INTEGRATED BARRIER ANALYSIS – A METHODOLOGY TO REVEAL WEAKNESSES IN OFFSHORE PETROLEUM OPERATIONS

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SUMMARY/ABSTRACT

The regulations from the Petroleum Safety Authority Norway (PSA) for the management of health, safety and environment of offshore petroleum installations call for a dedicated assessment and evaluation of all barriers against major hazards, both physical and non-physical, as well as any interdependencies and common threats to barriers and barrier elements. Such assessments and evaluations have not been carried out for offshore installations, although corresponding requirements apply in other industries, most notably in the nuclear power industry.

A comprehensive R&D program initiated by the Norwegian Research Council has set a goal to carry out an extensive demonstration project, whereby all relevant barrier elements are integrated into one comprehensive model, for a dedicated case study.

A method has been proposed based on use of Fault Trees, Event Trees, Influence Diagrams, Risk Influencing Factors and simplified analysis of dependencies between RIFs. The method was outlined in a PSAM7 paper in 2004.

Some case studies in order to demonstrate application of the method and explore the strengths and challenges of the analysis have been carried out in 2004 and 2005. The case studies have focused in particular on the robustness of the results, and the usefulness of quantitative results in a risk-informed decision-making context in the operations phase of an offshore petroleum installation. The case studies have been quite different with respect to input data available, which gives an opportunity to compare how these differences influence on the usefulness and robustness.

The focus in this case study has been on testing different methodologies for establishing platform specific values, both in relation to the containment barrier and in relation to two of the consequence barriers. Limited focus has been on establishing risk results as such, except as a means to provide information about the methodology and how it is suited for use in risk studies.

The overall conclusion is that the methodology that has been developed and tested shows a promising potential for use in practical applications. TTS (Technical Condition Safety) audits and expert judgement are the two most effective sources for scoring of RIFs.

It is considered that the methodology addresses some of the weaknesses identified in currently applied approaches. It is quite clear that more experience needs to be gained with use and that the details need to be developed further through practical usage, but it is considered that the basic framework is a sound and reasonable approach for addressing these issues.

As regards the work associated with implementing this approach into practical studies, it is also the analysts' opinion that it is possible to implement the key elements of this into QRAs without excessive additional amount of work. The experience from performing the case study work is that the work required to establish platform specific scores related to both technical systems and organizational/human factors is likely to be much more limited than what was expected before the work was started. There is no doubt that the process can be "streamlined" and probably also simplified in such a way that the work can be performed significantly quicker than what was the case in the case study. Through the introduction of "generic elements" (e.g. generic weights of RIFs) in the analysis process, further optimization of the work process can be achieved.

INTRODUCTION

The offshore petroleum industry has for a long time invested considerable resources in engineering defences, or barriers, against fire and explosion hazards on the installations. The performance of barriers is to some extent followed up through performance standards and Key Performance Indicators, though often not extensively. Safety systems are usually addressed on a one-by-one basis, not allowing dependencies and common mode/cause failures to be identified.

Half of the leaks from hydrocarbon containing equipment occur in connection with manual activities in hazardous areas, during which engineered defences often are partially inhibited or passivated, in order not to cause disruption of stable production. The occurrence of these leaks is a clear indication that system and human defences relating to containment of leaks are not functioning sufficiently well during these operations. There is an obvious need to understand better the performance of barriers, particularly non-technical, during execution of manual activities.

In a paper presented at ESREL 2003 [1], operational risk assessments were discussed. It was concluded that there is a clear need for improvement of the analysis of barriers. These aspects form the outset for an extensive research activity called the BORA (Barrier and Operational Risk Analysis) project [2]. A PSAM7 paper [3] gave some preliminary observations and introduced a proposed approach.

Two case studies with modelling and analysis of physical and non-physical barriers on offshore production installations have been carried out. Barriers intended to prevent the incident occurring along with those intended to eliminate/reduce consequences are included, and particular emphasis is placed on barriers during execution of operational activities. The results from the studies should enable both industry and authorities to improve safety through:

- Knowledge about overall performance of barriers and improvement potentials
- Identification of the need to reinforce the total set of barriers, especially during operational activities
- Identification of efficient risk reduction measures for barriers, together with effective modifications and configuration changes.

The analysis has been quantitative as far as was possible. Barriers are in general characterized by reliability/-availability, functionality and robustness. All of these performance measures are addressed. The Norwegian regulations require that dependencies between barriers shall be known. The analysis is therefore performed such that, where relevant, common cause or mode failures and dependencies between barrier elements are accounted for.

BORA METHODOLOGY

The BORA project has proposed a methodology in order to analyze failure of operational barriers, as outlined in [3], and presented in detail in [4]. Figure 1 presents the BORA methodology as well as the sources for scoring of RIFs. The methodology has three main processes:

- Qualitative analysis of scenarios, basic causes and RIFs
- Quantification of average frequencies/probabilities
- Quantification of installation specific frequencies/probabilities

Also the sources for the installation specific quantification of frequencies and probabilities are presented in Figure 1. The following sources are available:

- TTS/TST verifications
- MTO (Man, Technology and Organisation) investigations
- RNNS (Risk Level Project) questionnaire surveys
- RNNS barrier performance data
- Detailed assessments (Expert input)
- General background studies

The TTS/TST verifications [5] are focused on technical and documentation aspects of barriers. These verifications were developed by Statoil, and the approach has been adopted by several Norwegian offshore operating companies in Norway. MTO investigations [6] are investigations with special emphasis on human and organizational aspects that have been conducted for many accidents and incidents in the past few years, mainly by or on behalf of the Petroleum Safety Authority (PSA) in Norway. RNNS is a project conducted annually by PSA for the entire Norwegian Continental Shelf [7], which for the purpose of the BORA methodology has two applicable activities:

- Biannual questionnaire survey

- Annual collection of barrier performance data

The questionnaire survey has extensive questions relating working environment factors as well as a number of aspects relating to perceived risk and safety culture. The barrier performance data, see [7], is concerned with a selection of barrier elements, most of which are technical barriers.

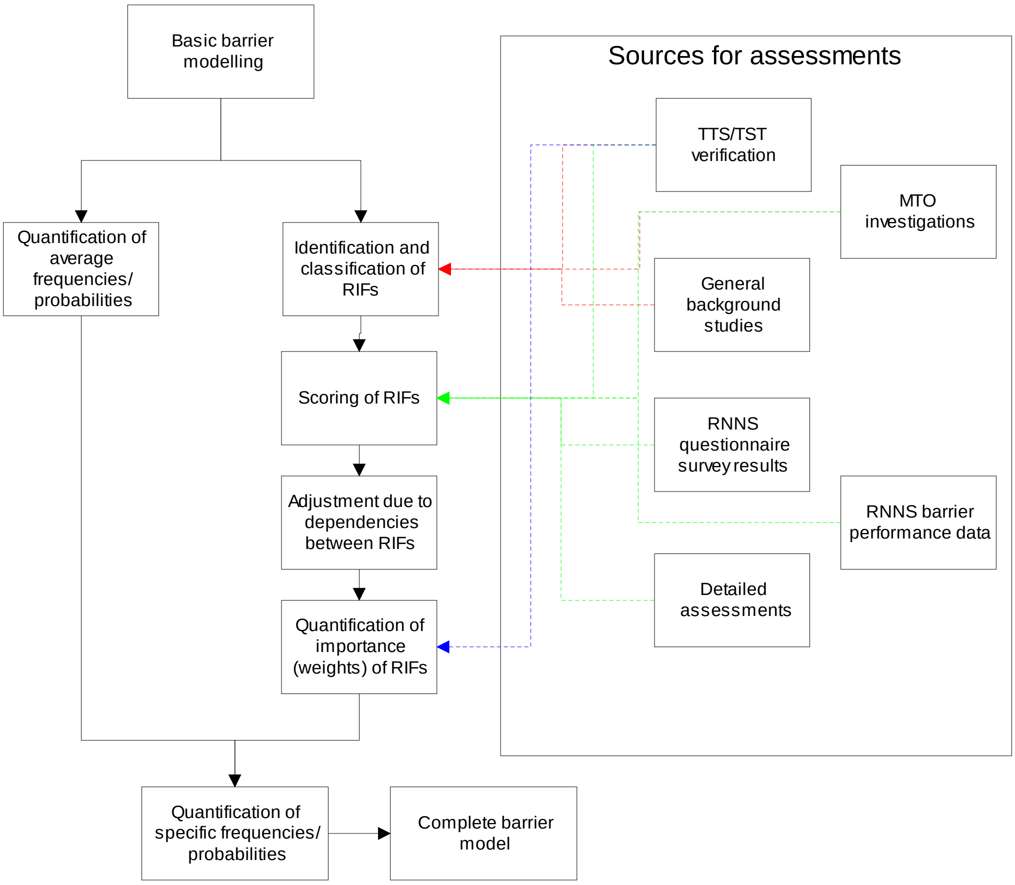

Figure 1 Summary of main combination of barrier failure causes

CASE STUDIES

Case studies were planned and conducted in order to explore how effectively the approach could be applied, the availability of sources, and the type of results that may be achieved through these studies. Two case studies have been conducted in 2004 and 2005:

- Case study 1: Four scenarios
- Case study 2: Two scenarios

The case studies were conducted for stand alone production installations in the Norwegian sector, the Case study 1 for an old installation, with steel jacket support structure, and Case study 2 for a relatively new floating production installation. The detailed scenarios that were analyzed were the following:

- Case study 1 [8]:
  - Scenario A: Release due to valve(s) in wrong position after maintenance
  - Scenario B: Release due to incorrect fitting of flanges or bolts during maintenance
  - Scenario C: Release due to internal corrosion
  - Scenario D: Release due to external corrosion (qualitatively)
- Case study 2:
  - Scenario A: Release due to valve(s) in incorrect position after maintenance

- Scenario B: Release due failure prior to or during disassembling of HC-system

The discussion of Case study 1 is limited to Scenarios A and B. Modelling of particular corrosion mechanisms had to be focused on in the Scenarios C and D, to the extent that these case studies are less suitable as BORA methodology illustration. Case study 2 also considered a selection of consequence barriers, i.e. barrier functions intended to limit the consequences of a hydrocarbon leak, if it occurs. Case study 2 considered the following consequence barriers functions:

- Prevent Ignition
- Reduce Release

SOURCES FOR SCORING OF RIFS

The sources for scoring of RIFs that may be used in order to capture the specifics of an installation and its operational conditions were briefly shown in Figure 1. The following sources were available for the case studies:

- Case study 1:
  - Some few detailed investigations were available, similar to MTO investigations
  - RNNS questionnaire surveys were available from two surveys
  - RNNS barrier performance data were available, but not used because the relevant barriers were not considered
  - Expert input was used to some extent.
- Case study 2:
  - TTS/TST verification for the installation
  - A number or investigations were available, MTO investigations and less detailed.
  - RNNS questionnaire surveys were available from two surveys
  - RNNS barrier performance data were available
  - Expert judgement input was used to some extent.

It may be observed that relatively few sources were available for Case study 1, whereas more sources are available for the installation in Case study 2.

EXPERIENCE FROM CASE STUDIES

Suitability and Robustness of Data Sources

The absence of TTS or similar data for the Case study 1 installation implied that the existing data was quite limited. The RNNS questionnaire data was only based on a limited group of employees, and there are indications that the results in the survey were not very representative for the operational performance of the installation.

There are therefore indications that TTS survey data, similar assessments, or specific assessments of the status of RIFs are required for the BORA methodology to be reliable. The second case study therefore had to involve an installation with available TTS evaluations.

The case studies have given indications of the strong and weak sides of the different sources for scoring of RIFs and it would appear that no single source is ideally suited for covering all aspects of an analysis such as this.

The most extensive information has been found from the TTS reports. In particular, this provides information related to technical Basic Events, especially for the consequence barrier systems. Since the release scenarios chosen in this case are related to operations, this is natural. However, the TTS reports do not only give information for technical systems; there is also information related to operational Basic Events. The use of TTS is on the other hand quite time consuming. There is a high number of detailed questions included in the TTS audits, and each must be evaluated in order to determine which are relevant in relation to specific RIFs.

Use of Expert Judgment for the scoring of operational basic events turned out to be a very efficient process with the additional benefit that it involves operational personnel. Expert Judgment is thus a very good supplement to the TTS reports and the two sources together give a good basis for performing the analysis. The involvement of operational personnel is likely to have the side effect that they will be more focused on barrier thinking in the future.

RNNS questionnaire information has also been applied, but the suitability of this information is more uncertain. The two case studies had quite different results in this regard. Case study 1 had this as the primary source for scoring of RIFs. The results for the installation in question were relatively negative, i.e. the installation had scores considerably more negative than the average for the Norwegian offshore industry. The use of these results from the RNNS questionnaire as source for scoring of RIFs led to installation specific results that are considerably higher than the ‘average values’. It was on this basis questionable whether so high frequencies could be supported on the basis of observed leak statistics from the installation.

Case study 2 had several sources for input data, including the results from the RNNS questionnaire survey. The survey results were quite close to the average for the Norwegian offshore industry. The adjustment factors therefore tended to be lower than what is found when using the other sources.

It was therefore concluded that the RNNS questionnaire data are not suitable as the only source for scoring of RIFs. However, the RNNS questionnaire data could be a useful additional source and if more specific questions were included in future survey, the applicability of this source could be improved.

As regards MTO investigations, this is the most limited source for scoring of RIFs that has been used and it has also turned out to be more difficult to use the data in the systematic manner that was originally intended. In one case study it was attempted to use the investigations to assess importance of RIFs, in the other case study the adjustment was made on the level corresponding to the basic events in the fault trees. The credibility of the approach was in both cases weak. However, it is believed that these data can be applied in a more systematic way by approaching the issue in slightly different ways. Some recommendations for further work have been put forward. Figure 2 presents a comparison of the results, based on which source that is used.

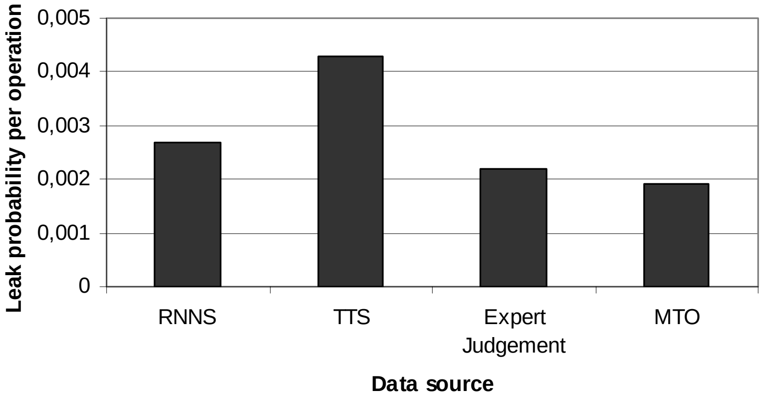

Figure 2 Comparison of results in Case study 2

In summary, a combination of TTS data and expert judgment appears to give a good basis for establishing scores on a high level. However, the other sources should also be applied and some further work is probably useful in finding efficient ways of utilizing this information as high level adjustment factors or for calibration/verification of the more detailed information available from TTS and Expert Judgment.

Use of Results in Absolute Sense

The lack of suitable and reliable sources for scoring of RIFs for Case study 1 implied that the predicted number of leakages based on the calculated installation specific leak frequencies was considered as particularly uncertain. In Case study 2, the results were presented on a 'per operation basis', which allows comparison with the results in Case study 1. The following is a comparison of frequencies per operation for Scenario A, Release due to valve(s) in wrong position after maintenance:

- Case study 1: 0.0051-0.0120 per operation
- Case study 2: 0.00190-0.0043 per operation

The ranges for these results reflect the choice of assumptions and data basis. The range for Case study 1 is consistently above the range for Case study 2, but the uncertainty about Case study 1 results note above, should be considered. Nevertheless, the results are in the same order of magnitude. The scenarios considered belong to the same category, but they are not the same operations. It is therefore relevant to compare these results, even though they are not directly comparable.

Use of Results in Relative Sense

Even though the absolute level of the number of leakages is hard to predict accurately, the case study has shown that useful input to the risk reduction process may be achieved from the results, when used in a relative sense. Based on the results from the case study, it was possible to identify and recommend one distinct procedural improvement, which would reduce the leak frequency with the analysed operations significantly. The proposed improvement involved an additional procedural barrier element.

Figure 3 presents a summary of the sensitivity studies conducted for Case study 1 (Scenario A and B). 'Industry average' results and the installation specific results are shown. For the industry average results the provision of an additional barrier was the only case considered to give significant reduction. For the installation specific results, also the improvement of all RIFs and the improvement of the RIF 'Time pressure' were considered to give significant reduction of the probability of a leak.

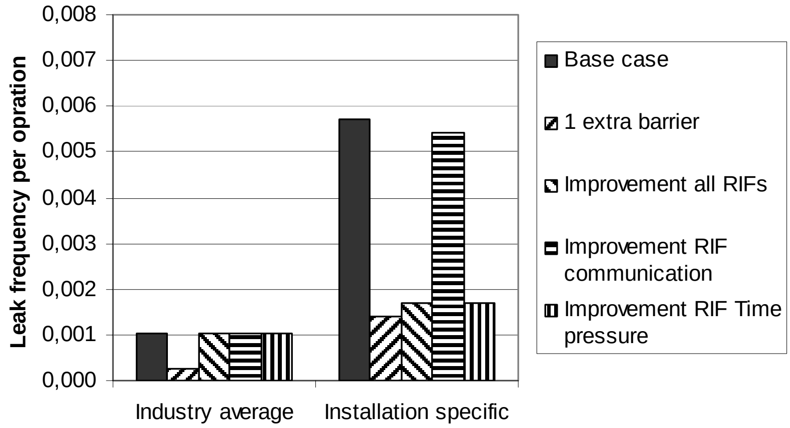

Figure 3 Results from sensitivity studies, Case study 1

Consideration of Dependencies

The BORA methodology report has recommended a relatively simple way to handle dependencies, whereby qualitative evaluations of dependencies between risk influencing factors are used in simple quantitative rules. Some reviewers have proposed a more comprehensive analysis of dependencies. An example of such an analysis is presented in Røed et.al. [9], involving a Bayesian belief network approach.

Future consideration of dependencies in the project is outlined below in the discussion of the methodology.

DISCUSSION

Use of Data Sources

The use of sources for scoring of RIFs should be considered in detail based on the application in the case studies. Some of the questions that are important to address are:

- Is the analysis capable of identifying and reflecting those human and organisational factors that really are important for risk reduction?
- Which type of input will be essential?
- Will general data (such as investigations from other installations operated by the same company) be relevant, or will the data have to be installation specific in order to be meaningful?

The table below presents the maximum and minimum adjustment factors that have been calculated using the different approaches.

Table 1 Comparison of magnitude of adjustment factors (Case study 2, Scenario A and B)

	RNNS	TTS	Expert Judgement	MTO
Maximum adjustment factor	1.06	2.27	1.05	3.00
Minimum adjustment factor	0.97	0.78	0.45	0.50

The results show variations in the adjustment factors when doing a comparison between the different approaches for scoring. Data from RNNS questionnaire surveys have very low variation range, while the largest variation is seen for MTO investigations. However, this is also the method associated with the lowest credibility and it is recommended that these results not are used as a single source for scoring of RIFs. The data basis would have to be larger for this to be a reasonable single basis for determining adjustment factors. For TTS and Expert Judgment, the variation in adjustment factors is larger, although they do not match very well. One reason for this is that the Expert Judgment scores only are established for the operational basic events while the TTS results clearly have their strength in relation to technical failures.

In general, it is noted that the variation range in adjustment factors is relatively limited. When considering that the allowed maximum variation range for each basic event is one order of magnitude up or down from the average (adjustment 0.1 to 10), the variation ranges in the case studies are small.

One reason for this may be that there will be a certain tendency that there are effects pulling in both directions, i.e. some effects indicate that the actual installation is better than the average, while others indicate that they are below average. This tends to reduce the differences. Most platforms probably have their strong and weak areas!

Another aspect is that the model has been constructed such that when we do not have information about the scoring of a RIF, that RIF score is assumed to be North Sea average. If the information is limited, this means that the adjustment factors tend to get closer to 1.0, with small variation range. There are also alternatives to starting out with this “average” assumption:

One approach would be to start with “blank sheets”, i.e. we make no a priori assumption about the status of the RIFs but use whatever (limited) information we have as the only evidence. If this information indicates that the deviation from average is large, this should be taken as an indication of the total status of the RIFs rather than using this to update an initial “average” assumption.

Another approach would be to use high level information about the platform, e.g. a comparison of leak statistics for the installation versus average leak statistics for the North Sea. If this information indicates a higher or lower leak frequency than the average, this can be used as a priori information about the status of the RIFs. These are fundamentally different approaches which also will give different results and it is difficult to conclude on what is the most representative approach.

If we look at individual Basic Events and the adjustment factors calculated using the different methods, we find that the largest difference is adjustment factors of 0.93 vs 2.27. In general, it is however difficult to find a consistent pattern or trend in the differences.

Dependencies

There are several aspects of dependencies between barriers in a wide sense that need to be addressed. Dependencies are important, it is a regulatory requirement that these are known and considered. The following are components of dependencies:

1. Common causes for failure of technical components
2. Technical components that are common for several barrier functions
3. Other barrier elements (M&O type) that are common for several barrier functions
4. Barrier influence factors that have influence on the performance of several barrier element failures
5. Dependencies between barrier influence factors that influence one barrier element.

The dependencies of Type 1 and 2 are traditional technical reliability dependencies that usually are included in Fault Tree analysis. This has also been done in the BORA project, to the extent relevant. Dependency of Type 5 has been included with a simplified approach, based on qualitative evaluations as briefly mentioned above.

Dependency of Type 3 will for instance occur if one or several human operators in the system have several functions with respect to barriers, for instance if an operator is essential in order to detect a gas leak as well as for the initiation of the shutdown function. The operator in question may not be capable of performing these tasks, because of lack of competence and/or training. The operator’s competence will then be a common factor for two barrier functions, which is the dependency of Type 4. Lack of procedures may be another example of influencing factors that may have effect on several barrier functions. Dependencies of Type 3 and 4 have been considered to the extent that the presence of these RIFs in the various barrier functions is reflected. What has not been considered so far is whether additional adjustment should be done in these cases.

Overall Use of the Methodology

The future use of the methodology has been considered, in order to determine what tools that need to be available. It is considered that the methodology may be used on 3 levels:

- As part of overall QRAs, in order to adjust the leak frequency based on RIFs
- For analysis of specific operations or problem areas in order to identify risk influencing factors and effect of risk reducing measures.

- For visualization (qualitative use) of modelling principles and approach in planning and preparations for operations offshore.

The approach may as such be seen as a ‘tool box’, which may be used for different purposes. Guidelines for use of the methodology for the three different purposes are being developed in 2006.

CONCLUSIONS AND RECOMMENDATIONS

The overall conclusion from the cases studies is that the methodology that has been developed and tested show a promising potential for application in practical studies of risk associated with process facilities and their operation. We see two key objectives that a new approach needs to address in order to be useful in such a context:

1. The approach must address some of the weaknesses currently found in QRAs. Examples of such weaknesses are causal analysis (especially for releases) and also how they are able to reflect the influence of operational, organisational and human aspects. This should also include the ability to reflect any common cause failures relating to these aspects.
2. Secondly, the work associated with using the approach in practical applications must be reasonable compared to the benefits that the new methodology provides.

It is considered that the methodology does cover some of the weaknesses identified in Item 1. It is quite clear that more experience needs to be gained with use and that the details need to be developed further through practical usage, but it is considered that the basic framework is a sound and reasonable approach for addressing these issues.

As regards the work associated with implementing this approach into practical studies, it is also our opinion that it is possible to implement the key elements of this into QRAs without excessive additional amount of work. The experience from performing the case study work is that the work required to establish platform specific scores related to both technical systems and organizational/human factors is likely to be much more limited than what was expected before the work was started.

The performance of just two case studies is a limited basis, but some conclusions on specific suggestions with regard to application of the methodology can still be put forward:

- Use of Expert Judgment for scoring of the operational status of an installation appears to be a very useful and efficient process. It involves operating personnel actively in the process and does not require excessive use of resources.
- For scoring of technical status, information from TTS reports also appears to be a good source of information. By adapting and modifying the investigations being performed when doing a TTS and reporting this, it is probably possible to develop this into an even more useful tool also as input to QRAs.

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ABBREVIATIONS

BORA	Barrier and Operational Risk Analysis
HC	Hydrocarbon
HES	Health, environment and safety
MTO	Man, Technology and Organisation
NCS	Norwegian Continental Shelf
OLF	Norwegian Oil Industry Association
PSA	The Petroleum Safety Authority [Norway]
PSV	Pressure Safety Valve
QRA	Quantitative Risk Assessment
R&D	Research and Development

RIF	Risk Influencing Factor
RNNS	Risk Level Project [by PSA]
TTS (TST)	Technical Condition Safety

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