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Abstract

Investigation of several accidents or near-misses in recent years has shown that there often is a clear causal relationship between a lack of control of the barriers and the final consequences of individual events on hydrocarbon-producing installations offshore.

Companies with operator status or the party responsible for operation often show a lack of understanding of the barrier's position in a risk management system. This applies particularly to the small and new operators, which in the recent years has started operation on the Norwegian continental shelf. The lack of understanding of the barriers significance and how these interacts with the risk level for a system or an installation often results in a maintenance or testing regime below what would be required to maintain the requested functionality and reliability.

This master’s thesis main purpose is to present the most important elements in a barrier management system for an offshore installation, through its lifetime. To clarify the various element, the suggestion for a method of establishment of a management system is split into four levels and presented one level at a time. The suggested system is developed based on experience from offshore installations, but can also be used for all other areas where barriers are installed to counteract the effects or further development of events.

Chapter 2 is dedicated to present the different underlying elements connected to a complete barrier management system. Relevant sections from the PSA regulations and underlying standards are presented. Some of the most relevant sections in the different regulations are reproduced in its entirety to make it more convenient for the reader. These regulations are later referred to in the report. Then the chapter presents theory about barriers and barrier management and explains terms such as barriers, barrier elements, and the correlation between barrier- functions and barrier systems before the chapter ends with an introduction to what a barrier management system is.

Chapter 3 presents, as mentioned, a barrier management system divided in to four levels. The system starts with a simple test- and maintenance program at Level 1, which in Level 2 is expanded by establishing a list of barriers, identifying safety critical elements and establishment of the barriers performance acceptance criteria. Level 3 introduce an extended test regime into the management system, and in Level 4 a management systems administrative part is implemented.

Preface

This master thesis is part of the master's degree study at the University of Stavanger. It is a time limited assignment and it constitutes 30 credits in the field of risk management with a specialization in offshore safety. The aim is that the student shall develop an independent work, based on the multidisciplinary competence gained through the study.

The thesis presents a barrier management system and the most important elements of such a system. It also describes how and why barrier management system is important to implement into the organization.

Working with this thesis has been challenging, and very interesting. Through my work with this thesis I have learned more about the big picture of safety work and barrier management, from the regulations set by the PSA down to systems ensuring the safety for personnel onboard offshore installations on the Norwegian continental shelf.

I sincerely wish to thank my company Xafe AS and my supervisor Ørjan Stien for all the help and support I have received during the work on this thesis. I also want to express my gratitude for the opportunity to write this thesis partly during my normal working hours.

I would also thank my internal supervisor at UIS, Erik B. Abrahamsen for good help and guidance.

Stavanger, June 13, 2012

Espen Røssland

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1 Introduction

1.1 Background

Investigation of several accidents or near-misses in recent years has shown that there often is a clear causal relationship between a lack of control of the barriers and the final consequences of individual events in connection with hydrocarbon-producing installations offshore.
Although some reports show that both the operational and organizational barriers are often broken, it turns out that management of technical barriers is one of the most difficult problems faced by operators. This applies particularly to the small and new operators, which in the recent years has started operation on the Norwegian continental shelf. This may be caused by a lack of operational experience and not having sufficient capacity or expertise in the area.

In oil and gas activities on the Norwegian continental shelf, barriers to avoid or mitigate the effects of accidents are well-known. Most systems on offshore installations have barriers to prevent, reduce or eliminate the risk associated with events that may occur. The authorities through the PSA have in recent years had a strong focus on barriers, and the technical condition of these. This focus is still there, and there has been given no indication that their emphasis of the importance of barrier control is going to be relaxed.

Studies/experience have shown that even if the barriers are implemented in the design, inadequate control / knowledge of or follow-up of the barriers over time, will reduce the risk reducing effect the barriers are intended to have.

Maintaining a low risk level depends on the barriers meeting the requirements set for reliability and functionality. This can be performed by having a system for monitoring the barriers to ensure always having an overview of the status, and where measures must be taken, to improve the situation.
The major oil companies, both domestic and international with long experience in oil and gas producing activities, often already have systems established that largely cover the issues described in this report. Such systems have been established over time as companies have increased their understanding of its importance. Statoil and ConocoPhillips in Norway are examples of companies that have established such systems. Although the methods and systems the two different companies have developed are significantly different from each other, the target objective is the same. Smaller companies may not have the same resources or expertise and therefore have not yet identified the need, or solution to cope with these issues.

This report describes the most important elements in a barrier management system for an offshore installation, through its lifetime. The suggested system is developed based on experience from offshore installations, but can also be used for all other areas where barriers are installed to counteract the effects of events. One example is computers and their antivirus programs. To keep up with the developments on new viruses, faster software etc. the antivirus program have to be updated accordingly in order to serve as the barrier it was when it was new. Another example is inspired by the note: *Prinsipper for barrierestyring i petroleumsvirksomheten* published by PSA[1]. A fence must maintain the intrinsic function over time. It is naive to believe that a fence will stay intact in infinite future, unless provision is made for inspecting and maintaining it regularly, and there is set aside time and resources to repair holes and damage when they are discovered. It does not help that the fence was "state of the art" when it was new if someone have subsequently kicked or cut holes in it.

The basic point in these examples is that one need to maintain the barriers over time in order to be able to trust them. Another important point is that one has to have a good reporting system to report back if one barrier element fails to carry out its function.

1.2 Problem description

As mentioned initially, barriers and especially the technical ones have a major focus from the PSA. In spite of this focus, companies with operator status or the party responsible for operation often show a lack of understanding of the barrier's position in a risk management system. The problem has been highlighted as one of more root causes through investigation of several accident or near-misses. The lack of understanding of the barriers significance and how these interacts with the risk level for a system or an installation often results in a maintenance or testing regime below what would be required to maintain the requested functionality and reliability.

One of the causes for the lack of focus and understanding from the operators may be that this relation is not documented well enough through specific requirements, and that proposed methods of goal achievement has not been established by the authorities; hence the companies fails to establish adequate systems as there are no good descriptions of what such systems should contain and how they are supposed to be used.

1.3 Purpose

The main objective for this thesis is to describe how and why a barrier management system should be implemented into the organization. As described in chapter 1.1, implementing a barrier system does not provide certainty that the risk reduction requested is provided for all eternity without maintaining the barrier system and by doing so keeping the reliability of the barrier system within the required range. But maintenance of a barrier system will only ensure that the barrier system reliability is as high as the maintenance is able to take it. The resulting reliability after maintenance with an associated risk reduction might not be sufficient after a few years of service and degradation.

And how do we make sure that we are maintaining the correct functionality of the various systems? The functionality of an ESD shutdown valve is most often only thought of as being able to close, and the vendors implement testing facilities and suggest a maintenance scope to test and maintain this functionality. But other properties of the component or system might be neglected, even if the risk reduction relies on these. For the ESD shutdown valve example, the internal leak of such valves, might be equally important, and should then also be implemented in testing and maintenance procedures. A proper barrier management system would ensure this property to be identified and followed up through the maintenance system.

Time is also of essence in this matter. If we for a second neglect the fact that systems do degrade, we still have to take into consideration that modifications to the installation might change the requirements on the barriers. New regulatory requirements may also be implemented and given effect. And the selected components or systems implemented may be outdated as new technology evolves.

The first step towards a complete barrier management system is to establish a transient barrier control system that continuously monitor the state of the barriers, and by such enabling correct decisions to be made based on the knowledge of the barrier situation.

The next steps would include input from updated risk analysis, regulatory requirements and company best practices. By verifying the implemented systems against these documents, any gaps could be revealed.

Changes in results from standard tests at the normal test intervals may also indicate if a barrier is going to be degraded beyond acceptable limits in a foreseeable future. Trending these results, and in advance preparing for upcoming, more comprehensive maintenance scopes may prevent a situation where an operator has to choose between continued operation with a faulty barrier, or shutting down due to the risk being too high.

These are some examples of elements that should be included when establishing a barrier management system. The objective of this report is to give a complete overview of the most important elements, and to put these elements into a system which may easily be implemented in any company.

1.4 Limitations

The main focus of this thesis is the use of the barrier concept within industrial safety, and especially prevention of the escalation of hazards that may lead to major accidents. Thus, occupational accidents are not a part of the scope of this thesis.

1.5 Abbreviations

ALARP	As Low As Reasonable Practical
BAT	Best Available Technology
CEN	European Committee for Standardization (Comitè Europèen de Normalisation)
EN	European Standard (European Norm)
ESD	Emergency Shut Down
FAR	Fatal Accident Rate
ISO	International Organization for Standardization
NCS	Norwegian Continental Shelf
NPD	Norwegian petroleum directorate
OLF	The Norwegian Oil Industry Association (Oljeindustriens landsforening)
OREDA	Offshore REliability DAta
PSA	Petroleum Safety Authorities
QRA	Quantitative Risk Analysis
SCE	Safety Critical Elements

1.6 Report structure

This master's thesis is divided in to 6 chapters. This section gives a brief introduction to the different chapters of the report.

1.6.1 Introduction

The introduction contains background, problem description, purpose, limitations, abbreviations and report structure as topic headings.

1.6.2 Requirements and theory

The purpose of this chapter is to give the reader an introduction to the theory behind the subjects presented. Based on this chapter the reader should gain enough background information to understand the subsequent argumentation in the following chapters. First the PSA regulations and relevant standards are presented. Some of the most relevant sections in the different regulations is reproduced in its entirety to make it more convenient for the reader, these regulations is later referred to in the report. Then the chapter covers theory about barriers and barrier management and explains terms such as barriers, barrier elements, and the correlation between barrier- functions and systems before the chapter finishes with an introduction to what a barrier management system is.

1.6.3 Barrier management

This chapter presents a way of organizing a barrier management system. A logical "level by level" approach is being used to introduce the different elements needed to form a barrier management system.

1.6.4 Discussion

The discussion starts with a recap of the key elements and main advantages of barrier management. It continues with a discussion regarding different elements in the system.

1.6.5 Conclusion

In this chapter some of the arguments for implementation of a barrier management system have been brought together, and a conclusion/recommendation has been made.

1.6.6 References

An overview of sources used and refereed to when writing the report is presented. The references are presented chronological and are marked as following in the report: [1],[2],[3]...etc.

1.7 Terms and Definitions

The following definitions are gathered from NORSOK Z-013[2]

1.7.1 ALARP - as low as reasonably practicable

ALARP expresses that the risk shall be reduced to a level that is as low as reasonably practicable

NOTE 1 ALARP expresses that the risk is reduced (through a documented and systematic process) so far that it is not justifiable to implement any additional risk reducing measures.

NOTE 2 The term reasonably practicable implies that risk reducing measures shall be implemented until the cost (in a wide sense, including time, capital costs or other resources/assets) of further risk reduction is grossly disproportional to the potential risk reducing effect achieved by implementing any additional measure.

1.7.2 DAE - dimensioning accidental event

Accidental events that serve as the basis for layout, dimensioning and use of installations and the activity at large.

1.7.3 DAL - dimensioning accidental load

Most severe accidental load that the function or system shall be able to withstand during a required period of time, in order to meet the defined risk acceptance criteria

NOTE 1 DAL is normally defined based on DAE.

NOTE 2 The dimensioning accidental load (DAL) are typically generated as a part of a risk assessment, while the design accidental load may be based on additional assessments and considerations.

NOTE 3 The dimensioning accidental load (DAL) are typically established as the load that occurs with an annual probability of $1x10^{-4}$.

1.7.4 RAC - risk acceptance criteria

Criteria that are used to express a risk level that is considered as the upper limit for the activity in question to be tolerable

NOTE RAC are used in relation to risk analysis and express the level of risk tolerable for the activity, and is the starting point for further risk reduction according to the ALARP-principle, see also 3.1.2. Risk acceptance criteria may be qualitative or quantitative.

2 Requirements and theory

This chapter presents relevant regulations and theory prevailing for the subjects discussed in this report. First the PSA regulations are presented. Some of the most relevant sections in the different regulations is reproduced in its entirety to make it more convenient for the reader, these regulations is later referred to in the report. Second, the most relevant standards are presented. Then there is a brief section on company requirements before the chapter goes in to theory about barriers and barrier management.

2.1 PSA Regulations

The PSA has the regulatory responsibility for safety, emergency preparedness and working environment on the NCS, and the petroleum related plants and associated pipeline systems. It is subordinate to the Ministry of Labour[1]. Before January 1st 2004 when the PSA was established, it was the NPD's responsibility, which reports to the Ministry of Petroleum and Energy[2][3].

The PSA is the regulator for technical and operational safety, including emergency preparedness, and for the working environment in all phases of the petroleum activity - such as planning, design, construction, use and possible later removal[3].

Authority has been delegated to the PSA by the Ministry to issue more detailed regulations for safety and the working environment in the industry, and to take specific decisions in the form of permits and consents, orders, enforcement fines, halting operations, prohibitions, dispensations and so forth[3].

Further the PSA is responsible for developing and enforcing regulations which govern safety and working environment in the petroleum activities on the NCS and associated land facilities.

The regulations assume that the activities maintain prudent health, environmental and safety standards. They are developed to be a good tool for the industry and for the authorities' supervision.

The regulations contain a large degree of functional requirements where standards and norms specify the regulations' level of prudence[3]. Figure 2-1 underneath shows the Norwegian regulatory hierarchy.

[1] Arbeidsdepartementet
[2] Olje- og Energidepartementet

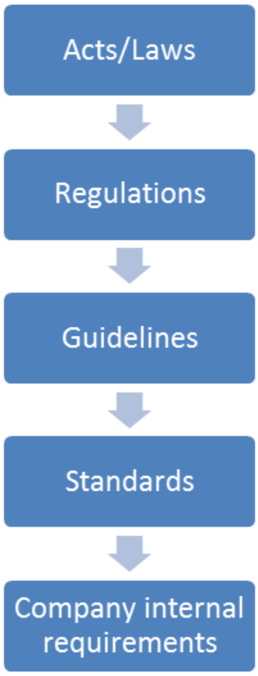

Figure 2-1 Norwegian regulatory hierarchy

The PSA shall stipulate premises and follow up to ensure that the players in the petroleum activities maintain high standards of health, environment, safety and emergency preparedness, and thereby also contribute to creating the greatest possible value for society. As part of this responsibility the PSA issues and enforce regulations[3]. Underneath the most relevant PSA regulations is presented and explained briefly and under each regulation the most relevant sections in the different regulations is presented.

2.1.1 The Framework Regulations

The Framework Regulations[4] are a high level regulation, and contains the overall principles given by the PSA. It forms a basis for the regulations, whereas the other regulations go more in to detail of the issues mentioned in The Framework Regulations.

Most relevant from The Framework Regulations is Section 11 *Risk reduction principles*. It contains the requirements which can be interpreted into the *As Low As Reasonable Practical* (ALARP) principle and use of *Best Available Technology* (BAT).

> *Section 11*
>
> *Risk reduction principles*
>
> *Harm or danger of harm to people, the environment or material assets shall be prevented or limited in accordance with the health, safety and environment legislation, including internal requirements and acceptance criteria that are of significance for complying with requirements in this legislation. In addition, the risk shall be further reduced to the extent possible.*
>
> *In reducing the risk, the responsible party shall choose the technical, operational or organizational solutions that, according to an individual and overall evaluation of the potential harm and present and future use, offer the best results, provided the costs are not significantly disproportionate to the risk reduction achieved.*
>
> *If there is insufficient knowledge concerning the effects that the use of technical, operational or organizational solutions can have on health, safety or the environment, solutions that will reduce this uncertainty, shall be chosen.*
>
> *Factors that could cause harm or disadvantage to people, the environment or material assets in the petroleum activities, shall be replaced by factors that, in an overall assessment, have less potential for harm or disadvantage.*
>
> *Assessments as mentioned in this section, shall be carried out during all phases of the petroleum activities.*
>
> *This provision does not apply to the onshore facilities' management of the external environment.*

2.1.2 The Management Regulations

The Management Regulations[5] describes the requirements related to management of offshore installations. The most relevant sections here regarding barrier management are sections 5 and 9. Section 5, called *barriers*, states why barriers shall be established. Further it points out the operator's responsibility to establish and maintain barriers. The regulation also states that the operator is responsible for implementing compensating measures when a barrier is missing or impaired.

The requirement related to barriers and barrier control is stated in The Management Regulations Section 5:

> *Section 5*
>
> *Barriers*
>
> *Barriers shall be established that:*
>
> *a) reduce the probability of failures and hazard and accident situations developing,*
>
> *b) limit possible harm and disadvantages.*
>
> *Where more than one barrier is necessary, there shall be sufficient independence between barriers.*
>
> *The operator or the party responsible for operation of an offshore or onshore facility, shall stipulate the strategies and principles that form the basis for design, use and maintenance of barriers, so that the barriers' function is safeguarded throughout the offshore or onshore facility's life.*
>
> *Personnel shall be aware of what barriers have been established and which function they are intended to fulfil, as well as what performance requirements have been defined in respect of the technical, operational or organisational elements necessary for the individual barrier to be effective.*
>
> *Personnel shall be aware of which barriers are not functioning or have been impaired.*
>
> *The responsible party shall implement the necessary measures to remedy or compensate for missing or impaired barriers.*

According to Section 9 in The Management Regulations, risk acceptance criteria for major accident risk and environmental risk shall be set for the four cases mentioned underneath. Criteria *a* and *b,* which is the most relevant for this thesis, are further elaborated in chapter 3.4.

> *Section 9*
>
> *Acceptance criteria for major accident risk and environmental risk*
>
> *The operator shall set acceptance criteria for major accident risk and environmental risk. Acceptance criteria shall be set for:*
>
> *a. the personnel on the offshore or onshore facility as a whole, and for personnel groups exposed to particular risk,*
> *b. loss of main safety functions as mentioned in Section 7 of the Facilities Regulations for offshore petroleum activities,*
> *c. acute pollution from the offshore or onshore facility,*
> *d. damage to third party.*

2.1.3 The Facilities Regulations

The Facilities Regulations[6]deals with the design of facilities, and contains more specific requirements for physical barriers in chapter V called *Physical barriers*. In section 7 the *main safety functions* are specified. It is important to know what is meant by main safety functions in relation to the loss of main safety functions citation in section 11.

> *Section 7*
>
> Main safety functions
>
> *A. Preventing escalation of accident situations so that personnel outside the immediate vicinity of the scene of accident, are not injured,*
> *B. Maintaining the main load carrying capacity in load bearing structures until the facility has been evacuated,*
> *C. Protecting rooms of significance to combating accidental events, so that they are operative until the facility has been evacuated,*
> *D. Protecting the facility's safe areas so that they remain intact until the facility has been evacuated,*
> *E. Maintaining at least one evacuation route from every area where personnel may be staying until evacuation to the facility's safe areas and rescue of personnel has been completed.*

Section 11 states that Accidental loads and natural loads with an annual probability greater than or equal to $1x10^{-4}$ shall not result in loss of a main safety function. This requirement is important and forms, among others, the basis for the whole barrier management system. This is further elaborated in chapter 3.4

> *Section 11*
>
> *Loads, load effects and resistance*
>
> *The loads that can affect facilities or parts of facilities, shall be determined. Accidental loads and natural loads with an annual probability greater than or equal to $1x10^{-4}$ shall not result in loss of a main safety function, cf. Section 7. When stipulating loads, the effects of seabed subsidence over, or in connection with the reservoir, shall be considered. Functional and natural loads shall be combined in the most unfavorable manner. Facilities or parts of facilities shall be able to withstand the design loads and probable combinations of these loads at all times.*

The facility Regulations go more in detail on describing the performance for the various physical barriers, section 34 is here presented as an example. It describes the demands for a *process safety system*:

> *Section 34*
>
> *Process safety system*
>
> *Facilities outfitted with or attached to process facilities, shall have a process safety system. The system shall be able to perform the intended functions independently of other systems.*
>
> *The process safety system shall be designed such that it enters or maintains a safe condition if a fault occurs that can prevent the system from functioning.*
>
> *The process safety system shall be designed with two independent levels of safety to protect equipment.*

2.1.4 The Activities Regulations

When it comes to The Activities Regulations[7], the first section worth mentioning is Section 26 *Safety systems*. Here the issues of overbridging or disconnection of safety systems are handled. It also states that the status of all overbridging, disconnections and other weakening of the system shall be known at all times.

> *Section 26*
>
> *Safety systems*
>
> *The measures and restrictions that are necessary in the event of overbridging or disconnection of safety systems or parts of the systems, or when the systems are impaired in some other manner, shall be set in advance.*
>
> *The status of all overbridgings, disconnections and other weakening of the system shall be known at all times.*

The Activities Regulations, chapter IX *Maintenance,* contain a couple of highly relevant sections, such as sections 45 *Maintenance*, 46 *Classifications* and 47 *Maintenance program*. These sections form the foundation of the regulatory requirements for maintenance on the NCS.

Section 45 states that the responsible party is responsible for maintenance of all systems on the facilities, which also includes the barriers.

> *Section 45*
>
> *Maintenance*
>
> *The responsible party shall ensure that facilities or parts thereof are maintained, so that they are capable of carrying out their intended functions in all phases of their lifetime.*

Section 46 addresses classification of facilities' systems regarding the HSE related consequences of potential functional failures. It further states that the responsible party shall identify the various fault modes with associated failure causes and failure mechanisms, and predict the probability of failure for the individual fault mode. And last, the most essential part of this section, stating that the classification shall be used as a basis in choosing maintenance activities and maintenance frequencies, in prioritizing between different maintenance activities and in evaluating the need for spare parts.

> *Section 46*
>
> *Classification*
>
> *Facilities' systems and equipment shall be classified as regards the health, safety and environment consequences of potential functional failures.*
>
> *For functional failures that can lead to serious consequences, the responsible party shall identify the various fault modes with associated failure causes and failure mechanisms, and predict the probability of failure for the individual fault mode.*
>
> *The classification shall be used as a basis in choosing maintenance activities and maintenance frequencies, in prioritizing between different maintenance activities and in evaluating the need for spare parts.*

Section 47 demand that there shall be established a maintenance program preventing all fault modes which constitute an HSE risk. The program shall include activities that ensure that fault modes are identified and corrected, and contain activities for monitoring failure mechanisms that can lead to such fault modes.

> *Section 47*
>
> *Maintenance program*
>
> *Fault modes that constitute a health, safety or environment risk, cf. Section 44, shall be systematically prevented through a maintenance program.*
>
> *This program shall include activities for monitoring performance and technical condition, which ensure identification and correction of fault modes that are under development or have occurred.*
>
> *The program shall also contain activities for monitoring and control of failure mechanisms that can lead to such fault modes.*

It also contains section 85 which is about *Well barriers*. It demands that the well barriers shall be independent, and if a barrier fails, activities shall not be carried out in the well other than those intended to restore the barrier.

> *Section 85*
>
> *Well barriers*
>
> *During drilling and well activities, there shall be tested well barriers with sufficient independence, cf. also Section 48 of the Facilities Regulations.*
>
> *If a barrier fails, activities shall not be carried out in the well other than those intended to restore the barrier. When handing over wells, the barrier status shall be tested, verified and documented.*

2.2 Standards

Even though the requirements states that there shall be a system in place, and to a certain degree describes the functionality required, the detail are often left to standards referred to in the regulations. NORSOK standards or other internationally recognized standards are often used for detailing requirements.

International (developed by ISO) and European standards (developed by CEN), forms the basis for all activities in the petroleum industry. Experts from a wide range of Norwegian companies participate heavily in the development of international and European standards in order to define safe and economical design and processes. However, Norwegian safety framework and climate conditions may require own standards, additions or supplements to International Standards (ISO) and European Standards (EN). The NORSOK standards are developed to fulfill these needs[8].

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for existing and future petroleum industry developments in Norway[8].

The NORSOK standard, *S-001 Technical safety*[9], together with ISO 13702 *Petroleum and natural gas industries — Control and mitigation of fires and explosions on offshore production installations —Requirements and guidelines* [10] are two examples of standards which details the requirements related to implementation of technology and emergency preparedness to establish and maintain an adequate level of safety for personnel, environment and material assets.

The preparation and publication of the NORSOK standards is supported by OLF and Federation of Norwegian Industries. NORSOK standards are managed and issued by Standards Norway[8].

2.3 Company requirements

In addition to the national and international standards, some companies have implemented their own company requirements with a more thorough level of detail or more stringent requirements, often using more specific figures than the national standards.

E.g. Statoil has a range of documents describing recommended practice, and ConocoPhillips details their company requirements through "*Technical controlling documents*".

2.4 Definition of barriers

Barrier: a fence or other obstacle that prevents movement or access[3].

The term safety barriers may be used for everything in range from a single technical unit or human action, to a complex system comprising technical barriers, organizational units and procedures. There are many different definitions of barriers. The PSA uses the following definition to explain a barrier[1]:

"Technical, operational and/or organizational elements that individually or together is to prevent a specific chain of events to occur, or affect it in an intended direction by limiting the damage and/or loss."

There is, as mentioned, numerous of definitions on what a barrier are, and a lot of work has been carried out in this field. The most thorough work and the best definition found during the research for this report was the work of Snorre Sklet. Sklet has in one of his articles in connection with his doctoral thesis tried to sum up the definition and has further come up with the following definition [11]:

"*Safety barriers are defined as physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents. The means may range from a single technical unit or human actions, to a complex socio-technical system. It is useful to distinguish between barrier functions and barrier systems. Barrier functions describe the purpose of safety barriers or what the safety barriers shall do in order to prevent, control, or mitigate undesired events or accidents. Barrier systems describe how a barrier function is realized or executed. If the barrier system is functioning, the barrier function is performed. If a barrier function is performed successfully, it should have a direct and significant effect on the occurrence and/or consequences of an undesired event or accident."*

2.5 The different barrier elements

Safety barriers can be divided in to tree different categories: Organizational, Physical and Operational, as shown in Figure 2-2. The PSA calls it barrier elements, and defines it like this[1]: "*Technical, operational or organizational measures or solutions that are part of the realization of a barrier function*." Examples of organizational barriers can for instance be to clearly define responsible positions for each system or task, or to ensure that the required positions are filled, and with personnel holding relevant and adequate experience. And operational barriers can be procedures or operative restrictions under given conditions. The third main category, physical barriers, can again be divided in to Active and Passive barriers.

---

[3] Oxford Dictionaries

This thesis will focus on the *physical* barriers. The figure underneath is a simple description of how the barriers can be divided into categories including a couple of examples of active and passive physical barriers.

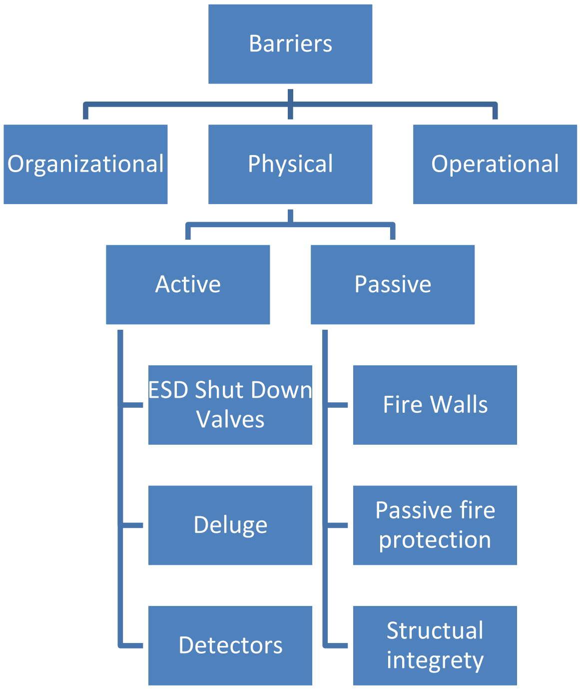

Figure 2-2 Physical barriers

2.6 Correlation between barrier functions and barrier systems

A barrier function is according to Snorre Sklet[11] a function planned to prevent, control, or mitigate undesired events or accidents, whilst a barrier system is a system that has been designed and implemented to perform one or more of the barrier functions.

He further states that barrier functions describe the purpose of safety barriers or what the safety barriers shall do in order to prevent, control, or mitigate undesired events or accidents. If a barrier function is performed successfully, it should have a direct and significant effect on the occurrence and/or consequences of an undesired event or accident. Like "*prevent leaks*" is a function of the process valve system. E.g. by closing the inlet to a vessel on high pressure or high level in the vessel, the upstream system is prevented from overfilling or over pressurizing the vessel, hence the likelihood of a leak is reduced.

A barrier system describes how a barrier function is realized or executed. If the sufficient number of barrier systems is functioning, the barrier function is performed. A barrier system may have several barrier functions. In some cases, there may also be several barrier systems necessary to carry out a barrier function, and based on experience the number of barrier systems covering each function is often exceeding the required figures. Se Figure 2-3 below. A barrier element is a component or a subsystem of a barrier system that by itself is not sufficient, to perform a barrier function. In the figure below the barrier functions is illustrated by 5 boxes. Underneath each function box is the boxes showing the barrier systems carrying out the functions.

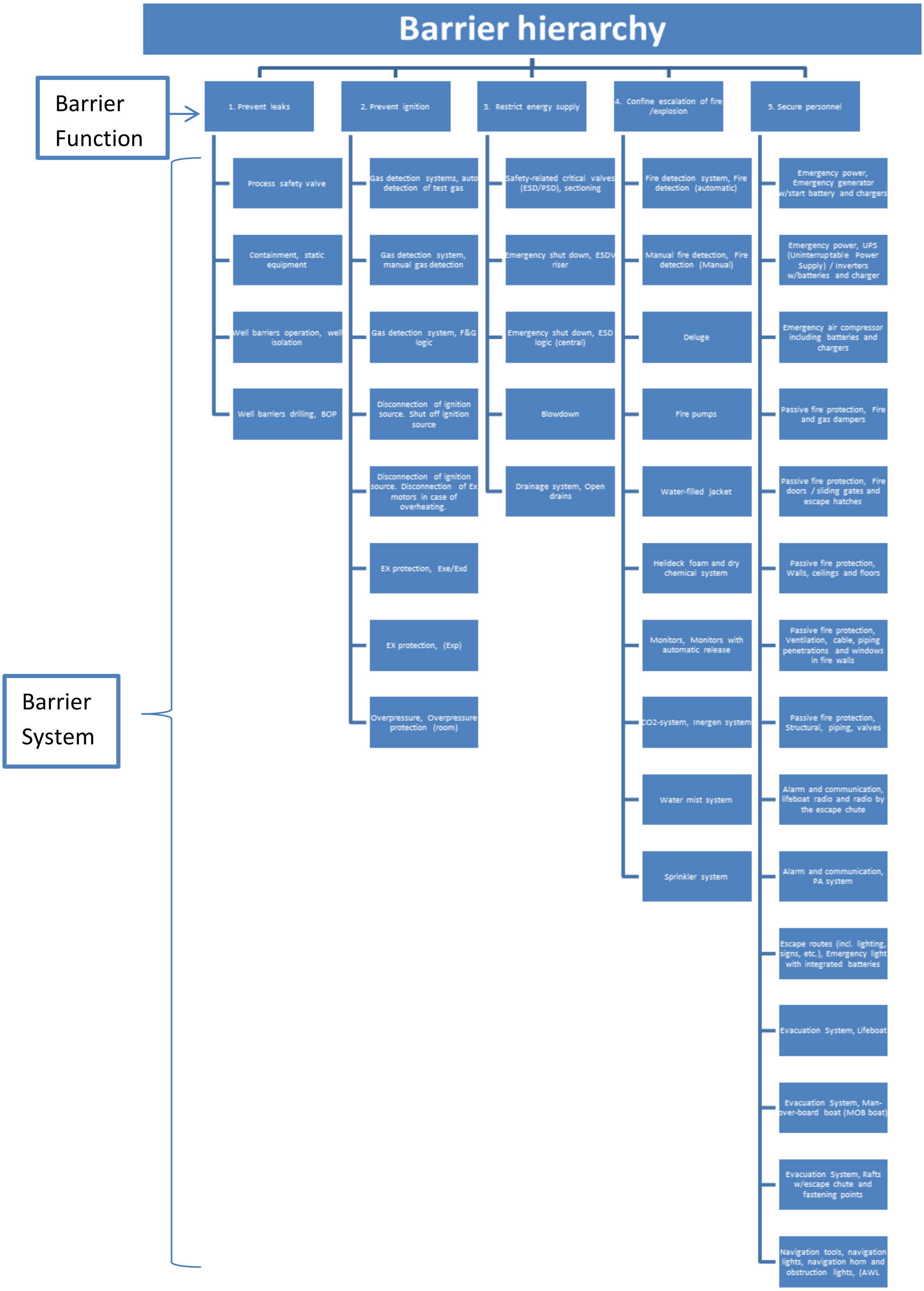

Figure 2-3 Barrier hierarchy

2.7 Barrier management system

This chapter describes barrier management systems and the aspects related to such systems in general. The issues discussed here will be further elaborated in chapter 3.

It is preferred to have all barriers functioning at excellent reliability at all times, but the possibility of failure is within their nature, hence it is important to have knowledge about the state of the barriers to be able to maintain production while providing a safe working environment. The maintenance programs given by the vendors are not always sufficient to make sure that the barriers keep up their function. As an example, a valve can close on demand, and within the required time, and thereby fulfill the acceptance criteria in the vendor maintenance program. But even if the valve has reached the “closed limit switch” it may still have internal leaks and thereby contribute to hydrocarbons letting through, which may contribute to the extent or duration of a fire. Further one need to ensure that the barrier element will be functioning when it is needed. The way to gain this control and improve the trust in the barriers is by implementing a barrier management system.

A barrier management system provides control of the functionalities and availabilities of the safety barriers; it contributes to build safety awareness and competence about barrier systems. Maintenance and inspection of barriers is a key to running a safe operation. Measuring the changes in the integrity level for barriers can be used to monitor changes in the overall risk level of an installation. A barrier management system contributes to control at all stages in the process, by e.g. establishing relevant acceptance criteria and optimized test intervals.

Companies like Statoil and ConocoPhillips have established such systems.
In 2000 Statoil started the project *Teknisk Tilstand Sikkerhet* – TTS (Technical Condition Safety). This is a continuous process where all facilities are evaluated on a regular basis to ensure a high level of safety. The goals for TTS is to map conditions, build competence within technical safety, keep a focus on the risk for major accidents and follow the rules and legislations[12]. ConocoPhillips has developed a comprehensive description of technical barriers through their barrier panel concept. The barrier panel facilitates a performance measurement system for monitoring preventive maintenance activities and the barrier systems for all installations. The objective of the barrier panel is to establish an effective management system to secure control of barriers to prevent major accidents. Other offshore companies have other initiatives, all with the same goal: to reduce the risk of major accidents.

A physical barrier may perform optimally when it is new, but as the times goes by, it all comes down to maintenance, and the quality of the system initiating the maintenance.

The maintenance program is an important part of a good barrier management system, and the following factors are key elements when establishing a maintenance program. The text is based on "*Prinsipper for barrierestyring i petroliumsvirksomheten*"[1]:

It is first of all important to ensure that the maintenance program is correctly set so that the program contributes to the maintenance of appropriate and comprehensive barrier performance in all phases of its lifespan. Preventive maintenance can prevent the degradation or reduction of performance of barrier elements. The degradation can be caused by for instance wear or ageing conditions.

Second it is important to use information from the barrier strategy and performance standards for the classification of equipment and systems with regard to criticality.

Further it is important to test the barrier elements so that the performance is verified in relation to the intended use and role. For example, one should test the valves under real operating conditions, including:

- That the deluge valve opens after the fire pumps has started and pressurized the system upstream the valve.
- That the wing valve can shut off the flow during a leakage in the downstream flow lines.

Last it is important to have good practices regarding the collection of the history of the equipment, and to use this basis for performance reviews and improving maintenance.

3 Barrier management

This chapter presents a method of organizing a barrier management system. The method is divided into 4 levels in a way that make it easy to follow the natural development of the system.

3.1 Level 1

Figure 3-1 shows a simple maintenance program used by some of the operators on the NCS today. It is common to use the test procedures and recommendations given by the vendors as a basis for the test and maintenance program. Components are tested and the test results are reported back in to the maintenance program. This feedback may in some organizations be used to adjust the test intervals, since the test intervals are a key factor in determining the reliability of a system.

An area where this system works well is the car industry where the consumers are the users. Most car-owners (at least for newer cars) follow the recommended service intervals, and the car service vendors perform the recommended service without any assessment of the necessity of this service. Of course the vendor may recommend further work, but this is often based on specified checks. The reason for buying into the specified service recommendations is often a combination of concern related to the car breaking down and a lack of knowledge of how to repair a broken down car. The end result might be a service level and interval that is totally out of sync with the actual need to achieve the required level of uptime.

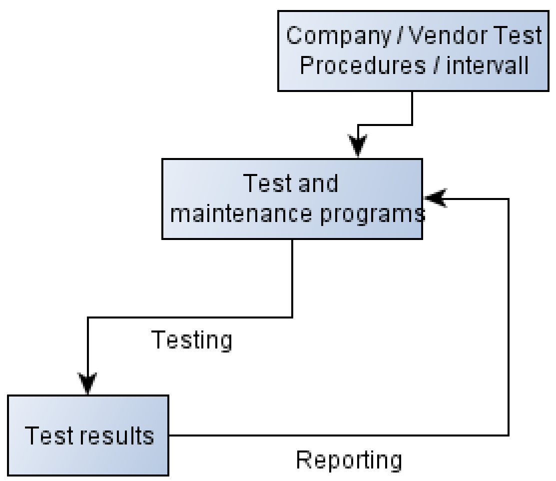

Figure 3-1 Barrier management system Level 1

The simplest maintenance theory for systems in operation is based on a binary up time model and is actually only applicable for systems which are either functioning or not functioning.

A light bulb can be used as an example. A light bulb is either functioning or not functioning, when you enter a room with one light bulb (which always is turned on) there is either light or not. When the first, new light bulb is put in, the expectation for the light bulb to function is at 100%. As time goes by the expectation for the light bulb to function is reduced. If a new light bulb is put in, and no one visits the room for three months, the expectation for the light bulb to function after those three months is lower than it was the day after it was replaced. As time goes by, the expectation will be further reduced, until action is taken to restore the expectation back to a higher level. For a light bulb, replacing the unit will restore the expectation to 100%. But verifying that it works will also according to this theory restore the expectancy to 100%.

To maintain an average level of expectancy towards the light bulb being functional, replacing or testing the light bulb at fixed intervals may be required, even if this means that functioning light bulbs will be replaced.

E.g. if the expectancy fell from 100% to 80% in the interval between checks / changes, the average expectancy would be 90%. See Figure 3-2.

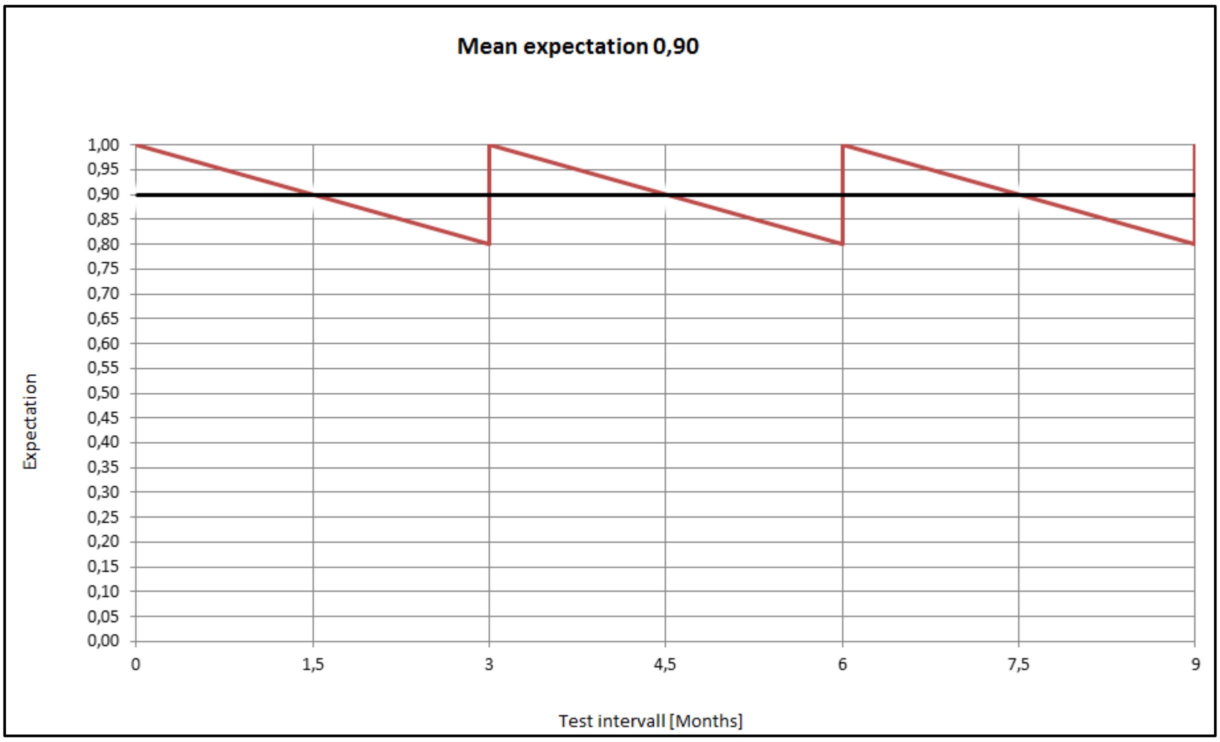

Figure 3-2 Mean expectation 0,90

When the light bulb has been tested, and if it works, the expectation is back up on 100%. And a new interval is started. To increase the mean expectancy for the light bulb to function the room has to be visited more often, i.e. decrease the test interval. The room cannot be visited daily. That will be too time-consuming, so a more optimal test interval has to be used for the object. In this case once every one and a half months is used. When the room is entered after one and a half months the expectancy of the light bulb to function is 90%, which gives an average of 95% see Figure 3-3.

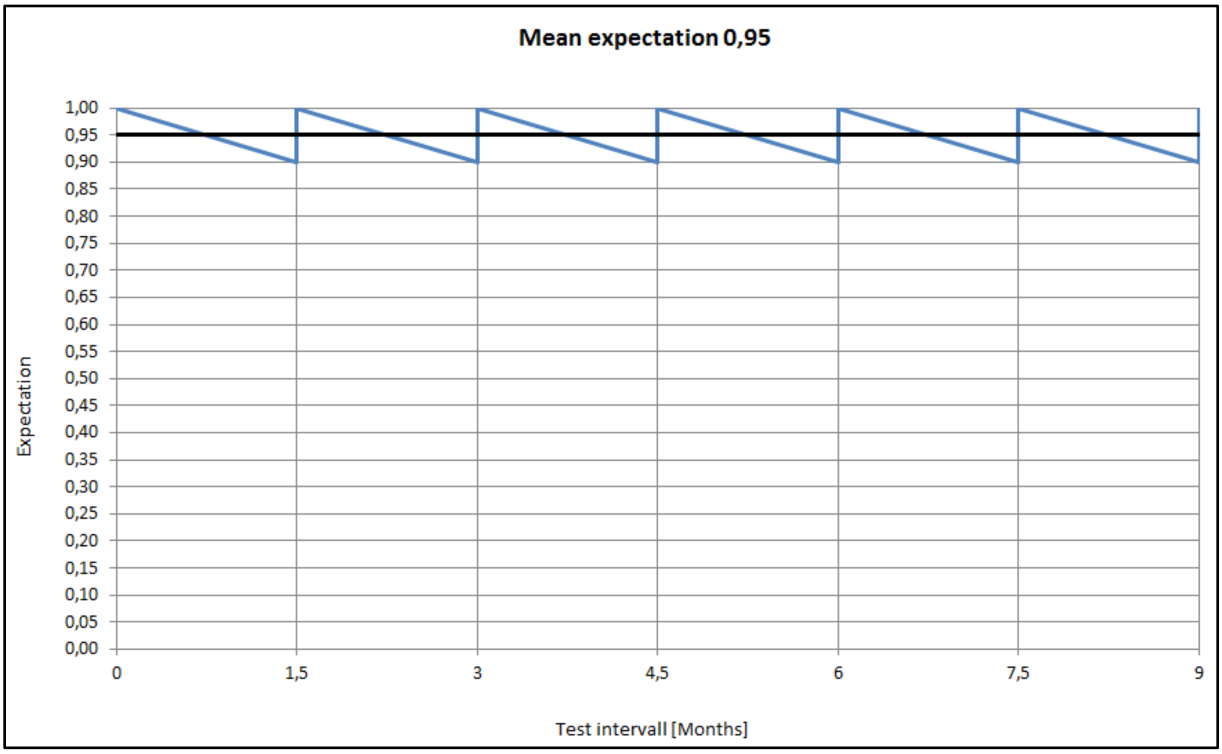

Figure 3-3 Mean expectation 0,95

So reduction of the test interval gives you an increased reliability.

This approach is not optimal for use on offshore installation because most of the barrier systems offshore are systems that do not fit with the above model. Most systems have more than two different states. And their expectancy curve is totally different. An example here can be a battery, the life expectancy of a battery is gradually reduced as time goes by. When the lifetime expectancy of a component is gradually reduced it is important to test it regularly to monitor the deterioration and contribute to keep the expectation as high as possible. This is done by implementing test intervals of varying duration depending on the component in question. As the expectation to the component is reduced it can be increased again by testing and implementing measures, as shown in Figure 3-4. Figure 3-4 illustrates two different expectancy curves of a component, e.g. a compressor. If a compressor is left without any maintenance or servicing of any kind, the life time expectancy curve will look something like the red line. Without change of the hydraulic fluid the expectancy will drop dramatically as time goes, until it reaches the acceptance criteria and must be changed, here illustrated by the black line. But if an interval based service and maintenance program is implemented where the hydraulic fluid is changed regularly, the expectancy will level out illustrated by the blue curve. The green arrows illustrate that by implementing measures the expectancy can be moved back up to a higher level again, until it finally reaches the black line and must be changed, and then the expectancy is back up to 100%. The dotted green lines illustrate that expectation does not necessarily have to be put back up to the level it was at last service. It can reach anywhere from the present status and up to 100%; it all depends on the measures taken.

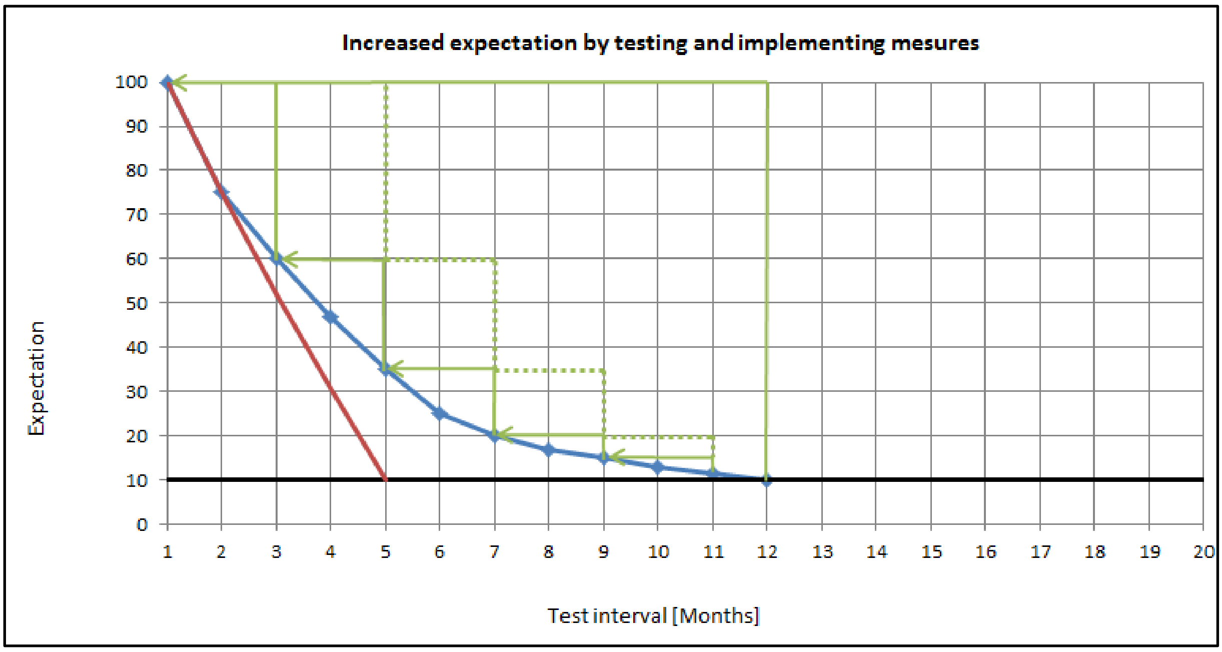

Figure 3-4 Increased expectation by testing and implementing measures

Another example of a measure can be greasing a valve to make it close within its acceptable time requirement. By conducting such measures, the reliability will increase back up to a higher level. The life time expectancy curve of the valve will then level out, and higher mean component reliability is achieved like the compressor in Figure 3-4.

Traditional maintenance where a component can be used until it fails does not meet the demands for a safety barrier system since such systems are used only on demand. Components in a barrier system must be changed before they fail due to the criticality of these systems. An example here can be a bus, compared to the car example used in the start of this chapter. A car owner can choose to use the car until it breaks down, and the consequences he faces is to walk home. For a bus company it is far more critical if the bus brakes down. If that happens it may have major economic consequences, and a lot of people have to walk home. So the bus company may have more focus on the regular maintenance and change critical components before they fail.

Another example, from the oil and gas industry, can be a firewater system. A fire water system can gradually get more and more corroded. If the fire water supply is limited by clogged or narrow pipes, the consequences can be fatal in case of a fire. To avoid that the system does not deliver enough water when it should, it has to be monitored and tested. And before the critical condition is reached the pipes must be changed out.

But as previously mentioned the test intervals have to be optimized. When safety systems are tested they may have to be inhibited with the result that the barrier is out of operation. To compensate for that, the redundancy can be increased by putting in e.g. two valves instead of one. The total reliability will then be improved. The point here is the total reliability and to avoid downtime. So if a component is inhibited by for instance testing, inspection or maintenance, it is necessary to compensate for this loss by having another component doing the inhibited components job.

Maintenance procedures given by the vendor do not necessarily cover all the aspects which are important seen from a barrier management point of view, and the acceptance criteria may not be adequate. In some cases it is sufficient that e.g. a valve closes on demand according to the maintenance procedure, but it may be important that it closes during a given time interval or that it closes completely and without any internal leak. It can also be of great importance that it can withstand a fire for a given amount of time.

The main reason for testing a component is to make sure it is functioning, and in that way maintain its reliability. The reliability of a component is impaired over time, and as time goes by it gets more important to implement it in the maintenance program and test it regularly.

3.2 Level 2

First step towards a barrier management system is to establish a list of the relevant barrier systems and separate them from the other objects in the maintenance and test program, as illustrated in Figure 3-5. The reason for this is that the barriers usually need a more stringent test regime than the procedures initially given by the vendor. This is caused by the vendors' lack of information regarding the criticality of the system and the components "role" in the overall safety system. With this knowledge one may optimize the service level according to the reliability level required.

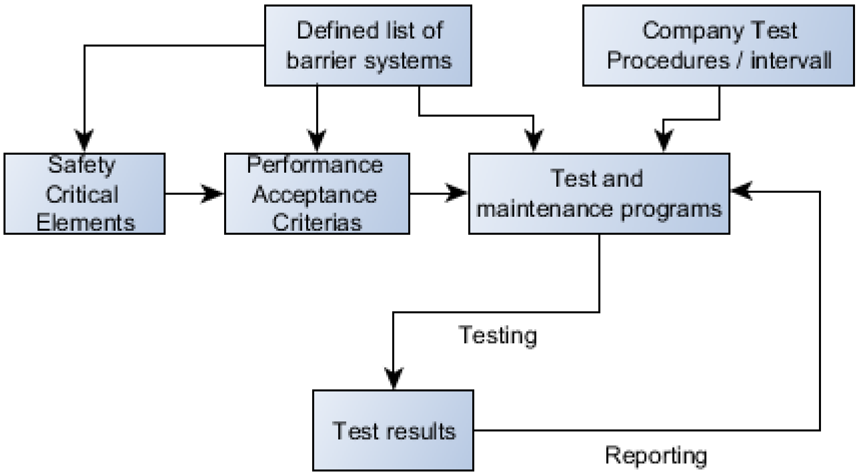

Figure 3-5 Barrier management system Level 2

Identification of safety-critical elements is often established on the basis of risk analysis, usually a total risk analysis. And for all barriers the same basis is used for establishment of performance criteria.

A total risk analysis is usually based on traditional risk models where experience databases from various recognized sources are used. To increase the probability of making correct risk based decisions, the NORSOK Z-013[2] standard dictates that all input data used are to be conservative if the data contain an element of uncertainty. With continued use of statistical data through the analysis, this may contribute to overestimating the risk, but the estimated level of risk and decision basis is at least on the right side of what may be called the "actual risk level".

Figure 3-6 and Figure 3-7 can be used as an example on how the estimated risk/probability is decreased as a result of implementing measures. Since the actual risk is also affected by the same measures, the actual risk decreases accordingly. The figures show example values for probability of impairment of the main safety functions listed in the Facilities Regulations section 7[6]. The grey columns illustrate examples of probabilities from a QRA and include a margin of conservatism. The blue column represents the actual risk which is unknown. The black line illustrates the acceptance criteria also from the Facilities regulation which stats that: *"Accidental loads and natural loads with an annual probability greater than or equal to $1x10^{-4}$ shall not result in loss of a main safety function."* In this example all the main safety functions but one is within the acceptance criteria. In this case, by implementing measures like improve the escape route network, the risk may be decreased, and the columns will decrease accordingly.

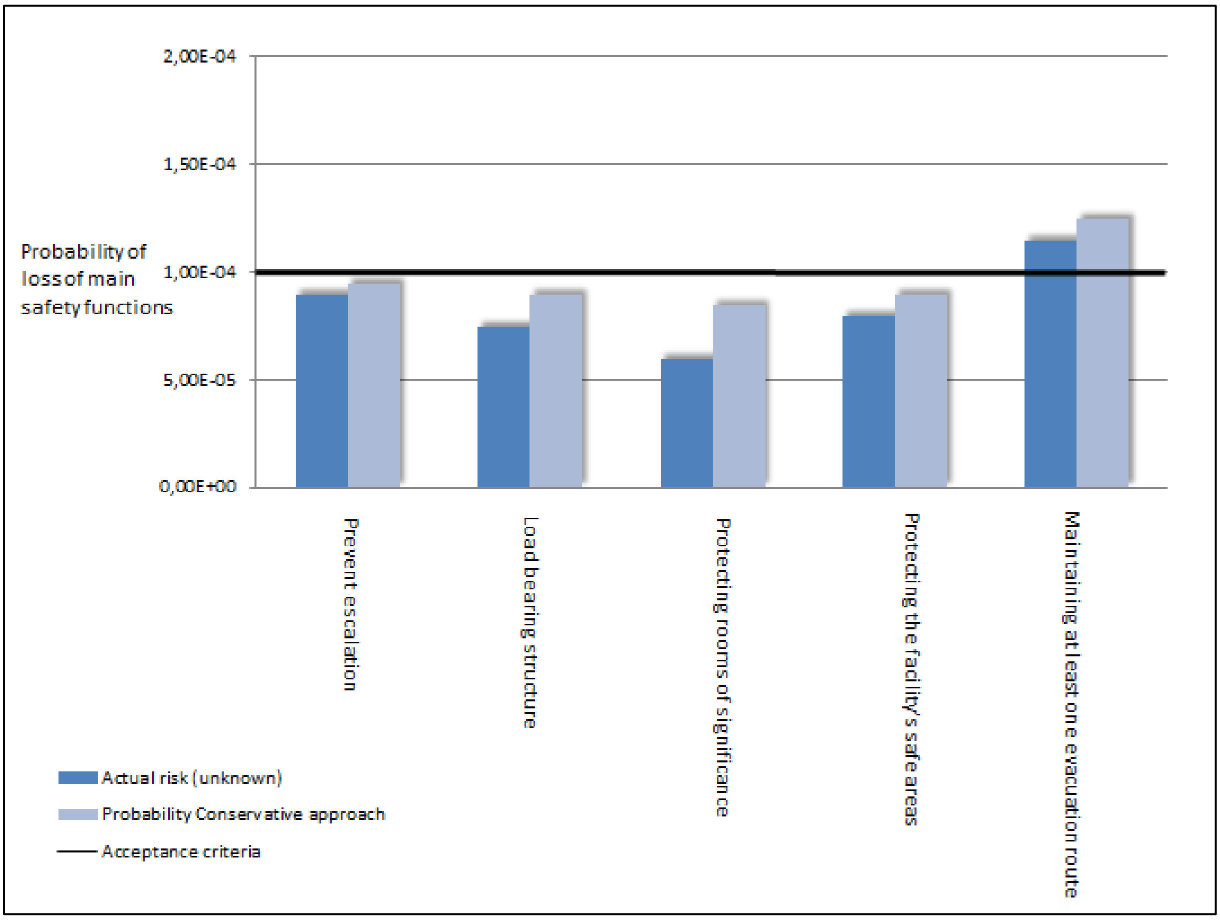

Figure 3-6 Exceeding acceptance criteria

By implementing measures like the one mentioned above in order to decrease the theoretical risk, a corresponding reduction in actual risk is obtained, as shown in Figure 3-7. As the figure illustrates, by implementing sufficient mitigating measures, the risk ends up below the acceptance criteria, and the total risk picture is acceptable.

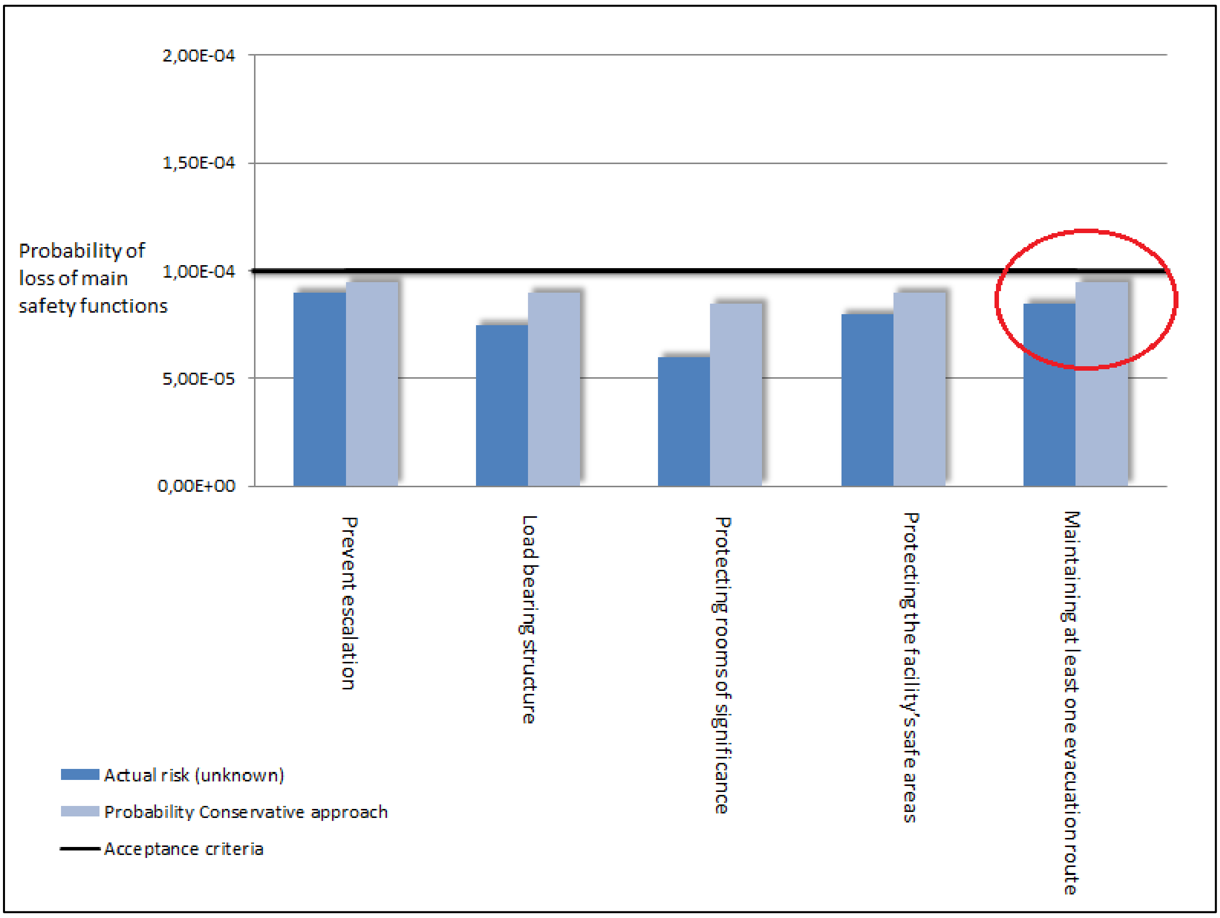

Figure 3-7 Satisfying acceptance criteria

When it comes to components input to the risk calculations, established databases such as OREDA[13] are often used. But these data often contain large amounts of old components and therefore often predicts lower reliability figures than what actual may be expected of a new modern component. In cases where suppliers have reliability data that can be verified through tests performed or experience data (proven in use) these statistics should be preferred.

Eventually, the companies themselves through own tests will be able to establish their own databases for the components that are actually installed on their installations, and then be able to use the reliability data collected from these test in the risk analyzes, in combination with statistical figures. This is in accordance with Bayes Theorem. This is done to a lesser extent today.

It is not considered to be a part of this thesis, but by implementing a system for return of collected data from the tests to the risk analysis this could force changes in requirements for barriers. In theory, this will reduce the uncertainty in the analyses, but one should be careful to implement figures from a small population as this can change the input considerably.

Since current standards involve conservatism in the choice of input data, this has secured a buffer against the unknown uncertainties in the analyses, for example errors in any software used. If this buffer is reduced and errors in methods or software contribute to underestimating parts of the risk picture, the overall estimated result may end up on the wrong side of the "actual risk".

As mentioned in chapter 2.7, there may also be criteria which are important in relation to safety that the vendor has not included in the maintenance program. One of the best examples of that is the internal leakage of ESD valves. A valve may have reached the end switch which tells the system it has closed, but still be leaking. From the defined list of barrier systems, the most critical/important of these systems is selected and included in the safety critical elements. Safety critical elements are defined later in this chapter. The reason for establishing safety critical elements is that not all the barrier systems are equally important. Failure of safety critical elements will normally result in a consequence worse than failure of the barriers that are installed on the basis of standards and regulatory requirements only. When these two elements are in place their performance acceptance criteria should be established. These criteria form the basis of what is expected of the different systems, and will go beyond the vendor requirements.

Safety critical elements are as mentioned the most important barrier systems on the installation. A safety critical element is defined like this by Rahul Dhar[14]:

Safety Critical Elements (SCE's) are such parts of the installation and such of its plant (including software programs), or any part thereof the failure of which could cause or contribute substantially to a major accident or a purpose of which is to prevent or limit the effect of a major accident. The term "contribute substantially to a major accident" is intended to include within the category of safety critical element those parts whose failure would not directly initiate a major accident but would make a significant contribution to a chain of events which could result in a major accident.

As shown in the above citation, some of the barriers are more important than others and can be defined as safety critical elements. Other barrier systems are less crucial for the safety level or operability of the installation, but are nevertheless necessary to have installed. The reason that some barriers are categorized as more critical than others can be the consequences of failure of such a barrier. Another reason can be the lack of redundancy, or too poor redundancy of the system, when it is too expensive or difficult to install additional units to increase the redundancy level of the system and hence the expected performance.

Fire water pumps are often categorized as safety critical equipment, and can be a good example of critical equipment. Firewater pumps are very expensive and take a lot of space, so it is not desirable to have more pumps than needed. Another example can be riser ESD valves. As for the fire water pumps, the consequences of dysfunction can be fatal. Such valves are large and heavy, and by installing more valves, more flanges are introduced, which means more leakage points. Buying such valves involves a significant cost, and it is made clear that there are many disadvantages followed by increased redundancy of riser ESD valves in series. In many cases, increasing the redundancy does not increase the uptime of the system (production regularity). E.g. in cases when one valve is repaired, the other one will also be out of function, thus the only gain from increasing the redundancy for such systems is higher barrier system reliability. It explains why riser ESD valves in many cases are categorized as critical equipment.

There are often stricter requirements attached to the safety critical elements. They may be related to how they are tested, the type of test which is used or the frequency of tests or services.

It is important to identify the safety critical elements based on the scenarios found in the QRA and not to include all kind of equipment in this list. There is a tendency to include too many systems and equipment units on the installation in the SCE list. This contributes to undermining the purpose of the SCE. The total barrier management system is based on amongst others the QRA, this will be more thoroughly elaborated in Level 4.

The management regulations, section 5, require that there are established requirements for the performance of the technical, operational and organizational elements that are necessary for the individual barrier to be effective. Performance is her used as the characteristics of a barrier function or barrier element needed to ensure that the individual barrier function is effective. Performance may among other properties include capacity, reliability, availability, efficiency, ability to resist loads, integrity and robustness.[1, 11]

Further, the PSA regulations require that it shall be known which barriers that are weakened or out of function. This means that the party responsible for operation must establish systems and processes which can verify that established barrier functions and their related barrier elements holds the intended properties. For certain properties, especially properties for technical barriers, testing and maintenance activities will contribute to reveal the barriers condition and its correlation with established performance acceptance criteria.

As shown in the sections above, there are requirements given by the authorities to the performance of the barrier systems. This is where the performance acceptance criteria come in to play. When equipment is tested, there has to be established acceptance criteria for the equipment to pass. The difference here is that the acceptance criteria for safety barriers often have to be stricter than for regular equipment, since the consequences of a system not functioning can lead to further escalation of an event. An example of an acceptance criterion that can be used is a NORSOK S-001 requirement which is found in chapter 20. It states that the fire water system shall be designed and calibrated such that the deluge nozzles will receive water at design pressure not later than 30 seconds after a confirmed fire signal has been given[9]. This test is important to conduct to make sure that the fire water contributes in the firefighting as early as possible to prevent escalation of the fire to adjacent areas or neighboring equipment. It is likewise important in case of an explosion since the explosion pressure will be reduced by the water spray in the air.

3.3 Level 3

With the safety critical elements established and the acceptance criteria in place it is time to introduce an extended test regime into the system. By establishing a way of reporting the test results and log them in the barrier management system, it is possible to monitor the whole barrier management process in a better way. The purpose of testing the various components is to obtain mean expectations for the components which make the total system comply with the required availability, as previously mentioned in Level 1. By testing and carrying out maintenance the goal is to put the component as far back to “as new” state as possible. Another important objective of testing is to monitor the changes in the performance of the component, and establish a history database which can be used to trend the performance and thereby the expectation of the component. The test outcomes can be put in to different categories based on the outcome. The test results then determines the action which should be taken. By trending the results, it is possible to predict the outcome in the future and prepare for more complex maintenance tasks for the component before it fails. One such task may be complete change out of the component. By exchanging the component before it fails, the time the component/system is out of use can be significantly reduced. And having the worn out part of the system or component available when it is time to change it, instead of waiting for a new part from the vendor can save much time. Car tires are a good example of a barrier which gradually becomes degraded. As the tires are used they become worn out and if the car follows a periodic service program where the tire tread depth are monitored you will be notified when the tread depth is expected to fail the acceptance criteria before the next service/test. There is set an acceptance criteria of 1,6 mm for summer tires and 3,0 mm for winter tires by the authorities. It is less expensive to change the tires while the car already is in the shop, than it is to wait for the tire to wear totally out. That increases the risk of a flat tire with all the consequences that may lead to, like losing the effect of the brakes in an emergency situation.

Figure 3-8 shows a schematic setup of how the extended test regime may be implemented. Instead of only reporting the test results back in to the test and maintenance program, the results can be categorized and actions can be taken. The test results should still be reported back to the test- and maintenance program, so that the results can be surveyed and trended, but this is not enough. There should be established a system which categorizes the test results. The figure underneath can be an example of a system for categorizing test results:

Many pressurized pipes are vulnerable to corrosion and the wall thickness must be monitored. Given a pipe with a wall thickness of 15 mm, the categories can look like this:

Deviations from original pipe wall thickness	Corrective measures
< 1 mm	Acceptable deviation, maintain current inspection interval
1-3 mm	Increase inspection interval
3-5 mm	Flush with corrosion-reducing agent
> 5 mm	Change the pipe

Figure 3-8 Corrosion example

When the test result of a component has been put in a category, action to put it back in to a better state should be taken. Then the new status of the component should be reported back in to the test and maintenance program.

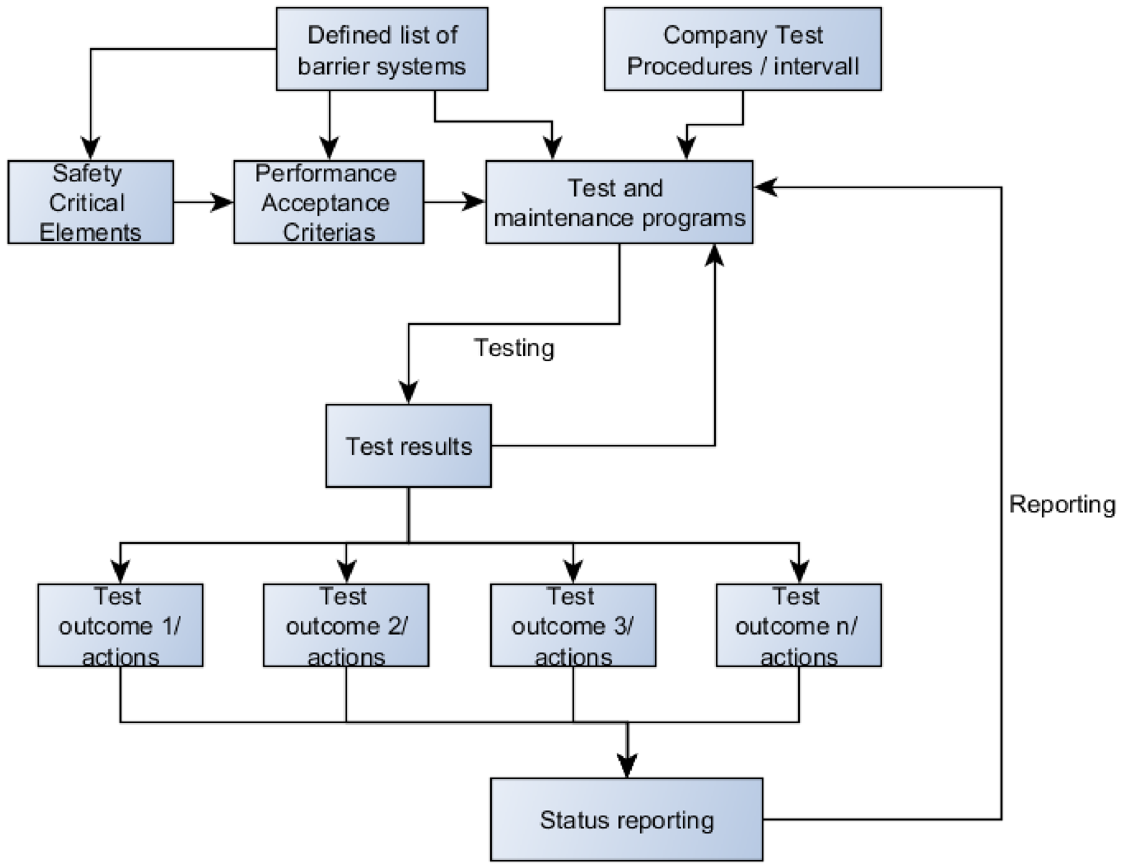

Figure 3-9 Barrier management system Level 3

The extended test regime should include predefined actions, customized for each different system. Like for instance a deluge system can be divided in to different test criteria intervals with corresponding actions. The example underneath is inspired by OLF guideline 075 *Anbefalte Retningslinjer for vannbaserte brannbekjempelsessystemer*[15].

The guideline recommends full scale testing of the deluge system regularly. This means that the system should provide full flow rate to the nozzles. The performance values for the deluge system is based on the number of clogged nozzles during testing, but the spread pattern for each nozzle should also be verified. If any nozzle is clogged up corrective measures should be taken.

1. < 1% clogged nozzles. Clean the clogged nozzles and consider the cause of the clogging. Consider whether another test is needed. New test will normally not be necessary.

2. 1 - 3% clogged nozzles or max. 1 nozzle close to each branch / loop: Clean clogged nozzles and consider whether new test shall be conducted.

3. 3% - 10% clogged nozzles or max. 3 pcs. clogged nozzles in each branch / loop: Clean clogged nozzles and carry out new test. Corrective measures to be implemented. Consider the test intervals.

4. > 10% clogged nozzles: clean the clogged nozzles. Implement permanent corrective actions. These corrective measures should consist of cleaning / upgrade / replacement. Compensatory measures or closure of production in the current module should be considered until the situation is remedied. The assessment must be based on the criticality of the equipment / area and risk. Consider reducing the test intervals.

This example shows how the different corrective measures can be implemented for each different test results, to achieve a higher expectation for the system. When the system does not meet the acceptance criteria, the components are changed out and the expectation is back to top level again, like shown in Figure 3-4.

There are a variety of different types of components in the safety barrier systems offshore, from simpler to more complex. Different components can have different life cycles, and there of different maintenance programs. A number of aspects can affect this. Like quality (use of original parts), the complexity of the component (number of parts), moving parts, exposure to weather etc. This contributes to make the test and maintenance program, and thereof the barrier management system a very intricate system.

3.4 Level 4

The last thing to implement in establishing a complete barrier management system, is the management systems administrative part, in Figure 3-10 called: *barrier management system*. This is the heart of the whole system. Here the daily management is carried out, regulation changes are implemented and all the input is followed up. The barrier management system is based on input from several different elements, like the QRA/TRA, the risk acceptance criteria and regulations and standards.

First the elements forming the basis for the barrier management system element is presented.

An important basis for the management system is the QRA/TRA and other risk analysis and assessment like e.g. bowties and fault/event tree analysis.

In the Norwegian oil and gas industry, risk analyses are used for monitoring the risk level for installations, areas, operations and personnel. Changes in e.g. layout, process systems, operation mode, activity level or even organizational changes may require an update of the risk analysis. When the overall risk level is being analyzed, this is often called a Quantitative Risk Analysis (QRA) or Total Risk Analysis (TRA). It is as the name reveals a quantitative approach to estimate a risk level[16]. The risk analysis model is based on several assumptions, hence the model will never reflect the “TRUE” risk level, but with a conservative approach the risk level should never be underestimated. For comparison with other installations or the average risk level on the NCS, this method is considered to be acceptable. Any risk analysis may also be used for sensitivity studies, forming the risk-related basis for smaller or larger decision processes. This is done by altering some of the input for the risk analysis and evaluating the resulting changes. It is stated in the facility regulations that all offshore installation on the NCS shall, among other safety documentation, have a QRA.

The second basis element is risk acceptance criteria. This is criteria that are used to express a risk level that is considered as the upper limit for the activity in question to be tolerable, according to NORSOK Z-013[2].

As required by the Management Regulations[5], risk acceptance criteria for major accident risk and environmental risk shall be set for the following four cases:

a) *the personnel on the offshore or onshore facility as a whole, and for personnel groups exposed to particular risk,*

b) *loss of main safety functions as mentioned in Section 7 of the Facilities Regulations for offshore petroleum activities,*

c) *acute pollution from the offshore or onshore facility,*

d) *damage to third party.*

The first two cases *a* and *b* are elaborated in the following sections, since the last two cases *c* and *d* are less relevant for this report. In the first case, *a*, the Management Regulations states that there shall be given acceptance criteria for the loss of personnel, these are not defined by regulations, but have to be defined by the responsible party. The second case, *b*, given for loss of main safety functions is elaborated. This is a set of specific criteria defined by the PSA and are given in the Facility regulations. The risk acceptance criteria shall be listed in the QRA.

The acceptance criteria for the loss of personnel must be defined by the responsible party itself. There are different ways of defining and expressing these criteria. The following is the ones mentioned in Jan Erik Vinnem's book Offshore Risk Assessment[16]:

- PLL
- FAR
- AIR
- f-N
- Risk Matrix

But other measures for the risk acceptance criteria are also used on the NCS.

FAR is among the most common and is here used as an illustrative example.

The fatal accident rate (FAR) is the expected number of fatalities per 10^8 hours of exposure[17]:

$$FAR = \frac{Expected\ no.of\ fatalities}{No.of\ hours\ exposed\ to\ risk} \times 10^8$$

The following example is based on an example in the book Risikoanalyse by Marvin Rausand and Ingrid Bouwer Utne[18]:

If 1000 persons work 2000 hours in 50 years it will make 100 million work hours. This is called 1000 “life's work”, even if it is closer to 1400 “life’s work” with the current working arrangements[4]. What is meant by the expression “No. of hours exposed to risk” or just “exposed hours” depends on the situation. If the goal is to establish the FAR-value on a given workplace it is natural to express the exposed hours equal to the work hours, but if the case is to establish the FAR-value of car drivers it is natural to use the hours the drivers spend behind the wheel. Accept criteria expressed as FAR-value is typically between 10 and 30. If the FAR-value is 10 (FAR=10) it means that an average of 10 people is expected to be killed during 1000 “life’s work”.

The loss of main safety functions criterion is given in the Facility regulations section 11[6] and is reproduced in full in chapter 2.1.

The loads that can affect facilities or parts of facilities, shall be determined. Accidental loads and natural loads with an annual probability greater than or equal to $1x10^{-4}$ shall not result in loss of a main safety function, cf. Section 7.

As seen from the quote above, the criterion given for loss of main safety functions is set to be annual probability less than or equal to $1x10^{-4}$. I.e. no loads with a probability greater than this number shall result in loss of a main safety function. The main safety functions are listed in the Facility regulations section 7[6], which is reproduced in full in chapter 2.1. The responsible party is free to define more main safety functions but the ones listed in the Facility regulations are a minimum.

The third basis for the management system is regulations and standards. In Norway the PSA is the regulatory authority for technical and operational safety, including emergency preparedness, and for the working environment.

From time to time the regulations and standards are revised, but the regulations will normally not require a change-out of existing equipment or systems. However; even if the systems installed were according to the requirements when the installation was new, this may not be true several years down the road. Acknowledging the fact that an installations risk mitigating measures are sub-standard may result in exchanging systems or components which otherwise only would be repaired.

[4] 1400 persons working 1730 hours for 42 years sums up to approx. 100 million work hours.

As shown in the Figure 3-10 below, the barrier management system should always have the regulations form a basis for the measures that are taken related to management on this level. This being e.g. when new equipment should be implemented, and routines changed.

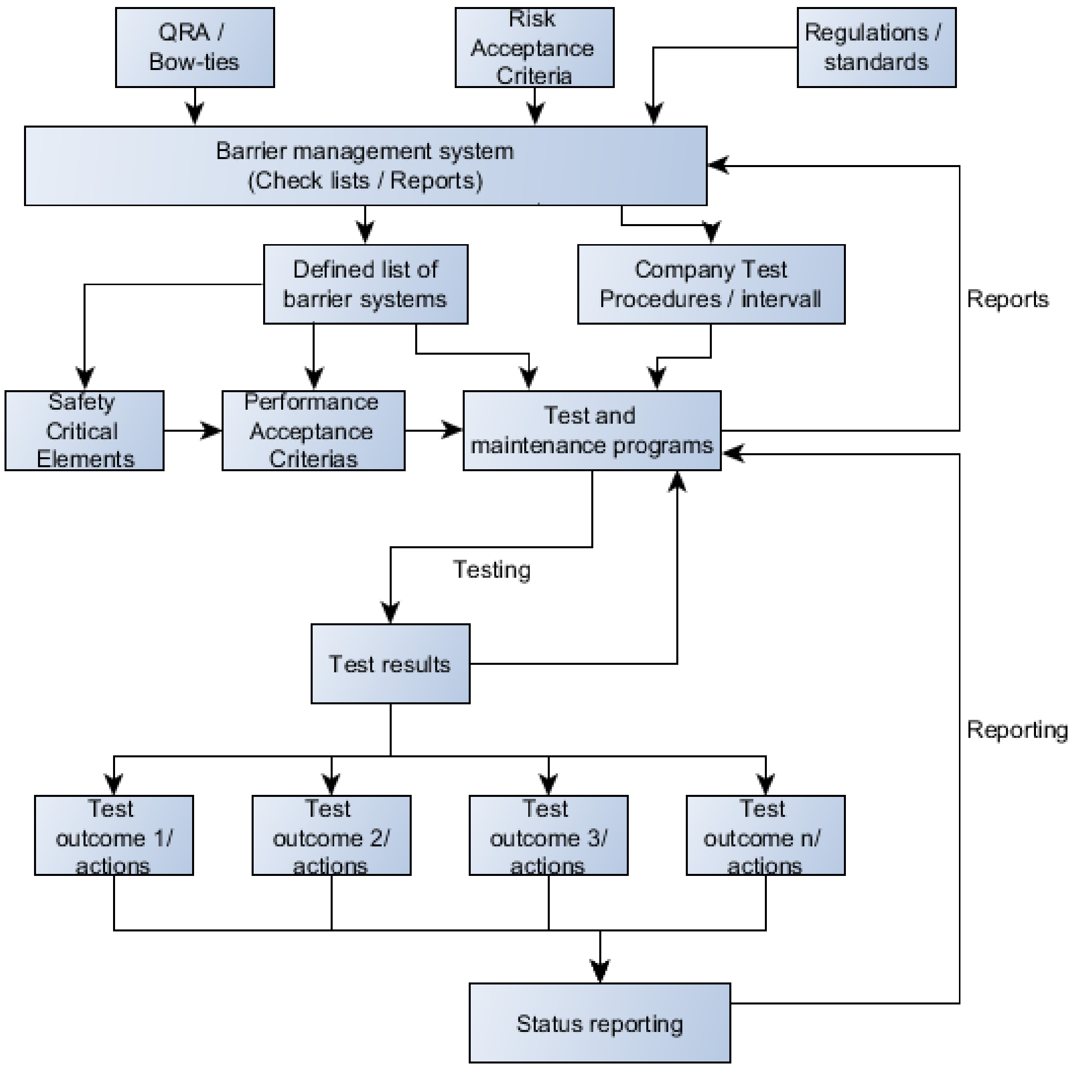

Figure 3-10 Barrier management system Level 4

Figure 3-10 shows the finished and complete picture of the overall barrier management system. As mentioned the barrier management system part, forms the basis for the rest of the system. As the figure shows, all the data in the test and maintenance program originating from the test results is reported back in to the management system for processing. Here it is systemized and handled. I.e. there is a full review of the results and they are logged for later use. This use can be trend curves and other statistic used to improve the maintenance- procedures and routines.

The overall barrier management system should also include verification of the barriers on a regular basis. 3 to 5 years is often used as an interval between these verification activities. Here the barrier systems should undergo a full review based on check lists, interviews with the responsible personnel for the barrier system and the trends / test results mentioned in the previous section. During such an exercise the barrier system in question should also be verified against all relevant standards and legislation.

The QRA should also be conferred, to check that the barrier system is in accordance with the risk picture. The QRA is a living document and is changing; the same goes for the risk picture.

Since the last review of the barrier system, new and better equipment may have been developed, or new and better technology may be available. This should be checked to make sure the safety equipment is up to date.

The text in section 11 in the Framework requirements, which is reproduced in its entirety in chapter 2.1, can be interpreted to mean that the operator always is to use the best available technology (BAT). There can also be economical advantages of this.

4 Discussion

4.1 Recap

This part summarizes the key points of the barrier management system presented. It also presents the main advantages of implementing each level of the described system, in a short and comprehensible manner.

4.1.1 Level 1

Level 1 illustrates a simple maintenance and test program. It is common to use the test procedures and recommendations given by the vendors as a basis for the test and maintenance program. Underneath three main points from Level 1 is shown.

- Simple system, easy to administrate
- Optimize the test intervals
- Usually not enough, should expand the system

4.1.2 Level 2

Level 2 is the start of what can be developed into a barrier management system. By implementing the three following actions the barrier management system is starting to shape.

- Establish a list of barriers, and include this information in the maintenance and test program
- Identify and distinguish the safety critical elements from the other barriers
- Establish performance criteria

The advantages of carrying out these actions are: The safety barriers get a stricter test regime which is more related to the actual risk level than the one given by the vendor. And by obtaining knowledge of the system and the components role in the overall system, the service level may be optimized according to the reliability level required.

4.1.3 Level 3

The following is the main points in Level 3:

- Introduce an extended test regime into the system.
- Report the test results and log them in the barrier management system

By establishing a way of reporting the test results and log them in the barrier management system, it is possible to monitor the whole barrier management process in a better way. By testing and carrying out maintenance, the goal is to put the component as far back to "as new" state as possible. Another advantage of logging all testing is that changes in the performance of the component can be monitored. The results can be implemented into a history database which can be used to trend the performance and thereby the expectation of the component. By trending the results, it is possible to predict the outcome in the future and prepare for more complex maintenance tasks for the component before it fails to meet the performance criteria.

4.1.4 Level 4

Level 4 makes the system complete, and underneath the key points in Level 4 is mentioned:

- Implement the administrative part of the management system
- Verify that the barrier systems is in accordance with the risk picture

To complete the barrier management system it is important to establish the administrative part of the management systems, in Figure 3-10 called: barrier management system. By establishing the administrative part, better control over the whole system is gained based on QRA/risk picture, risk acceptance criteria and regulations.

4.2 Discussion

The main objective for this thesis was to describe why it is important to implement a barrier management system into the organization, and how it can be done. This is done by description of the most important elements in such a system, and how to put these elements into a system which may easily be implemented by any company.

The entire described system does not have to be implemented at once; it can be developed over time. The big companies on the NCS already has systems like this in place, but many of the new ones do not have the capacity to implement an advanced system like this immediately. The pace of the implementation can also depend on needs or wishes, in addition to the size of the organization of the company implementing it. Considering the fact that every arrow in the complete flow sheet presented in Level 4 represents thousands of working hours, and requires extensive experience, it is easy to see that some companies choose to just go for a simple maintenance and test program based on vendor procedures, similar to the one described in Level 1. This type of program is easy to administrate and do not require a big organization.

But as this report argues, a more advanced system should be established. It is however possible to start implementing a low level system, but the last level should be kept in mind when selecting software or management systems if the company has intentions of eventually implementing the entire system. This can be implemented piece by piece as the organization grows stronger and gain the capacity and experience to handle it.

It has been shown that the barrier management system needs to be established to ensure that the updated risk picture from total risk analysis is reflected in the way the safety barriers as tested and maintained. See chapter 0. But the QRA could also benefit from information collected from the barrier management system. By extracting test results and performance information on the various components and implementing this into the QRA, the results in the QRA can be affected. This is because the test results and performance figures may deviate from the numbers that came from the suppliers or other statistical sources.

The reason the numbers may deviate from each other may be that the components are placed in an environment different from what they was initially designed for.

Another benefit from collecting data from tests is the increased knowledge on the component performance. These figures may be used for smaller, more dedicated risk analyses or sensitivities. Traditional risk methods involve the use of statistics only, but there have been episodes where the statistics from recognized sources gave reliability data far from the truth. In such cases, detailed knowledge on own components is crucial to enable more correct analysis.

According to Managing director of Xafe AS, Ørjan Stien, such an episode occurred for the Ekofisk 2/4 Alfa platform after a ship collision on the Ekofisk field. The Ekofisk 2/4 Alfa platform lost its ability to depressurize the production pipeline to Ekofisk 2/4 FTP, resulting in an increased probability for over pressurizing the pipeline from the Ekofisk 2/4 Alfa production. To evaluate this risk, a 3rd party consultancy agency was engaged to perform SIL calculations on the existing shutdown system. In the initial analysis the down-hole emergency shutdown valves were included in the fault tree analysis. And with exceptional good reliability data on these valves from OREDA, the resulting reliability of the shutdown system were satisfactory. Suspecting that the OREDA reliability figures for the down-hole emergency shutdown valves were better than what was expected for the nearly 40 year old platform, a quite thorough check of historical test data for the installed valves revealed that the closing tests initially had failed every time during the latter years. As a result of the findings, the continuously failing valves were removed from the fault trees, resulting in a reliability level for overpressure protection below the requirement. The end result was a requirement for additional pipeline overpressure protection systems, independent of the existing systems.

5 Conclusion

This report has described why it is important to implement a barrier management system, and shown a method of how it can be done. Through a model extended level by level the different component in the system has been presented and explained. There are different ways of solving the barrier management situation, and the described method is one option.

The size of the system can also vary to some extent, and the size depends on much the same factors as for the pace of the implementation mentioned in the discussion, which are factors like: needs, wishes and the size and competence of the organization.

But regardless of size, as it has been argued for in this report, a system like this can contribute to reduce the risk of personnel and assets, as well as reduce maintenance and operation cost. It can also contribute to increased uptime on the systems, by establishing a system which secure that components are changed before they fail.

The main incentive for establishing a barrier management system should be to provide a safer work place for the personnel. But regardless of what kind of focus this has amongst the companies, the PSA still requires that barrier management is established.

In the PSA regulations there are many requirements that directly and indirectly can be related to barrier management. A comprehensive and consistent management of barriers requires that one understands and maintains key relationships in the regulations. The requirements most related to this subject are found in the Management Regulations[5] Section 5, from this section the following arguments for why a barrier management system is needed can be extracted:

- There shall be established barriers that can both reduce the likelihood of error and hazard and accident situations evolve and limit potential damage and inconvenience.
- The barrier functions should be maintained throughout the lifetime of the facility.
- There shall be established strategies and principles for the design, operation and maintenance of barriers.
- There should be performance requirements for technical, operational and organizational elements that are necessary for the individual barrier to be effective.

All of the issues mentioned in the section over are covered by a barrier management system like the one mentioned in this report, and implementing a system like this contributes to make sure one operates accordance with the regulations.

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