ON THE ANALYSIS OF OPERATIONAL BARRIERS ON OFFSHORE PETROLEUM INSTALLATIONS

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SUMMARY/ABSTRACT

The Piper Alpha catastrophe in 1988 revealed the potential of operational failures with respect to dramatically destroying an entire offshore installation. When a severe hydrocarbon leak occurred due to operational oversights, other safety barriers collapsed mainly due to lack of a prudent safety culture.

Statistics for the Norwegian offshore industry show that each year there are about 5-6 hydrocarbon leaks at least the size of that kicking off the Piper Alpha sequence of events, the majority of these leaks have operational causes. The challenge with operational failures is that when leaks occur in such circumstances, other barriers may also fail due to common cause factors, as in the Piper Alpha case.

Accident investigations are often weak when it comes to analysis of root causes and common mode failures. In order to provide improved understanding of the operational failures that cause leaks, a set of incident reports have been analyzed in order to identify the common patterns in hydrocarbon leaks due to operational failures. Other scenarios where failures of operational barriers are dominating contributions are falling objects from cranes, as well as failure of station-keeping by large tankers in attendant mode. The former has been the dominating scenario for fatal accidents on Norwegian offshore installations for several years, whereas the latter is a potential scenario for extreme collision cases, where so far only near-misses have occurred. There are usually a number of redundant barriers against major accidents with technical causes on offshore installations, giving low risk values. With operational causes, there are significantly fewer redundant barriers, thus increasing the risk levels.

Of 40 incident reports and investigations, only six allowed a detailed analysis of barrier performance. It was shown that what was supposed to be four barriers for each scenario was reduced to only one barrier (the execution of the work itself) in five out of six cases, and two barriers in one case. The work execution failed in all cases, and this was the only effective barrier in five out of the six cases.

Also an analysis of a near-miss is presented, where it was shown that six operational barrier elements in sequence failed, and the seventh barrier element performed well in identifying the failure to conduct work in accordance with procedures (the initial barrier failure).

The analysis has demonstrated clearly that the simple barrier block diagram is useful in order to demonstrate performance of operational barriers in incidents and near-misses. The analysis has also demonstrated how hydrocarbon leaks are caused due to single failures in many cases, where it was supposed to be three or four barrier elements.

BACKGROUND AND INTRODUCTION

The Piper Alpha catastrophe in 1988 revealed the potential to cause a sequence of events resulting in destroying an entire installation. Statistics for the Norwegian offshore industry show that each year there are about 5-6 hydrocarbon leaks at least the size of that kicking off the sequence of events in the Piper Alpha accident, the majority of these leaks have operational causes. The challenge with operational failures is that when leaks occur in such circumstances, other barriers may also fail due to common cause factors, as in the Piper Alpha case. This is the topic of the BORA project [1].

Accident investigations are often weak when it comes to analysis of root causes and common mode failures. In order to provide improved understanding of the operational failures that cause leaks, a set of incident reports have been analyzed in order to identify the common patterns in hydrocarbon leaks due to operational failures.

Other scenarios where failures of operational barriers are dominating contributions are falling objects from cranes, as well as failure of station-keeping by large tankers in attendant mode. The former has been the dominating scenario for fatal accidents on Norwegian offshore installations for several years, whereas the latter is a potential scenario for extreme collision cases, where so far only near-misses have occurred.

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Previous Studies of Leaks

The first study of hydrocarbon leaks in the BORA project was the study aimed at classifying leaks in categories and outlining generic barrier models (Barrier Block Diagrams), see [2]. The study presented in this paper builds on [2], in order to identify performance of operational barriers against loss of containment, based on investigations into leak incidents.

There are a number of previous studies that have looked at causes of hydrocarbon leaks. The annual RNNS report gives an overview of leaks, but not causes of leaks. Some selected studies are [3], [4], [5], [6], [7].

None of these studies have looked particularly at the performance of barriers in operational situations. The present study should therefore be a supplement to existing studies.

OVERVIEW OF DATA BASIS

For the purpose of analysis in the BORA project, about 40 reports from hydrocarbon leaks in the process systems of Norwegian offshore installations were submitted, from the period 2001 through 2003. An overview of these reports is presented (in Norwegian) in [2]. The investigation reports supplied to the BORA project have been extended with some other investigation reports, from the period 2000-2004. An overview of the investigation reports is presented in the following, in an anonymous manner, see Table 1.

PSA has performed detailed MTO (Man, Technology, Organization) analysis of a number of HC leaks, based on investigation reports, supplemented with additional investigation and meetings with the organisation in question, where required. The main difference between the work done by PSA and the operators is that the MTO-investigations performed by (for) PSA have focused on following the trail of the events ‘back in time’ with respect to the life of the installation, into planning of work, and (if needed) also into the design phase for the facilities. The results of these investigations have been made available for inclusion in this report.

CLASSIFICATION SCHEMES FOR OPERATIONAL CAUSES

The following classification of MTO causes has been received from PSA (Ref. 8) and is used in order to have a classification system which is corresponding to that one used by PSA.

The generic modelling of operational causes of leaks in the BORA project may be illustrated by Figure 1. The diagram in Figure 1 implies that there are the following assurances (‘lines of defence’) against release caused by the maintenance work:

1. Actual operation (i.e. maintenance work) performed without errors
2. Self control according to checklist performed without errors
3. Independent control of work/inspection performed without errors
4. Leak test performed without errors

Table 1 Overview of incidents included in the detailed analysis

Release scenario according to [2]	Number of cases
1. Release during maintenance of HC-system (requiring disassembling)	
a. Release due to failure prior to or during disassembling of HC-system	4
b. Release due to break-down of isolation system during maintenance	
2. Release due to latent failure introduced during maintenance	
a. Release due to incorrect fitting of flanges or bolts during maintenance	9
b. Release due to valve(s) in incorrect position after maintenance	3
c. Release due to erroneous choice or installations of sealing device	2
3. Release due to operational failure during normal production	
a. Release due to maloperation of valve(s) during manual operation	
b. Release due to maloperation of temporary hoses.	
c. Release due to lack of water in water locks in the drain system	1
4. Release due to technical/physical failures	
a. Release due to degradation of valve sealing	3
b. Release due to degradation of flange gasket	
c. Release due to loss of bolt tensioning	
d. Release due to degradation of welded pipes	1
e. Release due to internal corrosion	1
f. Release due to external corrosion	
g. Release due to erosion	
5. Release due to process upsets	
a. Release due to overpressure	
b. Release due to overflow / overfilling	2
6. Release due to external events	
a. Release due to impact from falling object	
b. Release due to impact from bumping/collision	
7. Release due to design related failures	

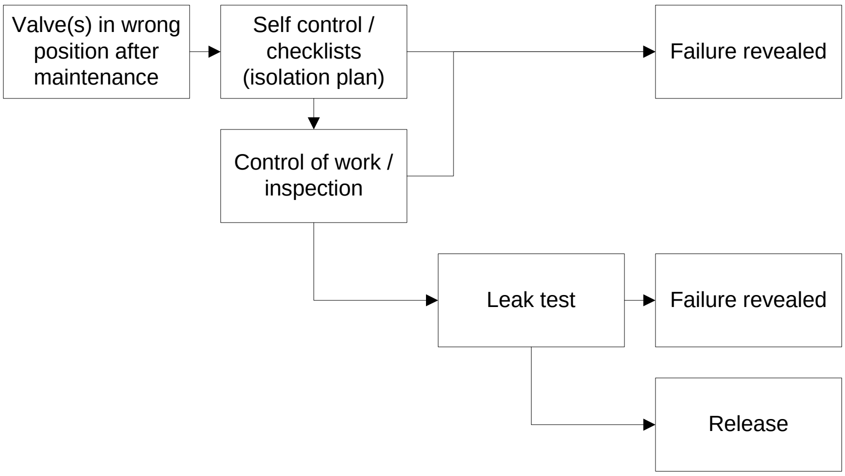

Figure 1 Barrier Block Diagram for leaks due to valves in wrong position after maintenance

The two first barrier elements are strongly correlated as they are performed by the same person(s). The third barrier element is less strongly correlated, as it should be performed by other personnel, such as area responsible technician or corresponding personnel. The leak test may or may not be performed by the maintenance personnel, and this barrier element may accordingly be more or less correlated.

BBDs are presented in [2] for a number of leak scenarios relating to different activities and operations. When the BBDs in [2] are reviewed, it is found that most of these diagrams are similar to the BBD shown in Figure 1, in the sense that there are 3-4 lines of defence, consisting of partly correlated barrier elements, involving the personnel that perform the operation and other personnel to some extent. An overview of the number of lines of defense is presented below for Leak scenario categories 2-5:

- 4 lines of defense are available in 4 of the 15 scenarios
- 3 lines of defense are available in 4 of the 15 scenarios
- 2 lines of defense are available in 6 of the 15 scenarios
- 1 line of defense is available in 1 of the 15 scenarios

These lines of defense are available if industry practice procedures are adhered to. The determining factor is therefore to what extent procedures and work practices are adhered to in practice. This is considered in detail below, based upon the investigation reports. If only the manually initiated leaks are considered, there is a clear dominance of multiple (3 or 4) lines of defense:

- 4 lines of defense are available in 4 of the 6 scenarios
- 3 lines of defense are available in 1 of the 6 scenarios
- 1 line of defense is available in 1 of the 6 scenarios

It may be noted that all the subcategories of Category 2, 'Release due to latent failure introduced during maintenance' have 4 lines of defense. It may on the other hand be argued that there are only 3 barrier elements involved, due to the strong correlation it will be between the operator executing the work without errors and his/hers self control of the work.

The actual number of leaks for which there are investigation reports available, is 26 leaks, see Table 1, out of the 40 leaks in total. 15 of the 26 investigations belong to Categories 2 and 3.

ANALYSIS AND DISCUSSION

Operational Barriers

The overview of lines of defence showed that 4 lines of defence were considered to be available in the modelling, for all scenarios belonging to Category 2, further that 2 of the 3 scenarios in Category 3 had at least 3 lines of defence. It may therefore appear according to the generic models that there are several lines of defence against hydrocarbon leaks, also in case of operational activities. But this may not be quite as obvious, when the investigations of the leaks are considered in detail.

First of all it should be noted that when leaks occur, one of the preconditions is that lines of defence (or barriers) will have failed. The leaks would not occur unless several barriers failed; multiple failures are the norm for these cases. But there is some important experience when we look at the way these leaks occurred.

Table 2 presents a summary of the cases where it was possible to determine which barriers that worked and which failed. This was possible in 6 out of the 15 cases. It should be noted that it was far from obvious even in these 6 cases what barriers that had functioned, and which that either failed or were not used. Some assumptions therefore had to be made, based on interpretations of the investigations. The observations that may be made based on Table 2 are discussed in the following subsections.

Work execution has obviously failed in all cases where leaks have occurred; otherwise the leaks would have been prevented. The next line of defence is the self control, although it can not be expected to be completely independent. A brief summary of the observations that may be made from Table 2 is as follows:

- Self control failed in 1 out of 6 cases
- Self control not done in 5 out of 6 cases

Again, if self control has been applied successfully, the leak would not occur, and there would be no incident to analyse. Due to the data in Table 2 however, there are reasons to believe that self control is not as commonly performed as would be expected. If it was commonly performed, it would be expected that the majority of leaks would be characterised by failure of self control, rather than 'not carried out' (or there would be less incidents).

The control of the work referred to here, is independent control by Area Technician, by CCR personnel, Supervisor or similar. In several of the cases, it has been bluntly stated that independent control is usually not carried out in the actual circumstances. As such, the following observation has been made:

- Control of work not carried out in 6 out of 6 cases

If the independent control had been carried out successfully, the leak would not occur, and there would be no incident to analyse. Due to the data in Table 2 however, there are reasons to believe that independent control is not as commonly performed as would be expected. If it was commonly performed, it would be expected that the majority of leaks would be characterised by failure of independent control, rather than ‘not carried out’ (or there would be less incidents).

Table 2 Summary of operational barrier status

Scenario description	Barriers			
	1. Error free work execution	**2. Self control**	**3. Control of work**	**4. Leak test**
Gasket in flow transmitter blown out due to missing bolts	Forgotten to install all bolts	Failed	Indications are that no control was carried out	Not carried out
Bolts on flange not tightened up	Wrong tables used Valve in wrong position	Stated as insufficient, i.e. most likely not done	No information stated that this was done	Not done
Leak from instrument connection during calibration	Procedure deliberately not followed	Obviously not performed	Area technician unaware of work task	Not done
Leak from flange against valve	Incorrect flange tightening	Obviously not performed	Area technician unaware of work task	Not done
3 ways valves left in wrong position after PM	Valve in wrong position	No indication that this was carried out	CCR did not carry out	Not applicable
2 valves left in open position after PM	Insufficient job preparations stated	Did not carry out	Did not carry out	Did not carry out

Figure 2 presents the main path of failures in the cases discussed above, as 5 of the 6 cases follow exactly the path shown in Figure 2. This implies that none of the checks that constitute the additional barriers were carried out.

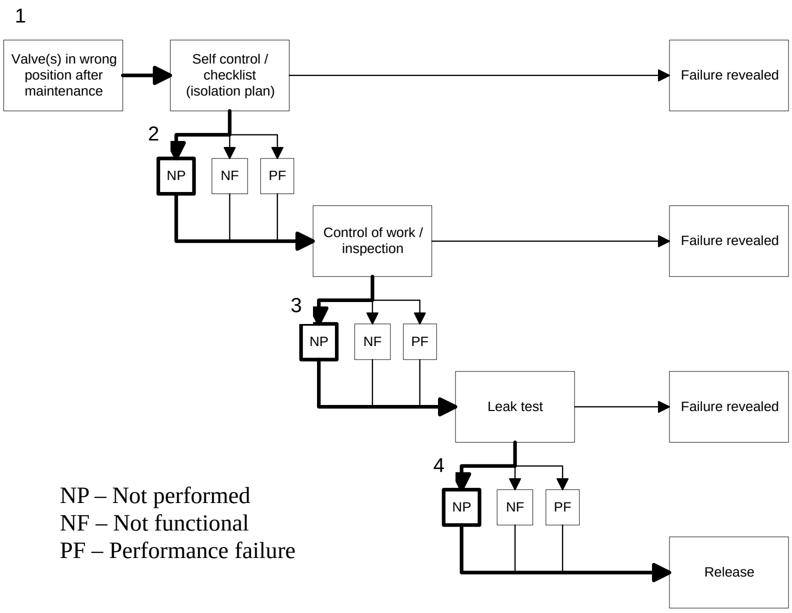

Figure 2 Summary of main combination of barrier failure causes

With respect to leak testing, the following are the observations from Table 2:

- Not applicable in 1 out of 6 cases
- Not carried out in 5 out of 6 cases

It would be expected that leak test is not practicable in all circumstances. But again, the suspicion is that leak test is carried out less frequently than what is expected.

Operational Barriers relating to Near-Miss

Figure 3 presents a Barrier Block Diagram for a near-miss gas leak, based on an extensive MTO analysis of the event, [9]. The incident does not quite fit the in task categories, but is nearest Category 1a; “Release due to failure prior to or during disassembling of HC-system”. The MTO analysis is special, because it applies to a near-miss, i.e. where one of the barriers has stopped the event from developing into a leak. The Barrier Block Diagram in Figure 3 has been based on the BBD for Category 1a in [2].

The thick lines in Figure 3 show the development of the incident, and demonstrate the performance of the different operational barriers:

- Barrier 1: Job leader when preparing WP: Successful
- Barrier 2: Review by safety coordinator in evening meeting: Successful, but redundant
- Barrier 3: Work execution by mechanics: Failed
- Barrier 4: Self check by mechanics: Failed
- Barrier 5: Job leader’s control of work: Failed
- Barrier 6: Area responsible technician’s control of work: Failed
- Barrier 7: Supervisor’s control of work: Successful in stopping the erroneous operation

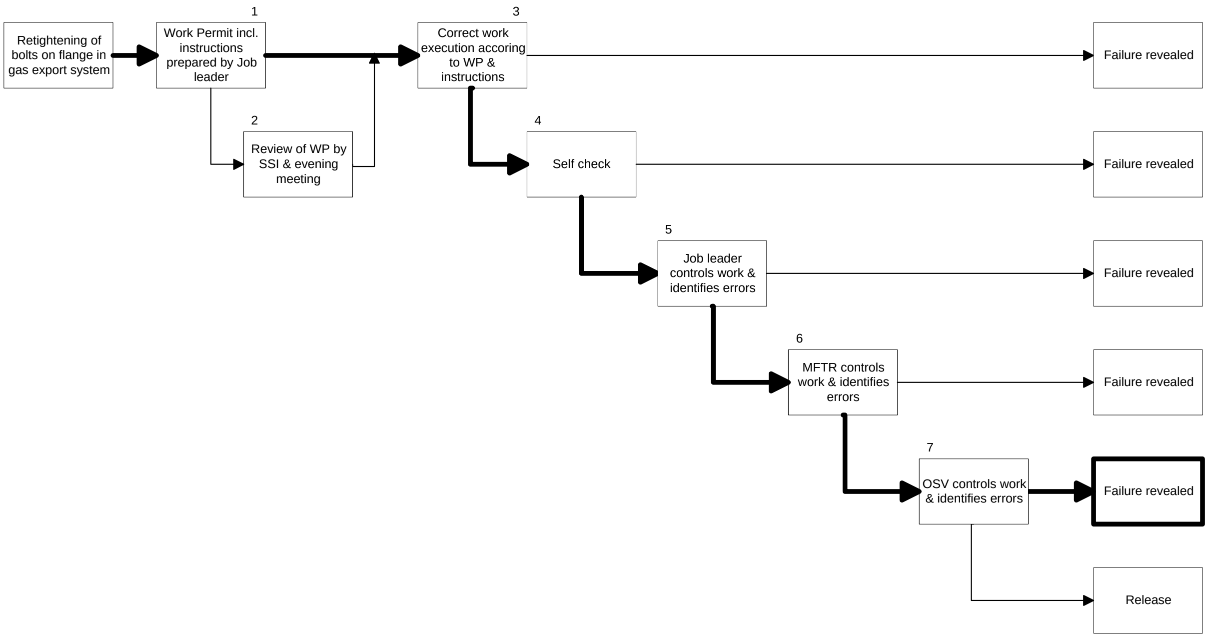

Figure 3 Barrier Block Diagram for near miss leak during ’Hot bolting’

The work was supposed to be conducted by a team of mechanics. The team actually consisted of plumbers (see further discussion below), and the team failed in several respects:

- They did not find the correct tools, and deliberately chose to carry out the operation with wrong tools without consulting with or informing job leader
- Even with the wrong tool did not follow accepted work practice
- Do not perform self check or reflect on the work practice they are using
- Continued to carry out the work in conflict with WP and accepted work practice for several hours (past lunch break), without informing anybody.

The management and supervision also failed in several respects:

- Job leader did not initially follow up the work in progress, as requested according to procedure
- Area responsible did not initially follow up the work in progress, as requested according to procedure
- Even when job leader after some time was notified that the wrong tool was being used, he did follow up the work performed by the mechanics.

The barrier element that succeeded in preventing the possible development of a serious event was an operations supervisor who performed a survey of work in progress. He realised that wrong tools and method were being used, and decided to stop the work in progress.

The investigation was thorough and did reveal the root causes for the near-miss. Some of the root causes that were revealed are as follows:

- Correct tool for the job had been ordered from shore, but not arrived in time
- Mechanics were contractor personnel, contractor had supplied not a team of mechanics, but plumbers, suitable for other planned work tasks
- Job leader had from onshore management been told to perform administrative work outside his responsibilities that had taken up all his time and prevented him from performing his normal duties.

The analysis of this incident shows again that self checking as a barrier has limited effect, due to its dependence on the personnel carrying out the work are able to realise that there is a need for self checks. The following is a summary of causes for failure of barriers:

- Barrier 3: Work execution by mechanics — Failed due to lack of competence and diligence
- Barrier 4: Self check by mechanics — Failed due to lack of competence and diligence
- Barrier 5: Job leader’s control of work — Did not carry out, due to absorption by other duties
- Barrier 6: Area responsible’s control of work — Did not carry out, due to unknown reasons.

Also the omission to follow procedures with respect to independent controls is clearly demonstrated, out of 3 persons who independently should check the work, only the highest level management performed the control and detected the wrong work execution.

MTO Causes – Hydrocarbon Leaks

The following is a summary of MTO causes that have been found explicitly and implicitly from the investigations. It should be stressed that the root causes that have been identified are quite dependent on what the investigation reports have identified, and sometimes these have obvious shortfalls in terms of taking a broad view of root causes. The root causes are therefore much more limited in scope compared to the MTO investigations performed by PSA.

- Inadequate work preparation
- Inadequate technical solution
- Insufficient handover/communication
- Not updated instructions/procedures
- Work practice deviating from instructions/procedures
- Inadequate self control.

The main category which has the highest number of marks, is the group ‘J’, relating to individual work practice. The 3 groups with the highest marks are:

- Work organisation
- Ergonomics/technical solution
- Work practice/individual factors.

Figure 4 presents a comparison of the main causes identified by the company investigations and the MTO analysis performed by PSA.

It should first of all be noted that the data sets are quite small, 7 incidents where the root causes could be readily identified from company investigation reports. The PSA incidents are 14. There is actually quite good correlation between the two data sets, with some exceptions. The exceptions are related to:

- Supervision
- Communication
- Company/platform management
- Change management.

It is not surprising that company investigations fail to identify causes relating to management system failure. It is often doubtful if an investigation team has sufficient independence and authority in order to identify failures or shortfalls of the management system.

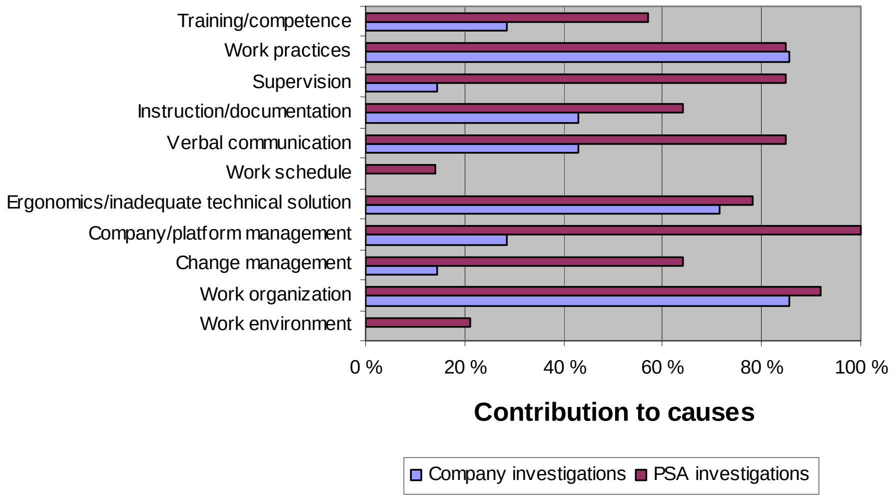

Figure 4 Summary of company investigations versus PSA MTO investigations

CONCLUSIONS AND RECOMMENDATIONS

The analysis has demonstrated how the simple barrier block diagrams as exemplified by Figure 1 and Figure 2 may be used in relation to illustration of operational failures in incidents and near-misses. These diagrams are considered to be very useful in order to demonstrate performance of operational barriers. The following failures of operational barriers are considered; not performed, not functional or performance failure.

There are indications [7] that more leaks in Norwegian offshore operations are caused by operational errors, compared to other relevant operations, such as in the UK offshore operations. It is therefore essential to have approaches that can put some focus on these aspects. The worrying observation which may be observed from the incidents reported in this paper is that operational barriers are not carried out at all ('not performed') in the majority of the cases.

This implies that whereas there is a requirement to have multiple barriers ('defense in depth'), the failure to use several of these barrier elements implies that in many cases there is only one active barrier element in function. The operations where this is the case are actually not according to the regulatory requirements. Further, the status of these barriers is not known, which also is a regulatory requirement.

The focus on operational barriers is in addition to the focus on operational errors and deviations which often are the focus in MTO investigations. The MTO investigations often focus on errors, deviations and failure of barrier elements one by one, without putting them into context. This is what can be achieved by using the barrier block diagrams in addition to the MTO investigations.

ACKNOWLEDGMENTS

The project is financed by the Research Council of Norway, Health and Safety Executive and OLF (Norwegian Oil Industry Association), whose contributions are gratefully acknowledged. Also the input of oil companies participating in the case studies is recognized as valuable contributions.

ABBREVIATIONS

BORA	Barrier and Operational Risk Analysis
HC	Hydrocarbon
MTO	Man, Technology and Organization
NCS	Norwegian Continental Shelf
PSA	The Petroleum Safety Authority [Norway]
RNNS	Risk Level Project [by PSA]

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