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Principles for barrier management in the petroleum industry

PSA

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Foreword

Barrier management is about ensuring, on a systematic and continuous basis, that barriers are relevant, effective and robust. Requirements include:

- a systematic process for selecting and designing barriers, based on a need to protect something of value – to manage a specific threat in an acceptable manner
- selecting and dimensioning robust barriers, which also take account of uncertainty – one can never be sure that all possible future incidents have been identified or that the barriers will function as intended in such events
- accepting that barrier management is a continuous process.

This document is a product of the PSA's main priority related to barriers. Supervisions, investigations and surveys of the risk level in the Norwegian petroleum activity have identified relatively substantial differences between the players over their understanding of, and thereby their compliance with, the regulatory requirements related to barrier management. As a consequence of this, a number of nonconformities with significance for safety have also been identified – something the PSA has followed up through its supervisory activities.

That follow-up has highlighted a need to make the regulatory requirements related to barrier management more easily accessible. An explanation is also needed of the way the PSA, for its part, relates the stipulations in the regulations and the guideline texts to the content of relevant standards. However, this document does not form part of the formal petroleum regulations.

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Summary

The main purpose of barrier management is to establish and maintain barriers so that the risk faced at any given time can be handled by preventing an undesirable incident from occurring or by limiting the consequences should such an incident occur. Barrier management includes the processes, systems, solutions and measures which must be in place to ensure the necessary risk reduction through the implementation and follow-up of barriers.

Risk management requires a systematic use of appropriate analyses and studies in order to support decisions which could be significant for the risk associated with the activity.

The risk assessment is intended to help establish the risk picture. This will then be used in part to assess the need for barriers in order to reduce risk to an acceptable level and allow specified requirements to be met.

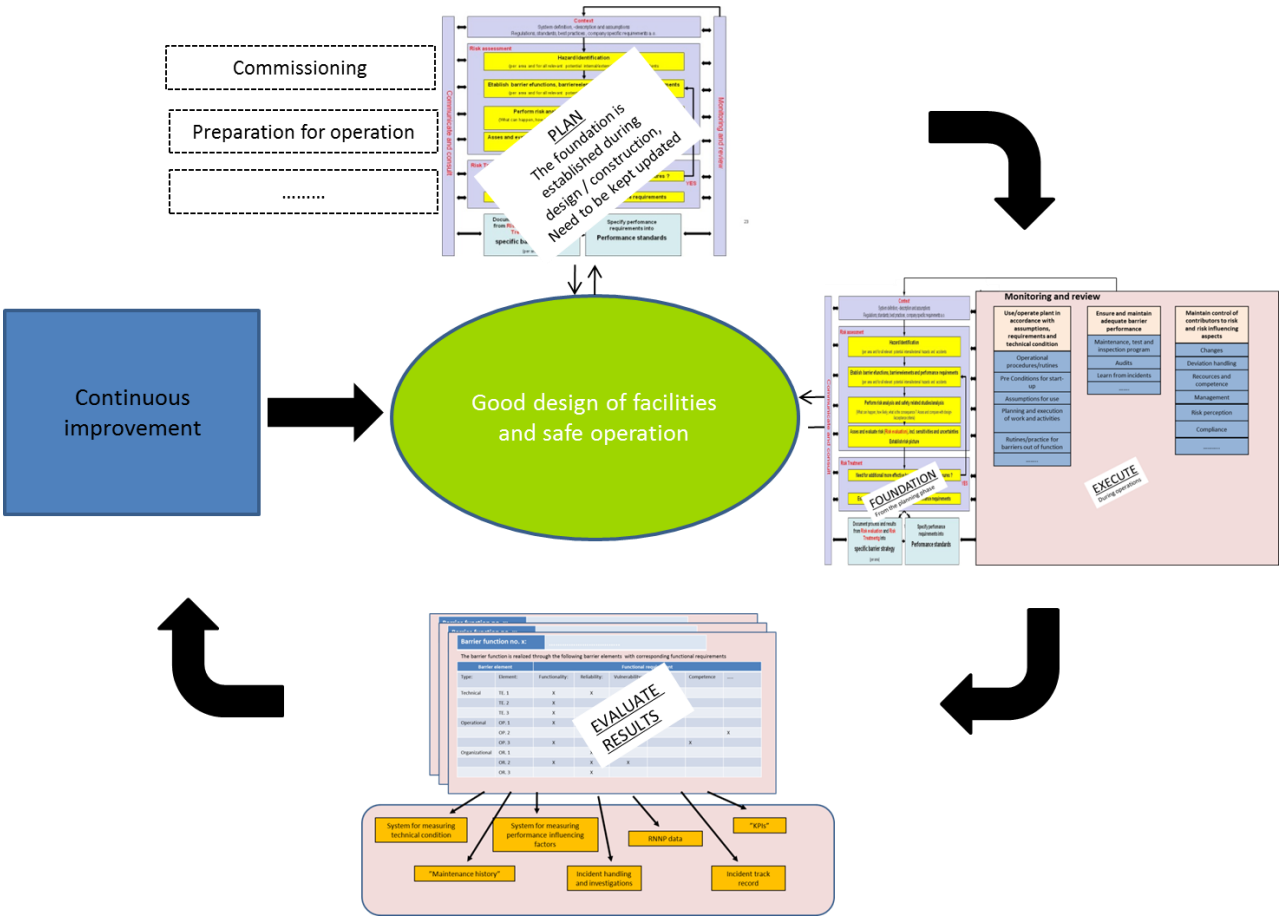

Figure 1 Model for barrier management

A precondition for ensuring good risk management is that the personnel involved have an understanding of why barriers are established (strategy) and of which performance requirements have been specified for the barrier elements intended to realise the barrier's function. Furthermore, relevant personnel must have an understanding of how decisions can directly or indirectly influence the risk picture or barrier performance. To deal with the risk over time, moreover, the

condition of the barriers must be monitored. That calls in part for a conscious attitude towards the presumptions and conditions (the context) on which the risk assessment has been based, and that changes are handled in a controlled manner.

On the basis of regulatory requirements, ISO 31000 *Risk management – principles and guidelines* and certain other ISO and NORSOK standards, the PSA has described a model for barrier management. This model is illustrated in figure 1 below. Generally speaking, it can be said that this model is based on a process for establishing the risk picture and barriers in a planning, design or construction phase. That basis must be monitored, reviewed and possibly updated during the execution or operational phase, and performance measurements or verifications have to be carried out in order to achieve continuous improvement and robust barriers throughout the life cycle.

Target audience

The target audience for this document is everyone with responsibility for or working on risk and barrier management.

Introduction

The following pages describe the principles for barrier management in the petroleum industry in Norway. This is about understanding and dealing with the potential hazards faced at any given time, finding solutions and characteristic which help to reduce a specific risk picture to an acceptable level, and planning to manage the residual risk. That also includes the need to design barriers to take care of possible uncertainties.

Good barrier management is not confined to the choice of good and robust solutions in the design phase. It also involves ensuring that the barrier's properties are not only maintained but also improved if possible over time. Furthermore, it requires that personnel who directly or indirectly influence the risk picture or barrier properties have an understanding of the consequences of their choices.

This document, on principles for barrier management in the petroleum industry, is a product of the PSA's main priority related to barriers. Supervisions, investigations and studies of the risk level in the petroleum industry have identified relatively substantial differences between the players in their understanding of, and thereby compliance with, the regulatory requirements related to barrier management. As a result, a number of nonconformities of significance for safety have also been identified. The PSA has followed this up through its supervisory activities.

That follow-up has highlighted a need to make the regulatory requirements related to barrier management more easily accessible. An explanation is also needed of the way the PSA, for its part, relates the stipulations in the regulations and the guideline texts to the content of relevant standards. However, this document does not form part of the formal petroleum regulations.

Definitions

Barrier**:** Technical, operational and organisational elements which are intended individually or collectively to reduce possibility/ for a specific error, hazard or accident to occur, or which limit its harm/disadvantages.

Barrier element: Technical, operational or organisational measures or solutions which play a part in realising a barrier function.

Barrier function: The task or role of a barrier. Examples include preventing leaks or ignition, reducing fire loads, ensuring acceptable evacuation and preventing hearing damage.

Barrier strategy: Result of a process which, on the basis of the risk picture, describes and clarifies the barrier functions and elements to be implemented in order to reduce risk.[1]

Barrier management: Coordinated activities to establish and maintain barriers so that they maintain their function at all times.

Performance requirements: Verifiable requirements related to barrier element properties to ensure that the barrier is effective. They can include such aspects as capacity, functionality, effectiveness, integrity, reliability, availability, ability to withstand loads, robustness, expertise and mobilisation time.

Performance influencing factors**:** Conditions which are significant for the ability of barrier functions and elements to perform as intended.

Context**:** External and internal frame conditions which must be taken into account in barrier management.[2]

Risk management**:** Coordinated activities to direct and control an organisation with regard to risk.[3]

Major accident**:** A major accident means an acute incident such as a major spill, fire or explosion which immediately or subsequently entails multiple serious personal injuries and/or loss of human lives, serious harm to the environment and/or loss of major financial assets. See the guidelines to section 9 of the management regulations.

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1 See NS-EN ISO 13702, referenced in the guidelines to section 5 of the management regulations and the way "fire and explosion strategy" (FES) is defined: "Results of the process that uses information from the fire and explosion evaluation to determine the measures required to manage these hazardous events and the role of these measures". In other words, "strategy" is used in a special sense in a barrier context. The fact that ISO 13702 uses the expression "risk reducing measures" while the PSA uses the term "barrier" has no practical significance.

2 See ISO 31000 Risk management, principles and guidelines. The use of term "context" in connection with barrier management corresponds to its use by ISO 31000 for risk management.

3 See ISO 31000 Risk management, principles and guidelines. ISO 31000 uses both the expression "risk management" and the expression "to manage risk". Generally speaking, risk management refers to the architecture (principles, framework and processes) for managing risk effectively, while "to manage risk" refers to the application of this architecture to specific risks.

Barrier management – an integral part of HSE management

Barrier management represents an integral part of the companies' health, safety and environmental (HSE) management which in turn forms an integrated part of their corporate governance. As a result, management standards such as ISO:9000 and ISO:31000 can also form a basis for barrier management.

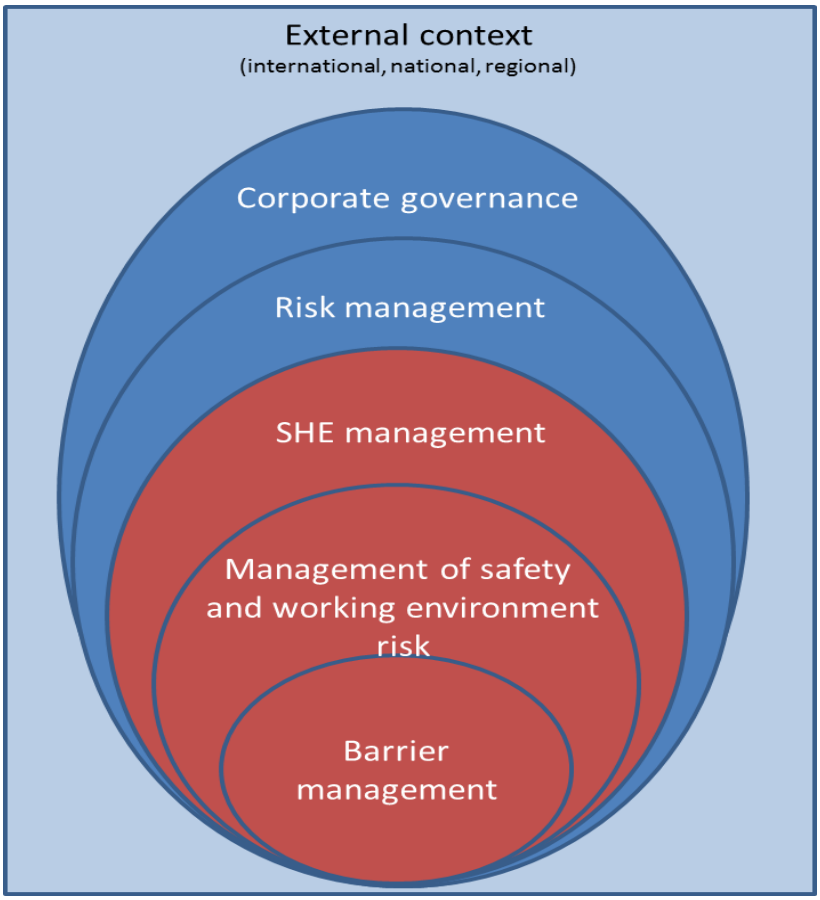

Figure 2: Barrier management – an integral part of HSE management

As the HSE regulations make clear, barriers represent a key element in reducing risk on both offshore- and land based installations. Requirements for barriers are rooted in the "energy and barrier" perspective, which encourages a separation between hazardous energy and assets such as life, health, the natural environment and material facilities. The barrier perspective is suited to prevent a broad range of hazards and accidents at facilities offshore and land based (fire, explosion, blowout, electric shock, chemical exposure, physical strain, radiation, falls, crushing and so forth).

Effective barrier management is a fundamental condition for prudent operation. At the same time, appreciating that it does not provide a complete solution for acceptable activity is also important.

An accident would hardly occur if the barriers in a facility cover the identified risks and are relevant, robust and effective. The activity will be safe: if the plant-specific context is adequately understood, if the risk and uncertainty have been adequately identified, if alternatives have been

assessed at the right time and are sufficiently consistent with the identified risk picture, if measures chosen to reduce risk are consistent with the decision base and the uncertainty in the latter, and so forth. Behind each of these "ifs" lies a number of more or less controllable prerequisites and operating parameters, a number of more or less interdependent variables, a number of more or less sequential processes and so forth. The systematic approach assumed by barrier management will not serve to address all the prerequisites and operating parameters necessary for success in this area.

Lessons learnt from accidents have contributed to recognition that the industry is complex and that a range of different perspectives and approaches are required to address every aspect of importance for ensuring acceptable operation and to ensure not least that important premises for effective barrier management are in place.

Barrier management covers many but not all of the important considerations for achieving prudent operation. It must accordingly be viewed in relation to management of important parameters for barrier management (culture, contracts, efficiency improvement processes and the like), even when processes for managing these parameters derive from accident perspectives other than the barrier perspective (such as the high-reliability organisation (HRO), information processing perspective, resilience engineering and so forth).

What is meant by barriers and barrier management?

The barrier concept is used by the petroleum industry and by society at large in a number of contexts and often with different meanings (differing/missing definitions of the concept). This means, in part, that one cannot assume a common and unambiguous understanding of the concept, and that one should therefore define what is meant and how it should be understood in the specific context.

A number of barrier-related requirements are specified in the regulations. Unambiguous definitions of the important terms will be fundamental for ensuring a common understanding of these requirements.

Personnel, equipment and systems are referred to or described not as barriers, but as barrier elements. Performance requirements must be set for the technical, operational or organisation elements required for the individual barrier to be effective (in other words, to realise its barrier function).

Realisation of a barrier function can be illustrated with the aid of a hierarchy, where barrier functions form the topmost level and barrier sub-functions and performance standards (PS) the lower levels. Figure 3 presents an example of some barrier sub-functions and PSs which will typically be involved in realising the barrier function "reduce explosion-related risk in the area".

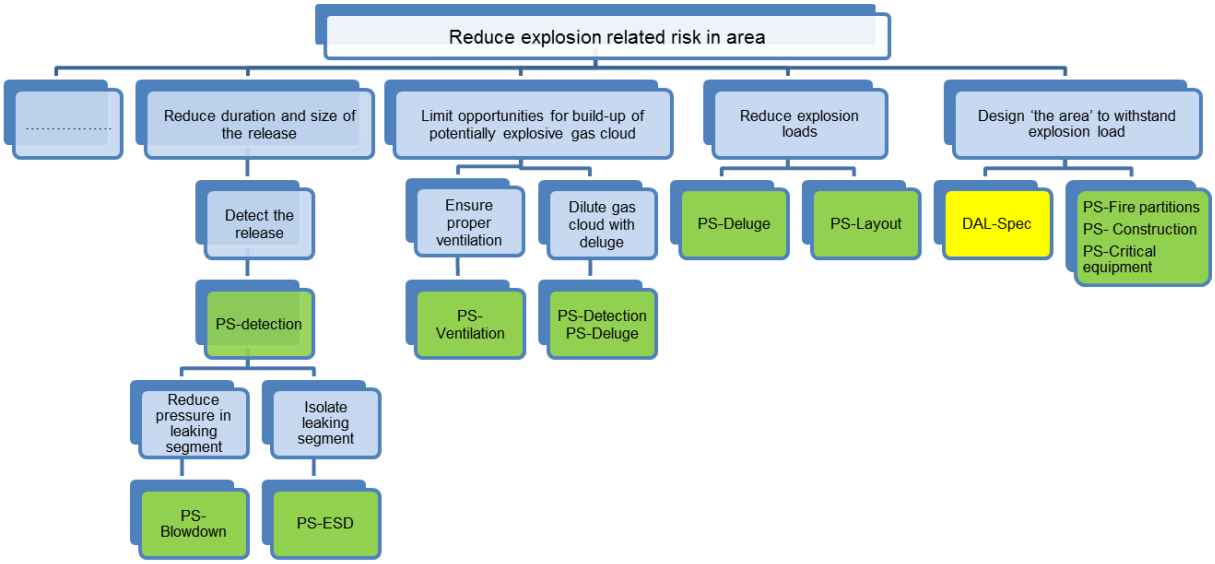

Figure 3: Example of barrier functions at various levels

For the barrier sub-function "blow down of the leaking segment", will as an example, push buttons, Fire & Gas logic and valves represent technical barrier elements. If a control room operator must initiate manual actions in order to realise the "blow down of the leaking segment" function, that person will be incorporated as an organisational barrier element. Actions carried out will be an example of an operational barrier element.

In order to manage risk in a proper manner, the necessary barrier functions and elements need to be identified. These must be based on the risk picture. Furthermore, the necessary performance requirements have to be established so that the barrier function can be realised as intended. The demand for effective barrier management applies throughout the life cycle of an offshore or land-based facility, including during the execution of every activity/operation. This means that many conditions must be monitored and continuously followed up after the design and construction phase. In addition to normal operational and maintenance activities, systems/routines must be in place to ensure efficient communication, competence management, monitoring of results and management of change.

On the basis of regulatory requirements, ISO 31000[4] *Risk management – principles and guidelines* and ISO standards for management and leadership, this document describes a barrier model which specifies principles for barrier management. Derived from ISO 31000, the PSA's starting point has been the risk management process shown in figure 4.

4 ISO 31000 is also used as the starting point for NORSOK Z-013 version 3 – Risk and emergency preparedness assessment, and in OGP report no 415 on Asset integrity – the key to managing major incident risk.

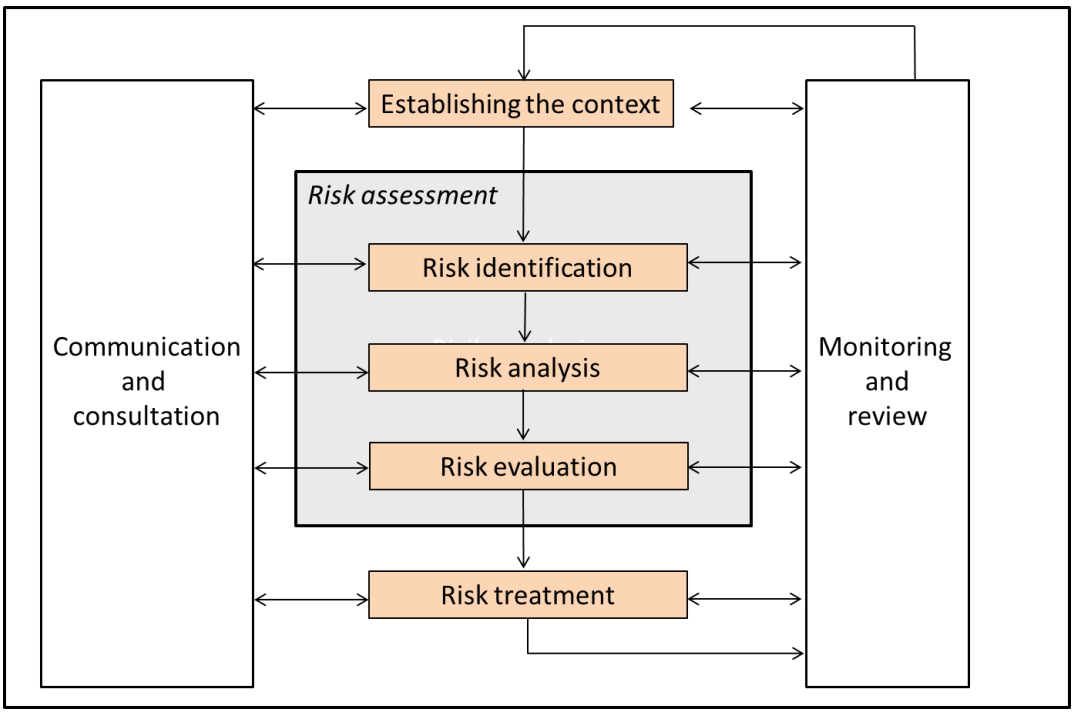

Figure 4: Process for risk management in ISO 31000

Figure 5 illustrates the barrier management model. Generally speaking, the model is based on a process for establishing the risk picture and barriers in a planning, design or construction phase. This basis must be monitored, reviewed and possibly updated during the execution or operational phase, and measurement and verification has to be carried out in order to be able to secure continuous improvement and to achieve robust barriers throughout the whole life cycle.

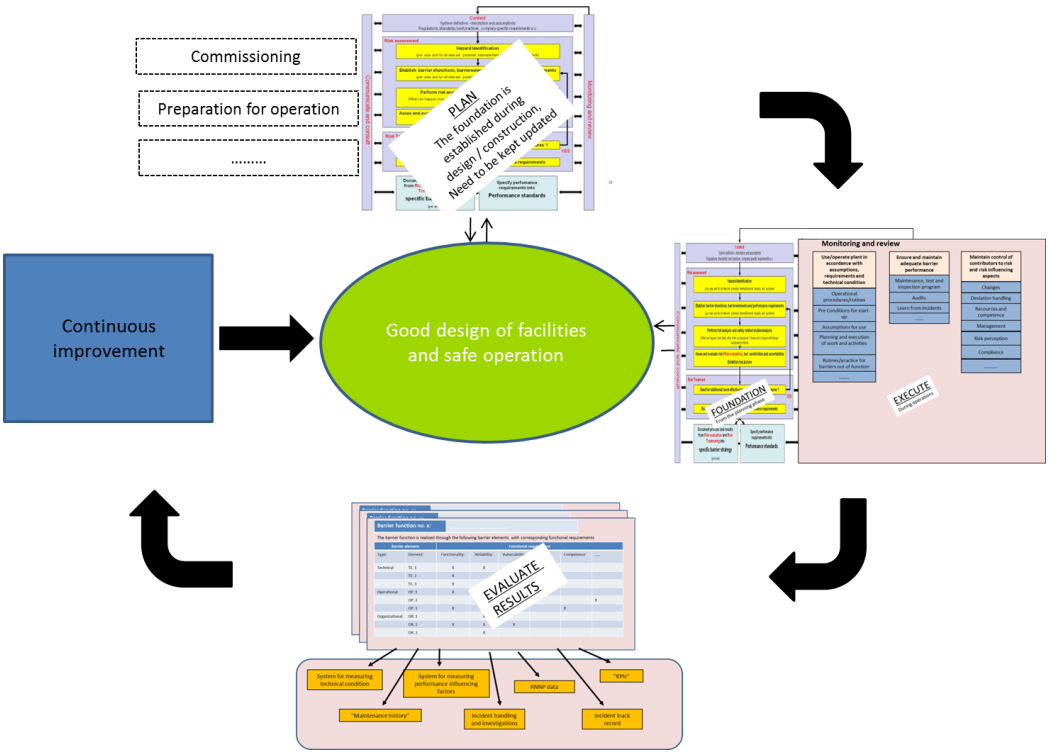

Figure 5: Model for barrier management

Barrier management process in the planning phase

Figure 6 illustrates a process for barrier management in the planning phase. This chapter discusses the various stages in the process (the various boxes) and the relationships or links between them.

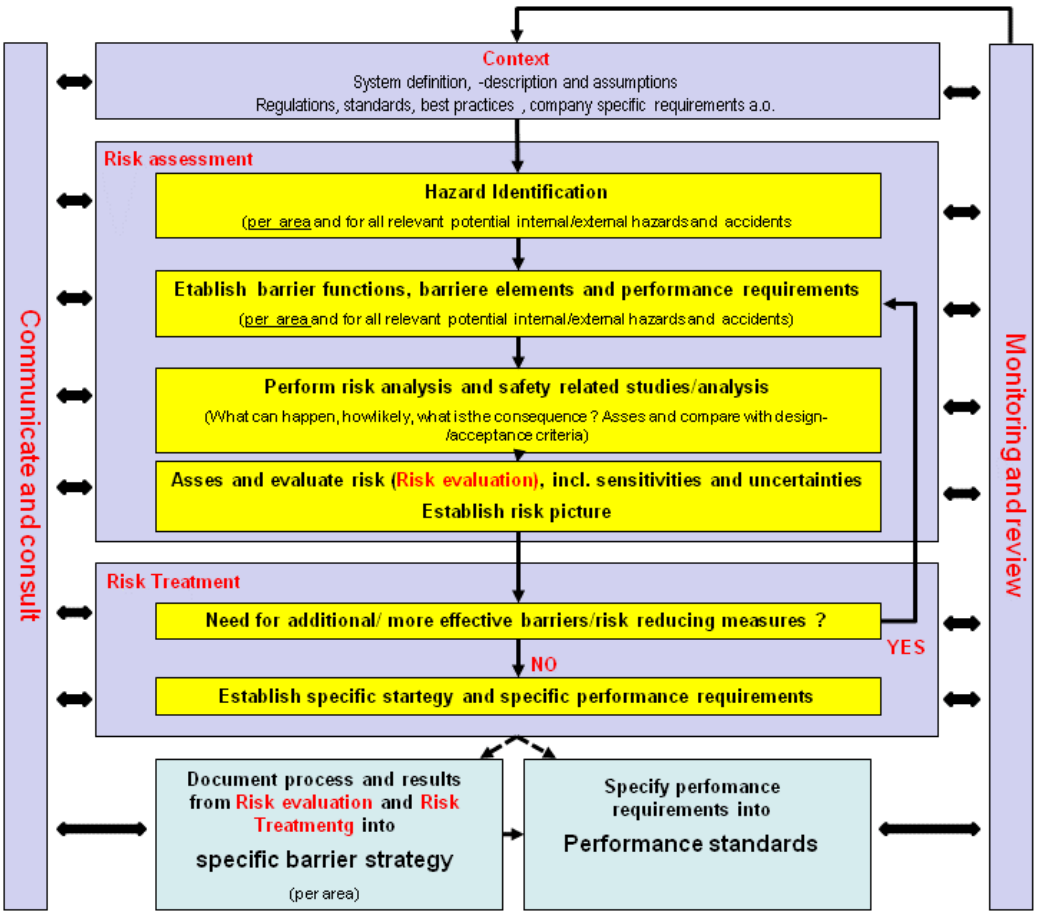

Figure 6: Barrier management in the planning phase

Managing and following up barriers in the execution or operational phase and how to measure and practise continuous improvement are described later in this document.

Determine the context

The context is the operating parameters and guidelines (external, internal and project/activity-specific) which are relevant for executing the other stages in the process. In other words, it encompasses everything which is or could be important for implementing the process and for shaping the strategy ultimately adopted for managing the specific risk identified by the process. Conditions significant for implementing the process and for the solutions which the process yields could include:

- requirements and guidelines in the regulations, standards, and company-specific guidelines
- company-specific strategies, goals and principles for risk- and barrier management
- the actual design and condition.

As illustrated in figure 6, the barrier management process will result in the establishment both of a specific barrier strategy and of specific performance requirements. This documentation will occupy a very important place when one in the operational phase execute activities, and verifies

that these are in accordance with the premise for operation. Being conscious of this aspect when establishing the context is important in order to ensure that the format and content of the strategy and performance requirements can be developed and communicated in a good and suitable manner.

To achieve continuous improvement which contributes to good and robust solutions, the requirement for risk reduction must also form part of the context. See section 11 of the framework HSE regulations. Steps must also be taken to ensure that this is taken care of throughout the process.

Establishing ambitious goals and performance requirements as part of the context means that the subsequent analyses will reveal whether robust solutions have been chosen. On a number of occasions, establishing performance requirements late in the planning process has meant delays and cost increases. In many cases, this can also result in less robust solutions.

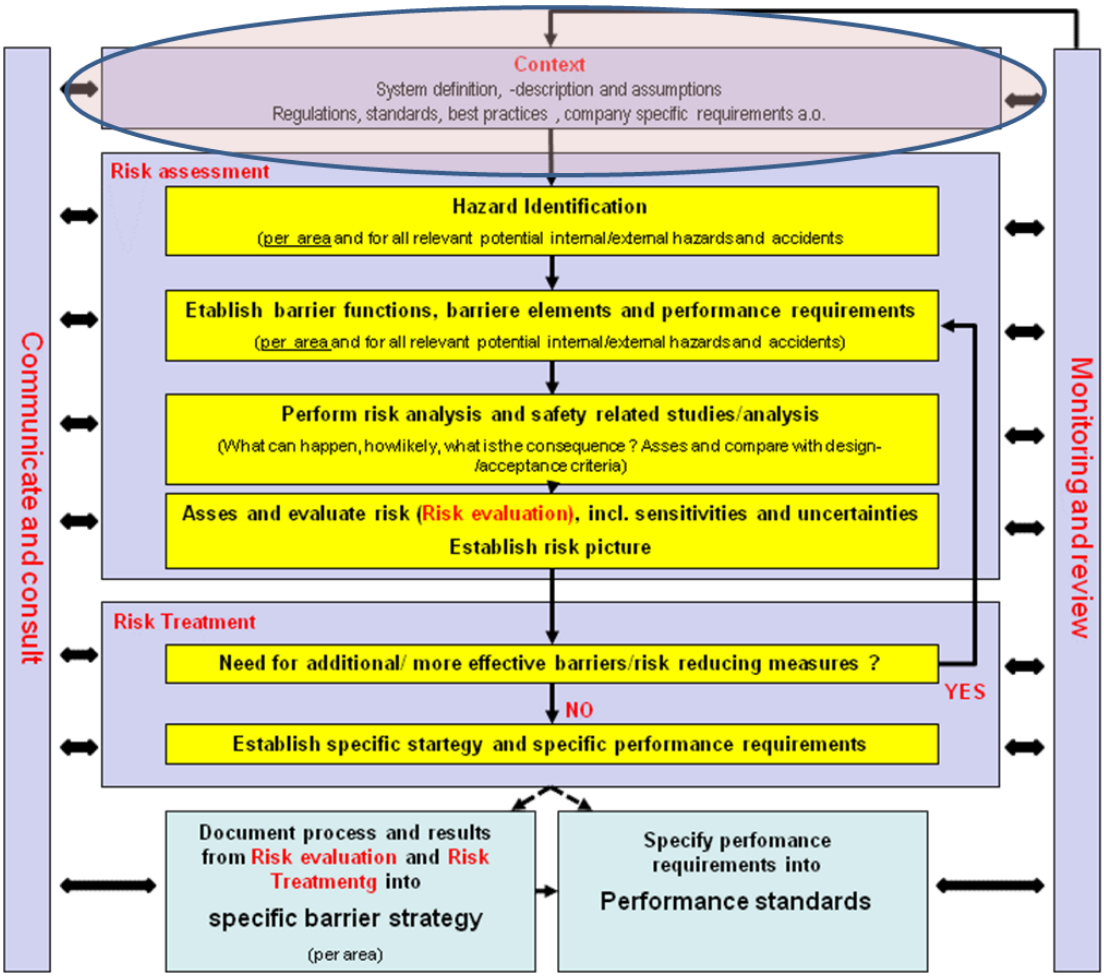

Figure 7: Context in the barrier management process

Risk assessment

Risk assessment is intended to identify, establish and describe barrier functions and to specify the properties of the individual barrier element.

The collective term "risk assessment" includes the following steps:

- identify potential hazards and accidents
  - what their causes might be
  - what harm and consequences they could result in
- establish barrier functions and elements, and associated performance requirements
- carry out risk assessments and necessary safety studies/analyses
- assess and evaluate risk, including sensitivity and uncertainty – establish the risk picture.

Each of these steps is discussed below.

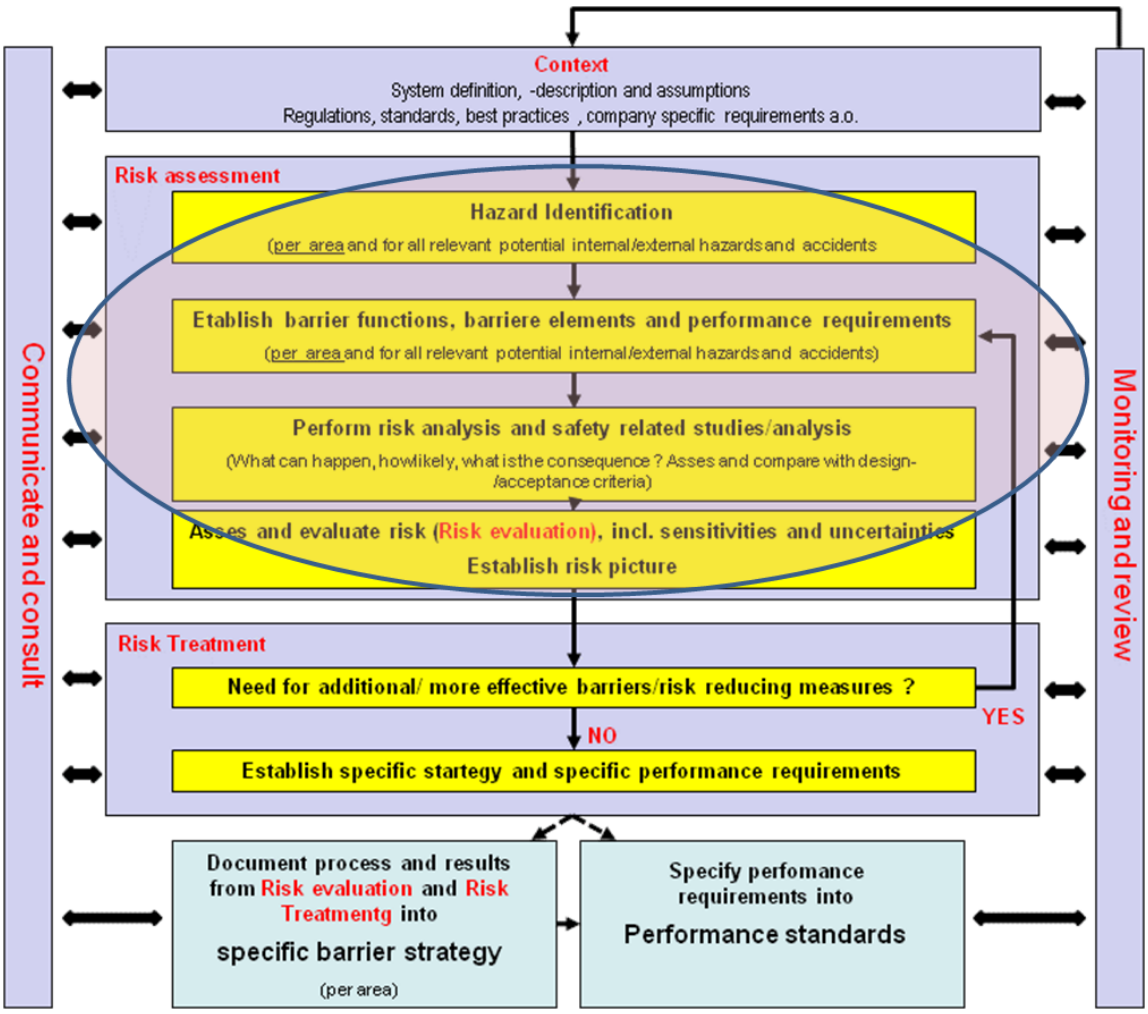

Figure 8: Risk assessment

Identify potential hazards and accidents

Identification of potential hazards and accidents must be carried out with a sufficient degree of detail, in order to identify all the situations which a specific barrier element could play a role in. In most cases, this means that identification must take place at an area level (by fire area, for instance) and that the assessment covers a) all incidents which might occur in the specific area and b) incidents occurring in other areas which could expose the specific area. For certain types of hazard, it could be more appropriate to adopt an exposure perspective and not necessarily an area one.

> *Example: For a fire pump room on a facility, all the hazards and accidents which could occur in that room must be identified along with all the external hazards and accidents which could expose the fire pump room (such as external fires and explosions). Hazards and accidents mean in this case those circumstances which in themselves could both cause injury/loss of human life, harm to the natural environment or damage to material assets, as well as those which could result in a fire pump failing to start when required or to deliver sufficient quantities of water at the right time and for a required duration.*

> *Example: Ear protectors are a barrier against hearing damage. The performance requirement for their technical properties can be expressed as a reduction in decibels, with the necessary safety margin, and this requirement must be tailored to the relevant noise environment in which the protectors are to be used. Examples of performance requirements for operational barrier elements could be rules for ear protectors to be carried or available at all times outside the living quarters, signs posted where they are to be used, or personnel being given instruction in where and how they are to be worn. Requirements could also be specified for maintenance and frequency of replacement.*

When finalised, the specific strategy must be able to document the need for and role of all the barriers established to deal with the specific risk. To be able to establish a strategy, thought must be given at an early stage in the risk assessment process to how the relationships between hazards and accidents and the established barrier functions (with associated barrier elements) is to be grouped and documented. Furthermore, the risk factors which require more detailed analysis in order for the necessary decisions to be taken must be constantly assessed and clarified.

Establish barrier functions and elements, and associated performance requirements

Once potential hazards and accidents have been identified and assessed, the necessary barrier functions and elements must be identified and the process on establishing associated performance requirements should start.

In many cases, requirements which can be derived from established standards or best practices will form the basis for the early design phase of a facility or early planning of an operation. This will be followed up by risk assessments, identification of uncertainties, and – as a consequence of additional details in the project's development/planning phase – reassessment and optimisation of

performance requirements. Establishing performance requirements for a number of barrier elements will first be possible after these have been subject to one or more iteration processes.

Ending up with good and robust solutions calls for great awareness of the need to establish necessary barriers against various types of injury/damage and incidents at an early stage. An assessment must accordingly be made of whether an adequate set of barriers has been established at an early stage, even though the specific performance requirements will first be finalized later in the design/planning phase.

Carry out risk analyses and necessary safety studies/analyses

Intuitively, dividing the identification of potential hazards and accidents from what has here been characterized as risk analyses might appear a little artificial.[5] However, these components have been consciously separated in the process described for barrier management. One reason is that the necessary barrier functions and the associated performance requirements for barrier elements can often be derived from relatively simple qualitative assessments of potential hazards and accidents. Another is that practice in the Norwegian industry often involves starting with quantitative risk analyses and related safety studies before sufficient attention has been paid to the steps described above. This can mean that the basis for large-scale/extensive risk analyses and safety studies has been not established in a way which is good enough. Quantitative risk analyses and other studies are necessary to establish or specify certain performance requirements, but have limitations as a basis for establishing the whole spectrum of specific performance requirements for all relevant barriers. Revision 3 of NORSOK Z-013 – and particularly the requirement that the analysis must be appropriate, see section 17 of the management regulations – will also help to make quantitative analyses significantly more suitable as part of the decision base for establishing and/or refining necessary performance requirements.

Risk analyses conducted as part of the decision base for barrier management must be planned and executed in such a way that they are sufficiently detailed and appropriate for their use. Among other purposes, such analyses will be used to identify the need for barrier functions and to establish some of the requirements to be set for the barrier elements. Risk analyses to be carried out must focus on what is required to achieve adequate independence between barriers and to end up with robust solutions. That part of the analyses which assesses and clarifies sensitivity and uncertainty, and which is also intended to form a basis for any further risk evaluation, will be important in this connection.

The prerequisites which form the basis for a decision must be expressed so that they can be followed up. This helps to ensure that operations accord at all times with the assumptions that forms the basis for the analysis. Risk analyses are based upon a numerous input data and preconditions. Established practice shows that in most cases a need will exist to make the preconditions more explicit and known. The specific barrier strategy must indicate which

5 Many people would correctly argue that identifying potential hazards and accidents is in itself an important part of the risk analysis, and/or that this is a risk analysis in itself. Interpretations of ISO 31000 accordingly also exist which choose to integrate these. See Aven, T, Risikostyring, Universitetsforlaget, 2007.

assumptions are significant for the individual barrier function and element. This does not necessarily mean that all prerequisites have to be described in one and the same document/system, but it must be easy to obtain such information by referring to the strategy.

Assess and evaluate risk, establish the risk picture

Results from the risk analyses carried out must be compared with and evaluated against established decision criteria. These criteria, or the basis against which the analysis results are assessed, can build on organisational goals, and on external and internal contexts. In certain cases, risk criteria can also be derived from standards and regulations.

Generally speaking, it is important that the risk picture is established, refined and evaluated with an eye to their specific use. Where barrier management is concerned, the risk picture will be used both to establish the necessary barrier strategy and to ensure that the barriers have the necessary properties. Risk evaluation and criteria's must accordingly be adjusted to the object of the whole risk management process. For a number of performance requirements, it will not be sufficient to measure the results against overriding acceptance criteria for personnel safety and/or loss of main safety functions. See section 9 of the management regulations.

> *Example: The results from analyses of hazards and accidents may indicate that certain barriers are not required, since they make only a limited contribution to quantitative values/results generated in traditional quantitative risk analyses. This could be, for example, because the probability of a fire is considered to be low or because the consequences of a fire with or without the relevant barriers produce insignificant differences in the results. Can it then be concluded that these barriers are unnecessary? A first check when assessing this question is to see whether the relevant barriers are specifically required. Regulatory provisions, for example, could mean that specific requirements must be set for fire protection of a compartment regardless of analysis results and/or whether a risk acceptance criterion has been satisfied. One purpose of the risk analysis for the relevant compartment will then typically be to assess whether protection is required over and above such minimum requirements.*

As specified in section 17 of the management regulations, sensitivity and uncertainty assessments must be performed as part of every analysis. The main purpose of this provision is to provide users of the analysis with the best possible basis for understanding the strengths, weaknesses and limitations of the individual analysis, which assumptions, prerequisites or assessments are particularly significant for the results of the analysis, and the uncertainties presented by the input parameters and assessments on which the analysis is based. It is furthermore important that the sensitivity and uncertainty assessments in analyses are utilised in the work of risk treatment, whether that involves communicating the need for risk-reducing measures in barrier strategies or detailing specific performance requirements.

In most cases, relying exclusively on quantitative risk analyses will not provide an adequate basis for concluding whether certain barriers are required, or for establishing specific performance requirements for the individual barrier elements.

Risk treatment

Section 11 of the framework HSE regulations provides that efforts must always be made to reduce risk as far as is practicable. The experience acquired by the PSA through its supervision has shown that working in a structured and purposeful manner to minimise risk at an early stage provides a significantly better chance of implementing good solutions without incurring substantial costs or facing major challenges.

Nor is the requirement to reduce risk confined to measures which can be quantified in the results of a risk analysis. "Preventing hot surfaces on equipment which could be exposed to diesel oil leaks", for example, will be a sensible measure in most cases even if its effect cannot be quantified in a QRA, TRA or the like. Common sense should therefore be the guiding principle when assessing the effect of measures, rather than relying exclusively on the results of risk and/or cost/benefit analyses. On the other hand, risk analyses will in many cases represent a necessary and important supplement when assessing the effect of various measures, so the one does not exclude the other. In other words, this is a case of finding the tools, analyses and so forth which provide relevant decision support for the various issues.

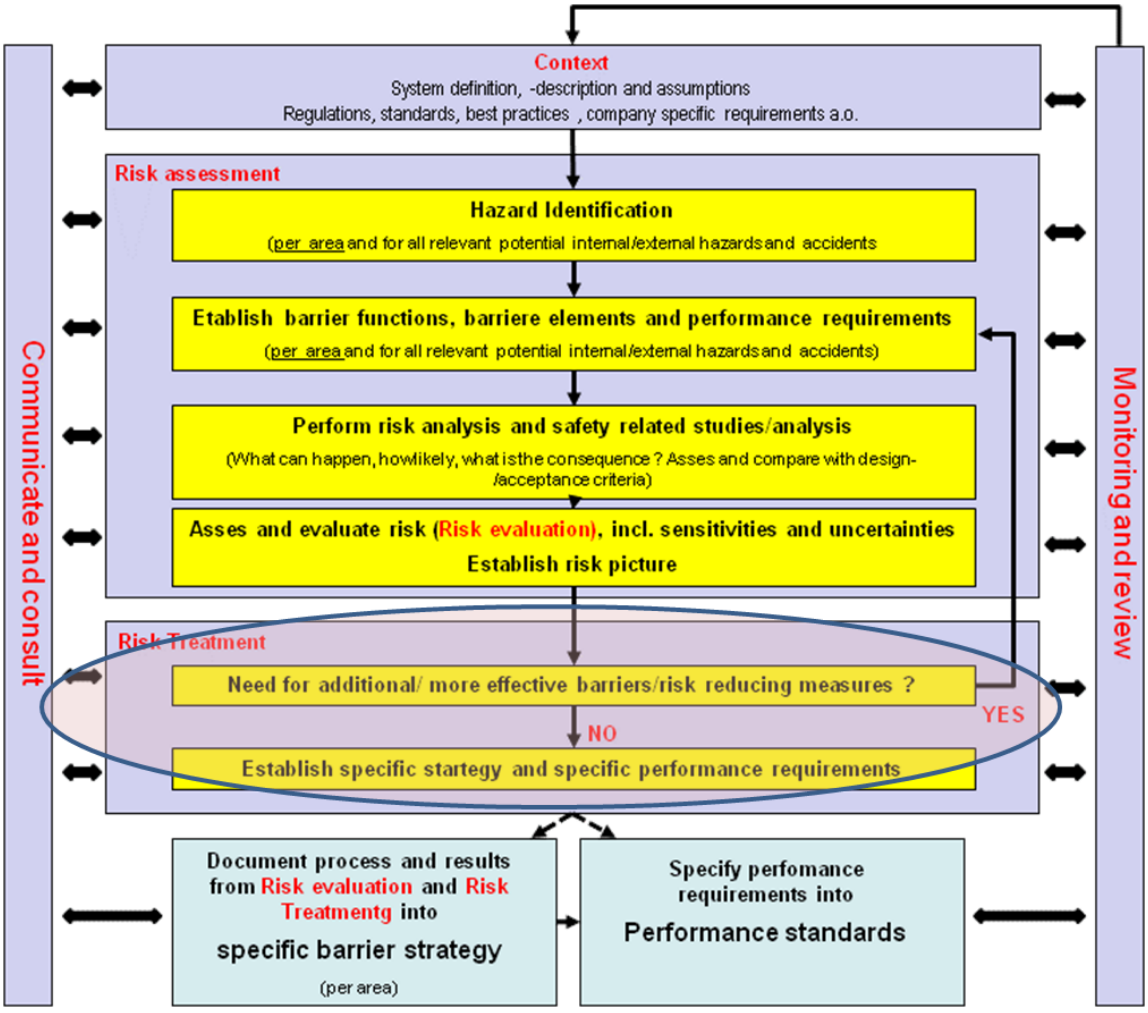

Figure 9: Risk treatment

Establish a specific barrier strategy and specific performance standards

The process for establishing, updating and maintaining a sufficient set of barriers involves two key end products:

- a specific barrier strategy
- specified performance requirements in specific performance standards.

A brief description of the principles and requirements related to establishing these end products is provided below.

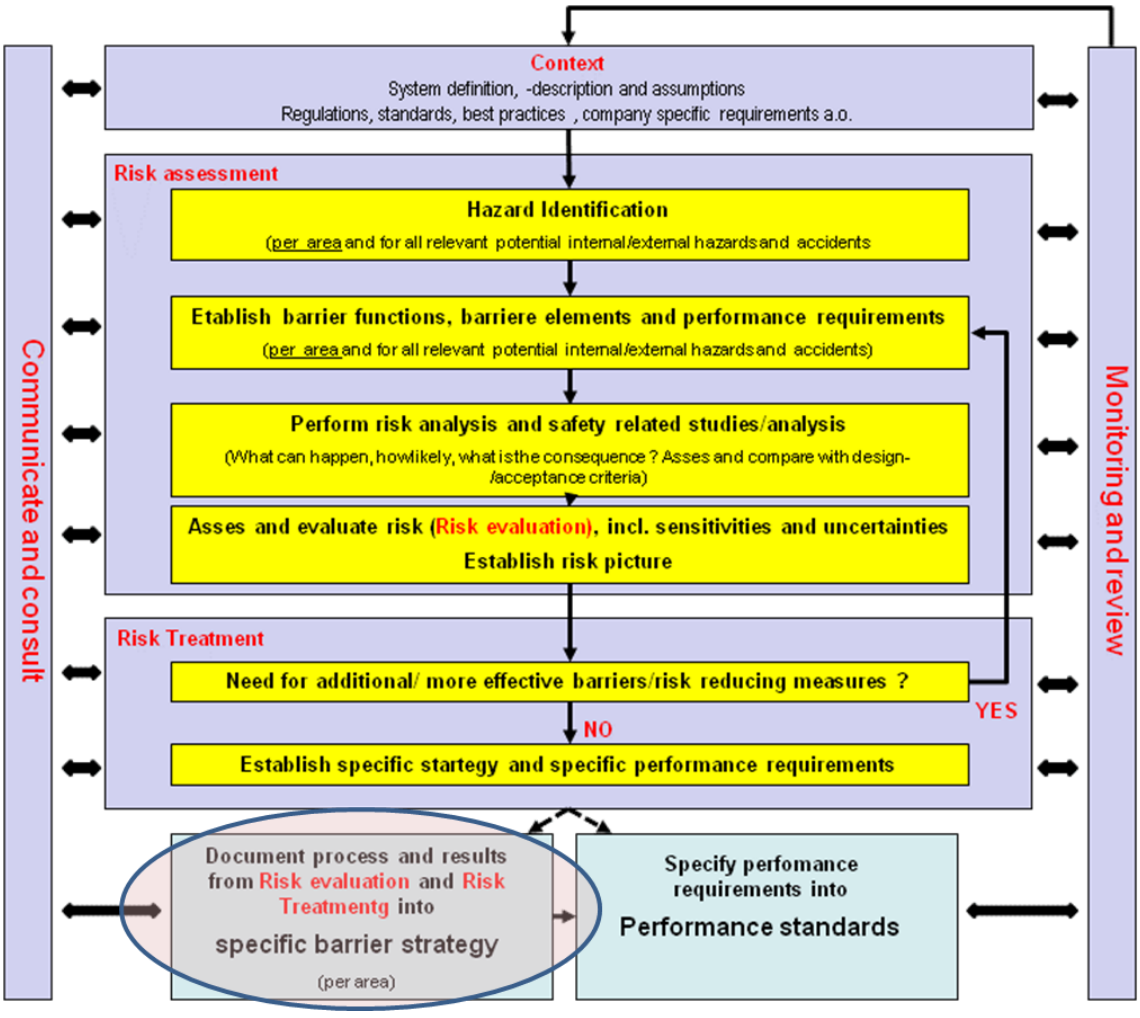

Figure 10: Specific barrier strategy in the barrier management process

Specific barrier strategy

The following principles should form the basis for a barrier strategy. It shall

- be shaped in such a way that it contributes to giving everyone involved a shared understanding of the basis for the requirements for the individual barrier functions, including
  - which phases, operations and activities the strategy has been established to cover
  - which harm, hazards and accidents could occur in the phases, operations and activities the strategy has been established to cover
  - which barrier functions are required to deal with these situations
  - where additional information is to be found about the performance requirements which specifically apply for the individual barrier
- be broken down to an appropriate level on/in the individual facility (such as area, system, equipment or node), this break down must be clarified for each case
- be broken down to an appropriate level to cover the various phases, operations and activities to which it applies
- be kept updated at all times
- identify the role/task of the various barrier functions, whether this is to prevent hazards or accidents from occurring or to limit harm/loss should one occur
- identify important prerequisites which are significant for the individual barrier function and element
- identify the transition between the strategy and the performance requirements established for the individual barrier – in other words, the strategy must provide information on where the various performance requirements for the individual barrier element and function are described.

Barrier strategies do not necessarily need to be described in separate documents, but can be included in other relevant documentation where this is natural and appropriate. The crucial consideration is not whether the title of the individual documents contain the word strategy, but whether the strategy is adequately described, detailed and updated to fulfil the intentions of the provisions on and for a barrier strategy as specified in section 5 of the management regulations. The need to develop separate barrier strategies should thereby be viewed in relation to the other documentation which exists or is drawn up at the individual facility.

Specified performance requirements in specific performance standards

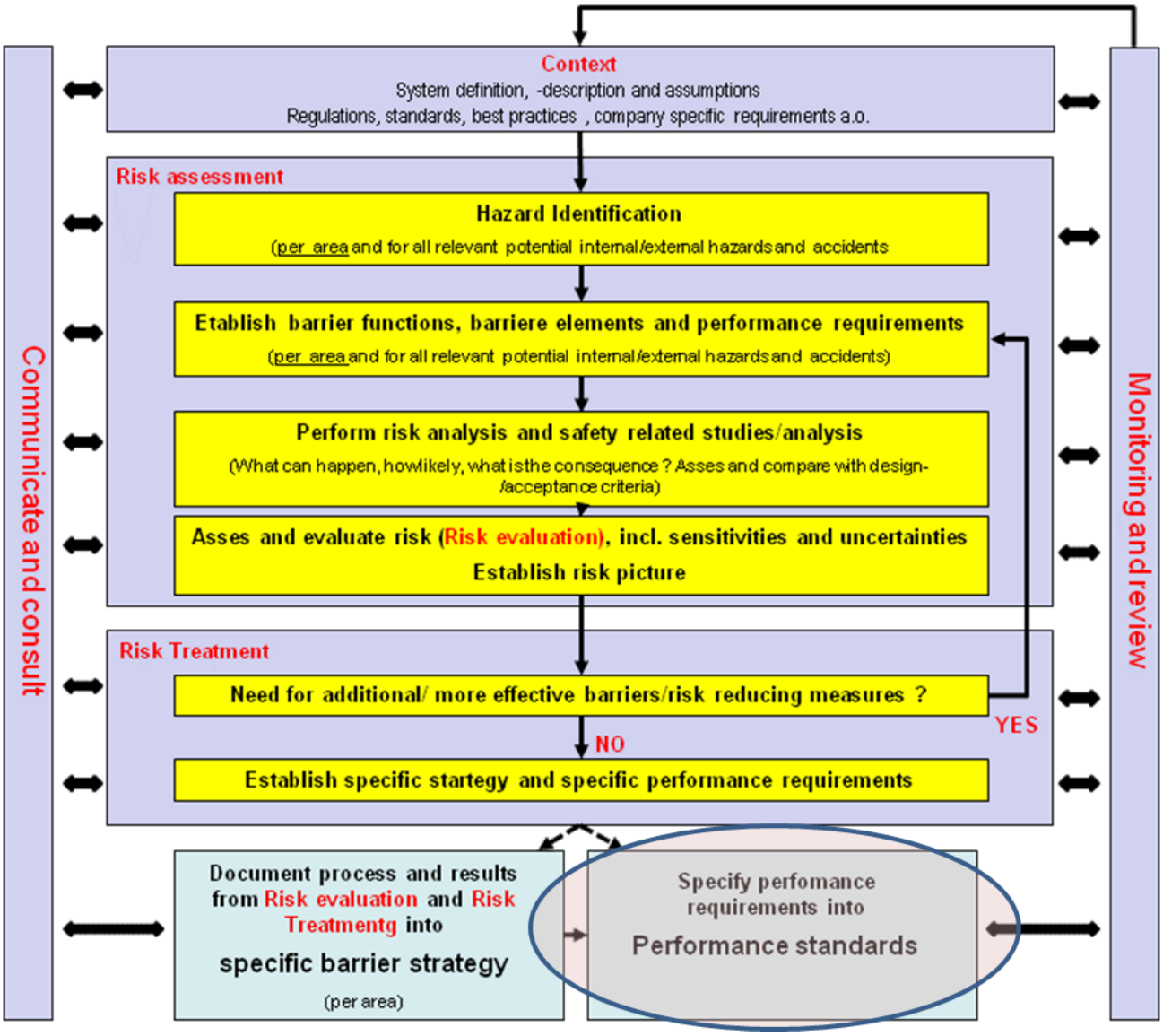

Figure 11: Specific performance requirements in the barrier management process

Performance requirements must be set for technical, operational and organisational barrier elements. See section 5 of the management regulations. In this context, performance means the properties which a barrier element must possess in order to ensure that the individual barrier and its function will be effective. It can include such aspects as capacity, reliability, availability, effectiveness, ability to withstand loads,[6] integrity, robustness and mobilisation time. One way to

6 It is important to be clear about the difference between "design accidental load" and "dimensioning accidental load" (DAL) as specified in NORSOK Z-013. Design accidental load means the accidental load which forms the basis for design. Dimensioning accidental load means the accidental load which barrier function(s) and element(s) must be able to withstand for a required period to satisfy the acceptance/tolerance criteria for risk. The design accidental load to be specified must as a minimum always correspond to the dimensioning accidental load. At the same time, it is important to be clear about the necessity in some cases of establishing a design accidental load which involves the capacity to withstand a higher accidental load than is specified by the

group and explain performance requirements related to technical barrier elements is illustrated in figure 12.

As with technical barrier elements, specific performance requirements must be established for operational and organisational elements which play a key role in realising various barrier functions. In many cases, technical, operational and organisational elements must all be present to realise a barrier function. More detail will be provided later in this document about which barrier elements can be characterised as operational or organisational. In addition, the concept of performance influencing factors will also be introduced as a means of identifying those aspects for which it would be inappropriate to establish performance requirements, but which are nevertheless important and which must be followed up in a barrier context.

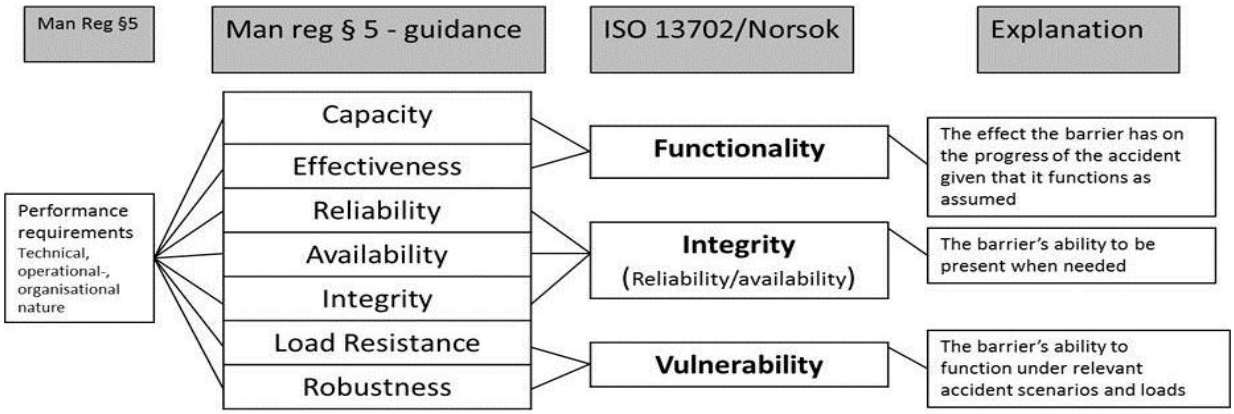

Figure 12: Categorising performance requirements for technical barrier elements

In some cases, it will be appropriate to establish performance requirements directly for the actual barrier function. NORSOK S-001, for example, uses the expressions/terms "ship collision barrier" and "containment". The function of these barriers is to "prevent ship collisions" and "prevent leaks". Performance requirements established for these two barriers are in some cases directed more at the barrier function than at barrier elements.

It could be appropriate to group the established performance requirements in performance standards at the system/function level, as some players in the industry have done. NORSOK S-001

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dimensioning accidental load. This is because the dimensioning accidental load is typically established in accordance with the "1x10-4" requirement for main safety functions. See sections 7 and 11 of the facilities regulations. In order to determine a design accidental load for a relevant accident type, however, other considerations must also be taken into account. In some cases, specific regulatory provisions may mean that a minimum design accidental load must always be set regardless of acceptance criteria for main safety functions and calculations of dimensioning accidental loads. One example is that the determination of a fire load to form the basis for a design must always as a minimum relate to specific requirements associated with ESD sectioning of the process plant. See section 33 of the facilities regulations. In addition, "as low as reasonably practicable" (ALARP) assessments will always be relevant for ensuring additional risk reduction. See section 11 of the framework HSE regulations. In practice, the result could be that the design accidental load must be set higher than the dimensioning accidental load.

is built around this thinking. In addition to specifying performance requirements for barrier elements, a performance standard should clarify interfaces with other barriers (systems/functions).

NORSOK S-001 provides the following explanation of the performance standard term in chapter 4.3:

> *Safety performance standard shall be the verifiable standard to which safety system elements are to perform. The objective of the specific safety performance standards is to add any supplemental safety requirements other than those specified by authority requirements and standards. The performance standards shall be based on the safety strategy document(s) and these should be read in conjunction with each other.*

The specific safety performance standards shall ensure that barriers, safety systems or safety functions:

- are suitable and fully effective for the type hazards identified
- have sufficient capacity for the duration of the hazard or the required time to provide evacuation of the installation
- have sufficient availability to match the frequency of the initiating event
- have adequate response time to fulfil its role
- are suitable for all operating conditions."

Establishing and using (a) specific barrier strategy(ies) and associated performance standards will be crucial for the ability to achieve effective barrier management. Good usage requires that this documentation is sufficiently well-known to relevant personnel on/in the individual facility. Specific barrier strategies and associated performance standards could be used, for example, to:

- clarify the relationship between specific risk assessments and the role of barrier functions
- provide an overview of specific performance requirements tailored to a specific risk picture and strategy
- describe and document solutions other than those specified in referenced standards/codes
- specify relevant supplementary documentation in connection with established performance requirements
- identify and classify systems/equipment in terms of the consequences of potential functional failures
- plan and/or execute maintenance to safeguard the performance of barrier functions and elements in every phase of the life cycle
- provide input for procedures
- provide input to performance requirements for technical, operational and organisational barrier elements required to handle emergency response in an acceptable and robust manner
- competence management
- management of change
- verification activities
- establish barrier-related measurement parameters
- maintain an overview of nonconformities and exemptions
- identify compensatory measures

- provide input for studies and analyses
- communication and consultation
- monitoring and assessment.

Communication and consultation

The responsible party must ensure (and demonstrate) that communication and consultation with both internal and external stakeholders are appropriate throughout the barrier management process. This is intended in part to ensure:

- good quality – by drawing on relevant expertise and experience throughout the process, including when establishing the context, when conducting risk assessments and management, and for supervising and monitoring at all times
- participation by and a sense of ownership among stakeholders who will be affected by decisions in every phase
- understanding of the background to decisions
- that risk analyses are communicated in such a way that target audiences obtain a nuanced and coherent presentation of the analysis and its results
- that documentation of the barrier strategy(ies) is actively used to provide those involved with a common understanding of the basis for the requirements specified for the various barriers.

Communication and consultation are not to be regarded as an independent activity, but as one which will pervade the whole barrier management process in every phase.

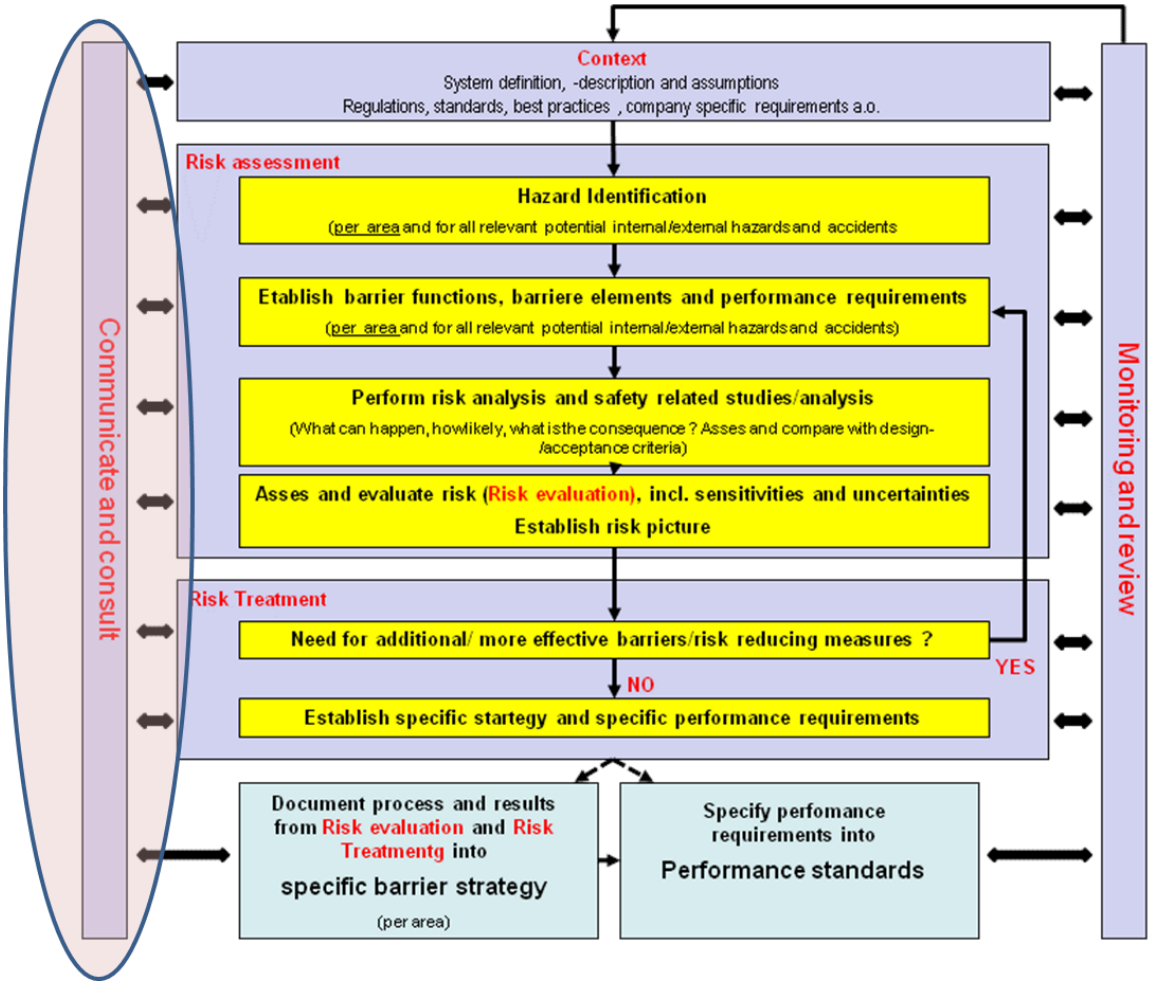

Figure 13: Communication and consultation in the barrier management process

Monitoring and review

To comply with the provisions on follow-up and improvement found in chapter VI of the management regulations, and the basic HSE and management provisions stipulated in chapters II and III of the framework HSE regulations, barrier performance must be monitored, followed up and, if possible, improved throughout the life cycle. This means that the barrier management process does not end when the above-mentioned steps in the process have been completed. These steps must be monitored and followed up as illustrated in figure 14, and improvements implemented.

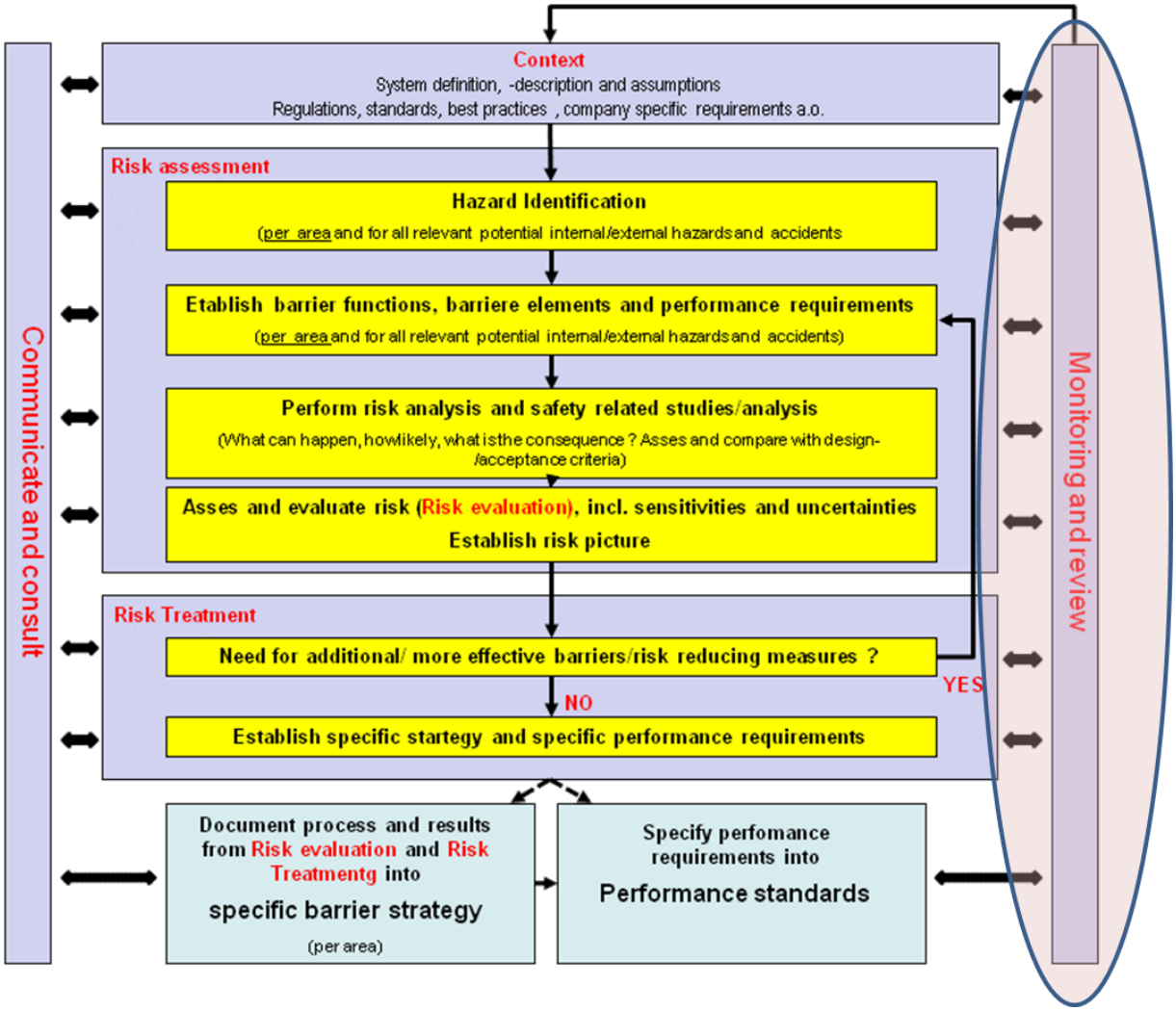

Figure 14: Monitoring and review in the barrier management process

Figure 15 provides a detailed presentation of the "monitoring and review" box, and includes some of the conditions which must be followed up to ensure good barrier management once the strategy and performance requirements have been established. This is not a full list, and the responsible party must accordingly identify the elements they themselves believe to be necessary for monitoring/following up that barriers retain their function throughout the life cycle, and clarify how these are to be followed up. This chapter will discuss some key considerations related to monitoring and review.

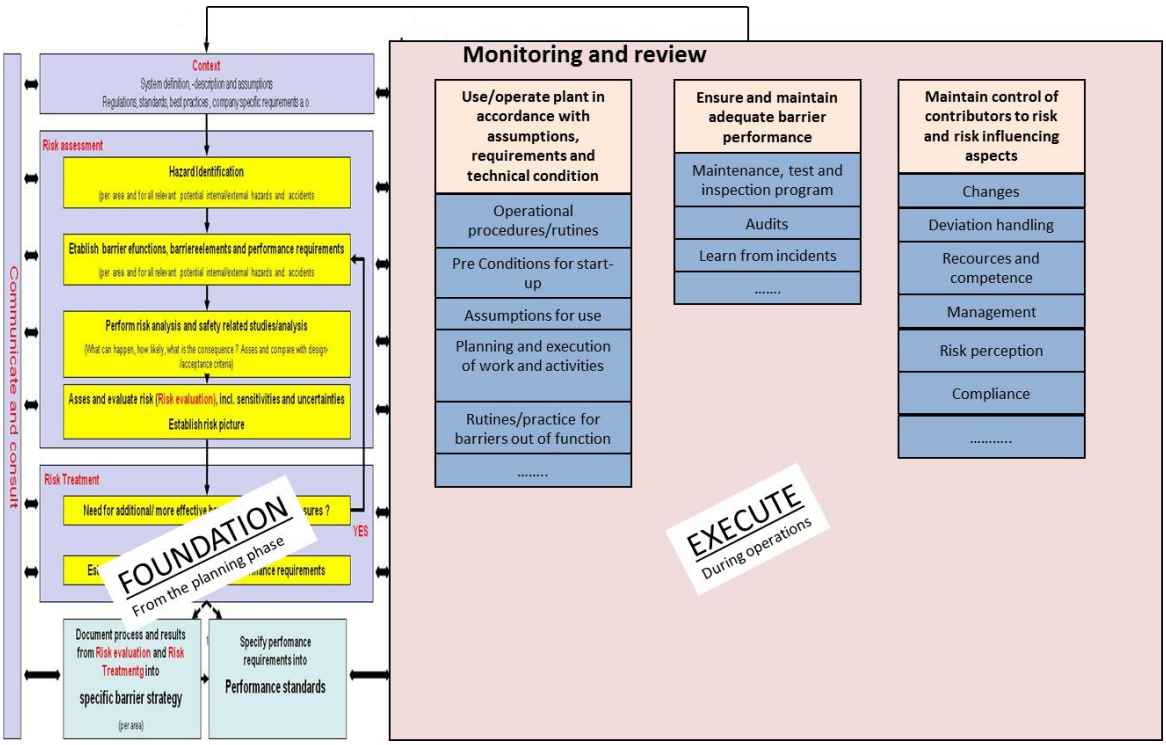

Figure 15: Examples of key elements for ensuring good monitoring and follow-up

A number of assumptions and prerequisites will underlie the process illustrated in figure 6. These could include prerequisites about the way a facility is to be operated or assumptions which influence testing and maintenance of equipment. These assumptions/prerequisites define the terms of the subsequent process, including the risk assessments to be carried out. Failure to conform with one or more of these prerequisites would accordingly invalidate the basis of the subsequent steps in the process. The most important job in ensuring good barrier management is accordingly to monitor, test and verify that operations accord with the prerequisites which apply at any given time.

For monitoring, testing and verification to have a value, systems and processes must be established to assess the results of these activities. Furthermore, this is worth little unless systems and processes have been established to identify, assess and deal with changes to and nonconformities from established assumptions and prerequisites. The regulations accordingly require that the responsible party has the necessary systems and processes in place to verify that operations accord with the underlying prerequisites applied to the activity, and has established systems and processes to identify and deal with nonconformities in an acceptable manner. See section 22 of the management regulations and section 19 of the framework HSE regulations. The sum total of several nonconformities – which are individually considered to be insignificant – could be critically important either for the risk picture or for the ability of the barriers to do their intended job. In other words, this means that systems and processes must be established to assess and deal with the significance of nonconformities from the context (including assumptions and prerequisites) which forms the basis for designing and determining requirements for one or more barrier functions or elements.

The regulations require that necessary measures are adopted to correct or compensate for missing or impaired barriers. Where some circumstances and situations are concerned, necessary compensatory measures will need to be clarified in advance. In other cases, conditions which have arisen will have to be dealt with there and then. It is crucial in any event that mitigating measures provide a genuine risk reduction relative to the barrier functions and areas affected by missing or impaired barriers.

Arrows have been drawn in Figure 6 between the "monitoring and review" box and all the boxes to the left of it. This is intended to illustrate the above-mentioned requirement for constant monitoring of the risk picture and conditions, and for assessing and dealing with changes or nonconformities in an acceptable manner. This will mean in some cases that parts of the process must be reassessed and in others that it has to be re-run in full.

What are to be regarded as barrier elements?

As noted initially in this document, the barrier term is used in many contexts and with meanings which differ significantly. The intention has been to clarify the regulatory provisions for barrier management, and to specify what is meant by various terms used to clarify or specify these stipulations. This chapter seeks to clarify what does and does not form the basis for describing something as a barrier element.

Figure 15 includes a number of factors in the "monitoring and review" box which are significant for ensuring that the established barriers retain the necessary properties at all times. An example is "maintenance, test and inspection programmes/routines". Does this mean that maintenance is to be regarded as a barrier function and/or a barrier element?

To answer this question, the first step must be to repeat the definitions of barrier, barrier function and barrier element:

Barrier: Technical, operational and organisational elements which are intended individually or collectively to reduce possibility/ for a specific error, hazard or accident to occur, or which limit its harm/disadvantages.

Barrier element: Technical, operational or organisational measures or solutions which play a part in realising a barrier function.

Barrier function: The task or role of a barrier. Examples include preventing leaks or ignition, reducing fire loads, ensuring acceptable evacuation and preventing hearing damage.

A number of conditions and factors are significant for the ability of barriers to function as intended when required. Conditions such as workload, capacity, attitudes, culture and so forth among those involved in operating an installation, for example, could be very significant for the properties of the barriers when these are needed. That relates both to the way maintenance, testing and follow-up of technical barrier elements are conducted, and how effective operational and organisational barrier elements will be when required. There is little point in including or considering "everything

of importance" as barriers or barrier elements. Such an interpretation will not contribute to more conscious barrier management and follow-up.

The term "performance influencing factors" has been introduced to supplement the barrier function and barrier element concepts.

Performance influencing factors means: conditions which are significant for the ability of barrier functions and elements to function as intended.

One of the stipulations for a barrier element is that performance requirements must be set for it, and that this performance must be verifiable. Investigations and surveys can be conducted into the culture in an enterprise, for example, but it will be difficult to establish verifiable performance requirements for that culture. So culture cannot be regarded as a barrier element. Similarly, none of the other factors included in the "monitoring and review" box in figure 15 can be regarded as barrier functions and/or elements. The duty to establish performance requirements for barriers, pursuant to section 5 of the management regulations, accordingly does not refer to these factors.

Finally, it is important to emphasise that, once performance requirements have been established for a number of barrier elements, solutions and measures must be put in place to maintain these properties over time. And it is in this context that the factors included in the "monitoring and review" box in figure 15 will be highly significant. A maintenance, test and inspection programme must be established, for example, which assures and verifies that the various performance requirements are satisfied. Maintenance is a necessary condition for sustaining the performance of a barrier over time. But such work is not in itself to be regarded in this context as a barrier function or element. On the other hand, the quality of maintenance – including its planning and its ability to sustain the performance of the various barriers – will be a key condition affecting performance.

Measuring and verifying performance

The regulations specify that non-functioning or impaired barriers must be identified. This requires the responsible party to establish systems and processes which verify that established barrier functions and associated barrier elements have the intended properties. For certain properties, and particularly for those related to technical barrier elements, testing and maintenance activities will in many cases provide a serviceable solution for verifying condition and compliance with established performance requirements. However, other systems and processes will be needed to verify the performance of a number of other properties.

Experience in recent years from serious petroleum-industry incidents, nationally and internationally, shows that substantial improvement is required in operational and organisational conditions (see the PSA's report following the accident to the *Deepwater Horizon* facility).

Assessing the validity of the assumptions included in the context is important when measuring and verifying. This means that routines and practice for verifying conformity with the established context must be in place, along with routines to assess the consequences of contextual changes.

The principles governing performance requirements for barrier functions and associated barrier elements are illustrated in figure 16, along with some of the indicators/activities/measures employed in the industry today to verify performance.

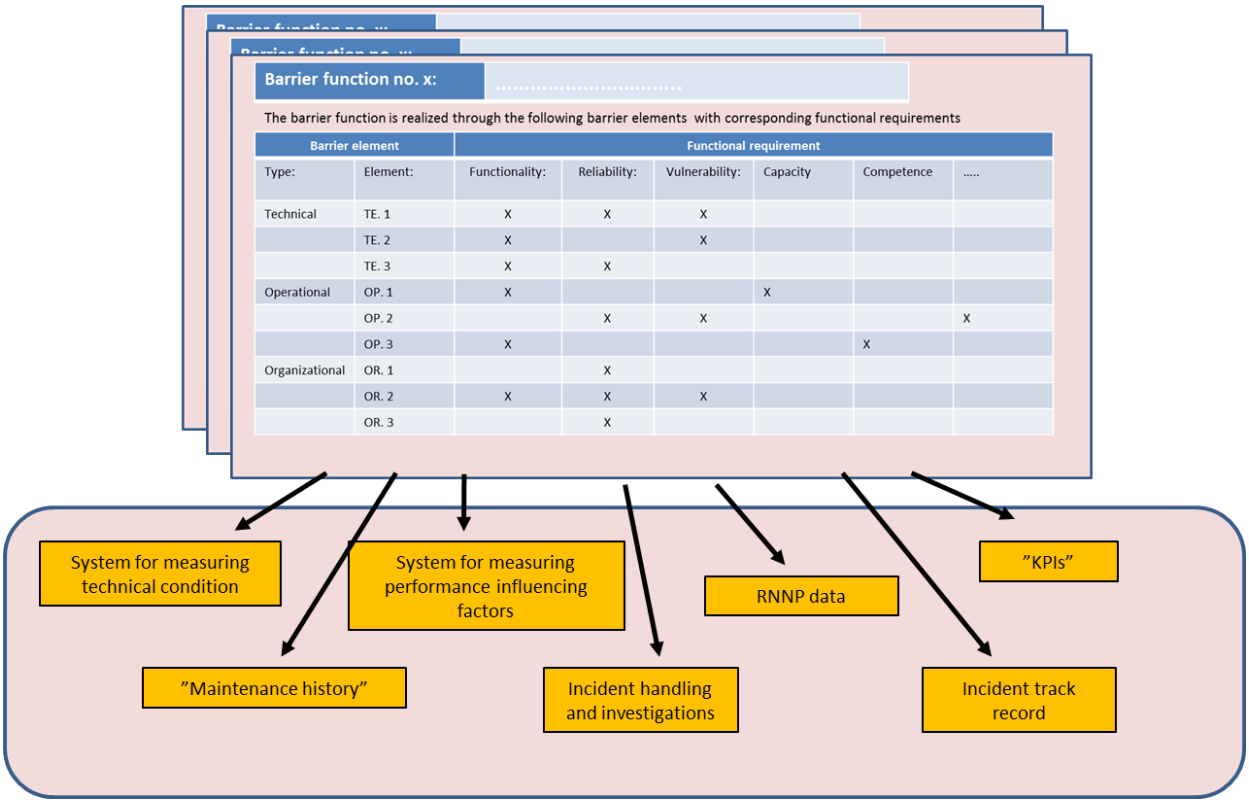

Figure 16: Performance verification of barrier functions and associated barrier elements

Considerations related to differences and relationships between technical, operational and organisational barrier elements and performance influencing factors

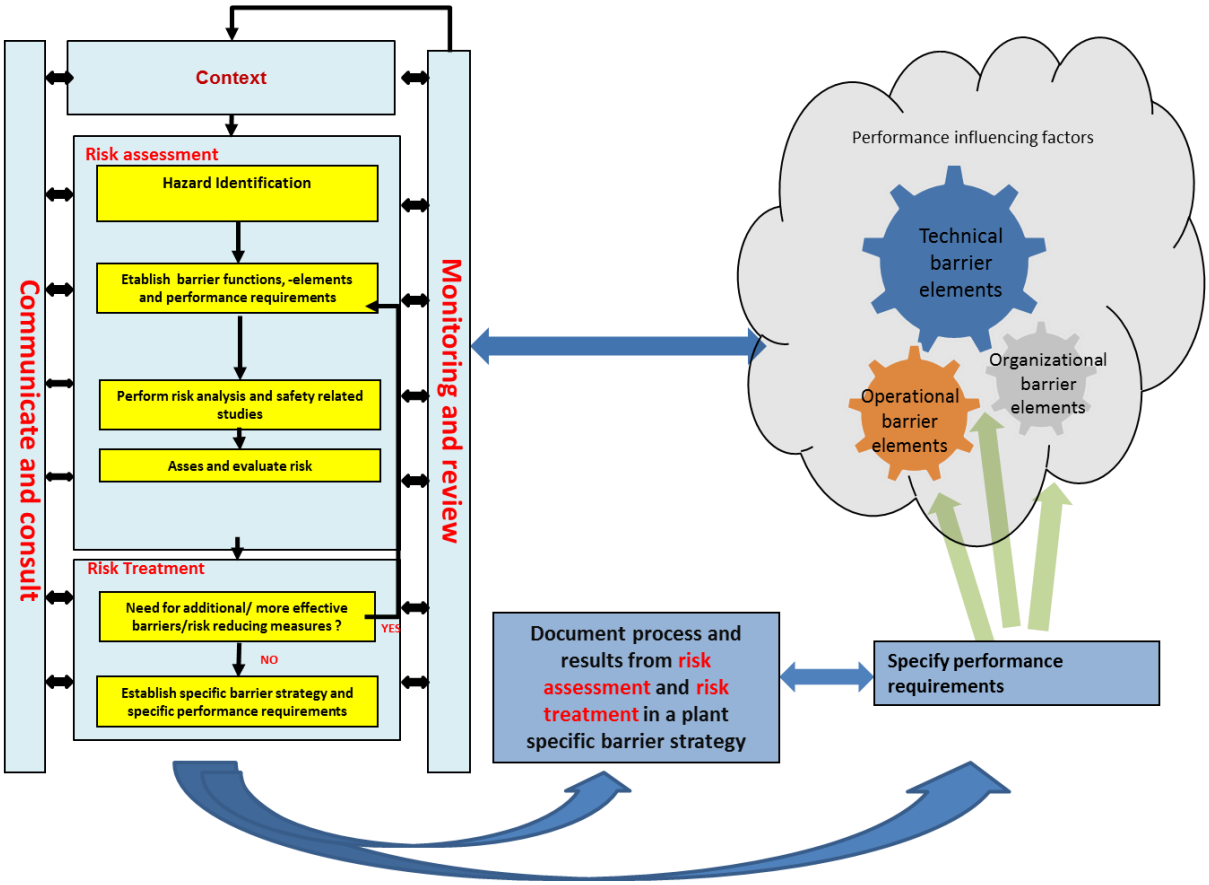

Figure 17: Technical, operational and organisational barrier elements

The most important consideration is not the label attached to the various barrier elements, but the presence of identified and established performance requirements for all the barrier elements regarded as necessary to implement the barrier functions. In many cases, technical, operational and organisational elements must all be present to realise a barrier function. Some barrier functions, such as "preventing ignition" or "preventing escalation", will mainly involve technical barrier elements, while others will often embrace a majority operational or organisational elements. An example of this is provided by the barrier function "securing an adequate fluid column" during drilling operations. Monitoring operation and initiating necessary countermeasures to prevent or possibly deal with a well kick will depend to a great extent on predefined routines/procedures and the possession of the necessary expertise by personnel so that they can understand and manage the position. At the same time, correct responses by personnel will be of little use if the equipment (technical barrier elements) required to deal with the situation – such as mud pumps and blowout preventers (BOPs) – fails to function efficiently.

Another example where technical, operational and organisational barrier elements are all required to realise the function is "preventing ship collisions". Technical elements could, for example, involve monitoring systems (radar, GPS, tracking, alarms and so forth). Organisational elements

could be personnel monitoring or responding to alarms from the system. Examples of operational elements include personnel initiating the necessary response when a ship is detected on a collision course.

Figure 17 illustrates the relationship between technical, operational and organisational barrier elements and conditions affecting performance. This figure and the examples given do not refer to a specific barrier function, but to elements which could be incorporated in one or more such functions.

Organisational and operational barrier elements are normally closely related. The first category relates to personnel and their roles in executing specific functions, while the other involves the specific actions and jobs these people are to perform. As mentioned above, however, the most important consideration is not the label given to the various elements but establishing and applying performance requirements to necessary barrier elements in order to realise the various barrier functions, and moreover that people are conscious of conditions affecting performance and take care of them.

Performance requirements related to the specific operational and organisation barrier elements could include specific stipulations for expertise in doing the work as well as criteria for action, response time, notification to the central control room, number of personnel and availability. Such requirements for technical, operational and organisational barrier elements may often display the same characteristics – capacity, functionality, effectiveness, integrity, robustness and availability, for example. Performance requirements are related specifically to the barrier elements whose quality they are intended to ensure. Personnel, for example, could be required to have taken a specific course in order to secure correct performance of a job required to realise a barrier function.

Performance influencing factors are more general, and not directly related to individual barrier elements. A general stipulation that employees must have the appropriate skill/trade certification to serve as process operators, for instance, could be a performance influencing factor.

To finalize this chapter some specific examples will be provided which illustrate what has been written about organisational or operational barrier elements and performance influencing factors. Procedures are not organisational or operational barrier elements, but can describe which personnel and actions are incorporated as barrier elements. Safe job analysis (SJA) is not an organisational or operational barrier element, but a tool for identifying the risk which must be managed by technical, organisational or operational barrier elements. Work permits (WPs) are not an organisational or operational barrier element, but can specify which barrier elements must be in place before a specific job is begun. On the other hand, the quality and availability of procedures, good systems for SJAs and WPs, and using these systems in the right way are examples of important performance influencing factors.

Generally speaking, management is not an organisational or operational barrier element, but can contribute to ensuring that routines and resources are in place for establishing and maintaining barriers. If managers at various levels are responsible, by virtue of their roles, for being present, taking decision or performing specific actions in the event of a hazard or accident – such as

ordering manual activation of abandon platform shutdown (APS) – they and their actions represent organisational and operational barrier elements.

Preparation for operation, maintenance management and commissioning

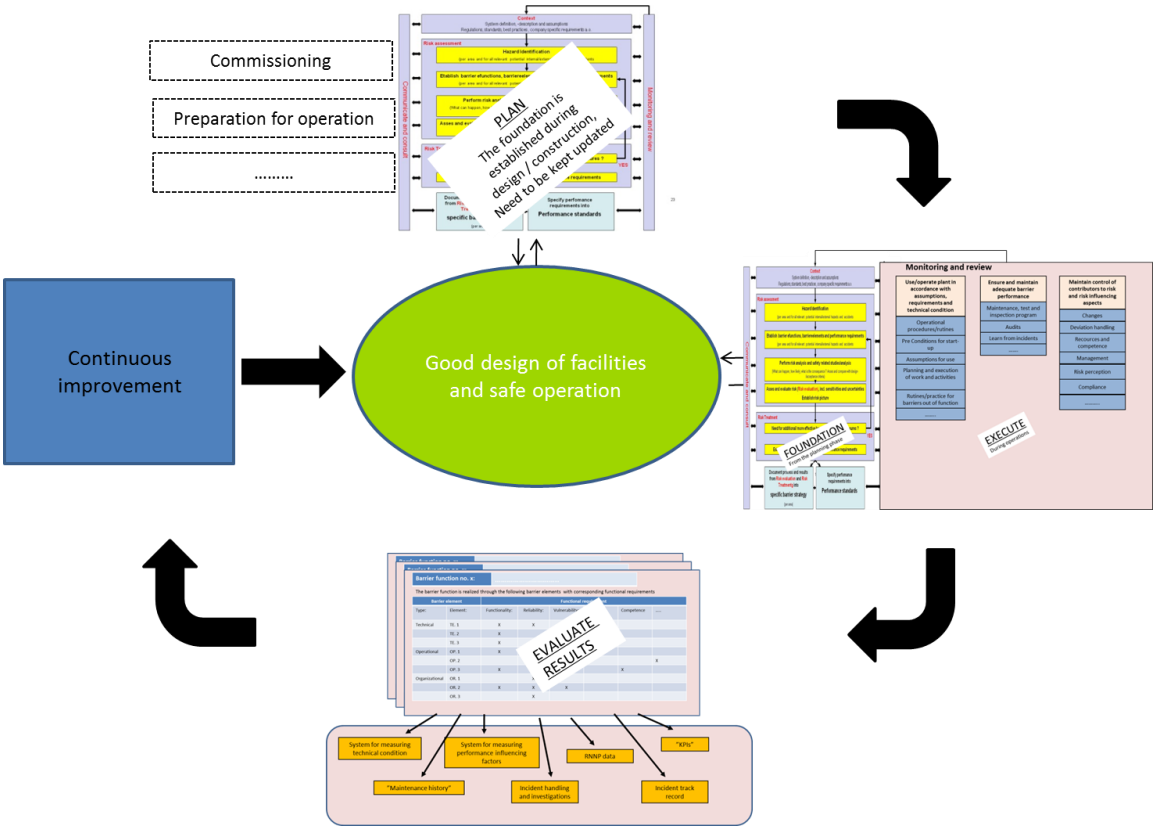

Figure 18: Preparation for operation in accordance with the box for communication and consultation

Preparation for operation

A key aspect of planning in the design/construction phase is to establish the necessary basis for execution during the operational phase. As indicated in the "execution" box for the operational phase, the following three conditions occupy a key role:

- operate and use the facility in accordance with prerequisites, requirements and technical condition
- secure and maintain the necessary barrier performance
- maintain control over contributors to risk and performance influencing factors.

Establishing a basis for taking care of the above-mentioned conditions will play a key role in preparation for operation where barrier management is concerned. Securing effective

communication and consultation at the planning stage and sufficient monitoring and review in the subsequent operational phase will be important for establishing and following up the underlying basis. Some overall conditions relating to maintenance management and commissioning are described below.

Maintenance management

The following considerations are particularly important where maintenance management is concerned.

- Ensuring that the maintenance programme is correctly defined, so that it contributes to maintaining necessary and coherent barrier performance in all phases of the life cycle. Preventive maintenance which can avert degradation of or reduction in the performance of barrier elements is equally important, whether the cause is wear-and-tear or aging.
- Using information from the barrier strategy and performance standards to classify equipment and systems in terms of their criticality.
- Ensuring use of classification – as part of the decision base when prioritising corrective maintenance jobs, for example, and to specify requirements for testing and maintaining barrier elements (whether these are called safety-critical equipment or safety-critical elements).
- Testing barrier elements in order to verify their performance in relation to their intended use and role. Valves, for example, should be tested under real operating conditions, including checks that:
  - deluge values open after the fire pumps have started up and pressurised the system upstream from the valve
  - that wing valves can be shut by the flow which may occur in the event of a leak/break in the downstream flowline.
- Possessing good routines for collecting historical data about the equipment, and for using this database to assess performance and improve maintenance.
- Having systems and resources available which make it possible to carry out planned and corrective maintenance.
- Understanding what modifications to or changes in operating/process conditions (such as water content, pressure or temperature) mean for maintenance requirements, so that such work can be adjusted accordingly.

Commissioning

Verifying that relevant barrier elements meet all the specified performance requirements represents a key job in the commissioning phase. A common challenge at this stage could be to verify or test equipment under realistic operating conditions. Should that be the case, it will be important to verify or function-test the equipment under the correct operating conditions as soon as practicable.