EXPERIENCE IN APPLYING HAZARD ASSESSMENT TECHNIQUES OFFSHORE IN THE NORWEGIAN SECTOR

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1. INTRODUCTION

1.1 Norwegian Offshore

The winning of the gas and oil resources of the North Sea is a demanding and challenging activity requiring safe, proven and reliable equipment and installations if the costs in human and economical terms are to remain within tolerable limits.

The implementation of a risk management system as a means for identification, evaluation and control of major hazards is laid down in the safety policy of Elf Aquitaine Norge A/S (EAN). Risk assessment techniques are applied from the early phase of a field development project and throughout subsequent phases. Special emphasis is placed on systematic follow-up and verification of assumptions and recommendations made in risk and reliability studies.

This paper focuses on the application of hazard assessment techniques to an offshore development project at the conceptual stage of design.

1.2 Heimdal Development

The Heimdal gas reservoir is located within Block 25/4 on the Norwegian Continental Shelf, approximately 180 km West North West of Stavanger and 35 km South of the Frigg (Figure 1).

The field is owned by the following partners: Statoil 40.000 %, Marathon 23.798 %, Elf Aquitaine Norge 9.639 %, Bow Valley 8.000%, Norsk Hydro 6.228 %, Sunningdale 3.875 %, Saga Petr. 3.471 %, Uglands Red. 0.169 %.

Elf Aquitaine Norge A/S is appointed operator.

The field was discovered in 1974 and confirmed by 4 wells. Landing application was issued 15th January, 1981 and approved by the Storting 10th of June 1981. The estimated recoverable gas reserves are approximately 35.6 x 10^9 standard cubic metres, with estimated duration of production from referred reserves being 10 to 11 years. The production rate will be 3.74 x 10^9 standard cubic metres wet gas annually.

An eight legged steel platform with Production, Drilling and Quarter facilities will be installed as shown in Figure 2. The produced gas will be processed and pumped through the Statpipe pipeline system via their riser platform No.1 to Ekofisk and then for export to Emden.

2. SAFETY AT THE CONCEPTUAL STAGE OF DESIGN

2.1 Background to the Norwegian Approach

During the past few years, probabilistic risk and reliability assessment has gained widespread application in development projects on the Norwegian Continental Shelf (NCS). Major accidents like the Bravo blow-out several helicopter crashes and the Alexander L. Kielland platform disaster have made the industry, the authorities and the public focus on safety in offshore operations.

Three safety research programmes have been successfully completed over the last 4-5 years, dealing with every facit of offshore safety. Risk and reliability assessment has been recognised as valuable means in the design and decision-making process, with operators setting up expert teams in this area within their organization. This has led to a better understanding of the practical benefits and limitations of probabilistic assessment, and a more wide-spread discussion of the application of such techniques and the results thereof.

Norwegian regulatory bodies appear to be moving from detail design regulations to regulations based on functional criteria. Having experienced a number of safety problems in some development projects involving large integrated platforms (accommodation, utilities, drilling and production facilities on the same deck), the Norwegian Petroleum Directorate (NPD) set out to develop a set of "Guidelines for Safety Evaluation of Platform Conceptual Design". These Guidelines were issued in September 1981. The Concept Safety Evaluation (CSE) is to be included in the Main Plan which forms the basis for the authorities approval of the proposed concept.

2.2 The Purpose of a Study at this Stage

The primary objective of CSE is to demonstrate an acceptable safety level and to identify Design Accidental Events in terms of heat radiation, blast overpressure and structural impact. The CSE is thus a design tool. The key to this preferred format is a basic philosophy of approach, which seeks to define and quantify a range of incidents which could pose serious problems for the operator in terms of loss of production or life. The balancing of the expected consequences of these incidents against a measure of their likelihood allows a realistic assessment of the extent of intrinsic safety that should be built into the concept at the design stage.

The Guidelines introduces a probabilistic cut-off limit with regards to Design Accidental Events:

"In practical terms, it may be considered necessary to exclude the most improbable accidental events from the analysis. However, the total probability of each type of excluded situation should not by best available estimate, exceed 10^{-4} per year for any of the main functions (escapeways, sheltered area and main support structure).

This number is meant to indicate the magnitude to aim for, as detailed calculations of probabilities in many cases will be impossible due to lack of relevant data."

The latter statement was probably included to comfort the opponents of probabilistic risk assessment and to allow for the really few cases when no relevant data can be found. Because in practice, the CSE which have been submitted to NPD over the last year have all included a comprehensive application of probabilistic assessment.

2.3 Approach to the NPD Guidelines

The Guidelines document sets out a specific method and philosophy of approach for carrying out the concept-stage evaluation, but it allows some flexibility in interpretation and furthermore specifically permits alternative approaches if a case can be made out for them.

The basic concepts of the NPD Guidelines are as follows:

1. The adequacy of the platform design is measured by the ability of the escapeways, the shelter areas and the main support structure to remain functional or partly functional during any one of the several "design accidental events", to permit personnel outside the immediate vicinity of the accident to reach a safe location.

2. The "design accidental events" are particular scenarios in each of which an initiating failure (e.g. pipe rupture) is considered in combination with particular conditioning circumstances (e.g. wind direction, protective system operation etc.).

3. Accidental events which do not fall in the "design accidental event" class because they would make all escape ways impassable should not have a total probability exceeding 10^{-4} per year; the same applies for shelter areas and main support structure. These events are sometimes called 'Residual Events'.

This basic approach has the valuable feature that it leads to the specification of clearly-defined design cases which can be fed into a conventional design process. On the other hand, the method by which these design events are chosen is a very modern scientific approach which recognises the inherently probabilistic nature of the problem and allows for the inevitable residue of extreme events which cannot be eliminated completely in any particable system.

In the implementation of these guidelines the following procedure has been adopted:

i) A selective but representative list of all possible initiating failures has been drawn up, covering faults in wellhead area, process, structure and risers.

ii) The frequency of each such failure is estimated from reliability statistics.

iii) The possible conditioning circumstances (operator intervention, protective system operation, weather conditions, ignition time delay) are evaluated, and a number of accidental events (i.e. complete scenarios) derived for each failure case.

iv) The frequency of each separate scenario is evaluated.

v) The consequences of each accidental event, in terms of effects on escapeways, shelter areas and structure are estimated. Those which infringe the survivability criteria are put in a separate list (called here the 'Residual List').

vi) The Residual List, with corresponding frequency estimates, is then considered as a whole. If the totality of all events on the Residual List has a frequency greater than the target for any one of the three functions (escape ways, shelter area, supporting structure), then recommendations are made to enhance the design specifications such that some of these events become 'design accidental events' and are removed from the Residual List. Otherwise, the design can be considered to comply with the Guidelines without further action.

vii) The Design Accidental Events are examined thoroughly to ensure that their effects can be accommodated within the design.

This procedure is shown diagrammatically in Figure 3.

The total allowable frequency for the 'Residual events' is made up of contributions of 1×10^{-4}/yr. from each of nine accident classes. Thus, the maximum allowable residual frequency is 9×10^{-4}/yr. for each main function, according to this interpretation.

This frequency criterion applies to the <u>total</u> frequency of the Residual Events. Therefore, it is not possible to decide whether or not a single failure case should be a design case in isolation. The designer is thus, in principle, free to select which events are retained in the Residual List and which ones become Design Accidental Events, so long as he stays within the criterion.

3. THE TECHNICAL ANALYSIS, APPLIED TO HEIMDAL PLATFORM

3.1 Overall Sequence of Steps

The overall sequence of steps has been given already in Figure 3. From this figure it can be seen that the 'core' of the evaluation is a conventional risk analysis, with its four main constituents:

1) Identification of the failure events
2) Expected frequency of occurrence
3) Consequence evaluation
4) Assessment of results

The first three of these steps are described below in their applications to Heimdal main platform. The fourth step is also described, but in the format dictated by the NPD guidelines:

4a) Platform Behaviour
4b) Assessment of the accidental events
4c) Results
4d) Feedback to the design

3.2 Identification of Accidental Events

Potential accidental events were identified by three different methods in order to obtain systematic coverage of all the major failure events.

First, a "checklist" method was used, in which the equipment items in each zone in the platform were identified. Containment failures for each item were then listed. This method was applied systematically to the whole platform so that a comprehensive set of major failure cases could be defined. Platform "zones" were defined to be half of each deck of each module.

Secondly, a "Coarse Hazard and Operability Study" was undertaken, in which the possible malfunctions of the process and utility systems were explored on a line-by-line basis.

Finally, a Qualitative Engineering Review of the design was carried out by engineering specialists. The main purpose of this task was to provide an engineering basis for comments on the measures taken in the design to prevent accidents, and to reduce the consequences of accidents. The review was used as a direct contribution to the safety evaluation, as it led to the identification of some of the potential accidents to be considered in the remainder of the analysis. It also provided engineering information relevant to the probabilities of failure.

Following this approach, approximately 200 accidental events were defined. These are distributed over the platforms as follows:

Platform Area	No. accidental events (approx.)
Process and Compressor modules	125
Utilities	16
Cellar Deck	10
Living Quarters	2
Wellhead Area	25
Near sea level (risers)	12
Structural damage	10
	200

These events are all fires, explosions, or structural damage from external impact/extreme environmental conditions. The events vary in severity, but all are of sufficient size to cause significant damage to the platform.

3.3 Expected Frequency of Accidental Events

The expected frequencies of each of the accidental events considered was evaluated in two parts: The primary accident expected frequency (i.e. the frequency of the initial mechanical failure), and the event tree conditional probabilities (i.e.the probabilities of the various possible final outcomes of the failure).

For example, for process system leaks (covering process module, compressor module, cellar deck and non-blowout-related drilling module leaks), the leakage rates have been based on the total number of accidental leaks expected over the whole platform. Three leak size ranges have been considered. The source data was threefold: Frigg field data, onshore liquefied gas peak shaving process plant (average of 25 plants), and incident data for the North Sea as a whole. For each leakage size, the estimated leak rate has been crosschecked against at least one of the other sources of data. These platform leakage rates have then been subdivided over the relevant primary accidents, on the basis of the completion of process equipment in each accident area.

The event tree probabilities that have been considered include factors for immediate, delayed or greatly delayed ignition, fire or explosion, fire fighting system successful/unsuccessful. These have been considered with wind direction probability, DHSV operation, and other conditional probabilities relevant to particular events. Whenever possible, crosschecks have been made with other data sources to establish the confidence to be placed in the mean figure to be used.

The confidence limits on each of the accidental event probabilities were evaluated using a Monte Carlo simulation technique.

3.4 Consequence Evaluation

The consequence of all the defined accidental events were evaluated in terms of heat radiation loading, blast overpressure and structural damage.

For the purpose of the consequence evaluation the accidental events were grouped into the following main categories:

- gas riser failure
- condensate riser failure
- wellhead blowouts
- process, compressor and utilities failure
- earthquake
- wind and wave
- ship collision
- helicopter crash
- dropped objects from crane

Both primary and secondary effects of such incidents were evaluated.

3.5 Platform Behaviour

The three safety functions, whose integrity may be affected by the accidental events, will withstand only certain heat and blast loadings. Same is true for other loadings such as earthquake, ship collision, etc.

The effect on the shelter area, escapeways and supporting structure were evaluated for each accidental event in terms of the associated consequence.

Shelter Area - The shelter area is considered to be affected if the loadings given above are exceeded within several hours of the design of the fire/explosion.

Such a duration represents a conservative assumption, given the design specification for free fall lifeboats.

Escapeways - The escapeways are considered to be affected if there is no single route that can be used from a central position to reach the shelter area, within one hour of the onset of the fire/explosion.

Supporting Structure - The supporting structure is considered to be affected if the integrity of more than one jacket leg may be lost within several hours of the onset of fire explosion, or if substantial cross branching damage occurs that might affect the integrity of the jacket.

3.6 Assessment of the Accidental Events

These events which did not infringe the acceptance criteria given above were initially considered Design Accidental Events. No attempt was made at this point in time to base the selection on any probabilistic criterion. Thus the frequency of the DAE is without relevance.

Those accidental events which exceed the design limits and thus infringe the safety functions are termed Residual Events. It is the total probability of these events which should not exceed the probability target. The interpretation of the NPD Guidelines outlined above fixes this target at a maximum of 9×10^{-4}/year.

If the total probability exceeds the target, the designer has three options:

1. Reduce the consequence of one or more residual events (i.e. move events to the left of the design limit in Figure 3).
2. Reduce the probability (per year) of one or more residual events.
3. Eliminate one or more accidental events through alternative design.

3.7 Results of the Analysis

The analysis of the likelihood and consequences of a large number of potential accidents were evaluated for Heimdal main platform.

The results of the analysis are expressed in terms of the total frequency with which certain types of accident exceed the design criteria. The exceedence of the design criteria is shown in Table 1 for residual effects in the shelter area. Similar results were prepared for the residual effects on the supporting structure and on the escapeways.

3.8 Feedback to the Design

The feedback to the design consisted of three inputs.

1. Specific measures that could be taken to reduce the likelihood of each of the residual events.
2. Specific measures that could be taken to reduce the consequences of each of the residual events.
3. Identification of the major risk contributors and the effectiveness of measures that could be taken to reduce that risk.

Since the output of the risk analysis indicated that the best estimate for the total residual risk was above the guidelines figure, several measures were proposed and adopted for reducing the risk. These principal measures are shown in Table 2.

The conclusion of the study was that the platform design satisfied the intention of the NPD guidelines for concept safety evaluation.

4. BENEFITS AND LIMITATIONS

4.1 What the Study Achieved

The application of the NPD Guidelines to offshore development projects is a new experience to both the authorities and the operators. The interpretation of the Guidelines adopted by EAN and applied by Technica Limited for the Heimdal development leads to a conservative approach and a practicable way of handling major hazards at the conceptual stage of design. The chosen approach is consistent with the one outlined in the Guidelines.

The completeness of a risk analysis is a difficult, if not impossible, parameter to measure. It is, however, an extremely important factor, and it is felt that the systematic approach adopted in this study with the professional input provided in engineering disciplines are key elements in ensuring an acceptable degree of completeness.

The primary output from the CSE is the set of Design Accidental Events. From an initial list of DAEs and Residual Events, various kinds of remedial actions were discussed in order to end up with acceptable risk levels. This process was a very useful one - practical engineering solutions were found by the design team which at the same time gained detailed insight into the significant accidental situations on the platform. Such a constructive discussion could not have taken place without the CSE to support it.

The Concept Safety Evaluation has also had a spin-off effect in terms of laying down requirements for risk and reliability studies at the later stages of platform design. A number of such studies have already been undertaken. EAN finds it extremely important to follow-up assumptions which are laid down in risk analyses, and a significant effort has been diverted to such activities in later stages of the Heindal development.

4.2 The Limitations

The perhaps most significant limitation to the approach suggested by the NPD Guidelines is associated with the timing of the study. The CSE, as the name implies, is intended for the conceptual stage of design, when limited information is available concerning system and sub-system design. On the other hand, the suggested approach requires quite a lot of engineering input. This inevitably leads to a high number of assumptions being made and/or a delay of the CSE. In our opinion, a more short-cut approach should be developed for the conceptual stage as more experience is being gained in this field.

In order to improve the engineering input from the CSE to the design team, steps should be taken to effectively bridge any gap between the safety evaluation team and the design team, by requiring the CSE to specify, in engineering terms, the design specifications, ie the CSE should not only give the heat load in a certain module, but should also specify the rating of the surrounding firewalls.

5. CONCLUSIONS

The guidelines issued by the Norwegian Petroleum Directorate for the safety evaluation of conceptual platform design are considered to be a modern, practical and constructive method of ensuring an acceptable level of safety in basic engineering design.

TABLE 1 : SUMMARY OF EXPECTED FREQUENCY OF ACCIDENTAL EFFECTS ON THE SHELTER AREA

ACCIDENT EFFECT	TOTAL EXPECTED FREQUENCY (/10^6/years)	CONFIDENCE LIMITS	
		95% Upper	52% Lower
1. Hydrocarbon fire extending into shelter area following fire on LQ firewall of greater than 30 mins duration (approx.) at 150 k2/m^2.			
a) Following explosion in the process system* breaching compressor module firewall (28 events).	255	526	121
b) Following prolonged duration fire in the process system* due to riser rupture in the process module (8 events).	305	505	117
c) Following prolonged duration fire in the process system* due to BLEVE (10 events).	4	7	1
d) Following wellhead blowout and diffuse flame (not jet flame) leading to extensive topsides fire (production phase) (5 events).	247	816	43
2. Non hydrocarbon explosion originating in utilities module breaching firewalls on each side, with subsequent fire intruding into shelter area.	18	54	6
3. Extensive hydrocarbon fire originating at or near sea level from riser leak and engulfing the shelter area (single riser) (4 events).	385	1020	90
4. Extensive hydrocarbon fire that results in local collapse of the module support frame due to heat loading (150 kW/m^2) with no direct deluge system, leading to structural damage that renders the shelter area unusuable (8 events).	67	147	25
5. Extreme earthquake of 10^5 year return period.	5	15	2
6. Passing vessel collision.	13	50	4
7. Helicopter crash onto utilities module and fire.	8	24	2
TOTAL	1307	3164	411

TABLE 2

Principal safety measures proposed and implemented for Heimdal main platform following the CONCEPTUAL SAFETY EVALUATION.

HAZARD	REMEDIAL MEASURES
Process system explosions	1. Update major firewalls between process and LQ. 2. Introduce additional hydrocarbon fire walls on cellar deck to prevent fire ingress under LQ.
Riser rupture in the process area	1. Relocation of riser ESD valve to cellar deck. 2. Deluge on riser pipe in topsides.
Wellhead fire	1. Location of drilling derrick at far end of platform in preference to alternative proposed location. 2. Protection of flare boom base against enveloping heat radiation.
Riser fire at sea level	1. Package of measures to reduce likelihood of leakage from riser at sea level.
Evacuation	1. Use of free fall lifeboats.

GENERAL ARRANGEMENT LOOKING NORTH-WEST

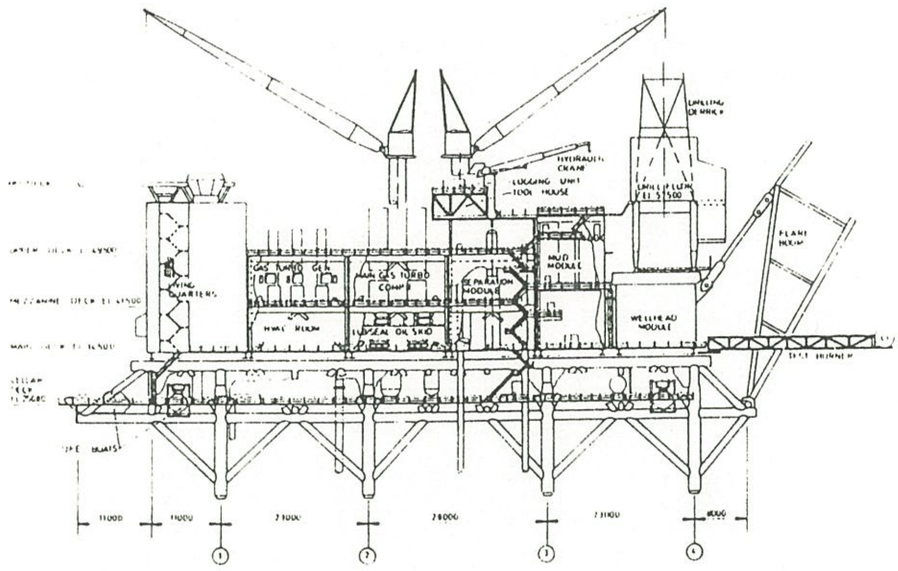

FIGURE 1

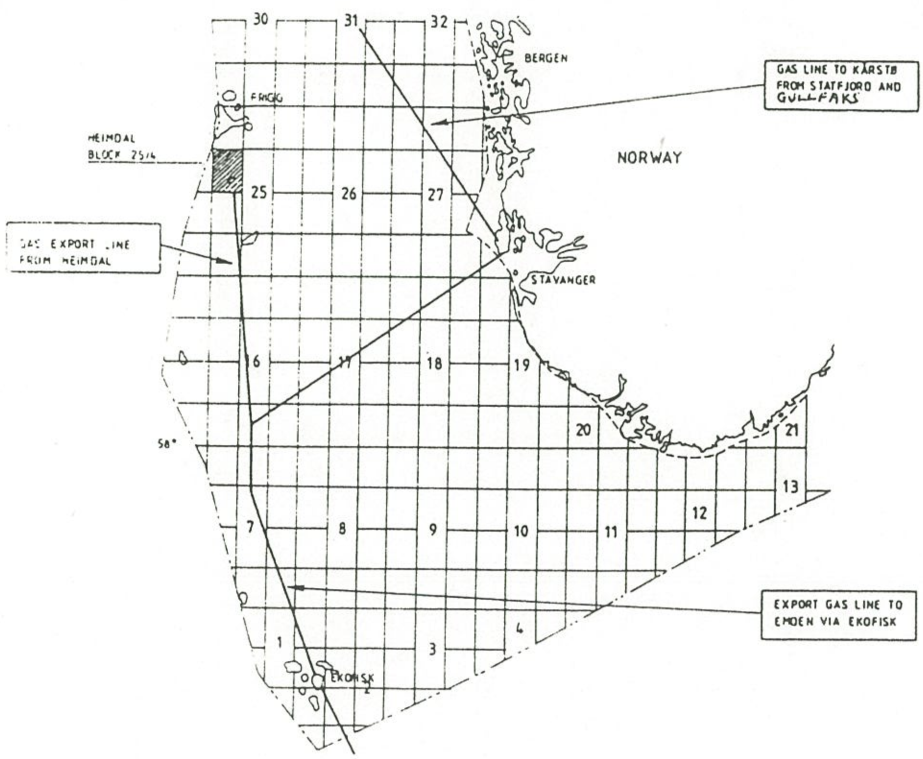

FIGURE 2

FIGURE 3 : SEQUENCE OF ACTIVITIES