to do More Analysis

7.1.1 <u>Understanding/Using the Results</u>

As mentioned above the competency of the assessors will determine the utilization of the results of the performance based approach. An experienced assessor or verifier easily addresses the cascading engineering project effect, of the decisions made with regards to fire loading.

APPENDIX A: FIGURE 10-1: OVERVIEW OF AN ASSESSMENT PROCESS



APPENDIX B: FIGURE 10-2: STRUCTURAL ASSESSMENT PROCESS AGAINST FIRE

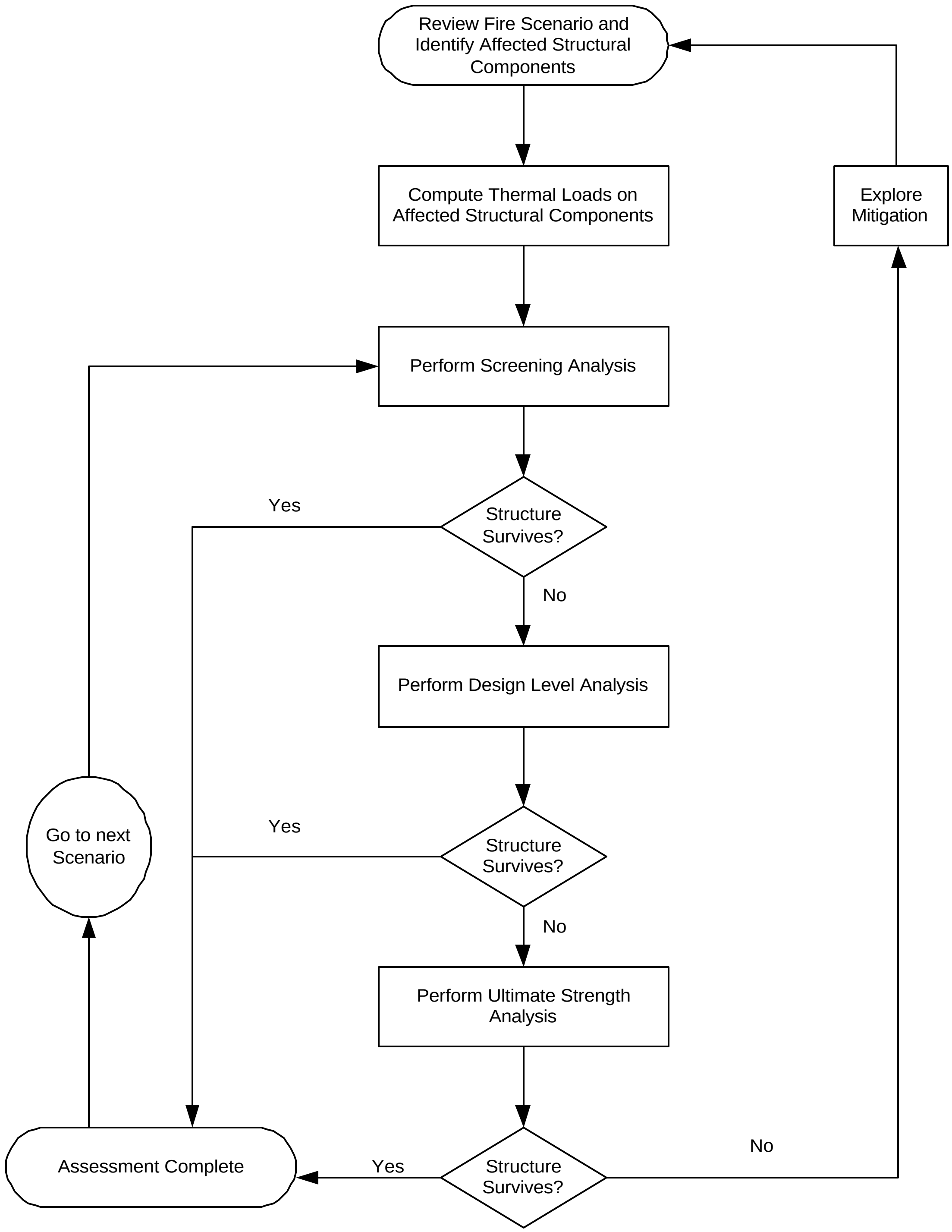
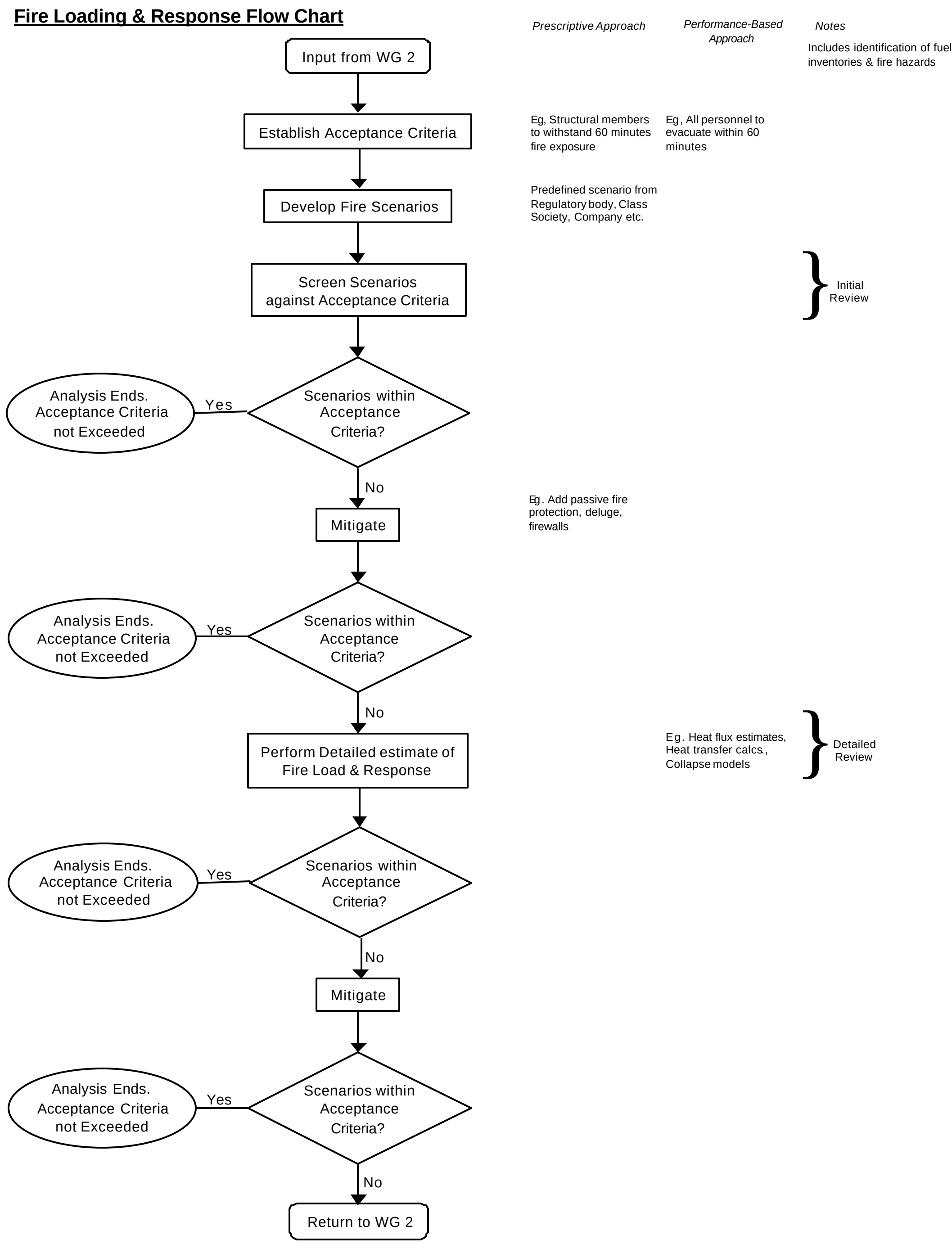


Figure 10.3: Simplified Fire Loading and Response Flow Chart.



8.0 Typical Fire Loading & Response Issues/Checklist

Loading Considerations
- Fire scenario define by WG2
- fire type (cellulosic, hc pool, jet)
- fire location & extent (may be time dependent
- exposure (engulfed, partially engulfed, radiant only), may be influenced by wind direction
- fire duration
- performance objectives (time to escape / evacuate, time to fight fire, F/N criteria)

Heat Load for Members Engulfed in Pool Fires
- Heat input is primarily radiation & convection
- Heat output is primarily re-radiation & conduction
- Radiation input & output depends on surface emissivity
- Heat conduction out is primarily from penetrations
- Heat flux values from fire tests do not necessarily represent actual conditions
-

Jet Fire Engulfment/Impingement
- Heat flux varies widely in actual jet fires
- Uneven heating of member
- Deluge for structural fire protection is ineffective against jet fire
- Thermal shock effects from impingement

Pool Fire Radiation Models
- tilted cylinder (single zone, multizone) requires flame height / flame tilt correlation
- shielding ?
- cfd combustion models (k-eps or LES turbulence) calculate heat load precisely

Fire Test Methods
- Cellulosic test methods (ASTM E119, ISO 834, etc) vary between standards & between furnaces using the same test method
- HC test methods (ASTM E1529, UL 1709 and ISO 834) vary between test methods
- Jet fire test methods (OTI 95 634)
- Failure criteria in test methods may not be the same as failure criteria for actual structure

Heat Transfer Calculations
- May need to consider pre-existing blast damage to structure or fireproofing
- Credit for manual / automatic fire response depends on philosophy / strategy (may be dictated by regulation)
- Fireproofing degradation, defects, damage from hose streams, etc

Structural Response
- Missing member analysis
- Temperature criterion based on yield ? Ultimate failure ?

Technical Resources
• API RP 2A
• SCI Blast & Fire Engineering Project for Topsides Structures
• HSE docs

APPENDIX C: DEFINITIONS

Condensate: A mixture of hydrocarbons (between C4 & C6) that condense from gas when compressed. It will return to gas phase when pressure is removed. It condenses from the gas stream in the compressor area and is collected in the compressor knockout pots.

Diesel, Gas Cylinders, Flammable Chemicals, Methanol, and Glycol: These were present in the fuel systems, hydrate injection, particularly in flare and remote well systems, gas drying and chemical handling, lay-down, storage and injection areas.

Egress – The movement of personnel from working areas on an installation to a place of temporary refuge

Escape – The process of leaving the installation in an emergency when the primary evacuation system is unavailable

Evacuate – The movement of personnel from an installation to a place of rescue by the primary means

Gas: Primarily methane(C1), ethane and propane. The content of the heavier gases and of any residual water reduces as liquids and are knocked out. This covers all gas in the processing plant.

Hazard – A physical situation with the potential for human injury, damage to property and/or damage to the environment

Jet fire – Combustion of high pressure gas and/or liquid

Liquid spray fire – Combustion of a pressurized or two phase fluid release

Pool fire – Combustion of a flammable liquid pool

Stabilized oil: Oil with low water and negligible gas content. Found in the Oil treater, main oil pipeline booster pumps, pipeline pumps, LACT unit, oil export piping, and oil export riser.

Un-stabilized oil: A mixture of oil with significant gas content and water. Present in the Test and Flash separators, LP separators up to the Oil treater degasser.

Well fluid: A mixture of hydrocarbon liquid, gas and water. Present in the production risers and into the Test and Flash Separators**.**

Acronyms

ABS – American Bureau of Shipping

AFFF – Aqueous Film Forming Foam

AISC - American Institute of Steel Construction

ALARP - As Low As Reasonably Practicable

API – American Petroleum Institute

BDV – Blowdown Valve

BLEVE – Boiling Liquid Expanding Vapor Explosion

CAPEX – Capital Expenditure

CFD – Computational Fluid Dynamics

CMPT – Centre for Marine and Petroleum Technology

DNV – Det Norske Veritas

ESD – Emergency Shut-down

FHA – Fire Hazard Analysis

FSV - Flow Safety Valve

LR – Lloyd's Register

MMS – Minerals Management Service

NFPA – National Fire Protection Association

NPD – Norwegian Petroleum Directorate

OPEX - Operating Expenditure

PFD – Process Flow Diagram

PFP – Passive Fire Protection

PSD – Process Shut-Down

PSV – Pressure Safety Valve

QRA – Quantitative Risk Assessment

SCSSV – Surface Controlled Sub-Surface Safety Valve

SDV – Shut-Down Valve

SIMOPS – Simultaneous Operations

SINTEF – The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology

SOLAS – Safety of Life at Sea

TSR – Temporary Safe Refuge

APPENDIX D: WEBLINKS

Classification Societies	
ABS	www.eagle.org
DNV	www.dnv.com
LR	www.lr.org
International Association of Classification Societies	http://www.iacs.org.uk/
Statutory	
Canadian Newfoundland Offshore Petroleum Board	http://www.cnopb.nfnet.com/
Code of Federal Regulations	http://www.access.gpo.gov/nara/cfr/index.html
Her Majesties Stationary Office (UK)	http://www.hmso.gov.uk/
MMS	www.mms.gov
National Maritime Safety Committee (Australia)	http://www.nmsc.gov.au/
Transport Canada – Marine Safety	http://www.tc.gc.ca/MarineSafety/Directorate/index.htm
United States Coast Guard	http://www.uscg.mil/
United Kingdom Maritime and Coastguard Agency	www.mcagency.org.uk
UK Health and Safety Executive	http://www.hse.gov.uk/research/frameset/offshore.htm
Organizations	
American Petroleum Institute	http://api-ec.api.org/intro/index_noflash.htm
Fire and Blast Information Group	http://www.fabig.com/
Fire Safety World	http://www.fs-world.com/
International Association of Drilling Contractors	www.iadc.org
Institute of Marine Engineering, Science and Technology	http://www.imare.org.uk/default.asp
Institution of Fire Engineers (UK)	http://www.ife.org.uk/
International Maritime Organization	http://www.imo.org
International Organization for Standardization	http://www.iso.ch/iso/en/ISOOnline.openerpage
National Fire Protection Association	http://www.nfpa.org

National Transport Safety Board	http://www.ntsb.gov/default.htm
Royal Institute of Naval Architects	http://www.rina.org.uk/
Society of Fire Protection Engineers	http://www.sfpe.org
SNAME	http://www.sname.org/
Steel Construction Institute	http://www.steel-sci.org/index.htm
UK HSE	http://www.hse.gov.uk/
UK Offshore Operators Association	http://www.oilandgas.org.uk/
Underwriter's Laboratory	www.ul.com
University	
Fire Service College (UK)	http://www.fireservicecollege.ac.uk/
Heriot Watt University	http://www.civ.hw.ac.uk/research/fire/
Hong Kong Polytechnic	http://www.bse.polyu.edu.hk/Research_Centre/Fire_Engineering/
Leeds University (UK)	http://www.leeds.ac.uk/fuel/
Lund University	www.brand.lth.se/english/
University of Canterbury	http://www.civil.canterbury.ac.nz/fire/firehome.html
University of Greenwich	http://fseg.gre.ac.uk/
University of Maryland	http://www.enfp.umd.edu/
Worcester Polytechnic	http://www.wpi.edu/
Research Facilities	
Building Research Establishment (UK)	http://www.bre.co.uk/frs/
Fire and Blast Information Group	http://www.fabig.com/
Human Factors Offshore	http://www.hfw2002.com/
National Institute of Standards and Technology	www.bfrl.nist.gov/
Norwegian Fire Research Laboratory	http://www.nbl.sintef.no/
Steel construction Institute	http://www.steel-sci.org/index.htm
South West Research Facility	www.swri.org
VTT	http://www.vtt.fi/indexe.htm
Warrington Fire Research Center	http://www.wfrc.co.uk/
Firenet (UK)	http://www.fire.org.uk/

9.0 References

[1] BP Amoco Upstream Technology Group, "Fire Hazards Training Course", Houston, February 2001.
[2] PHAST Professional 6.0, DNV Hazard Management Software, March 2000.
[3] BP Magnus Safety case
[4] Holstein Explosion Analysis, Vincent Tam.
[5] BP HSQ 01.05.07 "Impairment Criteria" for UK operations, Rev 0: 03/03/93
[6] Center for Marine & Petroleum Technology (CMPT), "A Guide to QRA for Offshore Installations", Rev 99/100.
[7] API RP521: Guide for Pressure-Relieving and Depressuring Systems Fourth Edition77

Workgroup 4 - Fire Loading and Response Workgroup Notes

Summary

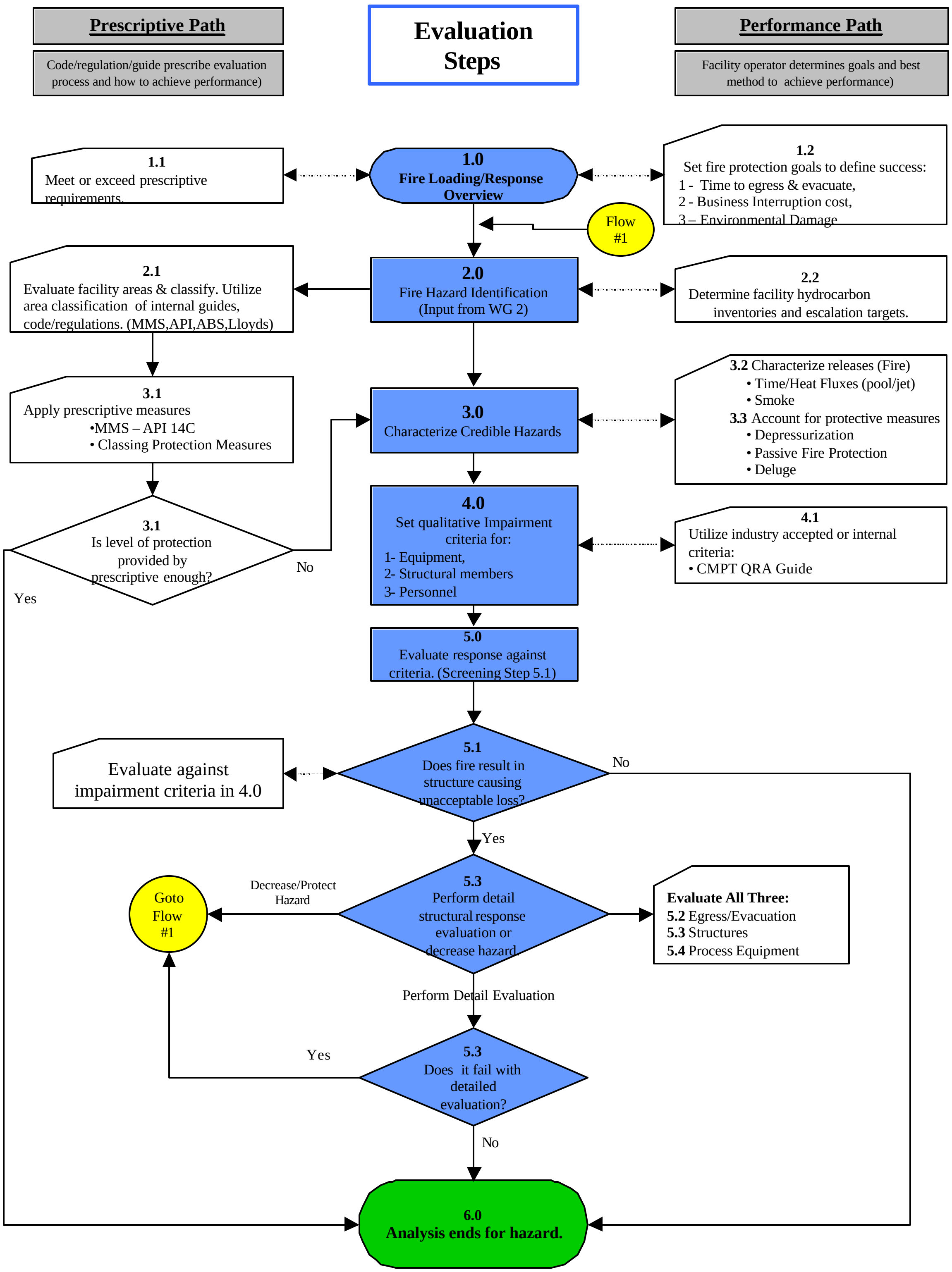
- Workgroup enjoyed sessions and everyone learned something new about the topic
- Excellent audience participation – contribution from all participants in the "peanut gallery"
- Very good mix of technical hazard/risk and structural contribution
- Some additional topics (living quarters) to be added to white paper

Workgroup Participants:

Chair – Joel Krueger (BP) / Ben Poblete (LRNA)

Mike Rivkind – ExxonMobil	Mary O'Hearn – KBR
Mark Andrews – Petro-Marine	Imraan Husain – KBR
John Buckingham – API	Tony Kwei – FMC
Christian Cuellar - ChevronTexaco	David Dykes – MMS
Dave Waterhouse – Granherne	Alex Wenzel – SRI
Tommy Laurendine – MMS	Steve Martin – Chartek
Paul Mather – Akzo Nobel	Duncan Smith – RRS
Pradeep Prakash – Amey	Geoff Redfern - CSO
Sherman Spear – Akzo Nobel	Milan Chakravorty - MSL
Bassam Burgen – SCI	Christy Franklin - RRS
Jens Kristian Holen- Statoil	John Alderman - RRS
USCG	Paul Jacob - MMI

The sessions utilized the flowchart, in Figure 1, as a starting point for the discussions presented below. The authors tried to concisely capture the queries and comments by the participants. The authors did not intend to extrapolate any further the discussions presented below but made every effort that the white paper captured the concerns expressed by the participants.


Prescriptive Path
Code/regulation/guide prescribe evaluation process and how to achieve performance)
Evaluation Steps
Performance Path
Facility operator determines goals and best method to achieve performance)
1.1
Meet or exceed prescriptive requirements.
1.0
Fire Loading/Response Overview
1.2
Set fire protection goals to define success:
1 - Time to egress & evacuate,
2 - Business Interruption cost,
3 – Environmental Damage
Flow #1
2.1
Evaluate facility areas & classify. Utilize area classification of internal guides, code/regulations. (MMS,API,ABS,Lloyds)
2.0
Fire Hazard Identification (Input from WG 2)
2.2
Determine facility hydrocarbon inventories and escalation targets.
3.1
Apply prescriptive measures
•MMS – API 14C
• Classing Protection Measures
3.0
Characterize Credible Hazards
3.2 Characterize releases (Fire)
• Time/Heat Fluxes (pool/jet)
• Smoke
3.3 Account for protective measures
• Depressurization
• Passive Fire Protection
• Deluge
3.1
Is level of protection provided by prescriptive enough?
No
Yes
4.0
Set qualitative Impairment criteria for:
1- Equipment,
2- Structural members
3- Personnel
4.1
Utilize industry accepted or internal criteria:
• CMPT QRA Guide
5.0
Evaluate response against criteria. (Screening Step 5.1)
Evaluate against impairment criteria in 4.0
5.1
Does fire result in structure causing unacceptable loss?
No
Yes
Goto Flow #1
Decrease/Protect Hazard
5.3
Perform detail structural response evaluation or decrease hazard
Evaluate All Three:
5.2 Egress/Evacuation
5.3 Structures
5.4 Process Equipment
Perform Detail Evaluation
Yes
5.3
Does it fail with detailed evaluation?
No
6.0
Analysis ends for hazard.

1.0 Fire Loading/Response

- Don't cherry-pick ideal solutions based on just a cost-basis. The hazards must still be considered, as well as the qualifications of the people who make the judgement. The hazard MUST be well understood.
- Recognize that smaller companies MAY tend not to have detailed safety specifications (and may not want to inve$t heavily in them).
- How to handle retro-fits?
- Recognize that this session is about FUTURE design; recommendations made should not be geared toward existing facilities.
- Applicable internet sites ARE included.
- Will documents listed as references are made public record?
- What prescriptive requirements address structural fireproofing?
- As performance path is more specific than prescriptive, is there the possibility of developing 3 levels of assessment: 10 minute vs 5 day vs intermediate answer?
- Is PFP better than deluge?
- Trade-off between performance and prescriptive
- What about performance-based prescriptive guidelines?

2.0 Fire Hazard Identification (Input from WG 2)

- Regulatory standpoint - can't take credit for any active systems.
  - Vessels and large bore piping will have deluge and blowdown (assumption).
- During an incident:
  - What will the people do?
  - Do they know procedures?
  - What are they expected to do?
    - Abandon
    - Stay
- Is there any precedent for what constitutes an adequate chemical FP system? Majority of fires cost less than $1000, event tree analysis should be done on these cases.
- Recognize the inherent hazards in deferring to OPEX 'that we can live with' while trying to lower CAPEX.
  - Identify potential hazards early in design
- When hazards are identified, their scale should also be identified.
- At what size of platform do prescriptive standards no longer apply?
- Integrated platforms are performance-based, as are deepwater platforms. Different methods for performance-based:
  - checklist
  - QRA
- Targets and assumptions need to be agreed on by committee.
- SFPE article regarding missing piece of fire protection cited size of leak-dominated time of leak.

- Secondary member protection?
- Inspection of FP system?
- What is a realistic offshore platform lifespan?
- Importance of material selection.
- Real time test data (pending Shell report)
- Ongoing manufacturer challenge to reduce element thickness in effort to reduce cost and weight.
- Prescriptive has safety factors built-in.
- Goals to be clearly defined
    - Asset protection, etc.

3.0
Characterize Credible Hazards

-
- LOPA
    - During production phase?
    - During commissioning?
    - Applicability to type of situation:
        - Complex
        - Simple
        - How much data required to perform LOPA?
- Modelling done for credible releases
    - Ex. 3 different hole sizes
    - Some scenarios cannot be designed for
    - Some scenarios cannot be protected againstProbability needs to be addressed during decision-making.
    - 'Design-basis accident' approach includes probability
- Cursory review can address 95% of hazards; remaining 5% will generally require more thorough (quantitative) approach.
- Protective measures need to be evaluated.
- Recognize inherent hazards are different in various facilities.
- Permit times must be considered in mean time to repair.
- In Stage 3, characterization of credible hazards, what governs the path to prescriptive vs performance?
- Management should agree to 'credible' ideas before QRA numbers are presented (ground rules).
- Factors to consider for duration (endurance)LQ intact
    - Escape routes accessible
    - Structural steel
    - Evacuation routes/boatsStructural behaviour to considerMaterial
    - MemberStructure

4.0
Set qualitative Impairment criteria for:
1- Equipment,
2- Structural members
3- Personnel

- 0.2% strain criterion is VERY conservative, European codes do not go this low
- Different strain criteria should be considered for different types of:
  - Steel (different types of steel display varying temperature sensitivity)
  - Cross-sectional area (buckling may be a factor)
- Obtain copy of OTC paper presented by Dr. Bassam Burgan (attached)
- Obtain copy of EC3 part 1.2 (includes time history)
- Replacing room temperature properties with high temperature properties is not sufficient.Consider effect of localized heating on a member (constrained by remaining 'cooler' section).

- Ultiguide Handbook for ultimate strength analysis of structures.
- Damage occurs when members start cooling down (tearing, deformation – time)
- API Strength Analysis methods (good as long as member specificity is considered)
  - Zone
  - Elastic
  - Plastic
- RP2A may not be ideal due to restraining effects of missing member analysis.
- Generalization on how long a structure can withstand fire
  - Depends on load.
  - Cannot make a 'sweeping' statement for an entire structure
- Code-based approach vs Non-linear analysis
  - Non-linear isn't always necessary
- PFP vs what the steel can handle?
  - How much PFP to put in?
- Critical path of PFP must not interrupt critical path of construction.
- SOLAS too stringent, led to revised coat-back
- When will pressurized equipment fail?
- How to analyse protection against escalation?
  - Testing of loaded railcars
  - Account for heat transfer, internal liquid convection
- Code for temperature effects of vessel blowdown
- JIP to expand on 520/521
- Proprietary modelling done on jet-fire impingement.
- 250 kW criterion may not be sufficient
- Thin walled sections experience hydrates during blowdown
- Minimum thickness specifications exist
  - Based on 3 hour furnace test
  - Non-applicable to jet-fire
- Reference: Determination of Temperatures and Flare Rates During Depressurisation and Fire

- Possibility of 3-phase separator BLEVE
- Need for comprehensive evaluation of large HC inventories

- Recognize that overpressure competes with heating, at higher temperatures, material will fail more rapidly
- Industry heading toward more PFP based on orders
- PFP allows ultrasonic/non-destructive testing
- Uneven heating is not readily addressed by code, 2 other methods exist:
  - NEWS (NorskHydro)
  - VESSFIRE (Petrel)
- Smoke modelling
  - Chameleon
  - CFD fire modelling
  - Address toxicity of materials in the smoke
- Sprinkler systems offshore vs manual fire fighting
- Laundry room may be the biggest fire hazard, use common sense
- Potential loss of facility control due to fire in command center
- Protection of platform cables
- LQ Fires
  - Sprinklers (poorly maintained – was then shut off)
  - Aggressive Fire Fighting
  - Smoke detectors

5.0
Evaluate response against criteria. (Screening Step 5.1)

- Platform activity can be 'controlled' by rules and procedures
- Can design against business interruption due to small fires
- Differing philosophies on deluge (area vs equipment)
  - Area deluge (water everywhere!)
  - Where is it applicable?
  - Different offshore (not an enclosed environment)
- Why large bore piping is treated differently from vessels?

WORK GROUP 5

Floating Production and Storage Systems

Contributors:

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1 INTRODUCTION

An increasing number of large floating installations with high inventories and throughput are being planned in the deepwater and ultra-deepwater offshore regions of the U.S. Gulf of Mexico (GoM). This activity has led to further applications of proven floating production systems in this region such as Tension Leg Platform (TLP), Spar, and Semi-submersible designs. In addition, the GoM deepwater development is also leading to detailed evaluation and development of designs for tanker-based (or ship-shaped) Floating Production Storage and Offloading (FPSO) or Floating Storage and Offloading (FSO) units. While the industry experience with deepwater TLP and Spar designs has been primarily gained through their applications in the US GoM fields, tanker-based FPSO designs have been used only in other regions of the world including deepwater regions of West of Africa and Offshore Brazil.

The objective of this Work Group was to share and discuss the GoM and international experiences and perspectives on fire and blast considerations for floating installations, including TLPs, Spars, Semi-submersibles and FPSO's. Floating installations differ from fixed installations due to their design, construction, marine operations, compartmentation, motion, station keeping, stability, and operations. General guidance on fire and blast considerations for floating installations is available in the existing API RP 2FPS. Detailed information on fire and blast considerations for offshore installations is given in Class Society rules, guideline documents, ISO and other standards. Additional API and HSE guidelines are under preparation to address fire and blast design of offshore installations including floating production units.

The four sessions in the WG 5 were organized as follows:

- Session 1 – Introduction, overview of sessions, and open discussion to identify issues
- Session 2 – Review of Spar layout, and initiated TLP topside discussion
- Session 3 – FPSO layout and design against fire & blast
- Session 4 – Review of ISO and NORSOK considerations and their applicability

This white paper presents the following:

- Background information on fire and blast considerations in FPS units to help discussion in the Work Group 5. The key considerations in FPS units in comparison to a conventional jacket in shallow water are identified, and the experience with fire and blast design in the GoM installations and in other regions is reviewed. This is supported by the information given in the following six attachments:
  - Attachment I - Fire and explosion incidents in deepwater platforms and FPSs
  - Attachment II - Lessons learned in MMS study on FPSO Comparative Risk Assessment
  - Attachment III - Lessons learned from installations in other regions
  - Attachment IV - Layouts developed in MMS study on FPSO Comparative Risk Assessment

  - Attachment V - Status of technology
  - Attachment VI - Fire and explosion considerations in ISO 13702 and NORSOK S-001
- Main themes for Work Group 5
- Discussion held during Work Group 5 sessions
- Acknowledgements

2 BACKGROUND

A FPS design in deepwater differs from a conventional fixed jacket design in shallow water, which is where the vast majority of experience for fire and blast design exists in the GoM, in the following important ways:

Subsystem	Considerations for FPS in Deepwater versus Conventional Jacket in Shallow Water
Drilling	Deeper reservoirs, higher pressures and temperatures
Catenary risers	Very little experience, confined space in FPSO swivel
Production and Drilling risers	Higher pressures and temperatures, greater water depth, confined space in Spar moonpool
Stationkeeping	Variety of mooring systems, greater deck movements
Wellheads, X-mas trees	Subsea trees in addition to surface trees
Process facilities	Larger facilities with greater production, stacked decks on Spars, greater space on tanker-based FPSOs
Marine systems	Hull integrity, pump rooms, additional personnel, additional mechanical systems
Storage/offloading	Hull integrity, inert gas systems, pump rooms, additional personnel, additional mechanical systems, increased potential for ship collisions
Safety/emergency systems	Greater personnel on board (POB), additional simultaneous operations, longer travel time to shore

The deepwater and ultra-deepwater GoM installations are becoming larger facilities, which in size could be similar to some North Sea platforms. This increase is due to increased production rate, topside area, enclosed spaces, personnel on board (POB), and distance from shore. Examples to highlight this are that the topside weight of the proposed Thunder Horse semi-submersible is about ten times greater than the topside weight for the Neptune Spar.

The experience in the GoM and in other offshore regions for fire and blast considerations in the design of FPSs is summarized in the following sections.

2.1 Experience in Gulf of Mexico

2.1.1 General Approach for Gulf of Mexico Installations

TLP and Spar platform designs in the GoM generally incorporates firewalls and passive fire protection to achieve the target design requirements for availability of means of escape and temporary safe refuges. In addition, blast protection is accomplished through hazard area classification, equipment classification and presence of proper ventilation to reduce the likelihood of a blast occurring.

The design of FPS against fire and explosion events is covered through recommended practices given in the following API RPs and other documents:

- API RP 2FPS provides the guidelines for treatment of fire and blast loading on floating production systems
- API RP 14J and other API RP 14 series
- API RP 75

The following recommendations are made in the API RP 2FPS:

- Consideration should be given to providing some means of fire protection for personnel escaping along the primary escape route from the accommodation spaces to the survival craft.
- The means of escape should be planned to allow personnel to move from the uppermost level of the FPS to successively lower levels, to lifeboats, and, if possible, to the water level. Wherever possible, two separate isolated escape routes from any working or accommodation area should be provided.
- On tanker shaped FPSs it may be prudent to install a temporary safe refuge at the end of the unit remote from the accommodation and escape tunnels along the FPS.
- A comprehensive, site-specific contingency plan should be developed for emergency evacuation of all personnel aboard the FPS. Such a plan should provide personnel with the direction and equipment necessary for a timely and safe evacuation from the FPS in an emergency.
- All Floating Production (FP) units should be provided with lifesaving equipment.
- A general alarm system is required.

Fire protection measures on a FPS consist of the following:

- Structural fire protection measures
- Fire water system
- Fixed fire extinguishing systems
- Portable fire extinguishers

- Safety equipment
- Fire/gas detection systems

The fire protection requirements for the marine components are addressed by RCS Rules, flag state administration requirements (if applicable), and international requirements. The requirements for industrial component of a FPS are addressed by API RPs, RCS Rules, and national/international regulations. Interface of the marine and industrial components of a FPS creates a design and operational challenge and requires rational analysis of the hazards to tailor the fire protection arrangements and systems to provide suitable protection for the overall facility.

API RP 2A, Section 18 (1996) introduced an amendment with an assessment process and considerations for design against fire and blast loading. API RP 2FPS (2000) introduced a risk based decision approach against accidental events. Significant advancements have been made in the assessment of fire and blast loading from those presented in API RP 2A, Section 18. Thus, API has undertaken to update the risk assessment process and guidelines for design against fire and blast incidents. These are being currently developed with support from the API Task Group on Fire and Blast Design of Offshore Platforms.

The evacuation philosophy for the GoM platforms follows the following general practice:

- Precautionary evacuation of installation upon hurricane warning using helicopters as preferred mode of evacuation.
- Emergency evacuation of personnel from installation immediately for all significant incidents. The preferred order of escape from installations is likely to be: lifeboats, life rafts, direct entry into water using ropes, and helicopter.

The use of helicopters is not considered as the first option for emergency evacuation in the GoM due to limited availability of helicopters. In addition, the higher likelihood of having calm water with high temperatures compared to other offshore fields provides adequate time for rescue of personnel from sea. This philosophy requires less time for evacuation, thus reducing the design requirements for temporary refuge and escape ways for GoM installations. This evacuation plan may lead to location of temporary refuge at lower levels on the installations and reduce the need for protected escape routes.

2.1.2 Fire and Blast Incidents for Gulf of Mexico Platforms

A review of the fire and blast incidents in the GoM deepwater installations, in water depth greater than 1,000 ft, during 1995 to 2002 was performed to provide background information to the Work Group. This review indicated that a total of 34 fire incidents and 1 explosion incident were related to FPS production units and MODUs in the GoM. The details of this review effort and a summary of incidents, initiating events description, chain of events, and control measures are given in Tables I-1 to I-6 in Attachment I. The details presented in the Tables I-3 to I-5 are based on the incidents occurring in 9 TLPs, 2 Spars, and 1 Semi-submersible. The following observations are made from review of the incidents in GoM deepwater units during 1995 to 2002:

- A total of 55 incidents occurred during the 1995 to 2002 period due to either equipment failure, human error, or a combination of the two causes. More than 75% of the incidents were attributed to equipment failure.
- Human error seems to have been the cause of fewer incidents. This may be due to better training and adherence to procedures for these major installations in the GoM.
- Floating Production (TLP, Spar, Semi-sub) units in the GoM had 28 fire incidents and 1 explosion incident. Out of these, 23 incidents were due to equipment failures and 4 due to human errors, and 2 were due to other reasons. The specific modes of equipment failure were identified as compressors/generators, electrical, welding, insulation, gas leaks, and other causes (see details in Attachment I). The maximum number of failures occurred in compressors/generators. Of the 29 incidents only 3 incidents lead to pollution or injury or damage.

The specific details of initiating events, chain of events, and control measures identified from this review are summarized below:

- In case of compressors/generators, many accidents occurred during start-up. Fuel line leaks were found to be common cause of many accidents. Hot surfaces of compressors/generators ignited stray fuels in several cases.
- In the case of welding related incidents, hot slag has fallen through gratings. Some welding incidents were related to fuel spray that was injected into the area the welder was safely working. Permission and area check incidents could be reduced significantly by abiding to pre-existing regulations regarding work locations.
- Insulation often becomes fuel saturated over time, leading to fires. Non-absorbent insulation materials may reduce this risk.
- The electrical incidents were caused by short-circuits in high power systems. These events are difficult to prevent as they can develop over time.
- The gas leaks were found to be mainly from loose seal or failed o-rings. They usually occur suddenly and rapidly ignite. The escalation of a leak to a fire scenario would depend on the surrounding machinery.
- In most incidents, the rapid response due to quality training effectively controlled the fires shortly after they had started. Most fires were extinguished in less than 2 minutes with the use of a 30-lb dry chemical extinguisher. The worst fire incident in the cases reviewed for deepwater installations was extinguished within 20 minutes.
- A large percentage of human error accidents are associated with the unfamiliarity with certain functions of the operation, or persons not following the company procedures.

Overall, the GoM deepwater incidents have shown that a good safety record has been achieved thus far. Further improvements in the safety against fire and blast could be achieved by reviewing and updating the operational and maintenance procedures for equipment, and by improving the layouts to eliminate escalation of incidents.

2.1.3 Lessons Learned from the FPSO Comparative Risk Assessment Study for the GoM

The lessons learned from the "FPSO Comparative Risk Assessment" study for MMS undertaken by OTRC are given in Attachment II. The purpose of this study was to compare the risk for a tanker-based FPSO in the GoM with accepted alternatives for deepwater development, including a TLP and a Spar. This study estimated that fires and explosions did not contribute significantly to either fatality risk or oil spill risk.

The major fire and explosion hazards that were identified for the floating production systems included: pump room explosions on tankers/ FPSOs, explosions in the turret area on an FPSO, and explosions in the moonpool for a Spar. Also, construction and maintenance activities were identified as a significant contributor to the potential for fires and explosions.

The following major differences related to fire and explosion risks were identified for the floating production systems:

- Gas can accumulate in the moonpool on a Spar.
- Equipment spacing on a TLP and Spar is closer than on a tanker-based FPSO (gas processing areas are particularly congested), meaning more potential for confinement, overpressure and escalation and more difficulty in fighting fires.
- Grated decks on a TLP and Spar can reduce the size of pool fires but also allow fires to spread to multiple decks.
- FPSO swivel provides additional points of hydrocarbon release. Also, hogging and sagging of deck could affect piping.
- FPSO has more deck area and POB benefit by greater separation distances.

2.2 Experience in Other Offshore Regions

2.2.1 Layout and Design Principles

In general all offshore structures have the following difficulties when dealing with fires and explosion:

- High degree of congestion
- Lack of escape routes
- Reliance on own resources

There are a number of ways to reduce the risk due to fire and explosion on an installation:

- Separating the different areas to prevent escalation or protecting personnel
- Introducing walls that prevent escalation between different areas
- Increasing strength of structure

- Increasing natural ventilation in each area to reduce likelihood and consequence

For onshore plants, it is easy to achieve separation of different process modules due to available space. In some cases of offshore production installation they may be divided into smaller installation to separate e.g. the living quarters and process modules.

When designing an offshore topside structure, one of the main issues is to establish the environmental and accidental loads, which may implicate the structure of the installation. The main accidental loads may be caused by fire or explosion, and during the design phase it is important to take these effects into account, since it is the most cost-effective time for fire and explosion assessment. There are more opportunities to implement fire hazard management strategies and there is also more room for recoverable error in the hazard management decisions during the early phases than later in the project.

The layout and design principles for design of fixed platforms and FPSOs against fire and blast events are presented in two illustrations in Attachment III.

2.2.2 Fire and Blast Incidents for Platforms in Other Regions

The incidents in UK Continental Shelf (UKCS) of the North Sea are presented in Table I-7 in Attachment I. The UKCS incidents were obtained from WOAD (Worldwide Offshore Accidents Databank, DNV, Norway) and SSS (Sun Safety Systems, HSE, UK) databases. The exposure data available for fire and blast related events in these sources was for 60 unit years of exposure for monohulls (FPSOs and FSUs). None of the reported events are related to process-events on the FPSOs and FSUs (see Table I-7).

FPS units in UKCS, North Sea had 9 fire incidents and 2 explosion incidents. Of these 10 incidents were due to equipment failure and 1 was due to human error. No consequences are reported from these incidents.

Since the statistical background (and number of events) is so limited and the cause of events is hidden in statistics, accident databases such as WOAD are not well suited for risk assessments for FPSOs and FSUs.

2.2.3 Specific Issues with FPSOs

The main focus in the following is on FPSOs as other types of offshore structures (TLPs, Semi-subs etc.) for production operations have similarities to fixed platforms with regard to fire and explosion risk. The major differences in case of TLP and Semi-sub compared to jacket platforms would be from hull compartmentation and marine systems operations. From experience it is clear that the use of FPSOs introduces a different risk picture compared to other concepts.

During the development and design of FPSOs in the North Sea, a number of issues have been identified as important. The key issues related to design against fire and explosion events are:

- Fire and explosion loads acting on tank deck and topside equipment caused by process events

- Explosion loads in enclosed spaces
- Evacuation and escape during major fire or explosion
- Location of living quarters and temporary refuge
- Flexible riser solutions

When designing FPSOs, the possibility to increase the distance between the modules is limited, thus necessitating a focus on alternative solutions such as increasing the strength of the structure, introducing walls to separate modules (fire walls/ blast resisting walls), and decreasing the potential over-pressures.

In addition, the nature of the FPSO leads to a different way of performing a risk assessment. The process modules of the FPSO are normally placed at the same elevation, thus making it difficult to use results from apparently similar fire or explosion analyses obtained from "conventional" offshore modules. If turret moored, the FPSO will move according to the environment (wind-direction/waves/currents). This will influence the natural ventilation consideration for different modules.

In general, the following are additional effects that have to be assessed during a risk analysis of a FPSO:

- The cloud size resulting from a hydrocarbon release is not restricted to a single area (or module), but is determined by the leak scenario. This requires usually a more detailed dispersion analysis to be performed, including a larger area in an analysis.
- Movement of the vessel may contribute to increased spreading of pool fires
- Fires or explosions may implicate the stability of the vessel
- The FPSO may be allowed to move away from the scene of a fire

Critical areas, including areas that are critical to the ships structural integrity and with a high degree of confinement/congestion are:

- Turret area
- Process area
- Cargo tanks
- Pump room

The features that contribute to reducing risk on FPSOs compared to fixed platforms include:

- Elongated shape enables good separation between process areas and accommodation area
- A weathervaning FPSO ensures that the accommodation area remains upwind of any hydrocarbon event (release, fire/explosion); integrity of accommodation and lifeboats ensured. Air intakes at accommodation area are upwind any hydrocarbon event.

- Good natural ventilation of process areas and turret area above deck level due to open design reduces probability of ignition and explosion overpressures
- If equipped with emergency disconnect system, the FPSO can abandon the field in an emergency
- On FPSOs with forward accommodation, a fire/blast wall is usually located between the turret area and the accommodation area. This improves the protection of personnel from probable hydrocarbon releases.

The following features of FPSOs contribute to increasing risk compared to more traditional concepts:

- Storage of crude oil implies potential for large explosion and fire incidents. This requires that the design solutions minimize the probability of escalation of process events to cargo tanks.
- Gas cloud accumulation on the FPSO from the cargo tank vent posts
- Explosion/fire in engine room

The safety risk picture will be somewhat different for a modified tanker having the accommodation at the aft end of the ship.

The following issues are normally addressed in establishing specific risk-reducing measures:

- Reducing the heat load on the main deck (which is also the tank tops) by reducing the duration of a fire scenario
  - Isolation of process stream segments
  - Rapid blow-down (also beyond recommendations given in API RP 521); a large amount of structural fire protection has been avoided on some FPSO projects, thus reducing the over-all weight.
- Proper location of the cargo tank vents (away from hot surfaces and ignition sources)
- Routing of the potential over-pressure due to an explosion away from an adjacent cargo tank
- Reduce the probability of leaks and ignition
- Improved fuel gas piping and gas detection

The following points for further discussion are identified based upon the experience with FPSOs in other regions:

- Living Quarter at aft or bow – pros and cons
- Approach to avoid process events to impair structure/buoyancy
- Effects of fires on the main deck. Possible escalation to cargo tanks?

- Principle for evacuation/escape ways
- Assessment method
- Main focus for improving safety on FPS
- Lack of data – need for numerical modeling and other ways of improving safety

2.2.4 Case Studies

2.2.4.1 Heidrun TLP

The details of assessment and design of Heidrun TLP, which is installed in the Norwegian North Sea, against fire and blast incidents are given in Attachment III. The main findings related to fire and explosion in the Heidrun TLP design case were:

- Well blowouts are the largest contributor to the risk of total loss of the platform
  - However, the risk level was comparable to other fixed offshore installations
  - The high blowout risk was caused by high drilling activity during initial years
- The consequences of blowouts were reduced by using fire-resistant concrete in exposed areas and by division of the wellbay area by a fire resistant wall
- Total impairment frequency caused by process/riser leaks was reduced by implementing SBV (subsea barrier valves) in all gas risers
- Tie-in of regional wells to the TLP increase the risk level
- Direct shuttle loading have insignificant influence on the risk level compared to other options for storage/loading

2.2.5 Åsgard FPSO

The details of assessment and design of Åsgard FPSO, which is installed in the Norwegian North Sea, against fire and blast incidents are given in Attachment III. Related to fire and explosion, process events are the major contributor to the risk to personnel. Explosions in the process module, followed by potential escalation to the rest of the vessel, may have very serious consequences. However, due to very low frequency of occurrence these events have a small contribution to the total risk.

At an early stage the following scenarios were identified as critical with respect to the design criteria:

- Riser events could result in impairment of escape routes and escalation
- Collision with shuttle tanker

Implementing risk-reducing measures such as cold flare technology and strict procedures for the shuttle tankers reduced the risk attributed to these scenarios.

In addition to the conceptual characteristics of the FPSO design, risk would reduce further by implementing the following:

- Draining of oil spills from process deck to prevent escalation to tank deck and cargo tanks
- Process deck kept as closed as possible to prevent fire escalation; openings (stairs) bounded by rims to prevent run-off to deck below
- Segregated ballast tanks surround cargo tanks to give double barrier
- Protected escape routes along the whole of the vessel capable of withstanding fire and explosion in process and turret areas
- Cold flare philosophy implemented to decrease probability of igniting riser/turret releases

2.3 Status of Technology

The applicability of technology and experience developed in the North Sea region to the Gulf of Mexico deepwater floating systems is summarized in this section.

Reference is made to ISO 13702, NORSOK S-001, and FABIG (Fire and Blast Information group, UK) documents for status of technology available with the offshore oil and gas industry. A list of key recommendations in ISO 13702 and NORSOK S-001 documents is given in Attachment VI.

A brief review of the excerpts from ISO 13702 and the general approach developed to perform assessment and design against an explosion event is given in Attachment V. The main elements in a fully probabilistic fire/explosion analysis, and in explosion modeling are identified in illustrations given in Attachment V.

The following reasons are identified for need of Computational Fluid Dynamics (CFD) models in detailed fire and blast assessment:

- Offshore installations have congested and confined areas.
- NFPA-68 and similar empirical methods do not model turbulence generation, which is determining the combustion process in an explosion.
- Global statistical fire/explosion data is insufficient. Thus data for equipment classes is used.
- All critical/typical scenarios may be covered in risk analysis on design/as-built geometries. Worst-case scenarios could be identified by CFD models.

The main advantage by incorporating detailed consequence assessment with risk analysis techniques is that risk-reducing measures can be quantified and ranked better than when using traditionally coarse consequence models. The technique also allows comparing risk-reducing measures related to different areas and consequently the risk reducing efforts can be focused in areas with potential for significant improvement in safety at lower cost. The method requires a multidiscipline project team consisting of: structural engineers, fire/explosions engineers, risk engineers, and cost engineers.

3 MAIN THEMES FOR WORK GROUP 5

A preliminary list of themes for discussion in the workshop was developed prior to the workshop and included in the draft white paper. This list was then updated in the first session of the workshop. The updated list of main themes and key issues is presented below. The discussion held and input received from participants is presented in Section 5. The applicability of the following considerations would vary for the different categories/designs of FPS installation types addressed in this paper.

Theme 1: Layout /arrangements.

There are major differences between the layouts for various types of floating installations, which has major effects on congestion, degree of enclosure, ventilation etc. The differences between the tanker-type FPSO and the Spar/TLP/Semi-sub are evident in this respect. The tanker based FPSO generally has ample deck-space and allow rather open solutions. The following issues were identified for discussion:

- FPS units with center moonpool and risk from explosion overpressure, a scenario for Spar and FPSO designs
- Density of equipment and vertical stacking of decks (a Spar at one extreme versus a tanker based FPSO at the other extreme)
- Impact of escape and evacuation plans on layout/arrangement requirements
- Connections between classified and non-classified area of FPSOs
- Explosion risk in pump room
- Welding machine grounding

Theme 2: The floating/buoyancy and stability function.

Loss of stationkeeping/ buoyancy (e.g. Petrobras P36 incident) is a grave consequence for FPS. The following were identified for discussion:

- A goal is to ensure that fire or explosion incident does not lead to loss of buoyancy
- Avoiding Hydro Carbon (HC) process or equipment in the hull/buoyancy structures, penetrations etc, are means of reducing the risk and effects of fire and blast.
- The effects of vessel movement with waves and wind with respect to escalation of fire and explosion incidents must be accounted for. This is

most relevant for oil spill incidents to identify means to avoid large size pool formation.

- Stability and marine systems could also impact fire and blast events

Theme 3: The HC storage area (the tanks).

The following were identified for discussion:

- How to avoid fire and blast exposing the cargo (storage-tanks)? For some concepts (like FPSO) the distance between the process and the storage is very short.
- Storage of product/fuel and offloading for an FPSO (more generally for a floater because of larger production and more flow assurance issues)
- Vapor recovery, inert gas. Represent complications due to "coupling" between process and storage.
- Possible offshore loading, like tandem or side-by-side loading from the FPSO
- Implosion of cargo tanks and cargo tanks internal pressure safety system
- Venting lines
- High pressure hydraulic lines in closed compartments
- Zero risk explosion philosophy

Theme 4: The exposure of personnel, means and ways of escaping.

The different floating installation concepts offer different solutions and problems. The following issues were discussed:

- As an example the layout of the Statoil FPSOs is such that a larger part of the manning (more than 80% on average) is located forward of the forward fire partition, upwinds of the process and storage (weathervaning). Evacuation by helicopter and drop-lifeboats are in the same area.
- On tanker shaped FPS it may be prudent to install TSR at the end of unit remote from accommodation and escape tunnels

Theme 5: The risers (in some cases flexible) and possible HC release from risers and sub-sea installations.

- Export riser isolation valves (not included on floaters due to SCRs versus having passive check valves at the mudline on shallow jackets)
- How are the flexible risers protected? – By passive means?
- Protection of gas injection risers

Theme 6: Lack of actuarial data on leak and ignition frequencies and consequences.

This is more of an issue for floaters than for shallow water jackets. The following were identified for discussion:

- Insufficient data for FPS units
- Use or extrapolation of fixed installations data
- Context of incident data – relation to the exposure that is assessed

Theme 7 : Risk metrics.

The following ways of quantifying risk were identified for discussion:

- FAR-value (Fatal Accident Rate)
- Risk per barrel of oil or risk per installation
- How to define/develop acceptance criteria for risks - comparative or a range?
- Performance criteria and historical data

Theme 8 : Christmas Tree – Dry or Wet.

The following were identified for discussion:

- Dry tree on TLP and Spar
- Wet tree for FPSO

Theme 9 : Simultaneous Operations (Drilling).

The following were identified for discussion:

- Drilling rig on TLP and Spar
- No drilling rig on tanker based FPSO
- Drilling risers and operations

Theme 10: Inspection of Double Hull Tanks.

The following was identified for discussion:

- Emergency gas inerting on wing ballast tanks (double sided or double hull FPSOs)

In order to facilitate the work group discussions, generic layouts for floating system options generated in the "FPSO Comparative Risk Assessment" study for MMS were provided to the participants. These layouts were developed in the MMS study with input received from DeepStar industry group and are given in Attachment IV. These plans provide a comparison of potential variations in layouts for different FPS designs. Additional layouts for the two examples for TLP and FPSO presented in Section 3.2 were also discussed and are given in Attachment III.

4 DISCUSSION HELD DURING WORK GROUP SESSIONS

The discussion in WG 5 sessions was held on the 10 Theme topics listed in Section 4 and a few additional issues identified and agreed upon with the WG 5 participants at the first session. In this section, a summary of the input received from the participants is given.

Reference is made to the key considerations for "Girassol FPSO and West of Africa experience with FPSOs", which are given in the keynote address by Mr. Henry Tonda. The presentation included in the Workshop proceedings.

An attempt has been made by the authors to organize the discussion according to the themes listed in Section 4, whereas the discussion may have been held in different order or repeated in different sessions. Authors have kept the participants input as received and no interpretations or judgments have been made.

Theme 1: Layout /arrangements.

1. Location and need of lifeboats.

   One participant suggested that lifeboats might not be placed in locations that are likely to be impacted by jet fires. In practice, there are very few scenarios, such as a process incident scenario, for use of second lifeboat. In order to use the lifeboat, it will require protection. It may be better to put the savings from "no second lifeboat" into providing escapeways etc. The second lifeboat does add redundancy, but it cannot be used for evacuation being in the process area.

   Another participant suggested that an alternate lifeboat would be necessary to take care of situations such as wind blowing the flame in the area between mustering area and lifeboat. Also due to small size there will be situations of smoke in the mustering area, thus an alternate lifeboat would be necessary. Thus, consideration of environmental directions and associated issues are very important.

   Another participant suggested consideration of free-fall lifeboats.

2. Risk assessment for future conditions.

   The potential of future facilities shall be considered in the risk assessment at an early stage to ensure safety considerations are implemented. The equipment density on platform could become worse when the production is decreasing due to tertiary recovery. The risk assessment without consideration of future projections would be meaningless.

3. Re-evaluation due to modifications. What are the triggers?

   A life cycle risk consideration is very important to perform, to identify triggers for re-evaluation. Anytime a (significant) change occurs on the platform, it needs to be re-evaluated. Considerations/understanding of triggers that would initiate re-evaluation shall be identified. Some triggers could be major changes or significant modifications requiring lifting of heavy modules by derrick barge.

4. Are fires on main deck important?

Fires on the main deck would be critical. It is important to control temperature on the main deck plating. For this reason, it is important to have solid main deck plating.

Explosion loads that affect secondary structure are very important to consider in design.

5. FPSO layout issues and safety measures.

   By moving turret to the middle of the floating installation, thrusters would be needed to weathervane. The onshore approach of separation of modules, and provision of blast/relief walls to separate modules or areas may be considered. It is important to maintain proper natural ventilation in modules.

   The following safety measures were identified for FPSOs:

   - Draining of oil spills
   - Segregated ballast tanks
   - Protected escape ways
   - Cold flare
   - Low manning/ no hot work in hydrocarbon areas
   - Living Quarters upwind of fires

   Process deck kept as closed (plated) as possible to prevent escalation of fires to cargo tanks. This raises concerns with regard to explosions. If deck is grated, it provides natural ventilation and would be better but design shall consider having a jet fire on the deck.

   It was mentioned that the cargo tanks have gas in all situations. Thus a plated deck will be a problem with potential for gas trapping.

   The converted tankers may have a lot of space, thus passive protection may not be necessary. The issue is about the type of ship.

6. Draining of oil spills.

   A participant mentioned that a closed drain should not be allowed, as it is a very dangerous system, which may result in gas entrapment. The open drains are being considered. It has been seen that a majority of accidents start from closed drains. It was suggested that it would be a human factors issue. In case of open drain system, it would require monitoring.

   Where possible, sloping of deck may be considered to drain out oil spills and minimize pool size. Thus, multiple drains may be required. It is important to consider vessel length and handling issues to keep deck as flat as possible.

7. Firewater piping.

   The firewater piping shall be reliable. Use of titanium for firewater piping in Åsgard platform was identified as a possible but expensive system. It was mentioned that some operators are testing it every 6 months. In some cases firewater systems are corroded and not operable. It was mentioned that titanium piping may have to be done in Singapore and it may not be of good quality.

8. Pump room vs. pumps in cargo tanks.

   The following issues were identified related to pump rooms:

   - Lots of activity in pump rooms
   - Confined space
   - Connected to cargo tanks
   - Limit number of pump rooms
   - Is Zone 1 but Class Society consider it as Zone 0
   - Leak and ignition source in the same area

9. Use of submersible pump.

   The following issues were identified:

   - Inspection and maintenance issues
   - Do not want to put a lot of water in storage tanks

<u>Theme 2: The floating/buoyancy and stability function.</u>

1. Moonpool in Spar platforms.

   The moonpool in a Spar platform constitutes of a long and confined space. Thus an accident occurring within the moonpool in Spar (or turret for FPSO) is likely to lead to increased movement of risers. In two design cases, export risers have been considered through the moonpool by provision of insert tubes. An active fire protection system, such as a sprinkler, has been used in two spar designs.

   A scenario to loose Spar buoy (hull) is very remote. The most likely scenario could be rupture of a gas line and loss of buoyancy.

   A pool fire in moonpool is more hazardous than in an open space. It was mentioned that the pool fire in moonpool would be ventilation controlled fire, thus it would not be the same as a tunnel fire, but be similar to an open surface crude tank fire. Thus, passive fire protection would be necessary along with an active system where the diesel fuel does not run out. The moonpool area may be suited to Foam type fire extinguishers.

<u>Theme 3: The HC storage area (the tanks).</u>

1. Marine and topside interface.

   The interface between marine and topsides or else floating and process functions, and a focus on the marine side are very important. A comparison of equipment failure incidents for fixed and floating production systems is required to understand the impact of interface between marine systems and topsides for FPS units. It was mentioned that 90% of process incidents are related to procedures, thus multi-disciplinary interface study involving marine, process, safety engineers is very important. The best solution is to have a compromise solution between topsides, marine, and safety. It is very important to have good interface or interaction between marine and process groups. In the same way, an interdisciplinary team during FEED stage would be valuable. The operational people from operating companies shall work from early stages of a project. It is very important to also involve safety people. Such groups shall be included in HAZID/HAZOP tasks.

2. Venting from cargo tanks.

   FPSO cargo tanks have large capacity venting requirement compared to vent stacks for fixed platforms. Thus two points for cargo tank vents were suggested, as sometimes one vent may not be available due to environmental conditions or due to congestion. It is very important to undertake a gas dispersion study to decide on the height (or elevation) above the cargo tank, the pressure be released. The Brazilian experience is that no vapor recovery system on FPSOs have been done so far. There are 2 types of tanks, such as normal and pressure vessel type. It is a problem to design vents in cargo tanks.

   Explosion simulation has not been done in cargo tanks. It is not feasible to design against the worst case due to practical and cost considerations.

3. HC storage area (the tanks) – inspection etc.

   How to do fire fighting?

   One participant mentioned that we only think about costs and forget about marine systems. The most important problems identified to solve are: whether 1 or 2 inert gas systems are required; whether 1 PV breaker or 2 are required; what happens in the cargo tanks; is there machinery in tanks; how to inform people doing maintenance at bottom tank about process fire topside. Thus, two escape ways were suggested from a cargo tank. The process alarm cannot be heard in the cargo tanks, thus an additional alarm or flashing were suggested in cargo tanks.

   - Need 2 vents for cargo tanks. Need emergency signals within cargo tanks to evacuate while cargo tanks are being inspected.
   - Provide individual PV breakouts.
   - Consider isolated cargo tanks and submerged pumps.
   - Continuous control of oxygen and hydrocarbons is necessary.

   The relationship between process and storage functions is very important. SOLAS provides minimum guidelines for FPSOs and additional guidelines are necessary.

4. Implosion of cargo tanks:

   Physical implosion was identified as an important issue. Brazilian experience is having 3 such incidents in their 20 years of operations. There is a new SOLAS requirement to have a true independence between LP and HP gas.

5. Hydraulic components in closed compartments

   It is very important to take care of hydraulic components in closed compartments, such as anchor winches.

Theme 4: The exposure of personnel, means and ways of escaping.

1. Escape Tunnels on FPSOs.

   The following issues were identified related to provision of escape tunnels in the FPSOs:

   - Ventilation required due to length of tunnel
   - Entry/access – hesitation to use escape tunnels or danger of entering
   - Tunnel likely to be damaged in an event that would require their use
   - There are no escape tunnels in Girassol FPSO because it is very long. In smaller FPSOs they may have provided escape tunnels.
   - It is very difficult to build tunnels and is of high value only for a catastrophic scenario

Theme 5: The risers (in some cases flexible) and possible HC release from risers and sub-sea installations.

On an average most GoM platforms have 75,000 bpd oil production and in some cases, it may be 150,000 bpd. In the GoM, there are no requirements for ESD valves in export risers or flow lines. The provision of isolation valves on export risers (gas and oil) depends upon company philosophy. The considerations vary with company policies, whether to protect people or save assets. Some operators put check valves at the pontoon level. There is no set way of doing it, however in deepwater applications the general trend is to provide some isolation.

One participant suggested that leak of oil from risers (rigid or flexible) is very important due to potential of a very large oil spill. It is strange that we do not speak about pool fire at sea, which would be a big problem with a spread moored FPS unit compared to a turret-moored system. It would be very difficult to avoid oil at sea from an FPSO.

Another participant asked why we are so concerned about export risers and not concerned with the production risers that support 10,000-psi wells and subsea trees that could not be easily replaceable.

It was suggested that a SSCV below the sea level would provide a double barrier, but it could by itself have gas leakage, which could influence the hull buoyancy.

It was mentioned that as such, designing of a riser in deepwater is complex, and thus introduction of additional structural discontinuity could add significant design and risk management problems.

Theme 6: Lack of actuarial data on leak and ignition frequencies and consequences.

1. Evaluation and comparison of accidents.

The following issues were identified:

- A comparison of equipment failure incidents for fixed vs. floating production systems would be useful
- Offshore Brazil, there are many collision events compared to those summarized for the GoM
- In trading tankers main fires are in engine room, which are operational most of the time, and pump rooms, which are confined. These incidents are very important for FPSOs.

2. Lack of data and relative risk levels.

   The following issues were identified:

   - A concern was raised on lack of data on accidents/events that have happened on FPS units. There is lack of experience for Spar and TLP, e.g., in case of TLPs it was mentioned that they may have only about 100-year cumulative experience. Industry does not have sufficient experience with similar systems to check on the risks. We can't say that TLP or Spar designs are safe installations, as we do not have any catastrophic experience due to short history. Spars with congested topsides and equipment stacked at 3 level decks is a risk issue.
   - TLP risks are likely to be similar to jackets and semi-submersible platforms
   - FPSO risks are related to a trading tanker

3. On accidents/collision between FPSO and shuttle tankers.

   It was mentioned that attention was placed on electronics etc., whereas better training is needed to avoid incidents.

   It was mentioned that Dynamic Positioning (DP) of vessels is not perfect but it is the best one available to avoid incidents. It would depend upon the type of shuttle tanker used. In case of use of tankers of opportunity, significant high risk may exist.

4. Other risk issues.

   In the GoM, deepwater facilities are bringing products through shallow water installations, which are not designed for such operations. This is a risk issue that requires consideration in an overall risk picture development.

Theme 7 : Risk metrics.

1. Use of FAR.

   It was discussed whether use of FAR would be acceptable. It was suggested that FAR should not be used for systems with large differences. It may be useful to look at contributors and differences between systems. In the North Sea, the typical practice is to establish acceptance criteria. It was suggested to look at sensitivity to a given layout, and comparison would give better understanding.

Theme 8 : Christmas tree – dry or wet.

Not addressed in detail.

Theme 9 : Simultaneous operations (drilling).

Not addressed in detail.

In order to assess the risk levels for TLP, Spar, and FPSO, it was discussed that in an overall sense, the key difference in risk picture would come from:

- Storage/ offloading risk and mobile offshore drilling unit (MODU) risk for an FPSO case (2 locations), and
- Drilling riser and drilling operations risks in case of TLP and Spar (1 location)

Theme 10 : Inspection.

1. Double hull in FPSOs.

   One participant mentioned that in case of double hull design, the minimum width of 2 meters used in the past may not be sufficient and 3 to 4 meters may be more appropriate.

   Emergency inerting on wing ballast tanks – applicable to double side or double hull FPSOs.

2. Cargo Tanks – Procedures for Entry.

   The following issues were identified by an operating company:

   - Static electricity inside tanks due to introducing anything in tanks
   - Need continuous survey of cargo tanks
   - To have fixed platform to inspect top of the tanks, which is impossible to navigate by a raft
   - Need adequate emergency signal system to evacuate
   - Need 2 escape ways from cargo tanks as only 5 minutes may be available
   - Redundancy of inert gas or PV system are very important
   - It is important to establish the inspection cycle

Additional Topic: Use of Codes.

SOLAS provides minimum guidelines for FPSO, which is more than a trading tanker. It was suggested that API RP differentiate FPSOs from trading tankers. The following issues were identified:

- Incidents on FPSOs are different than trading tankers
- SOLAS rules are not strong, because loss of a trading tanker is easily replaceable compared to a permanent FPS production unit

- Intermediate solution may be not to have any time lack of regulations
- API RP to include SOLAS + additional safe practices requirements

Relationship between process and storage functions:

- In order to design for relationships between process and storage functions, Brazilian common practice is to default to ship rules, which are much older and have more experience.
- Another participant did not agree with the above and believe that ship rules are more lax than regulations for fixed platforms.

5 Acknowledgement

The industry experts, listed in Section 1, who participated in the WG 5 discussions sessions are acknowledged for interesting discussion on key issues related to fire and blast assessment and design of floating production installations. Dr. Odd Tveit of Statoil, Norway is acknowledged by the WG 5 committee for initial input received on the important Theme Topics and key issues. Ms. Barbara Mather of MMS, New Orleans is appreciated for providing detailed individual accident reports, updates and clarifications on the fire and blast incidents that occurred in the Gulf of Mexico installations.

ATTACHMENT I

FIRE AND EXPLOSION INCIDENTS IN DEEPWATER PLATFORMS AND FLOATING PRDOUCTION SYSTEMS

OCS Events by Category: 1995-2002 YTD

	1995	1996	1997	1998	1999	2000	2001	2002 YTD
Loss of Well Control	**1**	**4**	**5**	**7**	**5**	**9**	**9**	**1**
Uncontrolled flows	1	4	2	5	3	9	8	0
Diverter events	0	0	3	2	2	0	1	0
Collisions	**6**	**5**	**10**	**5**	**10**	**9**	**17**	**4**
Explosions	**0**	**7**	**10**	**3**	**5**	**2**	**4**	**1**
Fires	**42**	**86**	**125**	**90**	**75**	**103**	**81**	**34**
Catastrophic	0	0	1	0	0	0	2	0
Major	0	3	1	2	3	1	2	0
Minor	3	11	11	7	4	5	0	0
Incidental	39	72	111	81	68	96	79	31
Unknown	0	0	1	0	0	1	2	3
Injuries	**31**	**62**	**83**	**66**	**47**	**64**	**60**	**11**
Fatalities	**8**	**10**	**11**	**14**	**5**	**5**	**7**	**0**

YTD = *Year to date.*

SOURCE: Tims database as of May 06, 2002.

A summary of OCS events to all platforms (fixed and floating) by category of incidents during 1995 to 2002 are given in the following table:

The MMS classification for fire damage in the above table is based on the basis of dollar amount of damage according to the following criteria:

- Catastrophic = Destruction of facility worth greater than $10 Million
- Major = Property damage greater than $1 Million
- Minor = Property damage greater than $25,000 but less than $1 Million
- Incidental = Property damage equal to or less than $25,000
- Unknown = Not enough information to classify

This indicates that a total of 636 fire incidents and 32 explosion incidents occurred in all OCS platforms in the GoM during 1995 to 2002. Only 15 incidents were classified as catastrophic or major events.

Out of these, 34 fire incidents and 1 explosion incident were related to FPS production units and MODUs. The details of these fire and explosion incidents for GoM operations since 1995 in Semi-submersible, TLP, Spar, and MODU (Mobile Offshore Drilling Unit) installations are given in Tables I-3 to I-6. The incidents that occurred in deepwater fixed jacket platforms in water depths more than 1,000 ft and in compliant tower platforms are also presented in Tables I-1 and I-2. The data was taken from MMS web site and additional information for specific incidents was made available by MMS.

The incidents in UK Continental Shelf (UKCS) of the North Sea are also presented in Table I-7. The UKCS incidents were obtained from WOAD (Worldwide Offshore Accidents Databank, DNV, Norway) and SSS (Sun Safety Systems, HSE, UK) databases. The exposure data available for fire and blast related events in these sources was for 60 unit years of exposure for monohulls (FPSOs and FSUs). None of the reported events are related to process-events on the FPSOs and FSUs (see Table I-7).

The details presented in Tables I-1 to I-7 are based on the incidents associated with the following number of platforms under each category:

- Floating Production Systems: 9 TLPs, 2 Spars, and 1 Semi-submersible
- Exploration – MODUs
- Fixed Structures in water depth > 1,000 ft: 3 Compliant Towers, and 5 Steel Jacket platforms

The following observations are made from review of these GoM and UKCS, North Sea incidents during 1995 to 2002:

- A total of 66 incidents occurred during the 1995 to 2002 period due to either equipment failure, human error, or a combination of the two causes.
- More than 75% of the incidents were attributed to equipment failure.
- Human error seems to have been the cause of fewer incidents. This may be due to better training and adherence to procedures for these major installations in the GoM.
- Floating Production (TLP, Spar, Semi-sub) units in the GoM had 28 fire incidents and 1 explosion incident. Out of these, 23 incidents were due to equipment failures and 4 due to human errors, and 2 were due to other reasons. Of the 29 incidents only a total of 3 incidents lead to pollution or injury or damage. The damage case from explosion of atmospheric tank in a TLP installation.
- MODUs in the GoM had 6-fire event and 3 were due to equipment failure, 2 were due to human errors, and 1 was due to other reasons. No significant consequences are reported from these incidents.
- Deepwater jacket and compliant tower platforms in the GoM had 20 fire incidents and no explosion incident. Out of these, 14 incidents were due to equipment failures and 6 due to human errors. Two incidents in deepwater jackets lead to pollution or injury consequences.
- FPS units in UKCS, North Sea had 9 fire incidents and 2 explosion incidents. Of these 10 incidents were due to equipment failure and 1 was due to human error. No consequences are reported from these incidents.

The specific modes of equipment failures were identified as follows:

- Compressors/generators – 28 incidents
- Welding – 7 incidents
- Insulation – 4 incidents
- Electrical – 8 incidents
- Gas Leaks – 4 incidents
- All others – 15 incidents

The specific details of initiating events, chain of events, and control measures identified from this review are summarized below:

- In case of compressors/generators, many accidents occurred during start-up. Fuel line leaks were found to be common cause of many accidents. Hot surfaces of compressors/generators ignited stray fuels in several cases.
- In the case of welding related incidents, hot slag has fallen through gratings. Some welding incidents were related to fuel spray that was injected into the area the welder was safely were working. Permission and area check incidents could be reduced significantly by abiding to pre-existing regulations regarding work locations.
- Insulation often becomes fuel saturated over time, leading to fires. Non-absorbent insulation materials may reduce this risk.
- The electrical incidents were caused by short-circuits in high power systems. These events are difficult to prevent as they can develop over time.
- The gas leaks were found to be mainly from loose seal or failed o-rings. They usually occur suddenly and rapidly ignite. The escalation of a leak to a fire scenario would depend on the surrounding machinery.
- In most incidents, the rapid response due to quality training effectively controlled the fires shortly after they had started. Most fires were extinguished in less than 2 minutes with the use of a 30-lb dry chemical extinguisher. The worst fire incident in the cases reviewed for deepwater installations was extinguished within 20 minutes.
- A large percentage of human error accidents are associated with the unfamiliarity with certain functions of the operation, or persons not following the company procedures.

Overall, the GoM deepwater incidents have shown that a good safety record has been achieved thus far. Further improvements in the safety against fire and blast could be achieved by reviewing and updating the operational and maintenance procedures for equipment, and by improving the layouts to eliminate escalation of incidents.

Since the statistical background (and number of events) is so limited and the cause of events is hidden in statistics, accident databases such as WOAD are not well suited for risk assessments for FPSOs and FSUs. In the following table, the explosion events recorded in the North Sea and the estimated frequencies are given.

North Sea Explosion Events During 1973-1997 (Source: WOAD Database)

Area	Events	Platform Years	Area Years	Frequency (event/platform year)	Frequency (event/area year)
UK	16	3,010	5,244	0.00532	0.00305
Norway	17	714	1,900	0.02381	0.00895
Holland	1	1,284	1,701	0.00078	0.00059
Denmark	0	355	429	0.00	0.00

Table I-1. Jacket Type Platforms

Accident Type	Event Date	Water Depth (ft)	Initiating Event Category	Initiating Event Description	Chain of Events	Control Measures
Fire	5/22/97	1,353	Equipment Failure / Human Error	Electrical fire started from a connection adapter		Adapter unplugged which extinguished fire.
Fire	5/29/97	1,353	Equipment Failure	Welding sparks ignited acetylene leaking from the tank valve		Extinguished using a dry chemical extinguisher
Fire	10/13/97	1,353	Equipment Failure	Insulation fire		Extinguished
Fire	6/27/98	1,353	Equipment Failure	Flash fire from generator startup	Generator caught fire when started	Extinguished, medical attention given to operator who was burned
Fire	7/20/98	1,353	Equipment Failure	Seal ring not torqued down sufficiently and leak caught fire		Extinguisher
Fire	3/17/99	1,353	Equipment Failure	Small Electrical Fire	Transformer shorted out and caused wires to smolder. No flames were visible.	Power was removed from transformer
Fire	2/28/00	1,023	Equipment Failure	Stainless steel sensing line rubbed through a 3/4" conduit and started a fire	Sensing line from a compressor suction scrubber	Extinguished immediately
Fire	10/15/00	1,130	Equipment Failure / Human Error	Oil dripped on the number 2 gas compressor exhaust causing a small fire	Lube oil tank for compressor 1 was overfilled causing excess oil to flow out the plastic vent line and drip on the number 2 exhaust below	Extinguished with 30 lb chemical unit
Fire & Pollution	2/11/01	1,290				
Fire	3/17/01	1,023	Equipment Failure	Insulation on air compressor caught fire	Relief valve leaked hydrocarbons onto compressor	Extinguished with 30 lb chemical unit
Fire	8/12/01	1,290	Human Error	Filling of lube oil day tank #1 was left unattended and led to burst of tank seam spraying a quart of lube oil onto engine exhaust causing a small flash fire	Half of left over oil removed to a containment tank until repairs could take place	Extinguished with 30 lb chemical unit
Fire	12/12/01	1,100	Equipment Failure	Upon generator startup generator caught fire	Insulation around oil leak had become saturated with oil due to leaking drain valve	Put out with water
Fire	3/6/02	1,023	Equipment Failure	Fire occurred when welding lead wire separated and caught fire		Extinguished immediately
Fire	3/20/02	1,023	Human Error	Grease fire in the kitchen		Galley hand extinguished with a 30 lb dry chemical unit

Table I-2. Compliant Towers

Accident Type	Event Date	Water Depth (ft)	Initiating Event Category	Initiating Event Description	Chain of Events	Control Measures
Fire	10/10/98	1,648	Human Error	Filter material left on top of solar generator	Generator start ignited material	Fire extinguished immediately
Fire	9/8/99	1,000	Equipment Failure	Gas leak came in contact with a coil and ignited		Extinguished with 5 lb chemical unit
Fire	10/18/99	1,000	Equipment Failure	Compressor fuel line leaked and came into contact with a coil causing a small fire	Bushing loosened due to vibration leading to failure	Extinguished with 30 lb chemical unit
Fire	10/28/99	1,000	Equipment Failure	Compressor caught fire		Extinguished with 30 lb chemical unit
Fire	11/1/01	1,754	Equipment Failure	Engine of west crane caught on fire	Duration was less than a minute. Cause was a small oil leak of a hydraulic hose	Engine shut down and fire extinguished with a 30 lb dry chemical unit
Fire	12/26/01	1,754	Equipment Failure	Small fire on water flood injection pump		Fire extinguished itself due to lack of oxygen and fuel because it occurred in enclosed area

Table I-3. Semi –Submersibles Floating Systems

Accident Type	Event Date	Water Depth (ft)	Initiating Event Category	Initiating Event Description	Chain of Events	Control Measures
Fire & Pollution	1/2/96	2,163	Equipment Failure	Fluid fill hose snagged on the travelling block guide rail and parted the lines that control the motion compensator. Wind sprayed fluid onto flash compressor and it caught fire.		Fire extinguished within minutes
Fire	7/25/99	2,163	Human Error	Minor flash fire	Welding near standing production riser caused accumulation of oil and condensate to ignite	Fire put itself out with no damage

Table I-4. Tension Leg Platforms

Accident Type	Event Date	Water Depth (ft)	Initiating Event Category	Initiating Event Description	Chain of Events	Control Measures
Fire	5/21/98	1,722	Equipment Failure	Outer shell of exhaust collector ignited oil soaked insulation	Oil originated from burst line. Compressor vibration and the stress bend caused the crack	
Fire	8/21/98	3,204	Equipment Failure	Oil leak from a damaged gasket on exhaust pipe	Heat from exhaust ignited oil	Motorman extinguished fire immediately
Fire	1/23/99	3,204	Exhaust Spark	Exhaust spark ignited residual oil on exhaust piping		Extinguished within 2 minutes with 30 lb chemical unit
Explosion in Atmospheric Tank	2/8/99	3,186	Equipment Failure	Static electricity ignited gas in tank		No fire or injury just loss of 210 bbl pressure tank
Fire	5/7/99	1,722	Equipment Failure	Fire occurred in insulation of a compressor		Extinguished with 30 lb chemical unit
Fire	9/30/99	2,930	Equipment Failure	Diesel hose came loose spraying exhaust of compressor and caught fire		Extinguished within 30 seconds with 30 lb chemical unit
Fire	10/4/99	3,204	Equipment Failure	Portable fan caught fire	Power disconnected	Fire extinguished immediately
Fire	12/16/99	1,722	Equipment Failure	Oxygen filled enclosure and when it combined with oil coated insulation it caught fire		Extinguished with chemical unit then shut down
Fire	6/15/00	3,800	Equipment Failure	Recycle gas compressor experienced a small fire within the turbine enclosure		Compressor was shut down and fire extinguished
Fire	6/24/00	2,930	Human Error	Tarp around a turbine gas generator caught fire	280 deg F exhaust ignited tarp	Fire was detected and extinguished immediately
Fire & Injury	7/28/00	2,864	Completion Fluids Reaction	Flash fire occurred in the Cetco Weir tank in conjunction with flowing well A-10	Employee in the area suffered 1st and 2nd degree burns to face hands and arms	Immediately Extinguished
Fire	8/3/00	3,216	Equipment Failure	During startup on a solar gas compressor, a small fire was observed at the end of the exhaust of the turbine enclosure		CO2 fire suppression activated. Fire extinguished immediately.
Fire	5/27/01	3,216	Equipment Failure	28" diameter riser spool came loose from sea fastenings and traveled toward vessel stern causing small fires as the spool bearings overheated aboard Oceaneering Intervention II		Fires were immediately extinguished
Fire	7/19/01	2,864	Equipment Failure	Small fire occurred in an air compressor	ESD actuated on drill floor. Fire caused by a loss of lubrication to a bearing causing overheating and then the fire	Extinguished with 30 lb chemical unit
Fire	1/31/02	3,186	Equipment Failure	Ground fault test on a generator caused fire to occur	Wires from generator were the fuel source	CO2 deluge system used to extinguish the fire
Fire	2/7/02	2,005	Equipment Failure	Small fire occurred due to backfire in the emergency generator engine	Backfire caused the exhaust filter to catch fire	Generator shut down and fire extinguished with a portable CO2 extinguisher
Fire	2/16/02	3,204	Equipment Failure	Operator performing a turbine flush of the fuel gas generator when an internal fire started in the turbine engine		Flash fire lasted one minute then extinguished itself
Fire	3/10/02	2,005	Equipment Failure	Failed turbocharger in emergency generator caused fire from oil seal leak	The oil then caught the filter on fire also	Very small fire burned itself out quickly
Fire	4/6/02	3,800	Equipment Failure	Cable tray near a transformer had and electrical fire		Extinguished with 30 lb chemical unit
Fire	5/6/02	3,216	Equipment Failure	Smoke started in glycol dehydration unit. Fire came from primary control panel.		Breaker turned off and fire extinguished on its own
Fire	12/3/01	2,950	Equipment Failure	Transformer windings shorted and failed		Complete shut in and shut down of well operations stopped fire

Table I-5. Spar Floating Systems

Accident Type	Event Date	Water Depth (ft)	Initiating Event Category	Initiating Event Description	Chain of Events	Control Measures
Fire	10/23/98	2,599	Human Error	Did not clear welding area of flammable material	Slag caught flammable materials on fire	
Fire	10/9/99	2,599	Equipment Failure	Natural gas line parted	Nearby rags caught fire	Extinguished with dry chemical unit
Fire	6/18/00	4,785	Human Error	Helicopter blew tarps on hot exhaust stack and they caught fire		Extinguished with water
Fire	9/10/01	2,599	Equipment Failure	Lube oil/air filter in air compressor caught fire	Fire grew to involve entire compressor	Required 2 no. 30 lb chemical extinguishers and fire hose to put out
Fire	10/26/01	4,785	Equipment Failure	Fuel leak from intake	Engine room fire	Extinguished with built in CO2 system and hose within 20 minutes
Fire	11/6/01	2,599	Equipment Failure	Dive Bell Heater Failure caught diesel fuel on fire		Extinguished in 5-10 seconds with dry chemical unit

Table I-6. Mobile Offshore Drilling Units (MODUs)

Accident Type	Event Date	Water Depth (ft)	Initiating Event Category	Initiating Event Description	Chain of Events	Control Measures
Fire	2/20/98	3,273	Equipment Failure	Fuel oil centrifuge belt failure	Caused fuel to continue to pump until it overflowed. The fuel then overflowed and vaporized and once it had spread through a large portion of the engine room it caught fire.	Secondary fuel sources from engines fed the fire until it was extinguished
Fire	3/15/98	2,097	Human Error	Welding Slag Ignited rag		Extinguished immediately caused little damage
Fire	6/10/99	1,718	Equipment Failure	Wire grounded to transformer	Wire overheated and caught fire	Extinguished with 30 lb chemical unit
Fire	10/22/99	6,950	Pending	Riser assembly fell into Gulf	Small fire also started	Put out within minutes
Fire	11/14/99	4,352	Equipment Failure	Sealed bearing in drill water pump started smoking. Caught fire when shut down.		
Fire	12/2/99	4,513	Equipment Failure / Human Error	Cascade combination of welding and pump blowout	When base oil transfer pump primed overflow shot out and ran down the side of the rig to a deck were welding was taking place. This caught the oil on fire and resulted in the well having to be shut in to stop the fire.	Well was shut in and fire went out in 10 minutes

Table I-7. North Sea Incidents in Floating Production Installations

Accident Type	Event Year	Initiating Event Category	Initiating Event Description	Severity
Fire	1,993	Equipment Failure	While doing fire system zone 300 cause and effects. Fault identified on zone 314, coz pushbutton release from bridge not working. While fault tracing in back of motherboard, inadvertently shorted two terminals with multimeter probe.	Insignificant
Fire	1,994	Equipment Failure	A production control room technician noticed flame/spark like flickering inside a stenofon p a control cabinet by the aft wall of the main control room on the port side. It was immediately investigated by a technician and the power switched off. Faulty wiring was found and attributed to poor workmanship during construction.	Insignificant
Fire	1,994	Equipment Failure	Gas compressor failed to start. On investigation by electrical technician, the switchgear isolating handle spring mechanism was found to be stuck in the off position and reset by touching the mechanism, which immediately sprung to the correct position. A second start was attempted and immediately an explosion occurred in the switchgear cubicle blowing off the door and starting a small fire, which was rapidly put out with CO2 extinguisher, subsequent investigation found misalignment of the circuit breaker truck knife connectors had resulted in incorrect contact resulting in arcing resulting in fire and explosion.	Accident
Fire	1,995	Equipment Failure	The welder was preheating a section of steel (longitudinal) prior to welding. Flexible ducting was close to the work site to extract any fumes. The ducting caught fire and the fire spread up the ducting. The extraction fan at the end of the ducting help to maintain the fire. The fire watchman attempted to extinguish the fire with an extinguisher but this failed. The tank watchman shut off the ventilation fan and the fire burnt itself out. Tanks were evacuated in a controlled manner. A full emergency muster took place.	Incident
Fire	1,995	Equipment Failure	Maintenance personnel were attempting to start \`a\` gas turbine alternator set, using fuel gas. The first start sequence failed on low servo hydraulic pressure. The controls were reset and "gas start" re-selected. The machine purge and gas valve checks were carried out automatically without a problem. However at the ignition step, ignition was not detected and a "bang" was heard. On investigation two expansion bellows in the exhaust trunking were found to be ruptured. It is assumed that an overpressure occurred as a result of a fuel/air mix igniting. The exact mechanism has yet to be established.	Insignificant
Fire	1,995	Equipment Failure	A fan belt on nitrogen compressor started to slip, the friction melted the belt and smoke developed in the room. A smoke alarm was triggered. Fans stopped and dampers closed. After approx. 30 mins the room was ventilated and everything back to normal.	Incident
Fire	1,996	Equipment Failure	2 x smoke detectors activated in the power module causing a gpa & ESD 3. On investigation by 2 production operators, they discovered smoke coming form between 2 of the diesel generators which drive the water injection package. On closer examination they discovered a small fire around the engine exhaust turbo charger area. The flames were quickly put out by the use of a dry powder extinguisher. During further investigation we discovered that the exhaust had been leaking causing a build up of heat, which ignited the paintwork and some redundant lagging.	Incident
Fire	1,996	Equipment Failure	Welder was using the burner in the workshop. To cut materials to use in the ground flare. He had light on the acetyl. On the burner and he put on his glasses, when the hose with acet started to burn he tried to stop the fire but did not succeed he went out of the workshop and started the fire alarm, fire team extinguished the fire.	Insignificant
Fire	1,998	Equipment Failure	The FPU was on location in the field, preparing for first commercial oil production, when light smoke was seen coming from the port propulsion room. The 74 crew members went to muster stations and a helicopter was sent to the scene. However, after 20 mins the crew was given "all-clear" and they returned to normal duties. No fire was discovered, but as a precaution the engine room was sealed and saturated with fire extinguishant. An overheated motor was probably the cause of the event.	Incident
Explosion		Human Error	Gas compressor B failed to start. On investigation by electrical technician, the switchgear isolating handle spring mechanism was found to be stuck in the off position and reset by touching the mechanism, which immediately sprung to the correct position. A second start was attempted and immediately an explosion occurred in the switchgear cubicle blowing off the door and starting a small fire, which was rapidly put out with CO2 extinguisher, subsequent investigation found misalignment of the circuit breaker truck knife connectors had resulted in incorrect contact resulting in arcing resulting in fire and explosion.	Accident
Explosion		Equipment Failure	Water injection pump \`B\` had been electrically de-isolated prior to the incident. The pump had failed to start and technician was called to check the breaker. He did this, found nothing wrong and informed production that the breaker was OK and the pump could be started. A little later another attempt was made to start the pump and again it failed to start. Technicial was again called to investigate and he met with a senior rod technician outside the HV switchbox room. They entered the room and found an alarm condition on the pump motor but no indication of the pump running. The alarm was acknowledged and it cleared. It was decided to examine the breaker truck micro switches to ensure that they were operating correctly. The cabinet was opened, the truck was pulled out and the micro switches found to be OK. The truck was then reinstated and the cabinet closed. Production crew were informed that they could attempt to start up the pump. On attempted start up of the pump the breaker energized and an explosion resulted within the breaker cubicle. The door blew open and were observed inside the cubicle. Used a CO2 extinguisher to extinguish the fire and reported to the CCR.	Incident

Attachment II

Lessons Learned from MMS Study on FPSO Comparative Risk Assessment

Background.

A quantitative risk analysis was performed to assess and compare oil spill and fatality risks for three representative floating production systems in the Gulf of Mexico: a Spar with oil pipelines, a TLP with oil pipelines, and a tanker-based FPSO with shuttle tankers for oil transport to shore (Figure II-1). A shallow-water jacket serving as a hub and a host for deepwater production was also included for comparison purposes.

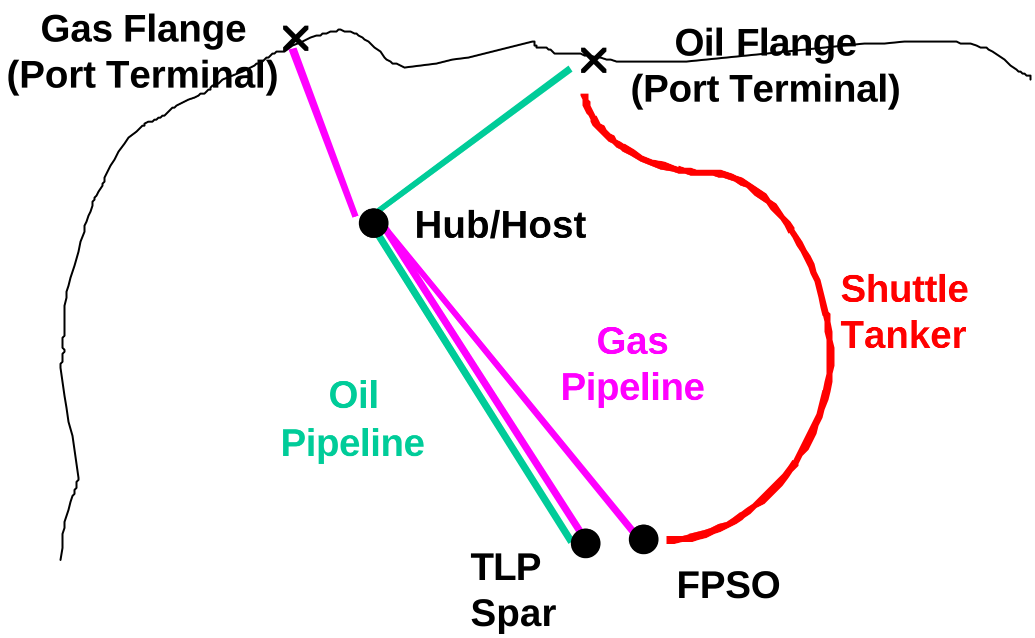


Figure II-1. Study System

The measures of risk used for comparison were the expected total number of fatalities and the expected total volume of oil spilled in a 20-year operational life.

Lessons Learned.

There were no significant differences in the oil-spill risk and the fatality risk between the study systems (Figures II-2 and II-3).

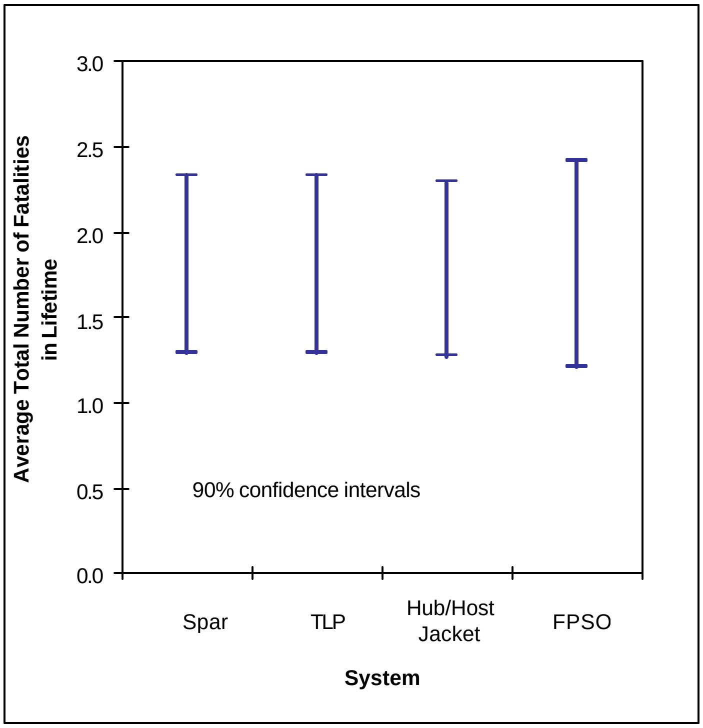


Figure II-2. Comparison of Fatality Risks

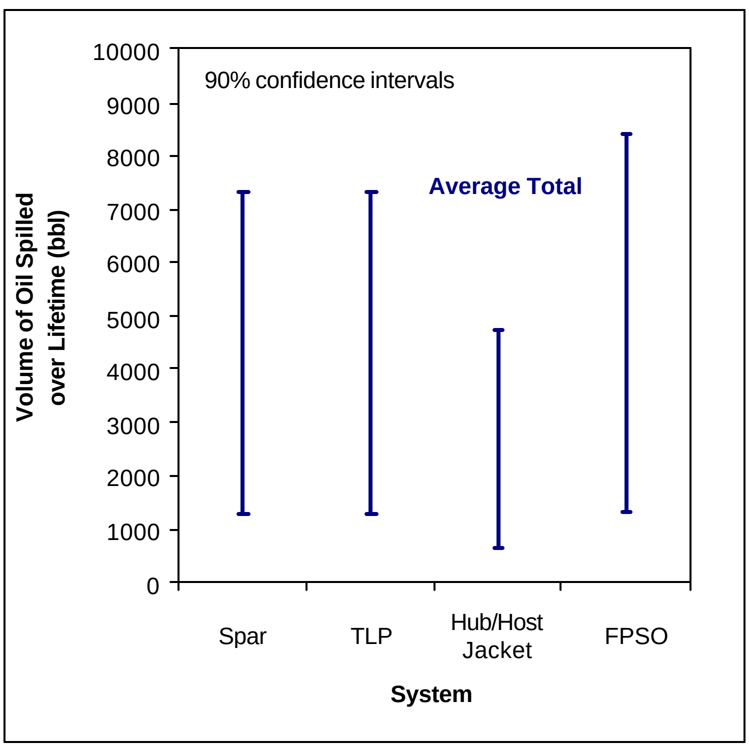


Figure II-3. Comparison of Oil-Spill Risks

The main contributors to fatality risk were production and drilling activities since these comprise the majority of the man-hours required to operate the facility over a 20-year lifetime (Figure II-4).

Fires and explosions did not contribute significantly to the fatality risk:

- Between 1992 and 1999 (the database used in this assessment), none of the 27 fatalities on platforms, 28 fatalities on drill rigs, 31 fatalities on supply vessels and 6 fatalities on tankers in the Gulf of Mexico were caused by fires or explosions.
- The “Major Accident” category was included to account for the possibility of a large-scale fire and/or explosion event that would result in upwards of 30 fatalities. However, even though the consequence is high, the frequency for this type of an event was estimated to be so small that it had a very small contribution to the total fatality risk (Figure II-4).
- One limitation to measuring risk by the expected number of fatalities (or the FAR or PLL), is that high-consequence and low frequency events, such as major fires and/or explosions, are not important. However, most operators and regulators are risk-averse to an incident with 30 or more fatalities (30 fatalities is more than 30 times worse than one fatality). Therefore, additional risk measures that account for this risk aversion should be used in evaluating and comparing alternatives.

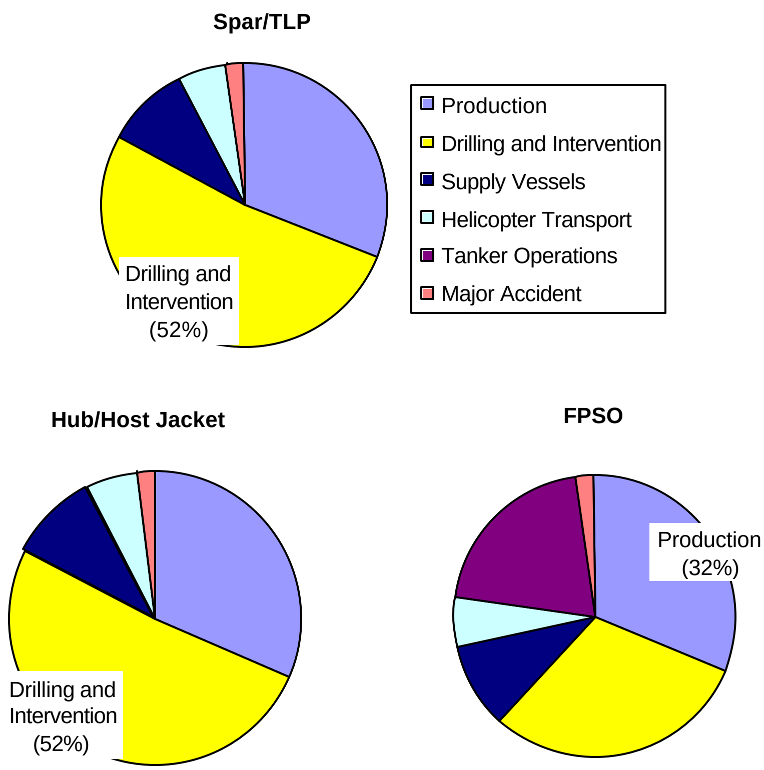


Figure II-4. Contributions to Fatality Risk by Activity

The main contributors to oil-spill risks were the oil transportation systems, pipelines for the Spar and TLP versus shuttle tankers and cargo for the FPSO (Figure II-5).

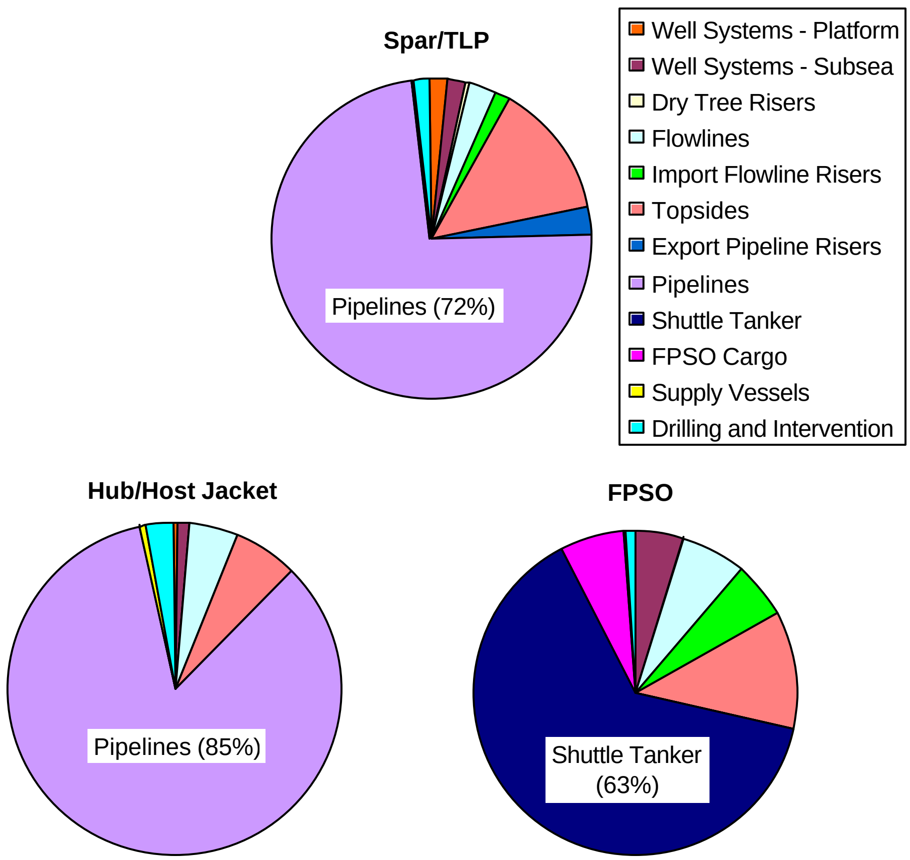


Figure II-5. Contributions to Oil-Spill Risk by Operation

The total oil spill risks were dominated by large spills with small frequencies of occurrence (Figures II-6 and II-7). The spill risks for pipelines are dominated by the possibility of spills between 10,000 bbl and 100,000 bbl in size that are expected to occur once every 600 years on average for a facility. The spill risks for shuttle tankers are dominated by the possibility of spills between 100,000 bbl and 500,000 bbl in size that are expected to occur on average once every 4,500 years for a facility.

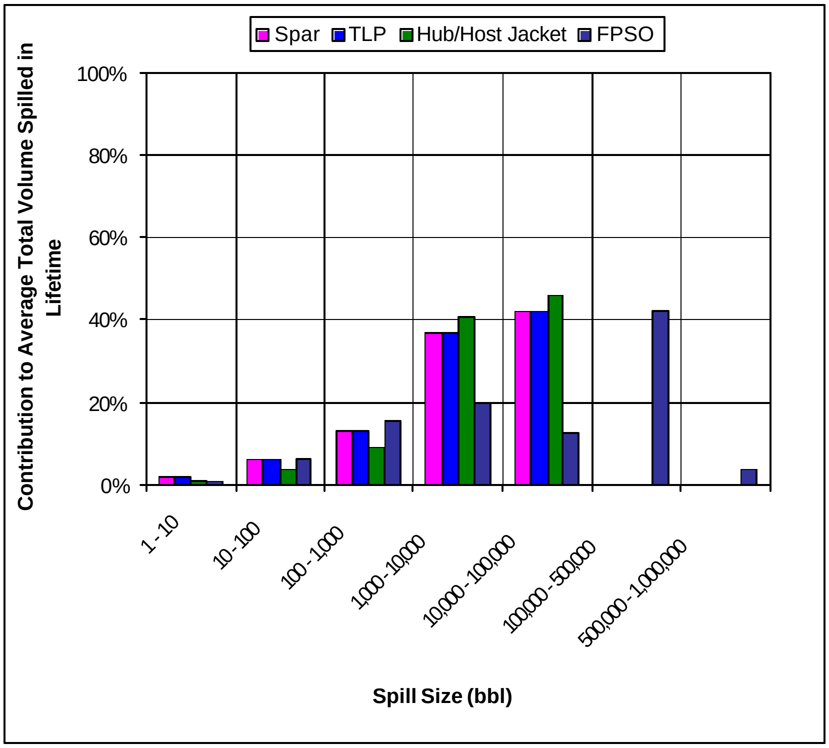


Figure II-6. Contributions to Oil-Spill Risk by Spill Size

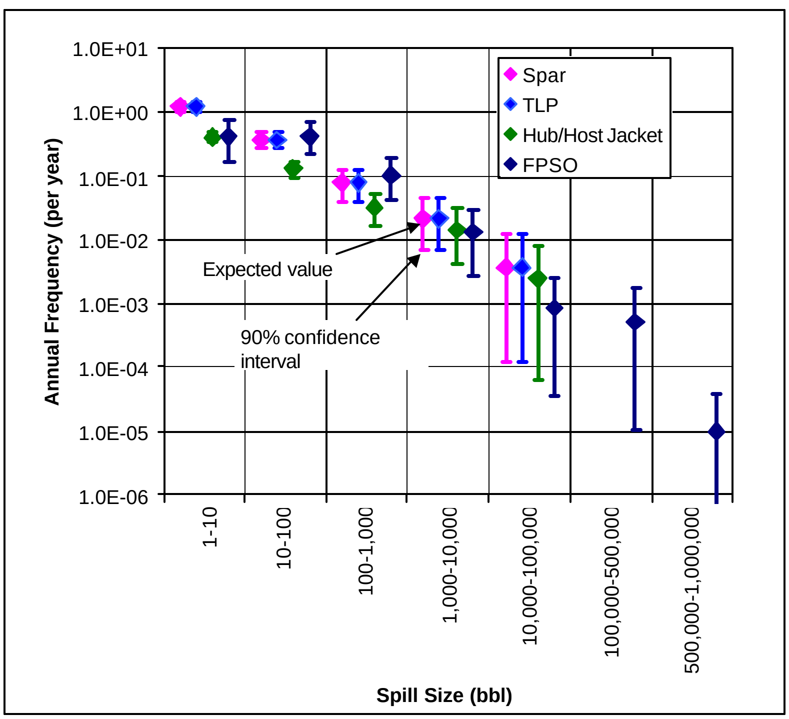


Figure II-7. Frequency of Different Spill Sizes

Fires and explosions did not contribute significantly to the oil spill risks:

- The major cause of pipeline spills was snagging and impact, while the major cause of shuttle tanker and FPSO cargo spills was collisions.
- Between 1992 and 1999 (the database used in this assessment), none of the oil spills greater than 100 bbls in size from oil production and transport were caused by a fire or explosion.

The major fire and explosion hazards that were identified for the floating production systems included: pump room explosions on tankers/ FPSOs, explosions in the turret area on an FPSO, and explosions in the moonpool for a Spar. Also, construction and maintenance activities were identified as a significant contributor to the potential for fires and explosions.

The following major differences related to fire and explosion risks were identified for the floating production systems:

- Gas can accumulate in the moonpool on a Spar.
- Equipment spacing on a TLP and Spar is closer than on a tanker-based FPSO (gas processing areas are particularly congested), meaning more potential for confinement, overpressure and escalation and more difficulty in fighting fires.
- Grated decks on a TLP and Spar can reduce the size of pool fires but also allow fires to spread to multiple decks.
- FPSO swivel provides additional points of hydrocarbon release. Also, hogging and sagging of deck could affect piping.
- FPSO has more deck area and personnel on board benefit by greater separation distances.

Finally, there is a limited quantity and quality of historical data available to estimate frequencies for rare events leading to large numbers of fatalities or large oil spills. This lack of data leads to significant uncertainty in the estimated risk measures (Figures II-2, II-3 and II-7). The following comments are related to this uncertainty:

- Uncertainty in failure rates should be presented clearly and considered carefully in drawing conclusions from and applying the results from a risk assessment.
- The quality of existing data sets for the Gulf of Mexico should be improved so that they are of greater value in future risk analyses. First, the type and quality of data that are currently collected should be evaluated, and any changes recommended from this evaluation should be implemented in a timely manner. Second, single agencies should be responsible for tracking and compiling similar types of data. Third, all data records should be reviewed annually by the industry and regulators to improve the clarity, quality and usefulness of the information in these records. Finally, the data should be published annually in a clear and an easily accessible format.
- Additional information about the populations of offshore facilities and operations in the Gulf of Mexico should be collected on an annual basis.

Specifically, the following information from federal and state waters in the Gulf of Mexico would be valuable: the length of active pipelines operating per year, the number of tanker on-loading and off-loading events in ports and lightering zones per year, and the number of man-hours in production-related activities, supply vessel operations and tanker operations per year.

References:

Gilbert, R. B., Ward, E. G. and Wolford, A. J. (2001), "A Comparative Risk Analysis of FPSO's with other Deepwater Production Systems in the Gulf of Mexico," *Proceedings*, Offshore Technology Conference, Houston, Texas, OTC 13173.

Gilbert, R. B., Ward, E. G. and Wolford, A. J. (2001), "Assessment of Oil Spill Risk for Shuttle Tankers in the Gulf of Mexico," *Safety & Reliability*, The Safety and Reliability Society, Vol. 21, No. 2, 80-105.

Gilbert, R. B., Ward, E. G. and Wolford, A. J. (2001), "Comparative Risk Analysis for Deepwater Production Systems," Final Project Report, Offshore Technology Research Center, Prepared for Minerals Management Service, 368 pp.

Attachment III

Lessons Learned from Installations in Other Regions

1. Introduction

There is significant experience outside the GoM with FPSOs. Areas with the highest concentration of FPSOs are the North Sea, South East Asia, and West Africa. The risks associated with FPSO and other types of installation in the North Sea and other offshore regions of the world are reasonably well understood through both operational experience and detailed risk assessment.

This Attachment includes details based upon the presentation made at a WG5 session. The presentation covered the lessons learned from applications and design of fire and blast technology to the North Sea installations. Illustrations and part presentation is included for the following:

- Layout and Design Principles
- Heidrun TLP
- Åsgard A FPSO
- Status of Technology
  - Elements in a Full Probabilistic Fire/Explosion Analysis
  - Experience with Fire and Blast Design and Simulations

2. Layouts and Design Principles

The issues associated with layouts for TLP, Spar, FPSO were discussed in detail at a session of this work group. These layouts are given in Attachment IV.

Additional layouts for the two examples for TLP and FPSO presented in Sections 3 and 4 in this Attachment were also discussed.

The topside layout options and design principles associated with the following were presented through the two illustrations in this section:

- Fixed platform in moderate water depth (Figure III-1)
- FPSO design with respect to minimization of gas explosion hazard (Figure III-2)

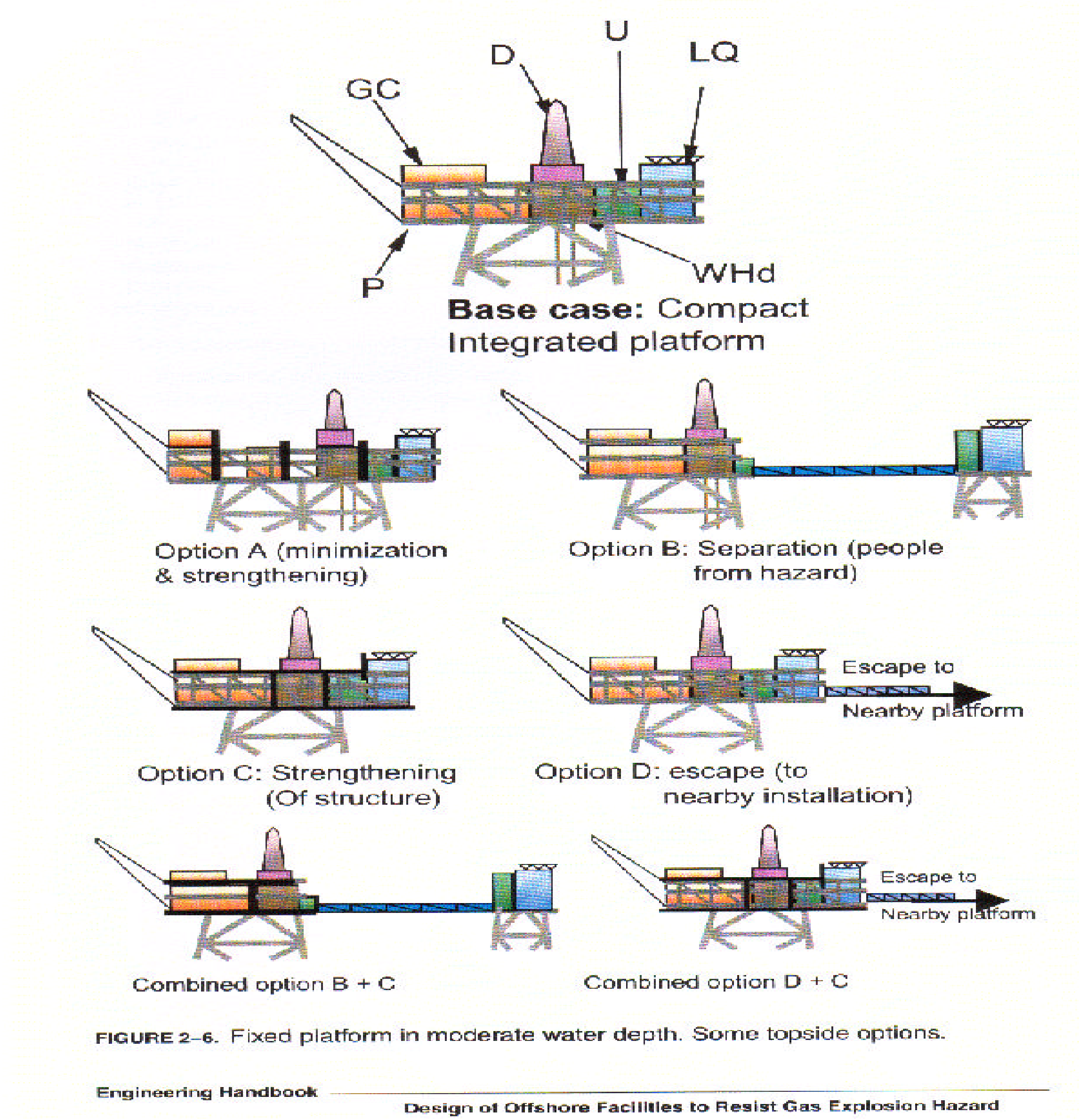


Figure III-1. Fixed platform in moderate water depth

(Source: Corrocean Handbook on Design of Offshore Facilities to Resist Gas Explosion Hazard, 2001)

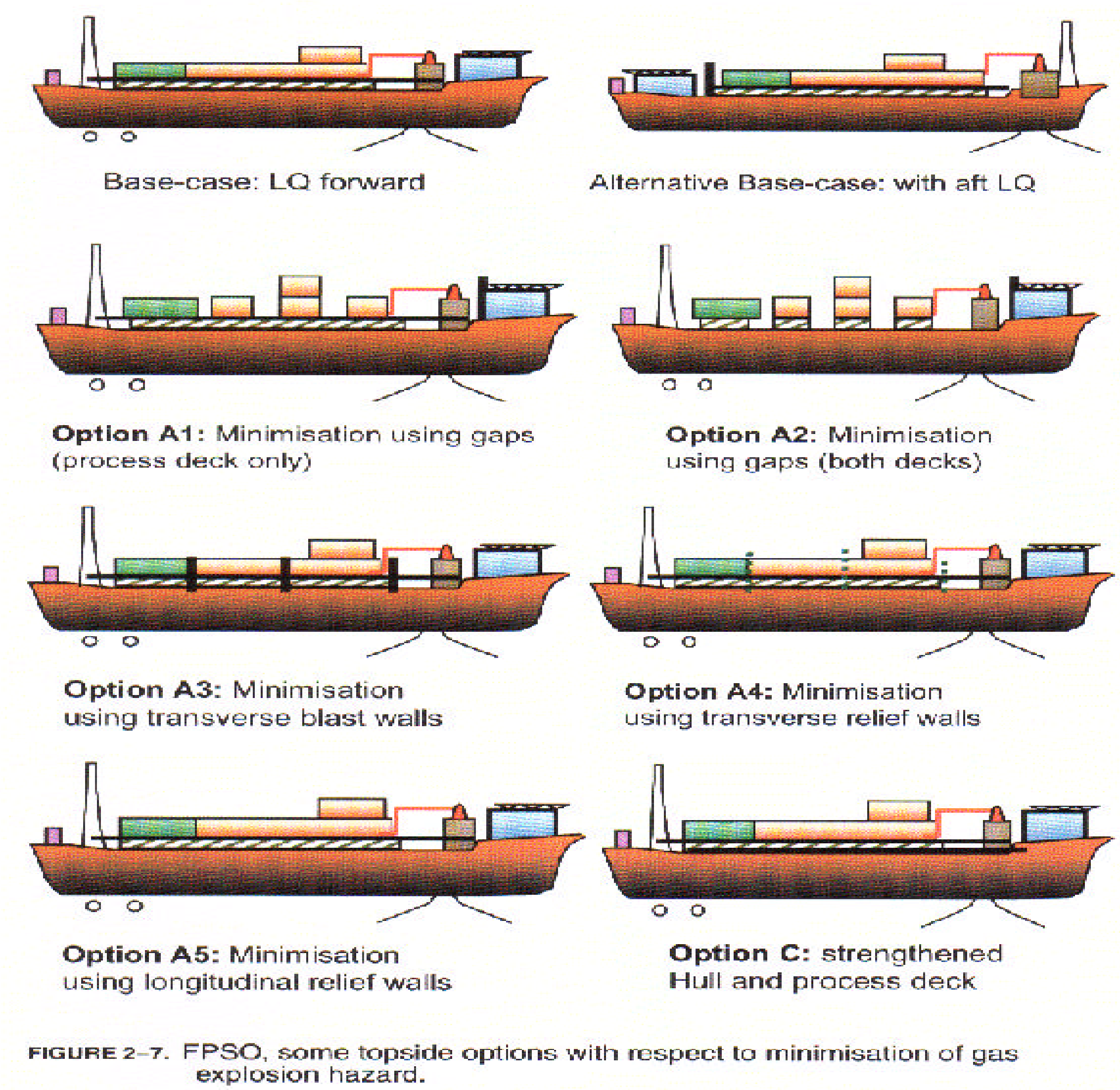


Figure III-2. FPSO design with respect to minimization of gas explosion hazard.

(Source: Corrocean Handbook on Design of Offshore Facilities to Resist Gas Explosion Hazard, 2001)

3. Heidrun TLP

Heidrun TLP is a tension leg platform with a concrete hull with modular topside supported by two concrete module support beams mounted on the hull columns. It is operating in the North Sea outside mid-Norway, producing low vapor pressure crude oil, in more than 1,000 ft water depth location.

CorrOcean Safetec performed an analysis for Conoco Norway Inc (CNI) in early/mid 1990s, assessing compliance with Norwegian Petroleum Directorate (NPD) regulations for design of load-bearing structures. The consequence analysis performed at that time was not very detailed due to available simulation programs, compared to the CFD-tools available now. The following design accidental loads related to fire and explosion were identified:

- Blowouts:
  - Ignited gas blowout at wellhead or BOP
  - Fire on sea fed by platform oil blowout
- Topside fires:
  - Gas leaks from pressure vessel (combined with ESD failure)
  - Liquid leak from pressure vessel (combined with ESD failure)
- Explosions:
  - Design pressure 1.2 bars

The accidental events were established based on a quantitative risk analysis, and risk acceptance criteria developed by CNI based on NPD requirements. Acceptance criteria were established for exceedance frequency of events that violate the design premises (Residual Accidental Events). The risk assessment addressed the following:

- Risk to defined safety functions
- Material damage risk
- Pollution risk
- Occupational risk to life

The main findings related to fire and explosion were:

- Well blowouts are the largest contributor to the risk of total loss of the platform:
  - However, the risk level was comparable to other fixed offshore installations
  - The high blowout risk was caused by high drilling activity during initial years
- The consequences of blowouts were reduced by using fire-resistant concrete in exposed areas and by division of the wellbay area by a fire resistant wall

- Total impairment frequency caused by process/riser leaks was reduced by implementing SBV (subsea barrier valves) in all gas risers
- Tie-in of regional wells to the TLP increase the risk level
- Direct shuttle loading have insignificant influence on the risk level compared to other options for storage/loading

4. Åsgard A FPSO

Åsgard A FPSO is installed in the Haltenbank field in the Norwegian Sea at about 125 miles from mid-Norway and in about 800 ft to 1,000 ft water depth. The installations consist of a monohull unit (Åsgard A), for oil and condensate production with a semi-submersible platform (Åsgard B). The other installations for development of the field are Åsgard C (a storage vessel – FSU) and the necessary sub sea production installations, as shown in Figure III-3. The subsea systems consist of 51 wells linked by 190 miles of flow lines. Åsgard B was towed out to the field on 14 April 2000, and came on-stream late 2000.

Figure III-3 Åsgard A FPSO.

The following characterize the Åsgard A vessel, which is typical for a vessel built specifically for FPSO operation:

- Forward section comprises: bow, helicopter deck, accommodation and forward machinery (i.e. always upwind)
- Mid-ship section comprises cargo storage tanks below the main deck, process deck above the main deck and turret mooring system installed through the hull at the forward end of the mid-vessel section
- Aft section containing the engine room and other machinery; on the raised aft deck the vessel funnels, the process flare and the cargo offloading systems

The separation into sections and the fact that the accommodation and temporary refuge is upwind, contribute favorably to the risk picture, i.e. reduces probability and consequences of escalation of events.

The acceptance criteria applied in the risk assessment of the installation address:

- Fatality risk (FAR)
- Risk of loss of safety functions (escalation of events and impairment of escape routes/means and accommodation areas)
- Risk of environmental damage
- Risk of material loss

Related to fire and explosion, process events are the major contribution to the risk to personnel. Explosions in the process module, followed by potential escalation to the rest of the vessel, may have very serious consequences. However, due to very low frequency of occurrence these events have a small contribution to the total risk.

At an early stage the following scenarios were identified as critical with respect to the design criteria:

- Riser events could result in impairment of escape routes and escalation
- Collision with shuttle tanker

Implementing risk-reducing measures such as cold flare technology and strict procedures for the shuttle tankers reduced the risk attributed to these scenarios.

In addition to the conceptual characteristics of the FPSO design, risk is further minimized by implementing the following:

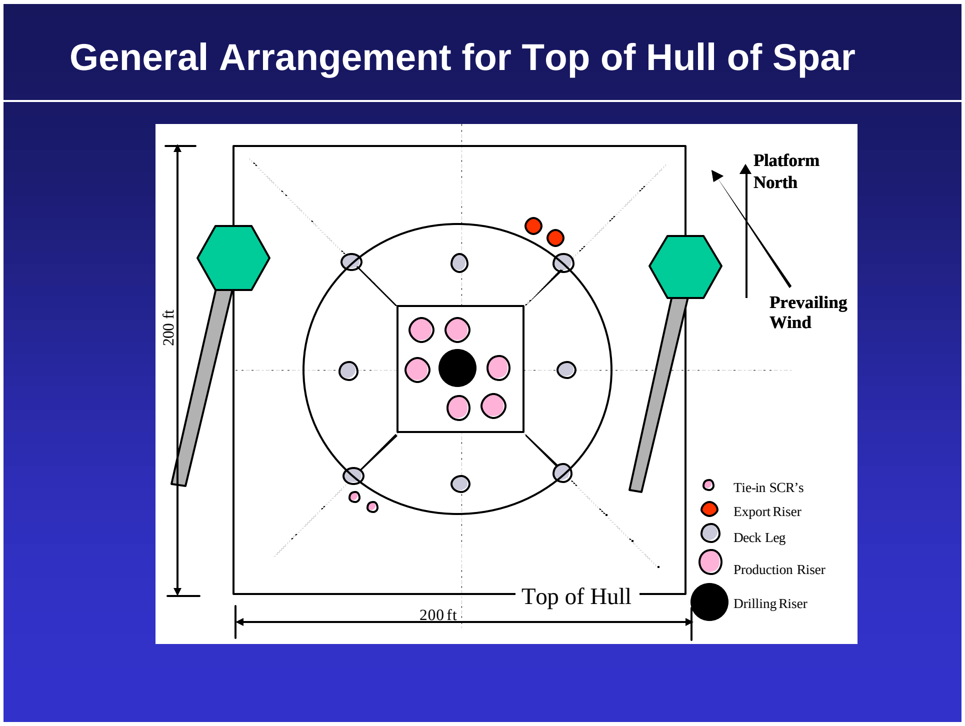
- Draining of oil spills from process deck to prevent escalation to tank deck and cargo tanks
- Process deck kept as closed as possible to prevent fire escalation; openings (stairs) bounded by rims to prevent run-off to deck below
- Segregated ballast tanks surround cargo tanks to give double barrier
- Protected escape routes along the whole of the vessel capable of withstanding fire and explosion in process and turret areas
- Cold flare philosophy implemented to decrease probability of igniting riser/turret releases

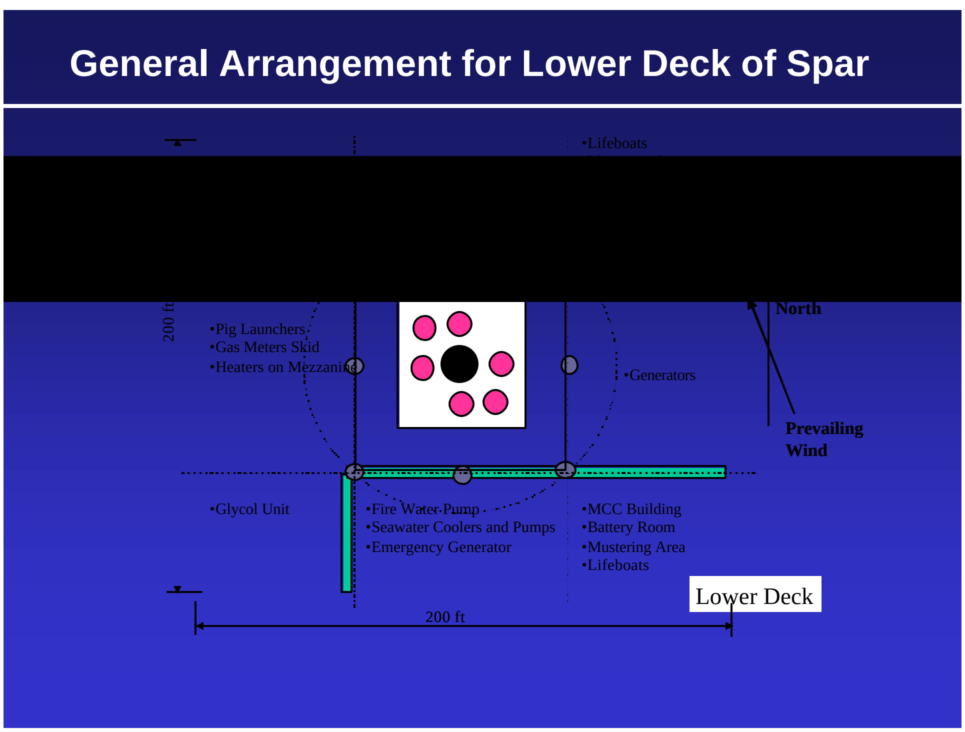
Attachment IV

Layouts Develope d in MMS study on FPSO Comparative Risk Assessment

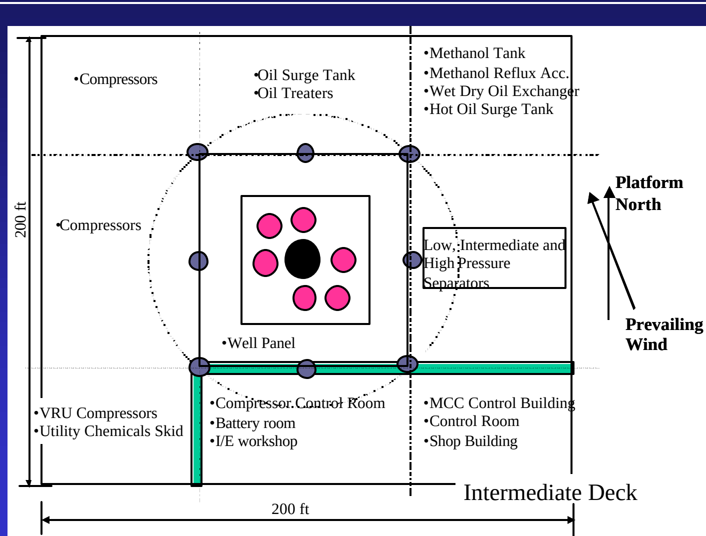
The topside layouts developed for Spar, TLP, Jacket, and FPSO platforms in the MMS sponsored FPSO Comparative Risk Assessment study performed by OTRC were presented at one of the WG5 session. These layouts were generated by OTRC and participating companies with input from industry representatives from the DeepStar program. These are part of the MMS study identified in Attachment II, which presents the lessons learned in the study.

I) Spar General Arrangement Drawings

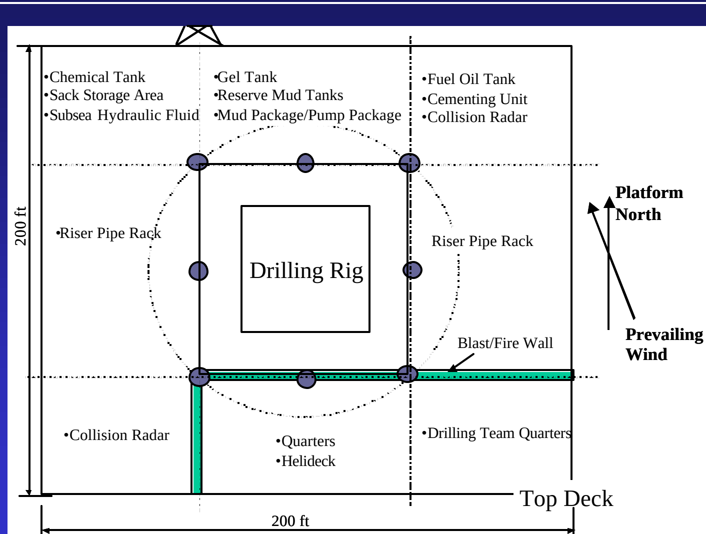




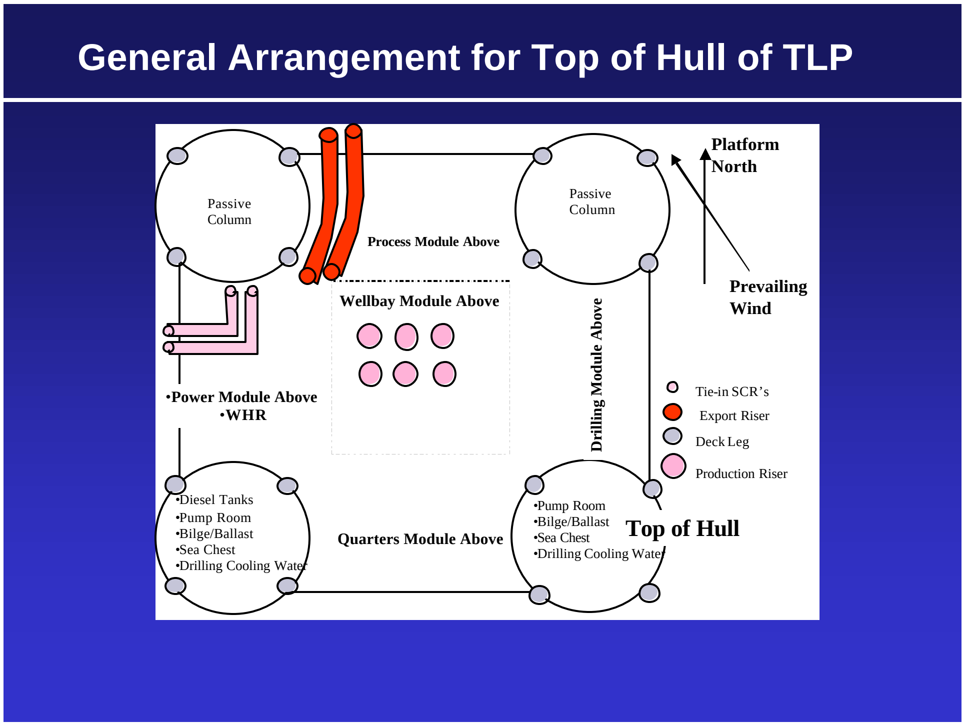
General Arrangement for Intermediate Deck of Spar

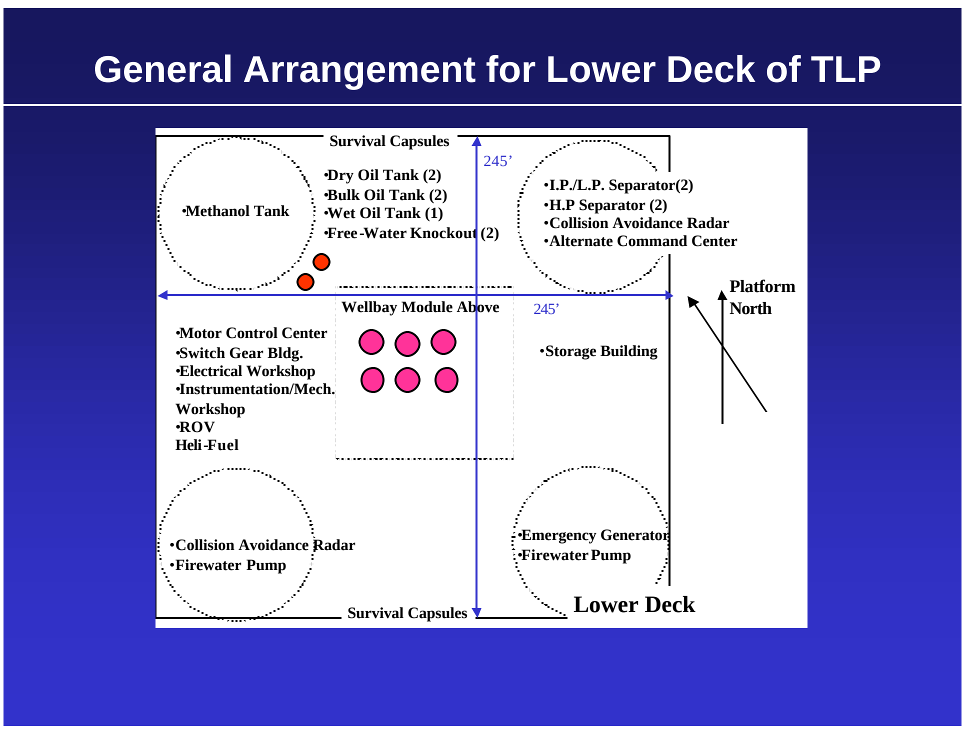


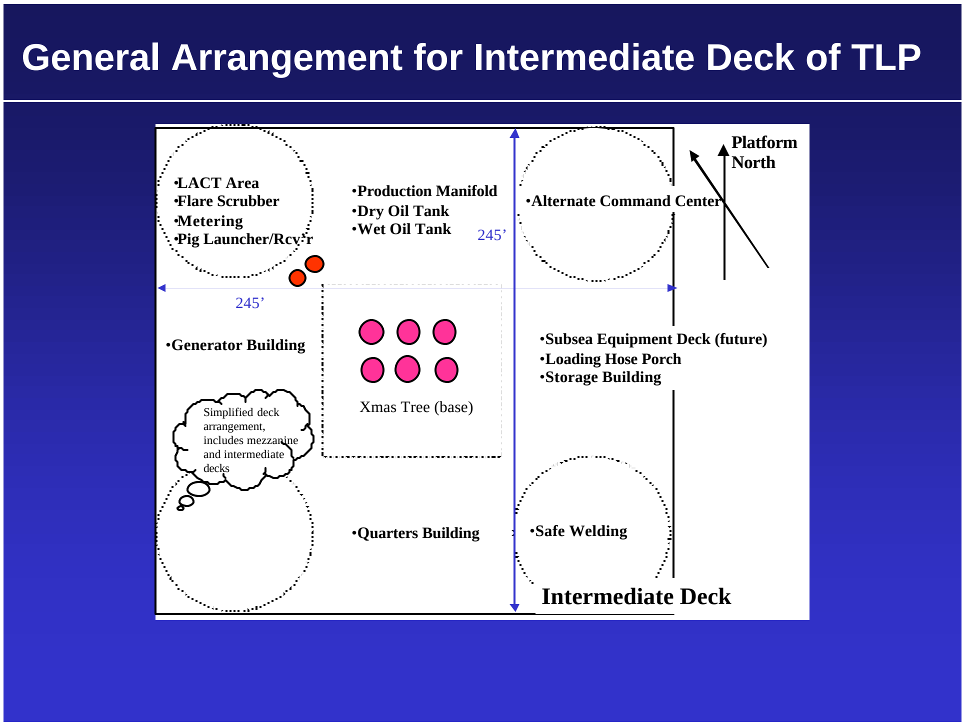
General Arrangement for Top Deck of Spar

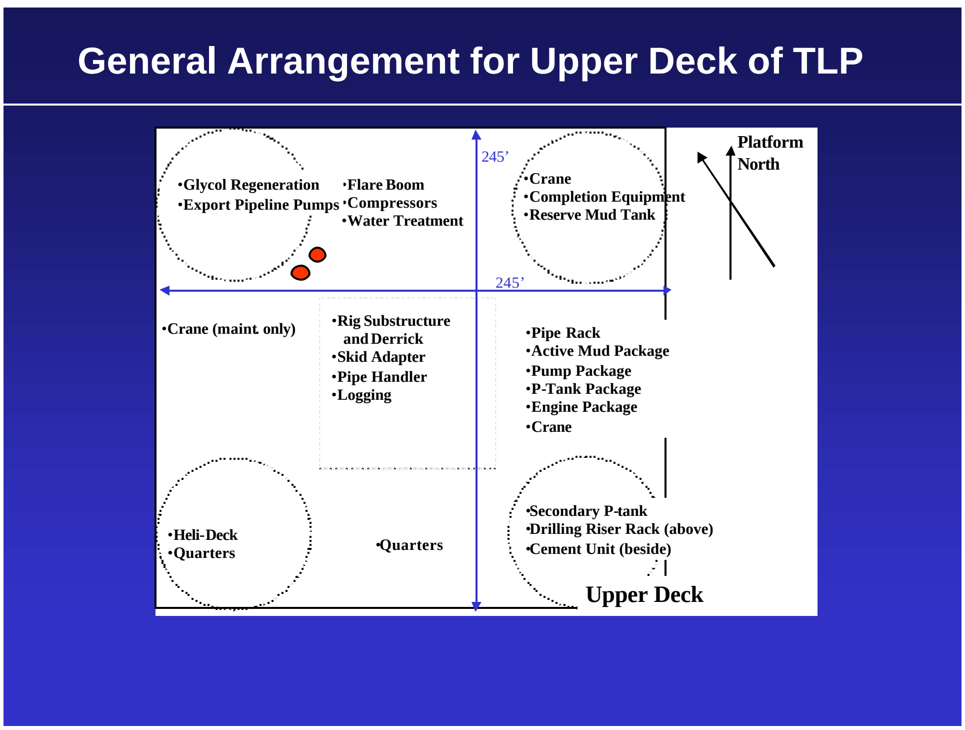


II) Tension Leg Platform General Arrangement Drawings

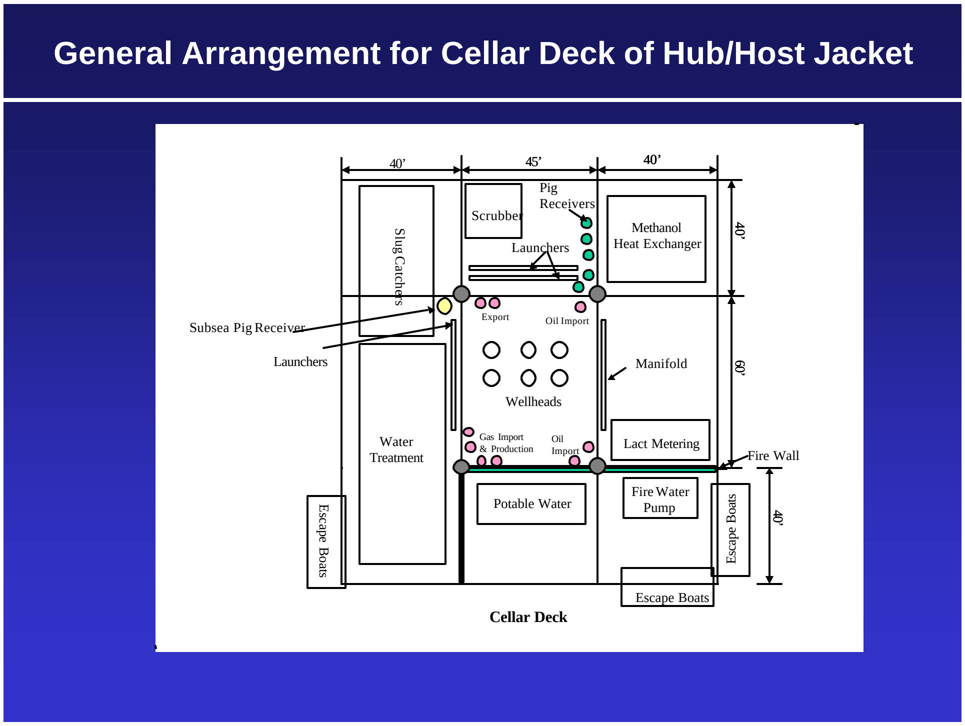


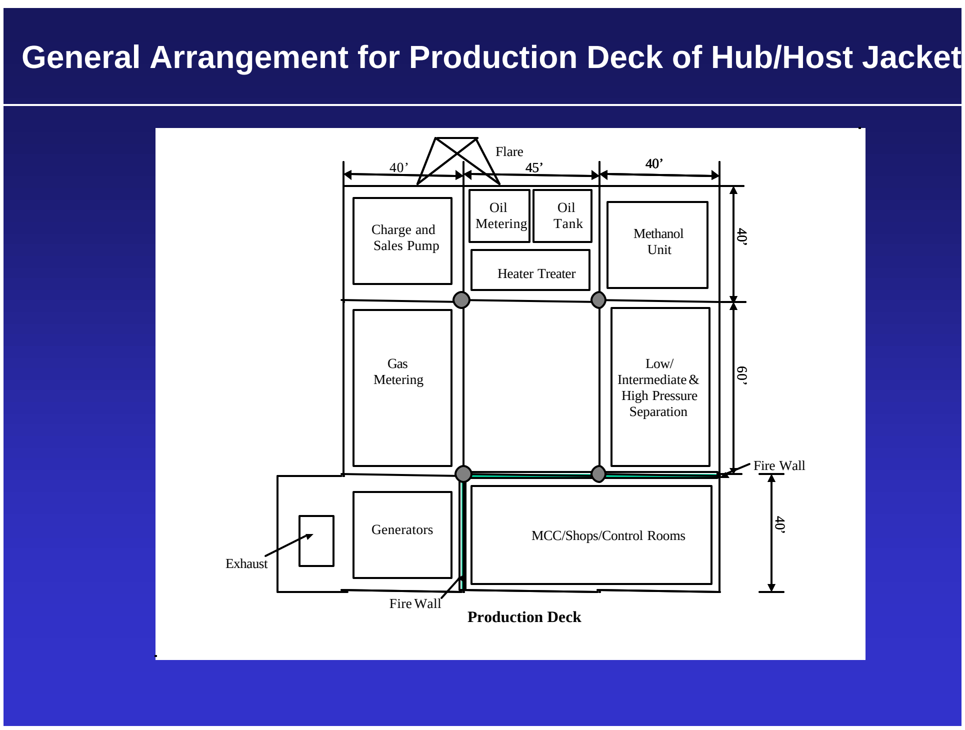



General Arrangement for Intermediate Deck of TLP
•LACT Area
•Flare Scrubber
•Metering
•Pig Launcher/Rcv'r
•Production Manifold
•Dry Oil Tank
•Wet Oil Tank
245'
•Alternate Command Center
Platform North
245'
•Generator Building
Xmas Tree (base)
•Subsea Equipment Deck (future)
•Loading Hose Porch
•Storage Building
Simplified deck arrangement, includes mezzanine and intermediate decks
•Quarters Building
•Safe Welding
Intermediate Deck

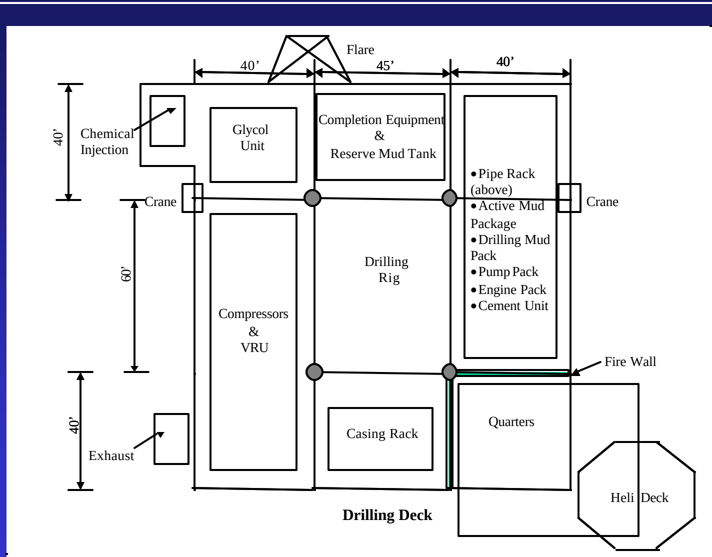

General Arrangement for Upper Deck of TLP
•Glycol Regeneration
•Export Pipeline Pumps
•Flare Boom
•Compressors
•Water Treatment
245'
•Crane
•Completion Equipment
•Reserve Mud Tank
Platform North
245'
•Crane (maint. only)
•Rig Substructure and Derrick
•Skid Adapter
•Pipe Handler
•Logging
•Pipe Rack
•Active Mud Package
•Pump Package
•P-Tank Package
•Engine Package
•Crane
•Heli-Deck
•Quarters
•Quarters
•Secondary P-tank
•Drilling Riser Rack (above)
•Cement Unit (beside)
Upper Deck

II) HUB/Host Jacket General Arrangement Drawings

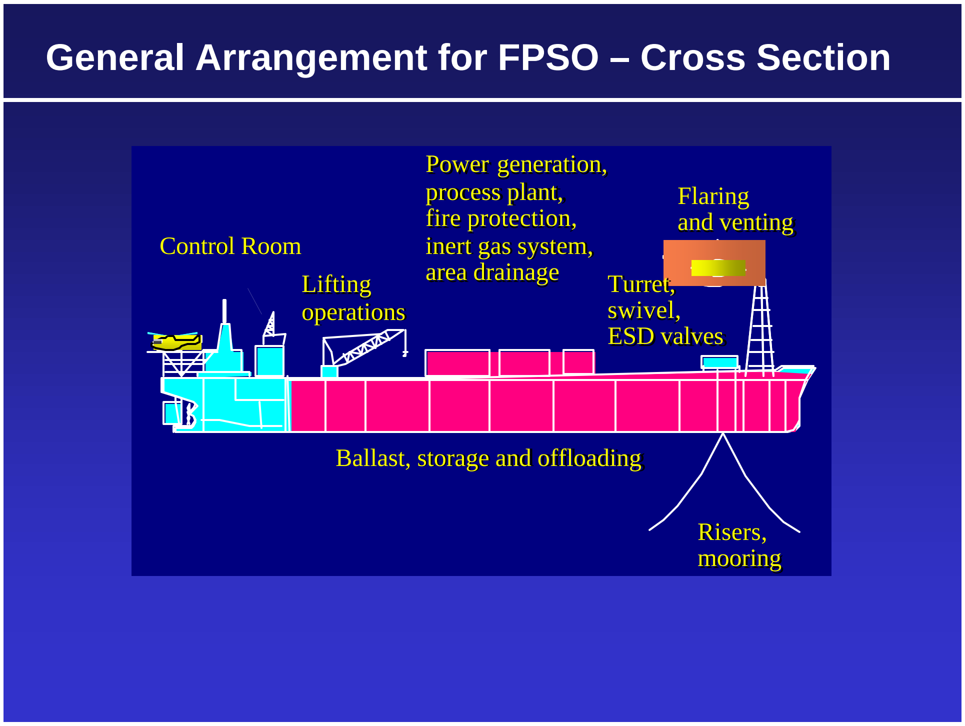


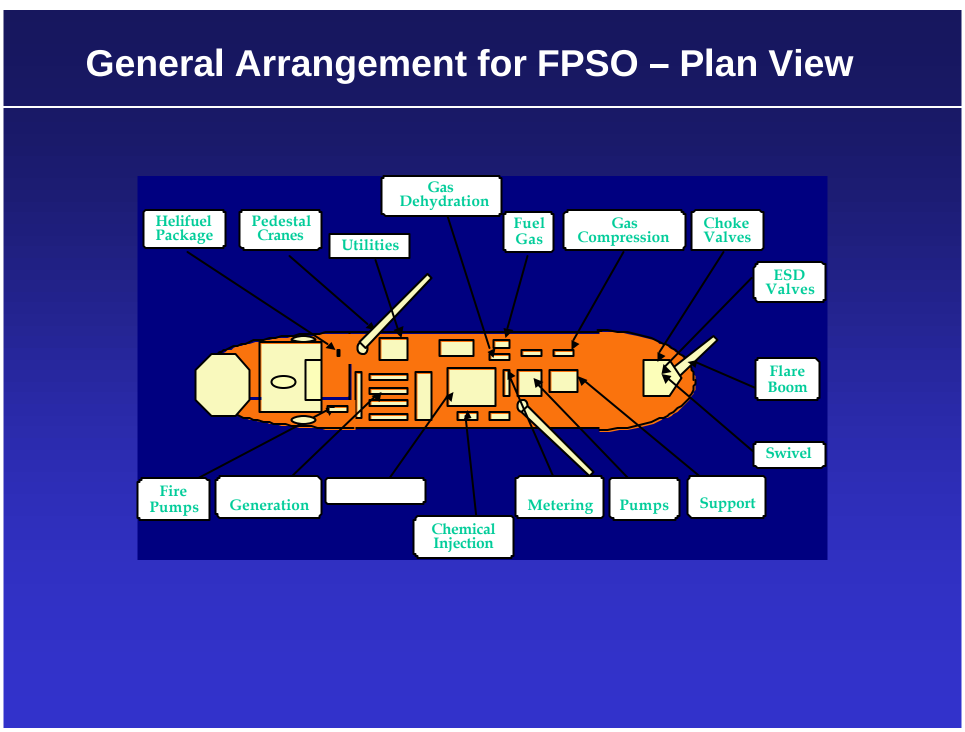


General Arrangement for Drilling Deck of Hub/Host Jacket



III) FPSO General Arrangement Drawings





Attachment V Status of Technology

Significant advancement has been made during the past years in simulation of consequences to floating production systems, to improve estimation of fire and blast loads. Several software tools and databases are available from multiple sources to undertake risk assessment and engineering against fire and blast events.

The International standard ISO 13702 puts forward a list of requirements and guidelines for design of offshore structures with relation to fire and explosion. In general the standard identifies the following objectives for control/mitigation of fire/explosion:

- Minimize the possibility of accumulation of hazardous liquids/gases (and provide adequate ventilation
- Minimize probability of ignition
- Minimize spread of flammable liquids/gases
- Separate non-hazardous areas from hazardous areas
- Minimize consequences of fire and explosion
- Provide arrangements for escape and evacuation
- Facilitate effective emergency response

These objectives are dealt with by performing a quantitative risk assessment or consequence analysis. New knowledge about gas explosions and fires in offshore modules and installations has resulted in the development of more detailed simulation models for assessing the explosion and fire risk at installations worldwide. Detailed models are capable of reflecting the detailed design and changes of an installation, and can therefore be used in cost benefit analysis to rank any risk reducing measures.

The basis for such a study is generally:

- Leak classes and associated leak frequencies
- Leak duration
- Ignition probabilities as a function of time
- Manning distribution
- Wind distribution
- Structural design reports and structural drawings, which provide input to structural modeling

To be able to establish representative leak classes/frequencies, adequate statistical information must be available, thus, requiring each area of an installation to be broken down into its characteristic segments where such data exist.

The main steps in an explosion analysis are as shown in Figure V-1:

- Explosion simulations of stoichiometric clouds with a variation of ignition position and gas cloud size
- Establishing a frequency distribution for gas cloud size at time of ignition by using a time dependent ignition model
- Structural response calculations

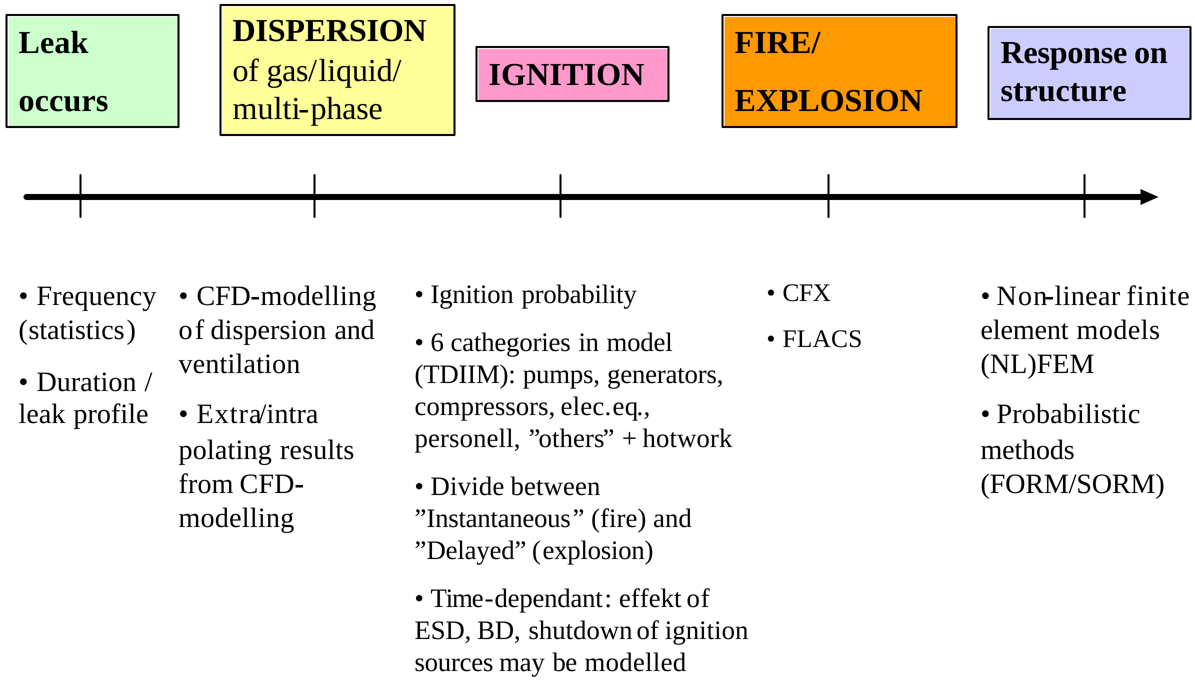


Figure V-1. Main elements in a full probabilistic fire/explosion analysis

Detailed 3D CFD dispersion/fire models such as CFX or Fluent and explosion simulation models such as FLACS are utilized in a typical consequence analysis, giving heat/explosion loads that are used in the further analysis (see Figure V-2). Structural response to fire/explosion loads is computed by use of non-linear structure response simulation tools such as MARC or USFOS, and the results are assessed based on guidelines given in national or international standards. In general, from a complete analysis of an installation, a list of risk reducing measures is developed. This process when integrated with a cost benefit analysis, which results in cost benefit indicators on personnel and economical risks, it is possible to rank between the various risk-reducing measures.

The main advantage by incorporating detailed consequence assessment with risk analysis techniques is that risk-reducing measures can be quantified and ranked better than when using traditionally coarse consequence models. The technique also allows comparing risk-reducing measures related to different areas and consequently the risk reducing efforts can be focused in areas with potential for significant improvement in safety at lower cost. The method requires a multidiscipline project team consisting of: structural engineers, fire/explosions engineers, Risk engineers and cost engineers.

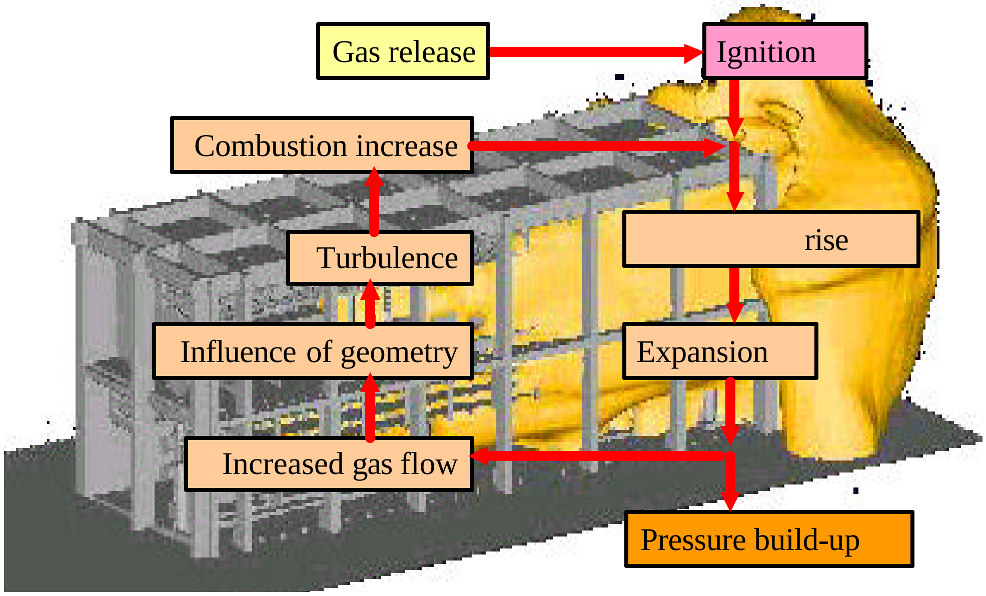


Figure V-2. Explosion physics - from release to explosion and pressure build-up

Attachment VI

Fire and Explosion Considerations in ISO 13702 and NORSOK S-001

A summary of various considerations given in ISO 13702 for design of floating production systems (FPS) against fire and explosion events, and in NORSOK S-001 for Technical Safety of offshore platforms were presented at a WG5 session. The summary information presented is given in this Attachment. For additional details the two standards be referred.

I) ISO 13702 - Control and Mitigation of Fires and Explosion

The following key issues identified by authors were reviewed at a WG 5 session:

- Layout objectives:
  - to minimize the possibility of hazardous accumulations of both liquid and gaseous hydrocarbons, and to provide for rapid removal of any accumulations which do occur
  - to minimize the probability of ignition
  - to minimize the spread of flammable liquids and gases which may result in a hazardous event
  - to separate areas required to be non-hazardous from those designated as being hazardous
  - to minimize the consequences of fire and explosions
  - to provide for adequate arrangements for escape and evacuation
  - to facilitate effective emergency response
- Consideration shall be given to maximizing the separation by distance of the TR, accommodation and EER facilities from areas containing equipment-handling hydrocarbons.
- Either separation by distance or the use of barriers can prevent the escalation of fire to another area. Any penetration of a barrier shall not jeopardize the integrity of the barrier.
- PFP shall be provided
  - to protect personnel in the TR(s), until safe evacuation can take place

  - to protect any section of the escape routes to the TR(s) for a predetermined time to allow for safe escape from the area and allow for emergency response activities
  - to protect any section of the evacuation routes from the TR(s) to the locations used for installation evacuation
- An evaluation of explosion loads and the associated probabilities of exceeding those loads shall be performed.
- It is recommended to evaluate the probabilities of critical structures and equipment responding in an unacceptable manner to these loads.
- The evaluation shall consider all areas where the potential for a gas or vapor-cloud explosion exists.
- The evaluation shall identify those systems required to maintain the integrity of the structure and the major equipment or piping systems.
- The possible benefits of using water deluge for explosion control shall be evaluated.
- The evaluation shall identify the potential for escalation resulting from damage caused by blast overpressures, which would impair the operation of essential safety systems, and the effect of any fire, which may occur after an explosion.

II) NORSOK S-001: Technical Safety

The following key issues identified by authors were reviewed at a WG 5 session:

- General requirements to layout and arrangement:
  - The utility area should serve as a barrier between hazardous areas and LQ/emergency service areas
  - Routing of hydrocarbon piping to or through the utility area shall be minimized and flanges avoided
  - Routing of hydrocarbon piping is not allowed in the LQ areas
  - The use of explosion panels and weather protection shields shall be kept to a minimum, with a preference to open naturally ventilated areas
  - Where explosion panels, walls or shields are provided, the possible utilization of fire fighting vessels during emergencies should be considered
- Low-pressure equipment containing large amounts of HC liquids should be located and arranged so that exposure to jet fires is minimized. If jet fire exposure cannot be eliminated, the need for PFP shall be evaluated.
- Accidental loads shall be identified and taken into account in the structural design:

  - Explosion loads affecting main structures
  - Explosion loads affecting secondary structures, e.g. walls acting as barriers between main areas
  - Explosion loads acting on support of pressure vessels, flare headers, fire ring main, ESD valves etc. shall be considered
  - Explosion loads shall be established by use of recognized computer models, e.g. FLACS
  - Heat loads caused by jet fires or pool fires on the installation or adjacent installation, from risers or from the sea surface
- Active and passive fire protection shall be arranged to ensure that a fire is prevented from spreading to other areas within a specified period of time, and to protect load carrying structure against critical heat loads.
- An explosion protection strategy shall be established with the objective of minimizing the explosion risk through
  - Preventing explosions from occurring
  - Minimizing the explosion pressure
  - Controlling the consequences of explosions
- Mitigating measures to reduce possible explosion overpressures, such as start of deluge on confirmed gas detection, shall be evaluated.
- Dimensioning explosion loads should be determined (a procedure is given).

<u>The specific aspects related to FPS installations are given as follows:</u>

- Large crude storage tanks shall be provided with an adequate and safe vent system, and gases shall be routed to either cold vent, flare or reclaiming system.
- Location of crude pumps shall be made based on a hazard evaluation for operation and maintenance of the pumps. Submerged pumps should be preferred.
- The turret shall be located and arranged to minimize probability and consequences of escalation of fires/explosions to/from neighboring areas.
- Hydrocarbon pressure vessels and heavy-duty equipment shall not be located within main hull structure.
- Process decks and relevant parts of the floater deck shall be arranged with the aim of minimizing the risk of large pool fires on decks and tank tops.

- Process areas, turret area and piping shall be designed to minimize the risk of jet fires towards tanks tops.
- On floating installations that will be turned up against the wind, equipment that may represent an ignition source should be located as far as possible upwind of potential leak sources.
- The turret design shall aim at achieving open naturally ventilated areas. Enclosed mechanically ventilated areas shall be restricted to containers or small rooms. Equipment that may represent an ignition source should not be arranged in the moon pool area.
- Anchor winches should be located in open area or in enclosed non-hazardous area.
- Production or export/gas injection risers shall be protected against fire in the turret by passive means.
- The need for quick re-positioning of the installation in case of specific emergency situations shall be evaluated.
- All interfaces between the maritime floater technology and offshore petroleum technology shall be clarified at an early stage in the design process.

6 WORK GROUP PARTICIPANTS

The following individuals participated in the workshop sessions of Work Group 5 on Floating Production Systems.

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WORKING GROUP 6

EXPLORATION & DRILLING OPERATIONS
USING THE IMO APPROACH TO CONTROL AND MITIGATION OF FIRE & BLAST

Contributors:
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1 INTRODUCTION

Exploration and Drilling Operations are generally carried out by independent Drilling Contractors using Mobile Offshore Drilling Units (MODUs). MODU owners together with Oil Companies were the instigators that developed the original Classification Rules for MODUs, and these in turn led to the International Maritime Organization (IMO) requirements for MODUs. The IMO MODU Code is an adaptation of the IMO SOLAS regulations made more applicable to drilling units. Nowadays coastal states for the most part accept Classification society and MODU Code requirements, which are prescriptively applied.

For vessels that frequently move around the world to different coastal state regimes, with various owner demographics, the prescriptive approach has worked very well. Based on a review of accidents involving fire and blast with MODUs engineering judgment confirms that this is a sensible approach. The nature of hazards relevant to MODUs is relatively predictable for units of relatively standard design, for typical drilling applications. To adopt a common approach with more complex site-specific production facilities appears neither necessary nor desirable. The prescriptive arrangements as they now are, seem very appropriate, and there is adequate mechanism to change these requirements on a relatively speedy basis, if there is any cause for change.

For a variety of reasons, largely to do with marine vessels, there has been recent revision to the IMO Convention on the Safety of Life at Sea which opens the door to accepting fire safety requirements that may deviate from the strict prescriptive regulations, which have heretofore been the hallmark of the IMO Convention. Many anticipate that these performance-based approaches may influence the fire safety requirements of the offshore industry. The performance-based approach may have a role in assessing hazards where new designs incorporate features not currently addressed by prescriptive standards, or where applications fall outside the scope of current experience. Use of risk-based approaches is however unlikely to significantly influence design of standard units in standard applications.

2 Current Regulatory Framework

The international standards for MODUs are contained in the IMO's Code for the Design and Construction of Mobile Offshore Drilling Units, (MODU Code). The MODU Code was first issued in 1979, was substantially revised 1989, and has been amended twice since 1989. Except for a limited number of MODUs employed by national oil companies in their domestic activities, and a number of flag states who have their own equivalent regulations (e.g. U.K. and Norway), the MODU Code is universally applied to all MODUs through regulations issued by their country of registry. As such, MODUs can move from country to country with few changes from place to place, and many of the legislative requirements of coastal states are based on the fundamentals contained in the MODU code.

One advantage of the IMO approach is that it establishes an integrated approach to fire protection which has proved successful, and based on experience and engineering judgment from reviewing detailed accident histories, can be shown to be effective. The principles upon which this integrated systems approach is based are as follows:

- Limiting and segregating combustibles;
- Providing for containment and detection;
- Providing a variety of systems for extinguishing fires
- Providing resistance to blast through measures such as open design, segregation of areas and mandatory use of structural fire-rated bulkheads and decks.

In addition to meeting IMO-based requirements, as a matter of commercial practice MODUs universally meet the requirements of one or more of the classification societies, which not only oversee their construction, maintenance and repair, and periodic surveys, but also often establish their own requirements for fire protection. The new DNV requirements (Ref. 5, 6) are recommended since they set out the comprehensive system of requirements and clearly state the source of the requirements, paragraph by paragraph, so there is no confusion as to the source and why it is there. Any additional classification society requirements are spelled out clearly with the reasons.

In anticipation of the future use of risk-based methodology DNV also provide an overview of the level of safety represented by their Rules in terms of how they address accidental loads. This is useful in evaluating non-standard designs or applications.

The IMO's approach is universally accepted for ships. Unlike offshore permanent platforms, MODUs in some respects are more like ships, in that they are considered vessels and move from place to place, and follow many of the conventions applicable to ships. They are not subject to the attention that many oil companies give their more important platforms, and are offered competitively to the operators of leases. As such there is a definite need to level the playing field, which is one of the advantages of using prescriptive requirements.

While many of the hazards associated with MODUs have much in common with production installations, the prescriptive requirements have attempted to anticipate these, based on experience and the relatively simple risk picture. Some of the hazards on MODUs are similar to those experienced on ships and here it has been possible to draw on an even larger body of operational experience in creating prescriptive requirements.

Many of the requirements imposed on MODUs would be overly conservative for many of the offshore platforms in the Gulf of Mexico, which are very small, often unmanned or lightly manned, and, have a very open architecture. Likewise training of personnel is much more rigorous on MODUs and the MODUs themselves are much more substantial structures than many of the platforms on which they perform work. Additionally the prescriptive approach is relatively inflexible and would impose unnecessary costs because of the difference in structure type, at least for the smaller platforms common in the Gulf of Mexico and many other parts of the world. Additionally though it may ultimately prove to be a good starting place, it may also be inadequate to address the hazards associated with large-scale oil production and processing.

At the other end of the spectrum are large and complex floating production installations. By comparison with MODUs it can be argued that they represent a more complex hazard picture, due to their unique design and the complex and integrated nature of their design.

There may also be a difference between personnel who regularly work on production units and those that work on exploration units. Because of the potential and anticipation for 'surprises' in exploratory work, the crew may tend to be somewhat more ready to respond, that the general personnel engaged in production activities.

In order to examine the record and establish if there are any gaps in the current prescriptive practice, databases of accident information were interrogated, with a view to supplying anecdotal information to indicate whether the fire protection standards applied to MODUs are generally adequate. Though this is not a comprehensive study, it generally is a good methodology to get a sanity check on the prescription. Like all regulations the fire and blast standards require periodic review and revision to incorporate new understanding and technology. Clearly in reviewing the accident record to date, there were a number of lives lost and injuries sustained in the early days in the offshore patch, which current records show is markedly reduced. Many of those were associated with blowouts. The precautions taken nowadays with passive fire protection, fixed systems and portable systems, together with vast amounts of training, have improved the track record to a higher level. It should however be remembered that much of the historic data is based on experience of drilling in shallower water and lower temperature/pressure regimes than anticipated future applications.

Having said that generally the record shows the MODU Code is adequate, there are changes in hand which again may lead to further enhancements in safety. Even though there have been very few damages or casualties from blast issues, studies in this area by the oil companies and others will lead to new understandings and that may prompt further revision to the MODU Code. Except in cases where missiles and mines have been part of the scenarios, there have been few "blast" issues on MODUS. The open arrangements adopted for the design of most drill floors, and the general lack of a process inventory, greatly reduce the likelihood of blast and blast overpressures on MODUs. Typical designs of MODUs have very clearly defined and limited areas where blast may possibly occur (e.g. enclosed shale shaker rooms) and this issue has been considered in the design process, usually by ensuring that any overpressure can be relieved.

During the past two years the IMO has been especially active in the area of fire protection and has promulgated new standards on fire resistance in the form of:

- Comprehensive amendments to Chapter II-2 (on fire protection, detection and extinction) of the Safety of Life at Sea Convention (SOLAS) – documenting many existing interpretations;
- An International Code for Fire Safety Systems
- A Fire Test Procedures (FTP) Code;
- Guidelines on Alternative Design and Arrangements for Fire Safety; and
- Guidelines for the approval of fixed aerosol fire-extinguishing systems equivalent to fixed gas fire-extinguishing systems.

IMO has also recently approved new work on developing performance testing and approval standards for fire safety systems, as proposed by the U.S. Coast Guard. While the amendments to the SOLAS Convention have not yet been incorporated into the MODU Code, designers of new units and classification societies are applying them.

3 Review of the Accidents

In order to examine the record and establish if there are any gaps in the current prescriptive practice, databases of accident information were interrogated to develop insights into the historical record.

A review of about 400 accidents involving fires and explosions and blowouts offshore was made. Significant causes of fires are chronicled for the offshore as follows:

- Fires on MODUs while they are in shipyards being repaired.
- Fires on attendant vessels, supply boats, and standby boats most often involving engine rooms

Both the above were not intended to be part of our review but are worth noting in passing.

Drillships are noted to be prone to fire damage during blowouts, sometimes from shallow gas events.

Floating vessels with engines are prone to fire, thus reinforcing the idea of passive fire protection around engine rooms.

Over half the fires that occur offshore do so on production platforms – this is probably in line with a reasonable comparison of the numbers of units most likely subject to fire.

Of the production platform accidents: helicopter accidents, and welding accidents where pipelines are involved, seem to recur.

The highest number of casualties involving offshore fires recently were sustained on a fixed production platform

The event was in January 18, 1995 when 10 people died and 18 were injured when a gas fire/explosion occurred when welding a new pipeline connection into a fixed platform off Nigeria.

There have been many small fires and explosions on the North Sea platforms. There does not appear to be any particular specific cause or pattern other than the obvious human failure to recognize dangers from performing work where high inventories of hydrocarbons are present.

One example on the Sleipner platform in 1998 where a fire from leaking diesel from generator - close to living quarters – shot flames 30 meters high. The loss and injuries associated with these various North Sea fires can best be described as occasional and not “heavy”: though all are of concern.

With all mobile platforms doing exploratory work, there is a fire risk from shallow gas hazards that need to be diligently guarded against. The most likely hazard is to the area around the well. Historically this has seldom been a problem to the personnel away from the drill floor, because the quarters area is protected with A 60 bulkheads.

In 1998 there was in interesting incident similar to that which caused a problem on a recent cruise ship:

Dust from tumble drier in laundry room caught fire and was drawn into the ventilation system

Setting a jackup's leg onto a pipeline can also lead to a sudden fire and loss of life as happened in 1995 when there was an incident with a rig, which jacked down onto a pipeline, and caused a fire where one person died. There have additionally been other incidents, similar to this, which were near misses.

Semisubmersibles are also prone to issues with shallow gas. Because of the location of the moonpool the consequences are possibly more severe for a semisubmersible than a jackup. However the semisubmersible has the possibility of moving off the location quite rapidly which may mitigate consequences. Because of the dimensions of the semisubmersible it is also more prone to damage than the newer large drillships where the accommodation is further from the well. Additionally, and this could well apply to many MODUs, there have been incidents of fires in the galley etc. Well control problems probably are more serious on Semisubmersibles largely due to the fact that the well is often located in the centre of the vessel. The semisubmersible fire protection is a little more of an issue. Though there have not been many "incidents" of horror, there have been occasional ones, in recent memory, such as the Ocean Odyssey, which was the subject of an enquiry and fines related to loss of life during that blowout and subsequent fire that destroyed the unit. Fires in engine room, small explosions in the mud pump room and other small fires, however, have all been addressed already in the prescriptive regulation.

What becomes clear, from the examination of the data, is that there are no outstanding scenarios which practical experience tells us need further requirements to improve the vessel's equipment for fire prevention and fighting. Clearly the diligent training, and adequate maintenance of the fire fighting system needs to continue. There appears to be no identifiable gap in the equipment and arrangements on board the various rigs, which could improve the situation except, of course, the continual need to be watchful and follow the existing practice and ensure that all the people on board follow the requirements. In general the records indicate that the accidental events are those essentially already anticipated by the prescriptive requirements (i.e. collision, blowout, fire in engine room).

To undertake the Exploration and Drilling Operations rigs, like ships, need to be able to go around the world and be internationally accepted in each and every coastal state to a common standard. Unlike Floating Production Units, which stay on location for a number of years in a single coastal state regime often with a huge hydrocarbon inventory on board, mobile rigs frequently change location and region. The need is different. The current IMO approach to MODUs has proven sufficient, and adequate to protect the life, property and the environment.

4 The Prescriptive Requirements – Discussion Information

Prescriptive guidelines are very useful to act as a reference document in contractual matters between purchaser and contractor.

In order to define the base information required by the prescription, the definitions are re-iterated here for passive fire protection, the first line of defence and then discussed in more detail.

Bulkheads are given a terminology "H" for Hydrocarbon fire resistance and "A" for ordinary (cellulosic) fire resistance.

Passive Fire Protection – The definitions are somewhat more specific than given here but for the purposes of discussion of the overall requirements the wording has been simplified. All passive fire protection is required to be:

- Constructed of steel (or equivalent)
- So gas smoke or flames can't get through
- Insulation keeps the heat rise to less than 140 degrees C average, behind the firewall, above original temperature, for the designated time.

Ordinary Fire	Hydrocarbon fire
A-60 for 60 minutes	H–120 for 120 minutes
A-30 for 30 minutes	H -60 for 60 minutes

"B" class divisions apply to bulkheads, decks ceilings, and linings again with the same average temperature protection as a function of the time.

"C" class divisions are basically other non-combustible materials.

The general strategy is for the various fire systems on the rig to attempt to extinguish the fire, but also to do their job in preventing the escalation of fire, providing temporary refuge for a specific time period until the unit can be evacuated, and maintain structural integrity to provide time for escape.

Although in this exercise we will only take an overview look at the fire protection system, there are very many detailed provisions, for example, for items such as ventilation ducts, which are specifically mandated to be steel sheet lined when passing through bulkheads or decks in order to offer protection from space to space. Providing arrangements such that for example, galley ducting is not led through the accommodation since you would not want a galley fire to lead into a disaster for the unit while on location. There are very specific rules for these items, which have been derived from lessons learned at sea and on board rigs for a number of years. ,

Not only do the bulkheads need to be constructed to these fire standard requirements but it must include the windows, doors, and even the galley serving hatches to ensure they are constructed to the same standard.

Within the prescription there are tabular requirements mandating what adjacent spaces need to be protected with a specified fire resistant bulkhead for example:

1. The portion of the accommodation that is within 30 m of the center of the rotary table has to have A-60 protection
2. Between a control station and a Hazardous area an A –60 bulkhead is required.
3. Between galley and machinery room an A – 60 bulkhead is required.
4. The fire integrity of decks is also specified i.e. not only the vertical bulkhead but also the decks in between floors have to be of a specified fire resistance. For example the deck between accommodations and machinery spaces is specified as A – 60.

In general terms the main passive fire protection on drilling units consists of A-class bulkheads. The main purpose of the firewall around the accommodation spaces is to provide shelter for personnel in the event of a major fire until they can be safely evacuated. The time estimate for North Sea evacuation is generally accepted as 2 hrs, by helicopter and as 30 minutes to lifeboat. Additionally the regulations also provide for safety of evacuation routes within the MODU itself, not just the accommodation, by specifying, for instance, an A-60 bulkhead between machinery spaces and corridors. They also require 2 separate means of escape from manned spaces.

Although the heat flux for a typical hydrocarbon fire follows a specified curve for simplification purposes and general understanding it may be appropriate to state that the Heat Flux applicable to each type of passive fire protection is as follows:

- A 60 Firewall – 100 kW/m^2 for 45 mins
- H 60 Firewall – 150 kW/m^2 for 1 Hour

The heat flux levels shown below and their effect on personnel have been extracted from several sources and are defined here in order to understand the adequacy of escape routes and shelter areas.

Heat Flux kW/m^2	Effects
1.0	Maximum for indefinite exposure of skin
1.75	Pain threshold after 60 seconds
4.0	Maximum acceptable exposure limit for escape ways if unprotected
12.5	Outside of lifeboat Capsule (allowable)
16.0	Severe burns after 5 secs
52.	Fibre wood ignites spontaneously

Flow rates on exploration wells are derived in terms of kg/sec and coincide with flow rates used in the Dept of Energy safety evaluation study following the Piper Alpha accident (Ref 8). For exploratory drilling the value of 60 kg/sec is regarded as the appropriately conservative flowrate. For comparison purposes, flowrates for production risers is considered appropriate at 180 kg/sec. To what extent the accommodation block will be exposed is dependent on many factors, which includes flowrate, distance, location and arrangement of the accommodation with respect to the derrick e.g. relative height. For "traditional" units you have moderate flowrates, a distance usually of 20-30 m, and a significant height difference at the drillfloor. This could in theory change if you have a design with an accommodation very close to the derrick, with a drillfloor at the same level as the living quarters base, and with very high flowrates from other high-pressure wells.

The capacity of an A-60 firewall is approximately 100 kW/m2 for the typical required duration of evacuation.

Risk studies show that for typical units, fire events would be unlikely to produce either horizontal jet fires or oil pool fires of such intensity as to affect the integrity of the A-60 wall of the living quarters. Typical units refers to current types of design of Jackups, semisubmersibles and drillships engaged in drilling.

If the service changed to production, however, with the higher flux rates by a factor of 3, or in exceptional drilling applications where very high rates could be anticipated some units are more prone to find themselves in need of further enhanced passive fire protection at the accommodation.

There are ways to enhance the capability of A60 firewalls, should the need arise. Water spray supplied at a rate of 0.25-gallons/minute/square foot is sufficient to increase the rating of the firewall above that of a H-120 firewall. These sprays have been successfully installed on a number of installations and are now considered to be normal technology.

5 Active Fire Protection Systems – Fixed Systems

In addition to the passive fire protection as part of the complete fire protection system, active additions are required. Fixed water protection systems in the well areas and wherever there are "dangerous areas" on the platform are a prescriptive requirement. The quantity of water and pressures it must deliver are specified in gallons or cubic meters per minute. Dangerous areas and areas which need protection in order to slow down the fire and protect the emergency systems are included in the plan.

Foam systems are specified, again in terms of volumes required, in areas where pool fires are likely. Helidecks are one example. The general philosophy is to be able to cover the whole area in foam for a minimum of 15 minutes.

Machinery spaces have their own requirements, and as the review of accidents has shown, these are necessary. There is a requirement for a fixed fire system, open to some choice, but basically designed to quell a very likely fire scenario since machinery spaces are quire prone to fires starting being as they have heat and fuel both present. It's important to ensure that a machinery space fire can be contained.

Areas that store gas cylinders are high-risk areas, which also require a fixed firefighting system.
The fire fighting system has to have some redundancy and specifically the pumps volume and pressures are to be prescribed, as is the fire resistance of the piping systems to deliver the water system/ foam systems etc.

6 Active Fire Protection Systems – Portable Systems

Portable systems are required together with spares capacity to contain the smaller fires any of which can erupt at sea and can become dangerous if not contained.
Fire Detection and Alarm

The foregoing has discussed the requirement for fire fighting systems, and protections. The IMO MODU Code, by reference to SOLAS, also addresses fire detection and alarm systems, which are most important in the early warning to the crew. This is all part of a prescribed, well-thought-out "system of protection".

7 Performance vs. Prescriptive Rules

The current suite of prescription is something that the exploration and drilling community has learned to live with. It is an arrangement that suits the type of vessels and the practices of the personnel who work in the industry. Drilling units are relatively standardized in design, with regard to those features, which influence hazards. Additionally it has historically been shown to be safe for the types of drilling operations typically engaged in.

Rigs are built much like ships and the ability to prescribe the fire and blast safety has enormous advantages when it comes to specification in a contract between an owner and designer/shipyard.

Without prescription it becomes incredibly important for the designers, regulatory personnel, and operators to have a deep foundation in MODU accidents and fire engineering. Peculiarities of particular vessels would make it more difficult to transfer personnel between vessels, and hope that they could function appropriately based on the specific characteristics of the rig. The time and changes on physical items from well to well, to use a non-prescriptive approach would add, considerably, to the cost.

Whilst many of the classification societies have talked about "performance-based classification" and effectively "risk based class" putting it into practice is comparatively difficult. There is, however, recognition that prescriptive requirements are largely based on experience with previous designs and applications so that major deviations from such may need a mechanism of case-by-case evaluation.

8 Conclusion

Whilst the conclusions to this session will be developed in the workshop suffice it to say that at the current time, the observations that the contributors would make, is that, on the basis of experience to date, it appears that the industry as a whole is satisfied with the current practice of prescriptive application of fire and blast issues developed using the primary backbone of Classification and the IMO MODU Code.

9 Workshop Issue Suggestions

Some of the questions therefore which the workshop session might address:

- Is there a need to perform additional hazard analysis on drilling units?
- Are current prescriptive requirements adequate to ensure the desired level of safety?
- Are there any anticipated applications in the future, which might not be adequately addressed by prescriptive requirements?
- Are there any anticipated design aspects, which might not be adequately addressed?
- Are additional hazards introduced by use of new drilling technology/techniques?
- If any hazard assessment is carried out, are there any recommendations on how such should be done.

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Additional Comments by: Roland Martland

Cuurent Regulatory Framework for IMO MODU's

1. It is common to find problems with PFP being A instead of H rated.
2. HVAC systems usually closed off manually rather than automatic which is preferable from a risk reduction viewpoint.
3. MODU framework can lead to problems with MODU's used for well testing where there is a potential large hydrocarbon inventory, some processing -e.g. test seperators.
4. Training of personnel to cope with fires is probably overstated in it's effectiveness and there is a move towards not expecting too much from such personnel, particularly due to the ageing workforce physical ability to fight fires - the UK is giving some consideration to the physical endurance capability of fire teams in particular.
5. Some fire protection standards for MODU's are set below reasonably forseeable hazards. For example, API521 heat flux levels on wetted areas of pressure vessels are between 1/3 to 1/4 less than those measured by pool/jet fire testing. This may not be so much of a problem for MODU's depending on the degree of processing/equipment. ESD systems therefore tend to be underdesigned to evacuate hydrocarbons under such hazards i.e. time to failure is less than assumed in risk studies.
6. Open module/deck areas on drill floors is a positive factor for risk reduction, however, the short distances to control rooms, TR and high POB mean that the hazard risk should be treated with case by case consideration with every effort being taken to drive down individual risk and PLL.

Review of Accidents

1. Diesel (oil mist) fires are also occuring in engine rooms (maybe not MODU's) and there has been developments in oil mist detection as such releases can be hard to detect by conventional detectors.
2. Should mention the Montreal protocol and the replacement of Halon with INERGEN.
3. There have been about 28 ignited releases over the last 8 years in the UKCS.
4. Using phrases like "there appears no identifiable gap in the equipment and arrangements" may give a degree of confidence that may dissuade owners from a critical review via FMECA, or other methods from properly assessing the performance of the MODU
5. "In an emergency" accidents (e.g. P36) always provide evidence of deficient protection by design, maintenance, operation etc than that which is taken for

granted bycodes which are generally not truly risk based in their development. e.g. little direct assessment is evident in piping, equipment (apart from electrical), instrument codes as to their functionality in extreme fire/blast situations.

Prescriptive Requirements

1. Passive fire protection - there is little done/researched as to the performance of PFP in a blast situation followed by a fire - deflection, debonding, ageing, PFP type etc may influence this outcome.
2. Machinery space divisions may be inadequate if A-60 rated if significant hydrocarbons are present.
3. Do not agree at all with the statement that there appears no need to H rate bulkheads on MODU's. The main driver for this statement would be costs rather than safety - and the costs are not great, especially for new build.
4. Note again that the A60, H60 resistance figures are deficient for some scenarios such as a large, confined, pool fire and a high pressure jet fire. (most MODU's may not encounter such events but the statement should be in the text)
5. Heat flux levels quoted Ok but after 20 secs or thereabouts at 12.5kw/m2 it is likely that fatalities will occur and at 50kw/m2 there is almost instantaneous collapse/death.
6. The statements regarding the effective enhancement of PFP with combined water spray needs back-up data from testing, or similar. We are not aware of such an enhancement and would welcome any data that is available.

Active Fire Protection Systems

1. Effectiveness of foam systems in controlling pool fires influenced by design of bunded areas and must be part of the overall design assessment.

2. Fire fighting systems - redundancy is part of the system reliability which is what should be assessed. Redundant systems with low reliability may be worse than less redundant, more reliable systems – maintenance outages, safety critical maintenance, testing, explosion resistance fire headers all spring to mind as issues affecting reliability and hence removing redundancy. Also the time to initiate such systems may be ineffective in reducing the temperature on steel, vessels e.g. large jet/pool fires heat up metal so quickly that the cooling effect of the water is not very evident as the water instantly evaporates on the surface, or is blown away by the jet momentum.

3. The P36 issues mentioned seem to focus on the wrong problem identification - it is not a problem with fire pumps, but rather the overall design of the pumps, rig stability failure mode identification, management of the rig (monitoring) etc.

WORKING GROUP 7
REGULATION AND CERTIFICATION

Contributors:

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Scope

This workgroup was tasked with exploring the existing worldwide practice for the regulation and certification of fire and blast design of offshore facilities, comparing different approaches and reviewing recent initiatives/opportunities for attaining greater consistency or harmonization.

Contents

Working Group Participants

The following individuals participated in the International Fire and Blast Workgroup 7 Workshop Sessions. The group included representatives from offshore facility owners, operators, consulting engineering organizations and classification societies with experience primarily in the Gulf of Mexico and the North Sea areas.

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1 Introduction

As with many other disciplines within the offshore industry, the regulatory requirements for fire and blast vary greatly between individual Administrations, classification societies and other regulatory bodies. In addition to the current regulatory requirements, the engineering approach to attaining the required level of fire and blast safety varies greatly from strict prescriptive regulations to those which permit a performance-based approach.

For those Administrations which have adopted a prescriptive regulatory approach, many of their regulations are a result of maritime disasters which have often occurred within their geographic area of jurisdiction. As a result, these regulations may only be appropriate for specific geographic locations. The development and adoption of performance-based alternatives to strict prescriptive codes presents the potential to remove these regional barriers, allowing for the global standardization, communication and acceptance of fire and blast safety requirements.

After presenting some key definitions, this paper discusses the alternatives to prescriptive regulations including sections on the characteristics of prescriptive and performance-based regulations. The benefits and drawbacks of performance-based regulations are introduced along with an overview of regulatory schemes for fire and blast related issues, currently being utilized by various Administrations. A section is provided on the perspective from the International Maritime Organization and from a classification society. The paper concludes with a listing of topics, and the input received from the participants, during the Workgroup 7 Workshop Sessions.

2 Definitions

Certification: verification of systems and equipment to some standard by an independent third party; for example, a classification society, Canadian Standards Authority (CSA) or the American Society of Mechanical Engineers (ASME).

Consequence analysis: a process to determine the impact of an individual scenario.

Performance-based code: a code that explicitly states goals and defines desired levels of safety in quantifiable terms.

Hazard: conditions that may have the potential to cause injury or harm to persons, property or the environment.

Risk: product of consequence and likelihood.

Prescriptive code: a code that explicitly states specific system or equipment requirements without tolerance for deviation. Such a code may or may not allow for equivalency determinations.

Risk-based decision-making: a process which organizes information about the possibility for one or more unwanted outcomes into a broad, ordered structure that helps decision-makers make more informed management choices.

3 Alternatives to Prescriptive Regulations

In the last two decades, many land-based building codes have undergone substantial revisions, incorporating a fire safety engineering approach as an alternative to strict compliance with the traditional prescriptive regulations. In these performance-based codes, the necessary fire and blast safety measures are dictated by the unique physical and operational characteristics of each building in conjunction with the principles of fire science. As a result, these revised building codes no longer require fire safety measures to be provided based solely on the generic classification of each space. As an example, the National Fire Protection Association (NFPA) has published the Manual on Alternative Approaches to Life Safety, NFPA 101A [1].

Within the general maritime industry, there are similar changes taking place including the publication of a guide by the United States Coast Guard (USCG) outlining the alternative fire safety engineering approach for use in the design of passenger vessels, known as Navigational and Vessel Inspection Circular NVIC 3-01 entitled "*Guide to Establishing Equivalency to Fire Safety Regulations for Small Passenger Vessels*" [2]. This global transition to a performance-based design methodology is reflected within the revised edition of the International Maritime Organization's (IMO) *Convention on the Safety of Life at Sea* (SOLAS) [3]. This publication, which entered into force on July 01, 2002, is expected to have significant practical and economic influence on the fire safety engineering aspects of the maritime industry.

In addition to the changes within the SOLAS Convention, the IMO has recently published the *Fire Safety Systems Code*, in Resolution MSC. 98 (73) [4]. This code, which also entered into force on July 01, 2002, extracts from SOLAS Chapter II-2 the performance standards and engineering specifications for fire safety measures onboard facilities; including means for smoke detection, fire extinguishing and means of escape. Due to its structure, this new code will be of critical importance in the integration of performance-based fire safety regulations.

Currently, risk-based designs may be submitted to the United States Coast Guard or the Mineral Management Service (MMS) under "equivalency" or "alternative compliance" programs established in their respective regulations. The United States regulatory agencies have authority to review and accept systems or equipment supported by risk based analysis. In the area of fire engineering, testing and calculations must generally be submitted to prove that the design meets or exceeds the provisions of the existing prescriptive regulations.

There are currently no requirements or standards for blast protection in the United States regulatory regime. As a result, risk analysis associated with blast protection on offshore facilities and drilling units is primarily driven by corporate philosophy and good engineering practice.

Some geographic regions, such as the United Kingdom sector of the North Sea, have adopted a Safety Case approach in which the onus of responsibility is placed on the owner/operator to demonstrate the level of safety provided on the facility is appropriate. Any country which establishes a safety case approach for the offshore industry must be in a position to understand the submitted studies, and have acceptance criteria. As a result, the Administration must have significant experience with all of the associated requirements of a safety case.

4 Prescriptive vs. Performance based-Regulations

Prescriptive-based codes traditionally establish the desired level of fire safety through a set of minimum requirements that are generic, with each space classified by occupancy type. An example of a current prescriptive regulation is the IMO MODU Code Regulation 9.1 [5] which requires that a galley, classified as a service space (high risk), be separated from an accommodation space by a boundary with an 'A-0' rated level of fire integrity. Such a prescriptive regulation establishes a minimum level of fire safety, however, the true performance objective of the regulation is not explicitly defined.

By comparison, performance-based regulations are quantitative expressions of the fire safety objectives based on the functional requirements of a space. As an example, a performance-based regulation may state “the objective of this requirement is to safeguard occupants from the effects of fire while they are evacuating a facility.” Performance criteria, as in this example, may implicitly include occupant tenability limits such as permissible levels of smoke obscuration, gas layer temperatures and the height of the smoke layer within a compartment.

A performance-based code thus establishes fire safety targets but provides the designer with the freedom to select the means to achieve these goals. As a result, the fire safety system is engineered for each specific facility, addressing a project’s unique characteristics. The outcome is a fire protection strategy in which the facilities structure and fire protection systems are integrated rather than designed in isolation. Additionally, during the design process the critical fire safety decisions can be based on the fundamental principles of fire science and not rely on potentially irrelevant generic regulations. Critical characteristics such as the Heat Release Rate (HRR), composition, quantity and configuration of a fuel source, along with environmental criteria, such as the ventilation conditions within a space, can be used to form the basis of sound engineering judgments.

4.1 **Benefits of Performance-based Design**

Advocates of a performance-based fire safety regulatory framework indicate the following benefits from such an approach:

Innovation – performance-based regulations allow a design team to select materials and arrangements outside the boundaries formed by prescriptive codes and standards. As a result, the vessel design is no longer restricted to the predefined conditions within the regulations; instead, the fire safety measures can be chosen to address the specific hazards present in each vessel.

Clarity - the overall fire safety objectives of the regulations, as outlined in the above examples, are explicitly defined and can be easily understood by all parties.

Potential for financial savings – since prescriptive codes apply to a wide range of potential design scenarios, they are generic in nature. As a result, prescriptive regulations are conservative, providing layers of protection with associated redundancy. In comparison, in a performance-based approach, the fire safety measures are designed for a particular facility with pre-defined occupancy and operational characteristics. The fire safety system can therefore be designed without the need for duplicated or overlapping safety measures, reducing the facilities construction and life cycle costs.

International harmonization - many prescriptive regulations are developed by individual Administrations as a result of previous fire incidents within their area of jurisdiction. As a result they may be only applicable to specific geographic locations. Performance-based codes have the potential to remove these regional barriers, allowing for the standardization, global communication and acceptance of fire safety requirements.

Improved knowledge of loss potential - since a performance-based design approach requires the fire safety of each facility to be independently considered an improved knowledge of the loss potential may be developed.

4.2 Drawbacks of Performance-based Design

Prescriptive-based codes are often cited as being inflexible and unable to evolve rapidly to meet the modern challenges of new materials and innovative facility designs. The following potential drawbacks have been identified with the performance-based design approach:

- Required knowledge - the facility designers and regulatory officials must have a thorough understanding of fire safety engineering concepts ranging from the phenomenon of fire growth, heat transfer and flashover to the physiological aspects of occupant behavior and human tenability.
- Service restrictions - any operational or service restrictions, upon which the alternative design and arrangements are based, must stay with the facility throughout its service life. Similarly, any future owners/operators must be fully conversant with the limitations under which the fire safety system was designed.
- Time - the design process can take longer due to the increased engineering analysis, which is required.
- Documentation – since a performance-based design does not strictly adhere to the established prescriptive regulations, significantly more documentation is required. Justification for all design decisions which deviate from the existing regulations must be recorded.
- Overall level of safety – it is possible that a reduced level of overall safety may result if the design is not based on sound fire science incorporating accepted methods, empirical data, calculations or correlations.
- Teamwork - the process requires teamwork among the individual parties; including the designers, owners, operators and regulatory officials. As with any team situation, this can create problems if it is not managed correctly.

5 Regulatory schemes from Individual Administrations

The individuals who participated within the Workgroup 7 Workshop Sessions primarily had experience in the North Sea and Gulf of Mexico regulatory regimes. As a result, the following sections primarily focus on these geographic locations.

5.1 Gulf of Mexico

From a regulatory standpoint, through the United States Coast Guard and Minerals Management Service, the Gulf of Mexico primarily utilizes a strict prescriptive approach. However, the requirements of classification societies, which are often in excess of the Administration requirements, permit a performance-based approach under some conditions.

One reason that the prescriptive method of regulation has worked well in the Gulf of Mexico, while some other areas have moved towards a goal setting approach to regulation, is that the environment does not demand a more complex regime. Additionally there have been no major offshore incidents in the Gulf of Mexico, which may have driven a higher level of regulation in other areas. Additionally, it is to be noted that while a Safety Case costs a considerable sum of money to generate, many individuals and organizations feel that there are unproven safety benefits of this approach when compared with other possible regulatory regimes.

In the Gulf of Mexico, it has been the perspective of many that there has not been the need for a Safety Case since, traditionally, the platforms were relatively small, the water warm, the weather relatively benign (except in hurricanes in which case the platform is evacuated), and the vast majority of platforms are unmanned. Those that are manned generally have relatively small crew sizes. However, with the move to deeper water, larger platforms, and more personnel on board, there has been a significant increase in the number and complexity of safety studies carried out by the oil larger companies. In most cases the major companies, and many minor companies, have also voluntarily adopted comprehensive Safety Management Programs, which include risk management components.

The following key points with regard to offshore operations are noted:

- Offshore installations in the Gulf of Mexico have traditionally been fixed platforms in shallow water. Over four thousand platforms currently exist in the Gulf of Mexico, however, less than ten percent are considered platforms with large topsides payloads. The last decade has seen a move towards deeper water, in the 1500ft to 7000ft range, along with the use of floating installation platforms, including Spars, Tension Leg Platforms (TLP's) and semi-submersible units.
- Topsides payload is increasing dramatically in conjunction with significantly larger throughputs of production. The advance of the technology is helping the designer place more equipment on a smaller marine footprint. This often results in a more congested topside arrangement.
- As some topsides are getting more congested with equipment, the potential for an explosion is becoming more significant. In comparison, the primary concern on the older traditional facility design was more frequently associated with a fire.

For the Gulf of Mexico, regulatory agencies offer no guidance with regard to explosion risks and structural requirements for blast loading. The primary approach from both designers and regulatory guidance has been a focus on reducing the likelihood of an explosion occurring as the result of a spark, through the application of "area classification", fire interdiction and gas detection requirements.

Unlike well-ventilated open platforms in the Gulf of Mexico, most North Sea platforms are enclosed, primarily due to the severity of the prevailing environment conditions. The potential for an explosion has always been a critical risk factor and a major concern to the North Sea designer and operator. As a result, the United Kingdom Health and Safety Executive (HSE) regulatory scheme is more accustomed to dealing with blast issues. Recent trends have shown that operators with large platform North Sea experience are bringing their knowledge and design philosophies into the deepwater Gulf of Mexico designs.

Classification societies have taken an active role in assisting both the United States Coast Guard and the Mineral Management Service to certify the floating installations under the provisions of NVIC 10-82 [6], NVIC 10-92 [7], NVIC 3-97 [8] and MMS Structural Certified Verification Agent (CVA) work.

For the Gulf of Mexico, regulatory requirements come from two different agencies and sometimes their requirements appeared to be overlapped. Nevertheless, the 1998 Memorandum of Understanding between the MMS and the USCG [9] helps to clarify the responsibilities of each of the organizations with regard to

- Mobile Offshore Drilling Units (MODU's)
- Fixed Installations
- Floating Installations

Based on the Memorandum of Understanding, the United States Coast Guard is responsible for:

- Fire protection, detection and extinguishing, including:
- Deluge systems in the wellbay area
- Firewater pumps, piping, hose reel and monitor equipment
- Foam extinguishing equipment
- Fixed gaseous extinguishing equipment
- Fixed watermist extinguishing equipment
- Portable and semi-portable extinguishers
- Fire and smoke detection
- Structural fire protection within accommodation spaces

The Minerals Management Service is responsible for:

- Gas detection
- Emergency shut-down systems

The Minerals Management Service and the United States Coast Guard share the responsibility for hazardous area classification; with the Coast Guard taking the responsibility for MODU's, Mineral Management Service for fixed facilities, and both organizations sharing the responsibility for floating structures.

A significant disparity exists in the USCG regulations for fixed platforms as compared to floating facilities. Only minimal firefighting and lifesaving equipment are prescribed for fixed facilities, whereas the requirements for floating facilities are aligned with MODU's and merchant vessels. For example, neither self-propelled lifeboats nor firemain systems are required by the USCG for any fixed platform. There is a pending rulemaking effort that seeks to expand the fixed platform equipment requirements. Although risk-analysis and performance-based initiatives exist within the USCG, the pending rule maintains a prescriptive format.

The implementation of the Memorandum of Understanding requires both agencies to revise their respective regulations to reflect the division of responsibility. This process has not yet been completed and in the interim, existing regulations govern design and operation. There is no discussion in the Memorandum of Understanding on the risk of explosions or any structural blast protection.

In connection with the current regulatory scheme within the Gulf of Mexico, the following issues were discussed and noted during the Workgroup 7 Workshop Sessions:

The Minerals Management Service regulations, which apply to fixed platforms, are prescriptive-based with limited risk-based alternatives. It was, however, noted that they have used a risk-based approach when considering the operations of Floating Production Storage and Offloading vessels (FPSO's) for use in the Gulf of Mexico.

In the future, it is anticipated that the Minerals Management Service will adopt more risk based industry standards, for example API RP14J [10], with some form of approval/oversight.

The Memorandum of Understanding between the USCG and the MMS was discussed. In addition, the potential future roles/mission of the USCG were discussed with regard to the recent attention to Homeland Security.

It was felt that the USCG should continue to adopt appropriate consensus standards.

The acceptance of performance-based options by the United States regulatory bodies will allow industry advances in technology to be more readily incorporated, rather than requiring a change to the Code of Federal Regulations.

The following table outlines the principal regulatory differences between the United Kingdom sector of the North Sea and the Gulf of Mexico for both floating and fixed installations.

	Floating Production	**Fixed Process**
North Sea (U.K. sector)	Safety Case review by HSE	Safety Case review by HSE
Gulf of Mexico	Requirements for Fixed facilities along with 46 CFR USCG/MMS MOU	33 CFR Subchapter N 30 CFR 250 CVA

Table 1 Principal regulatory differences bewteen the United Kingdom sector of the North Sea and the Gulf of Mexico for floating and fixed installations.

5.2 North Sea

The North Sea area utilizes a risk-based approach.

In its simplest terms, the approach to fire and blast safety in the North Sea involves:

- Determination of the required active and passive fire protection systems (this step involves establishing performance criteria)
- Demonstration that the proposed design meets or exceeds the performance criteria
- Demonstration that the performance criteria will cope with all credible hazards

This approach applies to both the active and passive fire fighting systems. As a practical example, it must be demonstrated that the fire pumps are sufficient to fight all credible fires.

There are no requirements that dictate the use of firewalls under the North Sea approach, since they are considered part of the "goal setting" approach.

5.3 Brazil

Traditionally, the Brazilian regulatory regime was in essence controlled by Petrobras. There has been a relatively long-standing requirement within the Petrobras project specifications that any new production facility be subjected to a Formal Safety Assessment. This was not the same as a Safety Case, but went some way towards ensuring that there were no major problems with respect to fire and explosion. Since the Brazilian market has opened up to outside oil companies, there is now a need for an independent regulatory body. Hence ANP (Agência Nacional Do Petróleo) has been established. They are now in the process of developing a format for their regulatory regime. The incident associated with the Petrobras P-36 unit has accelerated this process.

5.4 United Kingdom Sector of the North Sea

The United Kingdom sector of the North Sea utilizes a performance-based approach, governed by a Safety Case regime.

The intent of the introduction of a safety case approach in the United Kingdom sector of the North Sea was to move away from prescriptive regulations towards a Goal Setting approach. It has been argued that the failings of the prescriptive regime have been brought out a number of times, and the process stifles inventive thinking and improved safety. Because of these reasons, Lord Cullen concluded from his investigation into the Piper Alpha disaster that the United Kingdom regulatory regime should be put onto a goal setting approach. The first, and most widely understood, part of this was the introduction of the Safety Case Regulations, but since these were promulgated they have been supplemented by other regulations that now form a complete regulatory regime. The basic idea is to show that a facility is "fit for purpose", and can cover all reasonable eventualities. Any failings are addressed and corrective actions taken under the aegis of ALARP (As Low As Reasonably Practicable).

In its simplest form the UK regulatory regime for fire and blast can be summarized as:
Establish risk acceptance criteria

- Set a performance criteria (determine what is required with regard to fire fighting, blast protection, etc.)
- Show that the proposed systems meet the performance criteria
- Show that the performance criteria will cope with all credible hazards (it may be that the hazard is not necessarily controlled, but handled an alternative way)
- Demonstrate, through the Verification Scheme, that the system will be operational when needed

The following issues were discussed during the technical sessions:

Since the time of incorporation, acceptance criteria for the risk to an individual as an average on a per annum basis have been established for the ALARP concept. The following risk levels are generally accepted:

- Greater than 10^{-3} - unacceptable
- 10^{-3} to 10^{-6} - within the ALARP range
- 10^{-3} to 10^{-4} - worth the time, money and effort to reduce the risk
- 10^{-4} to 10^{-5} - risk may be acceptable but requires additional analysis
- 10^{-5} to 10^{-6} - reasonably acceptable in the offshore industry

The UK operators are now self-regulating (with some external third party verification)

5.5 Australia

Australia is very similar to the North Sea approach.

5.6 Canadian East Coast

Current approach is a combination of prescriptive and goal setting, including the certifying authority regime; but allows for risk-based deviations or exemptions. There is evidence of a move to harmonize with the International Standards Organizations (ISO) offshore structure standards.

5.7 Other Areas

The following issues were discussed during the technical sessions:

In undeveloped areas such as West Africa, prescriptive based regulations may be more suitable since the regulators do not have the necessary technical resources to review multiple alternative design approaches.

6 International Maritime Organization Perspective

As previously indicated, a substantial revision to the International Maritime Organization's (IMO) Convention on the Safety of Life at Sea (SOLAS), Resolution MSC. 99 (73) [3] entered into force on July 01, 2002. This text, along with a supporting IMO Circular, sets forth a procedure for accepting fire safety engineering aspects of facility designs, which deviate from the strict prescriptive regulations of the Convention. It is anticipated that this alternative performance-based approach will ultimately have significant practical and economic influence on fire and blast safety engineering design in the offshore industry.

7 Classification Society Perspective

Although classification societies have traditionally used prescriptive-based regulations, alternative approaches are being introduced.

A practical example of the application of a performance-based design approach concerns the fire integrity rating of the exterior bulkheads of an accommodation module on an offshore facility. The American Bureau of Shipping Facilities Guide [11] requires that these bulkheads be provided with an H-60 level of fire integrity when they are adjacent to a hydrocarbon fuel source.

The acceptance of the performance-based design approach by classification societies, as an alternative to strict compliance with the prescriptive rules, is seen to be an initial step towards accepting a performance-based analysis on behalf of an Administration. As with the recent changes to SOLAS, it is anticipated that performance-based fire safety regulations will become increasingly prevalent within classification societies' rules.

8 Body of Knowledge

Since a performance-based approach does not rely on the existing prescriptive rules, all design decisions which deviate from the current regulations must be based on sound fire science and good engineering practice, incorporating accepted methods, empirical data, calculations and correlations. Fortunately, within the past two decades, the discipline of fire safety engineering has grown rapidly with a considerable amount of research published in the areas of combustion science, heat transfer, performance of materials, toxicology and human behavior. This new and expanding body of knowledge is crucial to the success of performance-based fire safety regulations.

Examples of tools that can be used in the design process include a wide range of computer-based correlations. These models include FPEtools [12], a suite of relatively simple fire safety engineering mathematical relationships, published by the National Institute of Science and Technology (NIST), and TASEF [13], a finite element analysis model of temperature distribution through a structure, published by the Swedish National Testing and Research Institute. More sophisticated programs include zone and field type models which attempt to track the energy output from the combustion reaction are also available. Currently, there is significant interest in Computational Fluid Dynamics (CFD) techniques including the Fire Dynamics Simulator (FDS) and Smokeview programs [14, 15], again developed by the National Institute of Standards and Technology. The FDS model solves a form of the Navier-Stokes equation for the low speed, thermally driven flows of hot smoke and gas produced in a fire. This output is then used in the Smokeview model to produce a visual representation of the smoke and thermal energy released by the fire in a two-dimensional, three-dimensional or animated vector plot format.

As the computer models and other correlations become increasingly sophisticated and undergo further validation, their use in fire engineering design will become more widespread. Those using and interpreting the output of the computer programs must be fully conversant with the limitations and idiosyncrasies of each model.

9 The Future

The maritime industry, and the discipline of fire safety in particular, has been reactive to incidents involving major loss of life. Examples include the large suite of regulations that have followed major disasters such as the TITANIC, SCANDINAVIAN STAR and PIPER ALPHA incidents. With the introduction of a performance-based approach, the industry has the opportunity to become proactive, pre-empting these catastrophic incidents by adopting the findings from current fire safety research, and incorporating this knowledge into the design of facilities.

Alternatives from strict prescriptive-based regulations are already being utilized in the offshore industry in specific geographic locations, including the United Kingdom. Additionally, as the performance-based approach becomes more prevalent in land-based codes, and is adopted into the general marine industry, as with the United States Coast Guard Navigational and Inspection Circular 3-01, it is anticipated that the performance-based design basis will have a significant influence on the offshore industry.

From both a global and United States perspective, it is anticipated that performance-based fire safety design will become increasing prevalent in the offshore industry. Justification for this includes the developments that have been observed in land–based codes, the introduction of a performance-based approach within the United Kingdom sector and the development of alternative performance-based approaches by individual Administrations including the United States Coast Guard.

10 Topics Discussed during Workgroup Sessions

Is there sufficient knowledge within the offshore industry to utilize a true performance-based approach to fire and blast safety?

The knowledge required for the use of alternative approaches to fire safety engineering within land-based designs has been developed for many years through organizations such as the National Institute of Science and Technology (NIST), Building Research Establishment and top academic Institutions. While there are several prominent organizations and universities which conduct fire and blast safety in the offshore industry, the volume of research material is not as extensive as that available to land-based designers.

The following comments were noted during the Workgroup 7 Workshop Sessions:
Considerable technical data regarding fire and blast related issues already exists within the offshore industry. Some of this information may, however, not be available to all operators since only some of the larger operators maintain their own databases.
The current approach to explosion analysis typically used in the Gulf of Mexico may be too generic.
It was questioned whether the onshore knowledge base regarding fire and explosion safety could be applied to offshore installation. The Workshop participants felt that much of the information used in the onshore industry can apply to offshore.
The regulatory option between performance based and prescriptive approaches must remain.
There may be some areas where there is not a sufficiently complete understanding of the process involved to permit a risk-based approach.
Expertise is available to all companies but is used on a project-to-project basis dependant on capital expenditure (CapEx) and perceived value.
Prescriptive regulations can work well for facilities which have a traditional design. However they typically do not work well for facilities that incorporate non-traditional designs.

Do the United States regulatory agencies (United States Coast Guard and the Mineral Management Service) have the ability and resources to evaluate risk-based fire explosion analysis for offshore facilities?

The following comments were noted during the Workgroup 7 Workshop Sessions:
Both MMS and USCG have high-level commitments to considering risk-based alternatives.
The agencies acceptance of a risk-based approach for equivalency or alternative compliance rests on demonstrating an equivalent level of safety to existing prescriptive requirements.
Neither agency appears to have implemented formal processes for evaluating a risk-based approach.

Will the recent changes to the SOLAS convention have a significant influence on the offshore industry?
The latest revision of the International Maritime Organization's (IMO) Convention on the Safety of Life at Sea (SOLAS), due to enter into force on July 01, 2002, permits an alternative approach to fire safety design.

The following comments were noted during the Workgroup 7 Workshop Sessions:
SOLAS itself will not be applicable to the fixed or floating facilities because they do not make international voyages.
The USCG is tending to align their lifesaving requirements with SOLAS.
The USCG is not obligated to accept deviations or exemptions granted by other flag states.

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Appendix 1 - IMO Procedure for Adopting a Performance–based Approach

The recent revision and overhaul of SOLAS Chapter II-2 along with the supporting Circular, presents a general methodology for assessing fire safety design and arrangements, which deviate from the traditional prescriptive rules. As a minimum, the IMO indicates that in considering an alternative fire safety design, the following steps, as outlined in Figure 1, are to be followed:

1. Perform a preliminary analysis in qualitative terms to assess the viability of the conceptual design. This analysis should include a clear definition of the scope of the alternative design and arrangements, which are to be incorporated into the vessel. A preliminary analysis report should be produced identifying the members of the design team, their qualifications, the scope of the alternative design analysis and the functional requirements to be met. The acceptance of this report by the individual team members ensures that the design objectives are acceptable to the individual parties.
2. Develop credible fire scenarios. This involves:
    a. identification of the fire hazards. This can be obtained from historical data, expert opinion or through hazard evaluation procedures such as Hazard Operability Studies (HAZOP's), Failure Mode and Effects Analysis Studies (FMEA's) and "What-If" style analysis. Hazards that are present, and those which can realistically be expected to be present during the life of the vessel, should be considered.
    b. enumeration of the fire hazards. This process categorizes the effects of the fire hazards into one of three incident classes - localized, major or catastrophic.
    c. selection of fire hazards for the quantitative analysis. This process should identify a range of incidents that cover the largest and most probable range of enumerated fire hazards.
    d. specification of design fire scenarios. This should include a description of the design fire including details associated with the ignition source, first fuel ignited, heat release rate of the fuel source, mental status of the occupants and the available fire protection systems.
3. Quantify the implicit requirements within the prescriptive regulations. Since the IMO has found that the prescriptive requirements contained in the SOLAS Convention are acceptable, any arrangement that attains a similar, or greater level, of safety must also be acceptable.
4. Quantify the proposed performance-based design. To allow comparison, the performance-based system must be quantified, using sound fire engineering principles. Features such as occupant egress times, smoke obscuration rates and fuel package heat release rates may be required, depending on the extent of deviation from the prescriptive regulations.

5. Compare the differences in the level of fire safety offered by the prescriptive and performance-based designs.
6. Decide if the proposed design is acceptable. It is to be remembered that the purpose of the performance-based approach is not to build a fail-safe vessel but to specify a design with reasonable confidence that will perform its intended function(s) in a manner equivalent, or better than, the prescriptive fire safety requirements of SOLAS Chapter II-2.

Once the process has been completed, and the alternative arrangements found to be acceptable by the appropriate Administration, the IMO indicates that documentation outlining the assumptions, which were used in the design, along with a life cycle maintenance program, should be produced and kept onboard the vessel.