Barrier Analysis for New Technologies Technical Note

Submitted to
The Bureau of Safety and Environmental Enforcement (BSEE)

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Executive Summary

As the dynamic offshore industry moves into deeper, harsher and colder environments, Operators are proposing many new and emergent technologies to address the operational needs for drilling and production. The development of new technologies is advancing at a rapid rate and governing industry codes and regulations cannot develop at the same pace. Innovative technology is critical therefore, a systematic process must be established for the review and acceptance of proposed new design and technology concepts so that their readiness can be assessed and the associated risks identified and addressed. Because new technology applications can vary, the required level of review will also vary and needs to be tailored to the specific application. Any new technology evaluation process should be flexible to consider these variations.

The objective of this technical note is to provide technical details associated with the barrier analysis, which should accompany a new technology submission. The technical note intends to establish a clear understanding of barrier definition and other relevant aspects of the barrier models that will have to be developed by the Operator and submitted for BSEE's review as part of the request for new technology application approval. The barrier analysis concept is applied to the new technology through a combination of a barrier model and related barrier element attribute checklists. The proposed barrier analysis concept is applicable to both existing as well as new technologies. Key considerations, best practices and examples have been included within the technical note to illustrate the proposed barrier analysis approach.

Applying the proposed barrier model template to the new technology, will clarify its role and any interfaces with other barriers as a part of a barrier function to manage major accident risk. It will also help in visualizing the functions and the attributes that need to be considered during the life cycle of the technology. The life cycle approach provides better overview with respect to what specific factors need to be considered and when they are of significance to the new technology.

The barrier elements, with their related operational and physical tasks have given attributes that need to succeed in accordance with a success criteria to realize the function of the barriers through the operational and physical tasks of the barrier element/barrier critical system. A Barrier Element Attribute Checklist complements and links the barrier elements life cycle phase attributes to its success criteria.

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List of Acronyms

ABS	American Bureau of Shipping
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
ANL	Argonne National Laboratory
BOP	Blowout Preventer
BSDV	Boarding Shut-Down Valve
BSEE	Bureau of Safety and Environmental Enforcement
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
DWOP	Deep Water Operations Plan
ETA	Event Tree Analysis
FOSV	Full Opening Safety Valve
FTA	Fault Tree Analysis
GOMR	Gulf of Mexico OCS Region
HAZID	HAZard IDentification
HMI	Human Machine Interface
HSE	U.K. Health and Safety Executive
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
INSAG	International Nuclear Safety Advisory Group
IPL	Independent Protection Layers
ISO	International Organization for Standardization
LOPA	Layers Of Protection Analysis
MAOP	Maximum Allowable Operating Pressure
MPB	Multiple Physical Barrier Approach
MORT	Management Oversight and Risk Tree
NCS	Norwegian Continental Shelf
NDE	Non-Destructive Examination
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NORSOK	Norsk Sokkels Konkurranseposisjon (Norwegian abbreviation)
NTL	Notice to Lessees and Operators
O&G	Oil & Gas
OCS	Outer Continental Shelf
PFD	Probability of Failure on Demand
PSA	Petroleum Safety Authority Norway
RBD	Reliability Block Diagram
SCE	Safety Critical Elements
SCR	U.K. HSE Safety Case Regulations
SIL	Safety Integrity Level

SIS	Safety-Instrumented Systems
SSM	Safety Management Manual
SSV	Surface Safety Valve
TAS	BSEE Technical Assessment Section
TDL	Technical Direction Letter
U.K.	United Kingdom
WBE	Well Barrier Element

1. Introduction

1.1 Background

The Bureau of Safety and Environmental Enforcement (BSEE) is responsible for the oversight of exploration, development, and production operations for oil and natural gas on the Outer Continental Shelf (OCS). BSEE's regulation and oversight of Federal offshore resources ensures that energy development on the OCS operates in a safe and environmentally responsible manner. The functions of BSEE include oil and gas permitting, facility inspections, regulations and standards development, safety research, data collection technology assessments, field operations, incident investigation, environmental compliance and enforcement, oil spill prevention and readiness, review of Operator oil spill response plans, oversight of production and development plans, and resource conservation efforts.

As the dynamic offshore industry moves into deeper, harsher and colder environments, Operators are proposing many new and emergent technologies to address the operational needs for drilling and production. Title 30 CFR 250.200 defines *New* or *unusual* technology as equipment or procedures that:

1. Have not been used previously or extensively in a BSEE OCS Region;
2. Have not been used previously under the anticipated operating conditions; or
3. Have operating characteristics that are outside the performance parameters established by this part.

Operators are to review all their equipment and procedures to see if it qualifies as a *new* or *unusual* technology under the above definition. If identified as a candidate, Operators provide a submission to BSEE for the evaluation and approval of the proposed new technology. This request is made to BSEE by an Operator typically through the submittal of a project specific Deep Water Operations Plan (DWOP). Operators can also request conceptual approval of non-project specific new technologies through the BSEE Technical Assessment Section (TAS) or the BSEE District Operation Support.

The main objective of the submittal is to demonstrate that the proposed new technology presents an increased or equivalent level of safety in accordance with current OCS practices. This can be challenging for new technologies since there may not be any governing industry codes and regulations. Hence, it is critical that Operators and BSEE use systematic process for the review and approval of proposed new design and technology to ensure the readiness of this technology and address the associated risks. Because new technology applications can vary, the required level of review will also vary and needs to be tailored to the specific application. The new technology evaluation process should be flexible to consider these variations.

The three main steps in the new technology evaluation process are as follows:

1. New Technology Assessment,
2. Risk Assessment, and

3. Barrier Assessment

The new technology assessment step helps to determine if the submission involves new technology and categorize this new technology for further evaluation. There are four categories to consider in the first part of the new technology assessment:

1. Known Technology, Known Conditions
2. Known Technology, Different or Unknown Conditions
3. New Technology, Known Conditions, and
4. New Technology, Different or Unknown Conditions

Figure 1 illustrates the new technology assessment framework, which consists of four categories. Category 1 involves known technology used in known conditions. As such, Operators do not have to conduct additional analysis. Categories 2 and 3, involve changes to the area/conditions in which the technology used or to the technology itself. Analysis of new technology in these two categories would need to focus on the changes in the technology or the condition. Category 4 involves changes to both the area/conditions and technology and requires more in-depth analysis.

Operators considering the use of new technology in categories two, three and four, should conduct a hazard identification study to identify major accident hazards and identify the barrier functions affected (See Steps 2.1, 3.1 and 4.1 in **Figure 1**). Next, the Operator should identify the relevant barrier critical systems (See 2.2.1, 3.2.1 and 4.2.1 in **Figure 1**) and conduct any additional risk assessment as identified during initial hazard identification focusing on the changes to either the technology and/or the condition. (See Steps 2.2.2, 3.2.2 and 4.2.2 in **Figure 1**). Finally, a barrier analysis identifies barrier critical systems by developing a barrier model and identifying barrier element attributes and their success criteria (See Steps 2.3.1, 3.3.1, and 4.3.1 in Figure 1).

The objective of this technical note is to provide guidance on the barrier analysis step of this framework. The technical note intends to establish a clear understanding of barrier definition and other relevant aspects of the barrier models that Operators will have to develop and submit for BSEE's review as part of the request for new technology application approval. The barrier analysis method contained in this technical note is applicable to both existing as well as new technologies.

The main assumption considered throughout this technical note is that the new technology application submitted for BSEE's evaluation involves a barrier related barrier elements. For example, a new material in the barrier or a completely new technology proposed (replacing an existing barrier) to meet the barrier function are such examples.

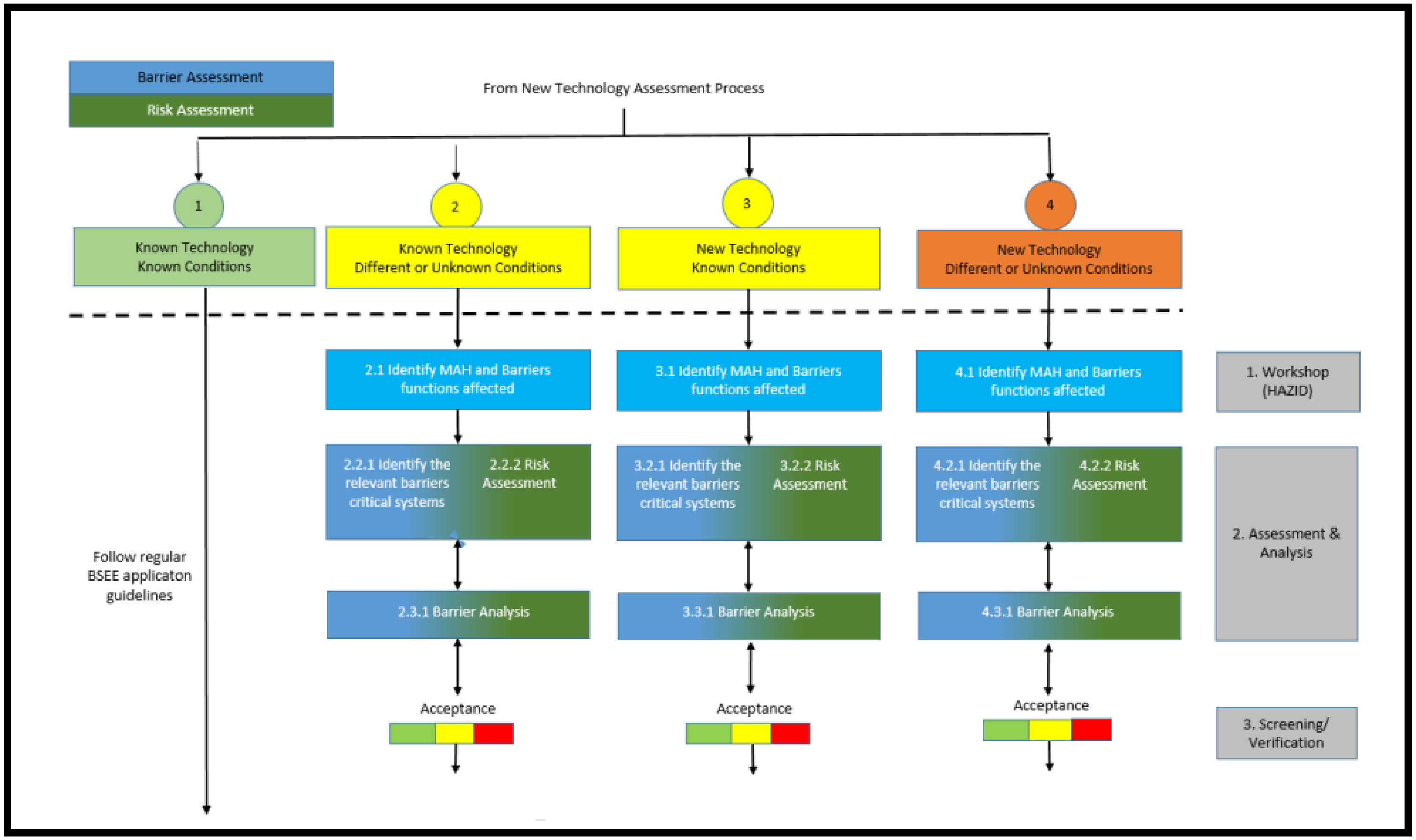

Figure 1: New Technology Assessment Framework

1.2 Barrier Analysis

Barrier analysis is not a new term and has been an integral part of many industries with the potential for major accidents including the oil and gas industry. Several industries have adopted regulations with a greater focus on barriers and the need for managing them after experiencing a major accident.

It is important to note that the focus of barrier analysis is on major accident hazards. This is an important distinction, due to the complexity of major accident scenarios. While occupational accidents have a linear development and simple root causes, major accident hazards (MAH) are complex with a combination of causes that are often hard to determine in advance.

The systems and their functions are analyzed differently and implemented to prevent, control or mitigate a major accident scenario in barrier analysis. In order to gain insight to the systems that are to function as a barrier, several types of breakdowns and modeling methods are often needed. Barrier analysis also helps to gain an understanding of the barrier's performance, vulnerability, robustness and any possible dependencies to other systems or their functions.

1.3 Technical Note Content and Structure

The following sections provide an overview of the technical note:

Section 1 – Provides background for the technical note along with objectives and assumptions.

Section 2 – Presents the barrier model template that ABS Group proposes for use by BSEE and Operators for the review of new technology applications in the OCS.

Section 3 – Provides key considerations and examples regarding the use of the Barrier Model Template.

Section 4 – Provides a detailed discussion on minimum attribute considerations for the different life cycle phases. The development of Barrier Element Attribute Checklist identifying the attributes and relevant success criteria is an important part of the proposed barrier model template.

Section 5 – Provides key considerations and examples regarding the development of Barrier Element Attribute Checklists.

1.4 Accompanying Case Studies

The technical note references the case studies below from a completed barrier analysis. The *New Technology Submission Guidance* and *BSEE's SOP for New Technology Evaluation case studies are* essential for the reader to gain a full understanding of the subject.

- Barrier Analysis Case Study 1: Ultra-Deep water Drilling with a Subsea BOP

    - Includes a Subsea BOP barrier model and its barrier element attribute checklists developed for a scenario involving the use of a subsea BOP for ultra-deep water drilling in GOM.
- Barrier Analysis Case Study 2: Deepwater Drilling with a Surface BOP from a Floating Facility
    - Includes a Surface BOP-Subsea Disconnect System barrier model and its barrier element attribute checklists developed for a scenario involving the use of a Surface BOP from a floating facility for deep water drilling.
- Barrier Analysis Case Study 3: Managed Pressure Drilling (MPD) in GOM
    - Includes a barrier model and barrier element attribute checklists developed for a MPD system applying the constant bottom hole pressure (CBHP) MPD variant in GOM.
- Barrier Analysis Case Study 4: High Pressure High Temperature (HPHT) and Sour Well Production with a Surface Controlled Subsurface Safety Valve (SCSSV)
    - Includes a barrier model and barrier element attributes checklist for a tubing retrievable SCSSV used in production operations for a HPHT sour well.
- Barrier Analysis Case Study 5: Arctic Drilling with a Capping Stack
  Includes a barrier model and barrier element attribute checklists developed for a capping stack used in an arctic exploratory drilling campaign.

2. Barrier Analysis using a Barrier Model Template

The project team developed a barrier model template based on barrier modeling methods and the review of barrier analysis applications in different industries. . The barrier model template has a top down tree structure, strongly influenced by the Fault Tree and ANL MPB approaches. This template will be a useful tool for BSEE and the Operators to perform barrier analysis in a systematic and structured manner. The barrier model template includes a success tree structure, where the realization of the top-level function is achieved by the success of subsequent levels of the tree.

The barrier model template when applied, provides insight about the realization of a barrier function by identifying contributing critical systems, their functional contribution and the elements of the system that are needed. To identify the barrier function the template includes the physical and operational task(s) of each element. Terminology

The barrier model template includes specific terminology. The definitions are as follows, and listed in the order of their appearance in the barrier model hierarchy (top down):

Barrier Function:

> *A function that needs to be realized in order to prevent, control or mitigate a major accident hazard.*

Barrier Critical System:

> *A defined system that by performing its intended function(s) realizes the barrier function, either alone or together with other barrier critical systems of the same barrier function.*

Barrier Critical System Function:

> *A function that is performed by the barrier critical system in order to realize the barrier function, either alone or together with other functions of the same barrier critical system.*

Barrier Element:

> *A physical element or a subset of physical elements that are needed as part of the barrier critical system, in order for it to perform its intended function.*

Physical Task:

> *Task performed, automatically or initiated by a human action, as intended by the design of the barrier element, in order to realize/perform the barrier critical system function.*

Operational Task:

> *Human action which is needed by the barrier element or the barrier critical system, by directly affecting the realization/performance of the barrier critical system function.*

Attribute:

External or internal characteristic features or conditions that influences the success of the barrier element, to perform the required physical or operational task needed by the barrier critical system.

Success Criteria:

The specific criteria for an attribute that needs to be met to ensure the ability of the barrier elements to successfully perform its intended tasks.

2.1 Barrier Model Template and its key features

2.1.1 *Barrier Model Template*

Figure 2 illustrates the barrier model template and its breakdown structure.

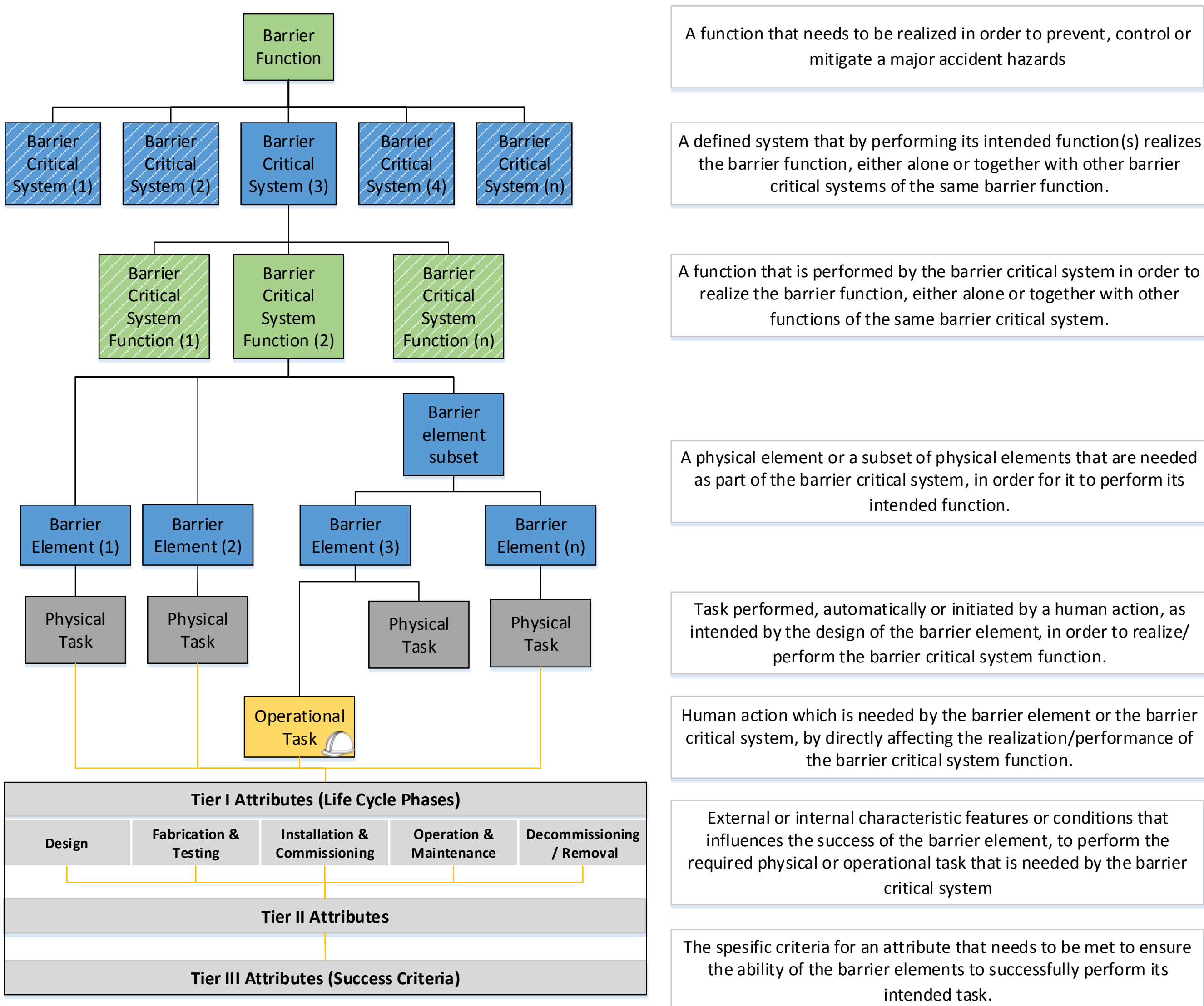

Figure 2: Barrier Model Template[1]

[1] Logic ports (AND/OR gates) are not shown in the generic template. However in the application of the barrier model template for modeling specific barrier functions, all necessary logic ports should be included as relevant.

2.1.2 *Barrier Model Key Features*

The barrier model template developed has the following key features:

- Includes the interfaces between multiple barriers
- Flexibility to handle the complex nature of different barrier critical systems
- Provides overview and insight using a combination of function and system breakdown
- Limited to "physical barriers", but includes operational and organizational aspects as supporting elements to the physical barrier
- Include success criteria for barrier element attributes in a life cycle perspective

Interfaces between multiple barriers

In order to understand the application of the new technology (as a barrier or part of it) in a bigger context, it is important that the modeling method ensure that the intent of the system and its constituting elements coincides with the intended system function. The interface between possible other collaborating system functions should be realized as well.

The interfaces and relations between collaborating system functions and related systems was captured in the design of the barrier model template.

Neither AND nor OR gates are included in the generic template. The following terms should be considered when required, redundant systems and elements and collaborating elements. AND / OR logic gates (shown in Figure 3) will be included when modeling specific barriers, as the redundancies and dependencies become apparent. Also, for a barrier element's operational and physical tasks, AND / OR gates should be included to illustrate potential redundancies in the tasks, e.g. an automatic activation and Operator initiated activation of a system.

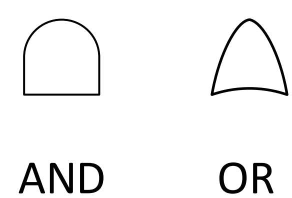

Figure 3: AND/OR logic gates

Flexibility to address complex barriers

The barrier model template consists of a breakdown structure with accompanying definitions and terminology. The breakdown structure is flexible and capable of capturing the complexity of different barriers.

Expansions for more complex systems is an example of individual modifications made by including a sub-systems level between the barrier critical system level and the barrier critical system function levels (Figure 2). Another possible modification is to compress the model as needed, for instance by removing the barrier critical system level entirely. For example, a barrier sub-function that is realized by a single element or elements are not configured to be a logical system.

Using a combination of function and system breakdown

An important aspect of the barrier model template is the use of “function” in addition to “system” to describe the barriers. It is not what the barrier is, but what it shall accomplish that is at the highest level. This is due to several factors; a system is often a very complex entity that can perform several tasks, and in many cases, both safety critical tasks and non-safety critical tasks. In order for the designers and developers of new technology to make the right decisions, it is important to bring focus to the function of the system that is a barrier.

Moreover, for new technologies, both functional decomposition as well as system breakdowns are widely used in the product design processes. The proposed barrier analysis concept implements a combination of processes that will help the designer and users, to ease the transition from design requirement(s) documentation [i.e., the functional specification (by the user) and technical specification (by the designer)].

The barrier model template is a tool to develop insight about the realization of the barrier functions, when the barrier critical system and its subset of barrier elements are applied.

Focus on Physical barriers with operational and organization aspects as its supporting elements

Barrier critical system(s) and related barrier element(s) are realized as a barrier function. The barrier critical system/barrier elements are limited to physical barriers only. The barrier element includes to tasks, physical and operations (human actions). These tasks are the specific actions (both active and passive) that enable the barrier element/barrier critical system to work in relation to the possible major accident scenario, i.e. the barrier function. Organizational aspects, in terms of procedures and company guidelines, are relevant when they influence a barrier element’s ability to perform the physical tasks, and the human’s ability to perform the intended operational tasks for a barrier element.

Success criteria for barrier element attributes in a life cycle perspective

In reviewing the new technology and its ability to perform its intended barrier functions, a range of attributes and their success criteria are considered. The attributes need to succeed in order for the barrier to be able to realize/perform its barrier function. The barrier model template helps identify relevant attributes from all life cycle phases and the related success criteria for evaluation.

2.2 Barrier Model Template Example Applications

Table 1 provides examples of the application of the barrier model template for barrier analysis using five scenarios. These five scenarios highlight the application of the new technology evaluation process to select candidate technologies.

The barrier analysis for these scenarios have been drafted as independent case study reports but excerpts of these barrier models are used throughout this technical note to illustrate key considerations and best practices for barrier model development.

Table 1: Barrier Model Template Example Applications

Scenario No.	Scenario Description	Barrier Function	Barrier Critical System	Reference Report
Scenario 1	Ultra-deepwater drilling in the Outer Continental Shelf with a Subsea Blowout Preventer (BOP)	Shut In Well and Control Well Bore	Subsea BOP	Barrier Analysis Case Study 1: Ultra-Deepwater Drilling with a Subsea BOP
Scenario 2	Deepwater drilling using a Surface BOP from a floating facility	Shut In Well and Control Well Bore	Surface BOP with Subsea Disconnect System (SDS)	Barrier Analysis Case Study 2: Deepwater Drilling with a Surface BOP from a Floating Facility
Scenario 3	Managed Pressure Drilling in the Gulf of Mexico	Prevent an influx by monitoring and precise dynamic control of the annular pressure profile/bottom hole pressure	Manage Pressure Drilling (MPD) System	Barrier Analysis Case Study 3: Managed Pressure Drilling in the Gulf Of Mexico
Scenario 4	Production in High Pressure High Temperature (HPHT) and Sour Well Conditions in the Outer Continental Shelf	Prevent Loss of Subsea Well Control	Surface Controlled Subsurface Safety Valve (SCSSV)	Barrier Analysis Case Study 4: HPHT and Sour Well Production with SCSSV
Scenario 5	Drilling in Arctic Conditions	Limit Environmental Consequences of Blowout	Capping Stack	Barrier Analysis Case Study 5: Arctic Drilling with a Capping Stack

3. Key Considerations for Barrier Model Development

The following considerations are identified when developing a barrier model for a specific barrier function, or a specific barrier critical system. Recommendations are based upon the experience gained through application of the barrier model template for barrier analysis of the five scenarios. The main objective of this section is to elaborate on these aspects.

Based on the extent of changes to either the environment or the technology, the scope of assessment and the sequence of the first two steps in the barrier model development may vary. While in the case of a known technology used in new or different environment, considerations on the barrier function level may triggers the assessment. For instance, if the scenario in question is a new type of Blowout Preventer (BOP), the need to identify the barrier functions that a BOP would influence. On the other hand, if the scenario in question is production in HPHT conditions, one needs to assess the barrier functions related to loss of subsea well control to identify the barrier critical systems relevant for those barrier functions affected by the change in conditions.

The barrier model template is flexible and versatile for systems and combination of systems with different levels of complexity. Hence, the level of breakdown of the barrier critical system and the details on the barrier element level should be adapted based on the level of detail needed for the evaluation of the proposed new technology. For verification of known technology in new conditions, the level of detail does not need to be extensive but more focus would be on those barrier elements affected by the new condition. Attributes that influence the performance of the barrier element in the new condition would are along with its success criteria. In the case of a completely new technology, the level of effort needed for detailed verification and validation may be more extensive and complex and reflected in barrier model breakdown.

3.1 Barrier Functions

A barrier function is the top-level function, and in most cases not system specific. A general description should be used to describe *how* a Major Accident Hazard (MAH) can be prevented, controlled or mitigated. The focus should therefore be on the MAH rather than the systems that are to perform the function, when formulating the barrier function.

In many cases, the starting point for the process will be the new technology assessment. In these cases, it is important to understand which barrier function or functions the barrier critical system/new technology will be a part of the new technology. As the barrier critical system in question can be part of several barrier functions, it is important to assess all of these, in order to prove that the barrier critical system is able to realize all barrier functions. An example for this would be the Subsea BOP for a Mobile Drilling Unit (MODU), where the main barrier function that it contributes to can be *Shut in Well and Control Wellbore*. However, in the event of a ship on collision course, the need to seal the well, and quick disconnect from the well, if the MODU is required to move off location to avoid the collision. In this example, different elements of the BOP will be relevant and the requirements for the operational and physical tasks would be assessed differently. Hence, the importance of considering all barrier functions where the BOP contributes as a barrier critical system is important. Conducting an early workshop or HAZID identifies relevant MAHs and barrier functions.

3.1.1 *Barrier Function examples from the Barrier Model Application*

Examples of barrier functions are:

- Shut in well and control wellbore
- Prevent an influx by monitoring and precise dynamic control of the annular pressure profile/bottom hole pressure
- Prevent loss of subsea well control
- Limit environmental consequences of blowout

All four barrier functions above relate to the major accident involving loss of well control. While the first three barrier functions aim to prevent the accident from happening, the last one has a focus on limiting the consequences once the major accident has occurred. It is evident from the list that the level of detail required in the description of the barrier function, is different for each barrier function and dependent on the scenario. The second barrier function is more detailed, and description of the barrier functions relation to the system then the other barrier functions listed. This is both due to the fact that the systems used for this barrier function are used for more specialized activity and could be considered temporary equipment, as it is not used for all drilling activities. Hence, the barrier function does not come in conflict with other barrier functions established for the permanent parts of the setup. The barrier function could also be simplified or generalized to say for instance *Prevent Unwanted Influx into the Wellbore*.

3.2 Barrier Critical Systems

The Barrier Critical Systems to be included in the barrier analysis need to perform some function, which by itself or by interacting and working together with other systems fulfills the required barrier function. Only systems that are *critical* to the realization of the barrier function should be evaluated.

It is also important to note that it may be only parts or elements of a system that is crucial to the realization of the barrier function, while the system as a whole may be thought of as not barrier critical. For instance, when analyzing the capping stack as a barrier critical system, the BOP is a related barrier critical system for realizing the barrier function *Limit environmental consequences of blowout*, but in this specific case, it is only the Attachment Point (BOP mandrel/hub) that will need to be included.

When assessing new technology, it is important to consider if this barrier critical system has a role in several different barrier functions. All of the barrier functions should be explored no matter how obvious the main function may be.

It is also important to make sure when developing barrier models that all relevant barrier critical systems are identified and included for the given barrier function. This is important for both (1) to ensure that the barrier function can be realized, and (2) in order to visualize dependencies that may not be evident if only assessing one barrier critical system. The identification does not necessarily imply that all barrier critical systems need to be developed in further detail. In some cases, it can be identified through a HAZID or some other workshop during the risk assessment step, which specific barrier critical systems are of interest for further evaluation through a barrier analysis. In other cases, it may be evident that there is a new system involved along with several known and well tested systems, and that only the new technology needs to be assessed in detail.

3.2.1 *Barrier Critical System examples from the Barrier Model Application*

Figure 4 below gives an excerpt of the barrier model for Scenario 5. For this scenario, the barrier function is *Limit Environmental Consequences of Blowout*. The selected barrier critical system for further analysis is the Capping Stack, but several other barrier critical systems are needed for this system to perform its barrier critical system functions. The Capping Stack cannot be installed or operated without a ROV being available. The mechanical integrity of the wellhead or BOP along with that of the casing and cementing is important as well to realize the barrier function. The shading of the boxes representing barrier critical systems other than the Capping Stack indicates that they have not been developed further.

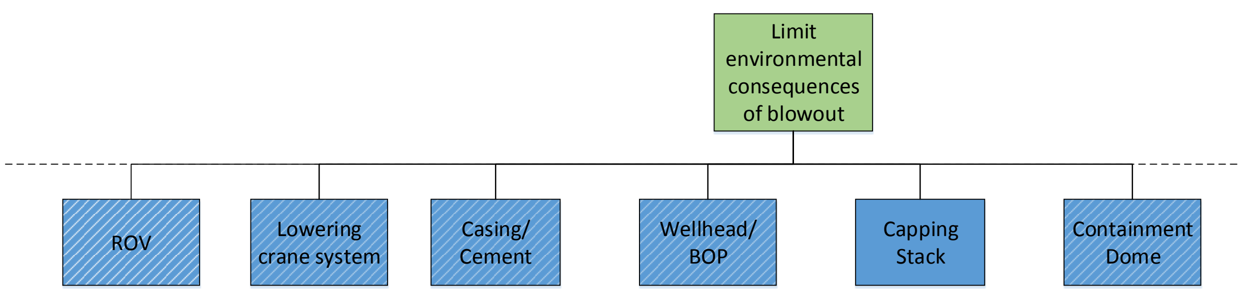

Figure 4: Barrier Critical Systems Example – Limit Environmental consequences of Blowout

There are several systems that need to interact and work together in most barrier functions. If there are clear connections that can be identified between some systems, it could be beneficial to group these together, or even make logical structures with several levels of barrier critical systems. This of course depends on the level of detail needed, and what types of systems are to be assessed in the barrier analysis. The interactions and interdependencies to other barrier critical systems should also be captured through the barrier element attributes developed for the selected barrier critical system.

For Scenario 2 with *Shut in Well and Control Wellbore* as barrier function, the relevant barrier critical systems, when using a Surface BOP, are presented in Figure 5. Here both the Surface BOP and the Subsea Disconnect System are developed further.

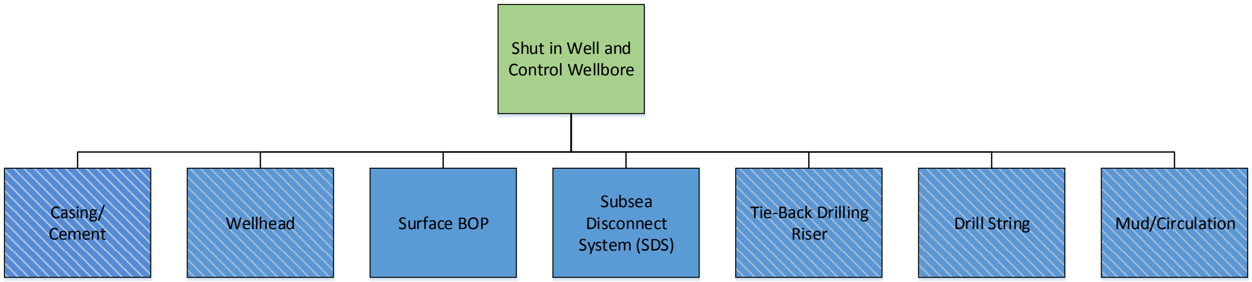

Figure 5: Barrier Critical Systems Example – Shut in Well and Control Wellbore

ROV intervention can be used as a secondary control system for activating functions on the Subsea Disconnect System. Therefore, it could be considered a barrier critical system. However, as a choice with regards to system boundaries, the ROV is considered a barrier element, under the Subsea Disconnect System. This is because the ROV here has only a single purpose, and is not relevant for other barrier critical systems.

In the previous example related to Scenario 5, the ROV was treated as a separate barrier critical system. The analyst identifies the system boundaries and builds the model in the appropriate way to capture the key aspects. Assumptions should be clearly documented and included in the barrier analysis report during analysis and system boundaries.

3.3 Barrier Critical System Functions (BCSFs)

The barrier critical system functions are specifications of what roles the system has in realizing the high-level barrier function. One system may have several functions. In some cases, these functions can be defined in relation to the sequence in which the operation is carried out to fulfill the barrier function (i.e., the Capping Stack needs to attach and seal on the subsea attachment point [BCSF 1] before closing the open bore [BCSF 2]).

The barrier critical system functions can also have redundant aspects that may be needed to realize the barrier function depending on the specific condition or operation, for instance in the case of the BOP, where the BOP can seal around the drill string, or cut the drill string before sealing the wellbore. Both these barrier critical system functions for the BOP are needed depending on the well control situation to realize the barrier function *Shut In Well and Control Wellbore*. When developing the barrier critical system functions, one should ask, "how does the barrier critical system realize the barrier function"? This is key to understand the relation between the barrier critical system and the top-level barrier function.

The best source for identifying the barrier critical system functions will be the functional specification or basis of design from the end user/Operator. For known technologies, design codes/standards may also exist that have defined the relevant system functions. These can also serve as a good starting point when defining the barrier critical system functions.

When replacing a barrier critical system with a new type of technology, the system functions that have been defined for the previously used technology may still apply, even though different components or different configuration of components are used to achieve the same function. This helps in developing an initial list of barrier critical system functions for the new technology.

It is also important, to always keep in mind that the overall goal is not to define all the possible system functions for the barrier critical system but to focus on those that help realize the barrier function and to understand how they contribute.

3.3.1 *Barrier Critical System Function Examples from the Barrier Model Application*

The barrier critical system functions need to be defined in relation to the top-level barrier function. The only functions needed are those that either directly or indirectly help fulfill the top-level barrier function.

In the case of the barrier function *Limit Environmental Consequences of Blowout* and related Barrier Critical System (Capping Stack), four barrier critical system functions have been identified as critical for the realization of the Barrier Function, as presented in Figure 6.

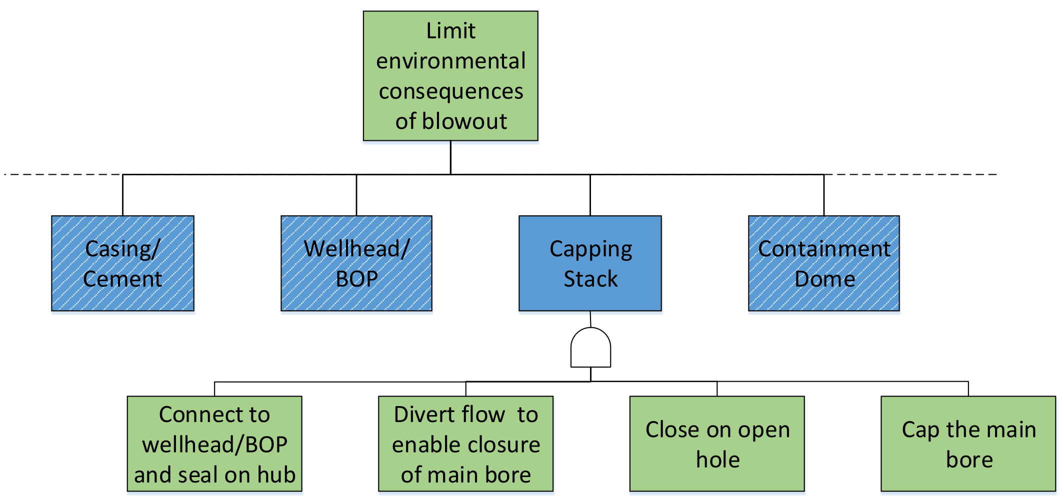

Figure 6: Barrier Critical System Functions Example – Limit Environmental consequences of Blowout

The four barrier critical system functions are organized in sequence, based on the order in which the capping operation is carried out. The wording of the barrier critical system functions are based on the API 17W functional descriptions for the Capping Stack. Also as seen from the example, the AND logic gate is used, as all identified barrier critical system functions are needed to realize the barrier function.

Another example is the Barrier Function *Prevent Loss of Subsea Well Control*, where the Subsurface Safety Valve system for which two barrier critical system functions have been identified as shown in **Figure 7**. However, unlike the Capping Stack example, only one of these functions is needed in order for the top-level barrier function to be realized. The redundancy is visualized through the OR-gate.

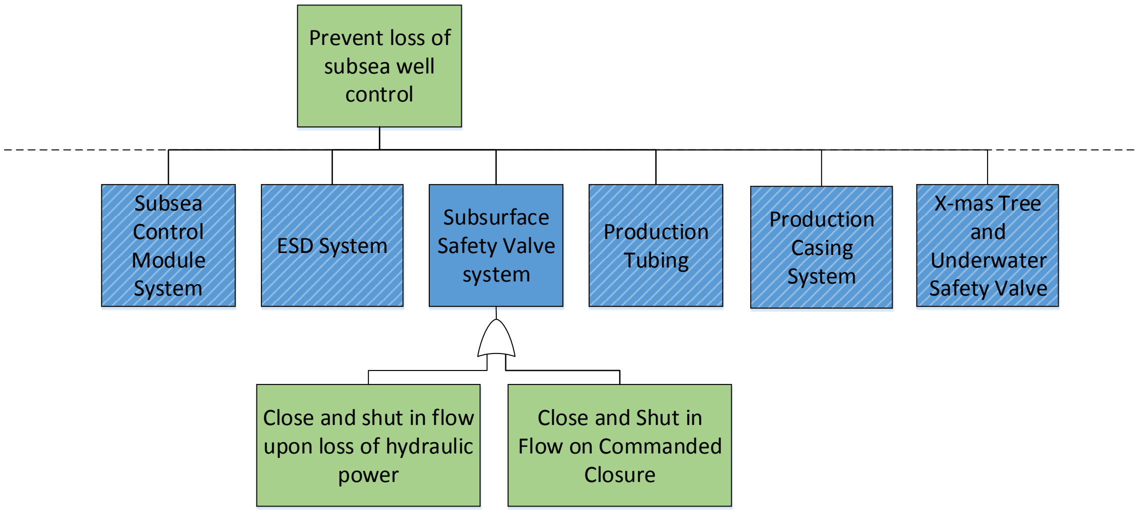

Figure 7: Barrier Critical System Functions Example – Prevent Loss of Subsea Well Control

3.4 Barrier Elements

The barrier elements are the physical components that are part of the barrier critical system, or elements integral in realizing the barrier critical system function. As the definition states, these are the elements *needed* in order for the barrier critical system function to be performed. It should therefore not be all elements in the system, only those needed.

One barrier element can also be part of several barrier critical system functions, and should then be repeated in all relevant barrier critical system functions. This helps in understanding the criticality of the barrier element based on its contribution to multiple barrier critical system functions. An example of this could be a control panel that is used to initiate the actuation of several barrier elements. This will in most cases not involve additional attributes and success criteria, as most of the attributes for a barrier element will be the same across all barrier critical functions, though it is important to also capture the differences. Further information on attributes and how they are linked to the barrier model is presented in Attribute Checklists and Success Criteria.

As described previously, it is important to note that the level of breakdown into barrier elements have to be relative to the level at which attributes can be identified and validated. In many cases, a breakdown to the subsystem level will be sufficient without having to go further down to components. To summarize, the level of detail needed for barrier element breakdown is a reflection of two things; (1) at what level the change is made to a system making it a new technology and (2) at what level can attributes be identified and validated.

For some systems, where a detailed breakdown of barrier elements is needed, it may cause the model to become less intuitive and clear due to the sheer number of elements. And it may be harder to visualize the success logic of the barrier model. It is therefore recommended to introduce a barrier element subset where needed, to ensure readability and coherence in the logic paths. It is also encouraged that redundancies are captured within the barrier model where needed.

Components or subsystems of other barrier critical systems can be included as barrier elements contributing to the barrier critical system functions of a select barrier critical system. This highlights the interactions/interdependencies with other barrier critical systems in order to realize the function. However, it is preferred to narrow down the system boundaries as much as possible, to avoid double counting.

3.4.1 *Barrier Element examples from the Barrier Model Application*

Figure 8 and Figure 9 below show that there can be varying levels of breakdown for barrier elements depending on the specific scope of assessment.

The first example (Figure 8), relates to the Barrier Function *Prevent Loss of Subsea Well Control*, the elements related to the Valve Control System have been grouped together in as a subset of barrier elements. This is in order to better visualize the interconnections between these elements.

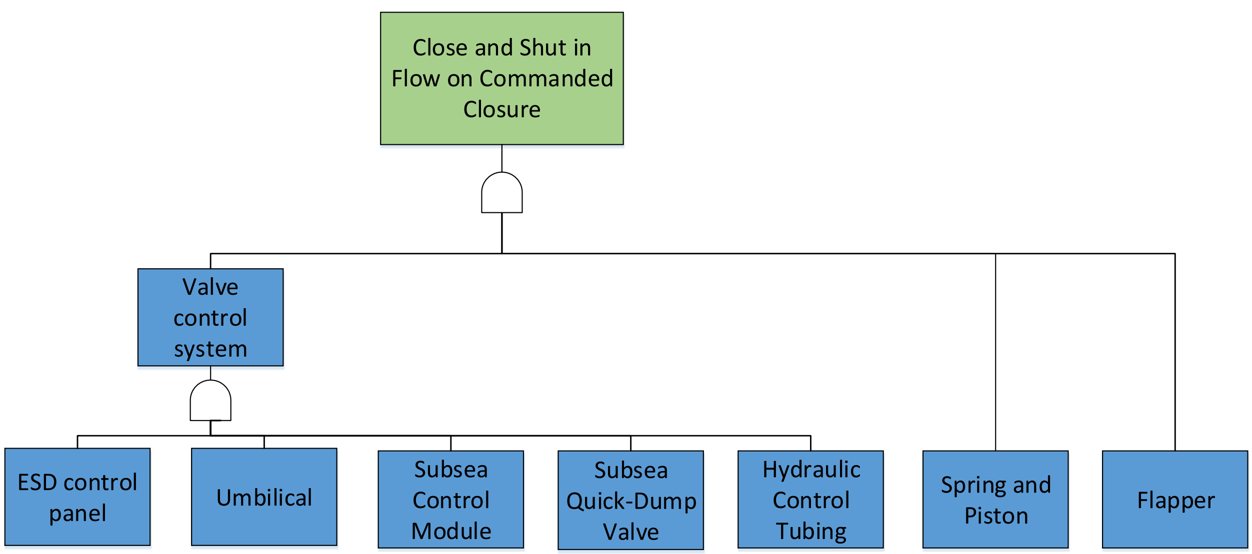

Figure 8: Barrier Elements Example – Prevent Loss of Subsea Well Control

The second example (Figure 9), relates to the barrier function *Shut in well and Control Wellbore*, with the Subsea BOP, there are several layers of logic gates to provide the reader with a representation of the inherent redundancies and dependencies in order to realize the barrier critical system function. Note also, that the barrier element "Main Control System" is repeated several times. This is due to the focus on functions rather than the system. This repetition can be an indication of the importance of the element. If a barrier element is needed to realize many different barrier critical system functions, or is repeated in redundant subsets of barrier elements, as is the case here, the model inherently shows that the element is of high importance. However, it should not be used as an absolute measure of importance. Hence, the use and understanding of the logic-gates is important when developing and reading the model.

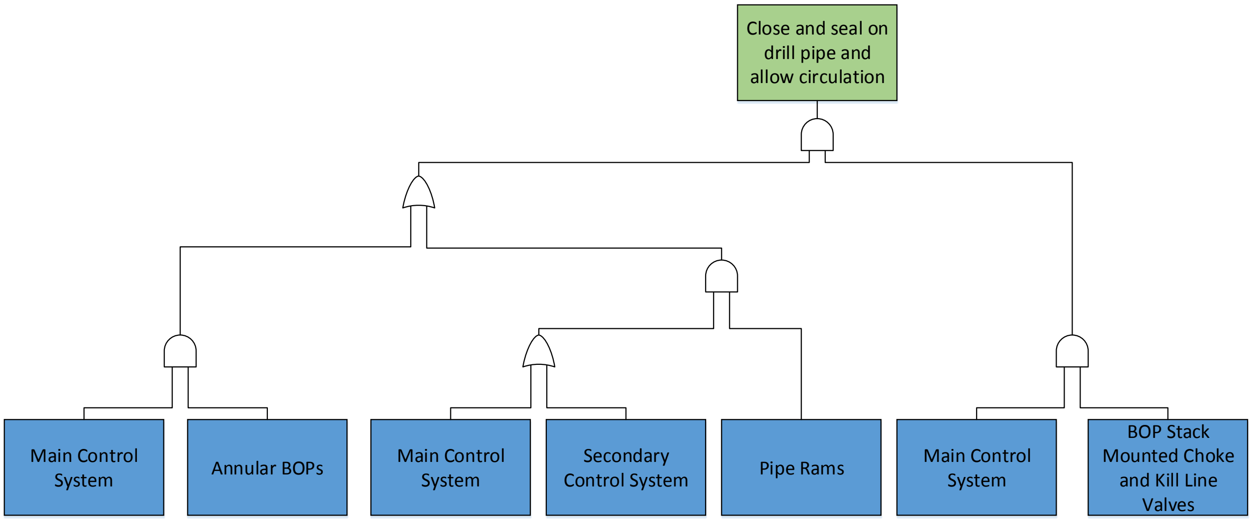

Figure 9: Barrier Elements Example – Shut in Well and Control Wellbore

3.5 Physical Tasks

The physical tasks are descriptions of what the barrier element does in accordance with its design intent to perform the barrier critical system function needed. Physical tasks should, as much as practically possible, be single tasks, or simple series of tasks, and not an accumulation of all tasks the barrier element is to perform.

The description should aim at being the simplest representation of the task that is to be performed, without losing its meaning, i.e. one sentence should be enough to describe the physical task of the barrier element.

If a physical task is too complex to be described in a single sentence, considerations on whether the barrier element needs to be broken down into several parts should be made. Another option is to break the physical task into several smaller tasks. This exercise is considered important to ensure the understanding of the system at all levels. Logic gates can be used when there are more than one physical tasks corresponding to a barrier element.

It is also important to consider the attributes at this point, to ensure that the physical task is defined such that it can be assigned success criteria that can be verified.

3.5.1 *Physical Tasks examples from the Barrier Model Application*

The physical task is dependent on both the barrier critical system function and the barrier element. Figure 10 demonstrates how logic gates may be used to show redundancy or interconnections between tasks.

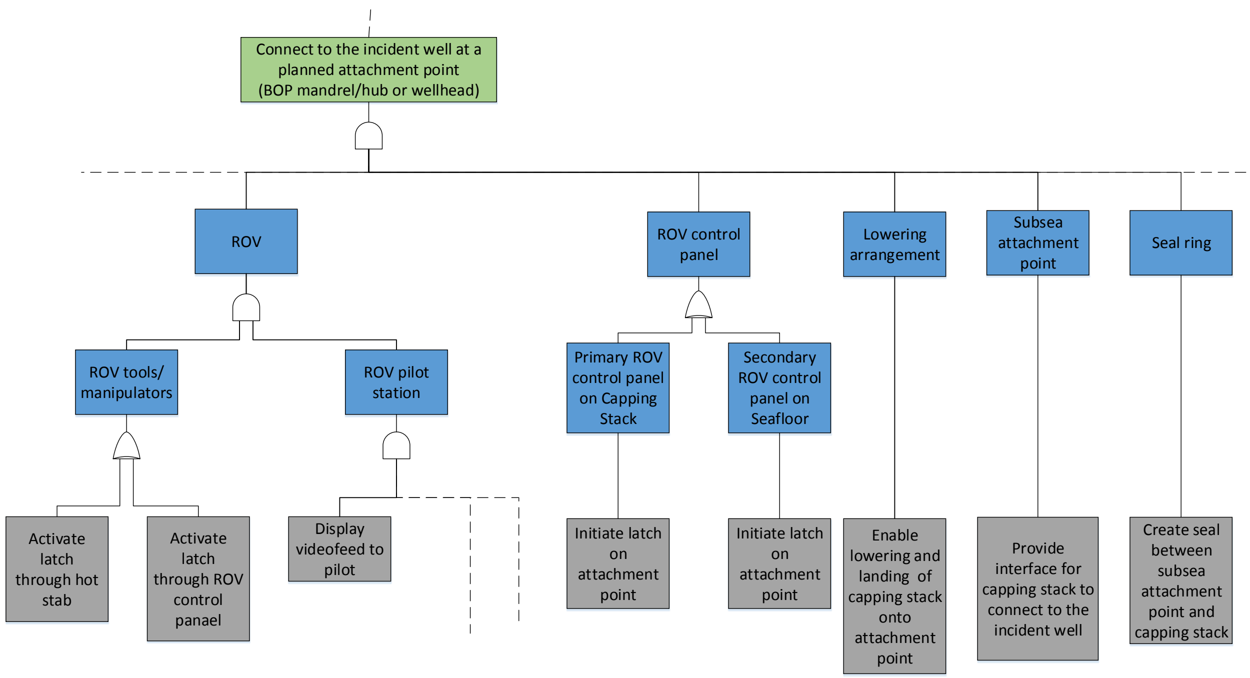

Figure 10: Physical Tasks Example - Limit environmental consequences of blowout

Most barrier elements have a single physical task as shown in Figure 10 and Figure 11. However, when developing the tasks for the elements, and based on the complexity of the element, the analyst can choose to incorporate several tasks on a higher level, or break down the system into several barrier elements, and then have a more specific physical task defined for each.

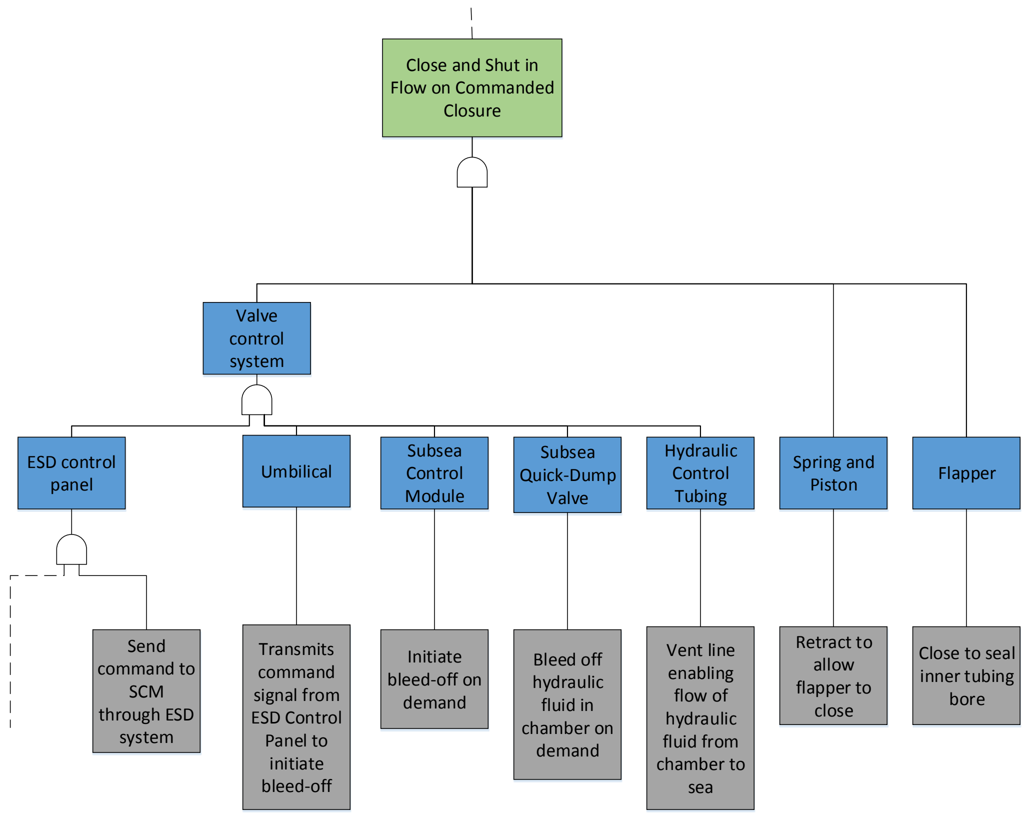

Figure 11: Physical Tasks Example - Limit environmental consequences of blowout

3.6 Operational Tasks

Operational tasks are human actions which are needed by the barrier element or the barrier critical system, by directly affecting the realization/performance of the barrier critical system function. Only tasks that directly influence the ability of a barrier element to perform its physical task or barrier critical system function are defined as Operational tasks in the barrier model template.

Several human activities may be identified in relation to barrier critical systems, however not all of these are necessarily operational tasks. Activities such as maintenance, inspection, testing and ensuring a good design are critical for the assurance of barrier functions, but is not defined as operational tasks in the barrier model template.

In order to bring in a level of consistency to the type of actions that can be considered as operational tasks, it is recommended that the task should be covered by one of the following categories:

- Activate/Actuate
- Monitor
- Act on alarm
- Operate according to procedure

In the barrier model, more descriptive names should be used for these tasks as shown later in examples below.

3.6.1 *Activate/Actuate*

"Activate" and "actuate" are good examples of operational tasks. The barrier model for the subsea BOP includes several tasks in this category; "Activate annular BOP on demand", "Activate Blind Shear RAM on demand" and "Activate pipe RAM on demand". The activation is done by pushing a button on a control panel (part of the control system).

The SSSV barrier model incudes only one operational task, "activate SSSV closure through ESD system", this is done by pushing a button on the ESD control panel.

3.6.2 *Monitor*

Monitor can be an operational task, but only if the monitoring is directly related to the realization of the barrier function in the critical situation and is done manually through visual checks.

In the barrier model for the capping stack several monitoring activities are included as operational tasks. "Monitor sensor readout" is an operational task (critical human activity) in all phases of the capping stack installation and use; during connections, diverting flow, main bore closure and main bore seal. The objective is to verify that the operation is successfully completed. Figure 12 illustrates the operational task. by the control system as a physical task.

Normally, in most computer-based systems, monitoring is done automatically (sensor and logic solver), and connected to an alarm (actuator unit), i.e. the operational task will be to "act on alarm", while the monitoring itself is taken care of Act on alarm

To act on an alarm can be an operational task if related to the realization of the barrier function.

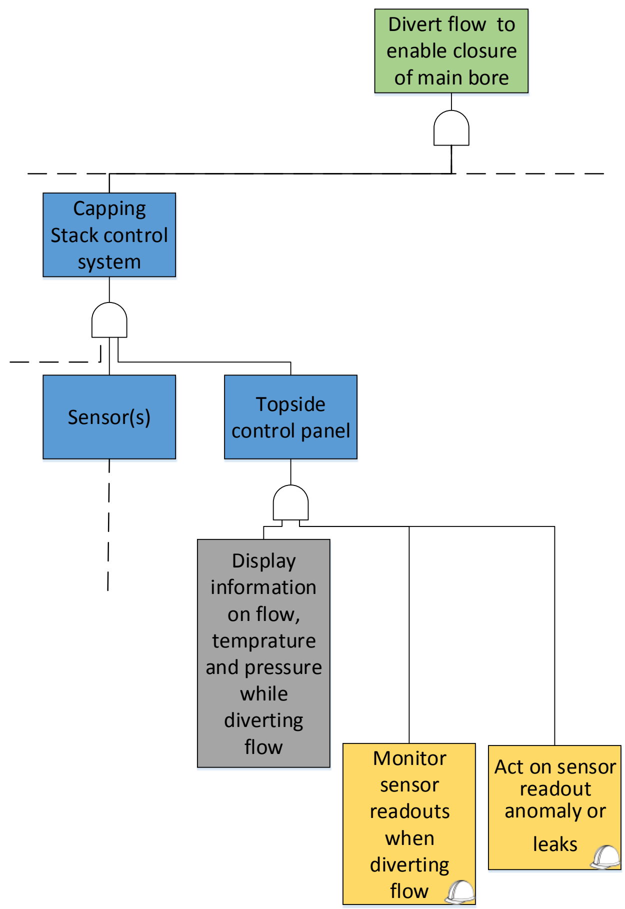

Figure 12: Operational Tasks Example - Divert flow through capping stack

Figure 12 illustrates the Capping Stack barrier model and includes the operational task "Act on sensor readout anomaly or leaks". The Operator needs to act on readouts and changes in critical parameters such as pressure, temperature and flow in order to ensure that the capping stack can be closed, and that no hydrate formation or other issues arise that may obstruct the flow.

3.6.3 *Operate according to procedures*

Some operational tasks are more complex, and may need several actions to be carried out in sequence often in accordance with procedures as opposed to simple "push the button" operations. Operation of the ROV to install and use the capping stack is one example. The operational tasks included in the barrier model will be more specific for each operational step, such as "Pilot ROV and control ROV tool/Manipulators to activate Capping Stack connector latch" as shown in Figure 13 below.

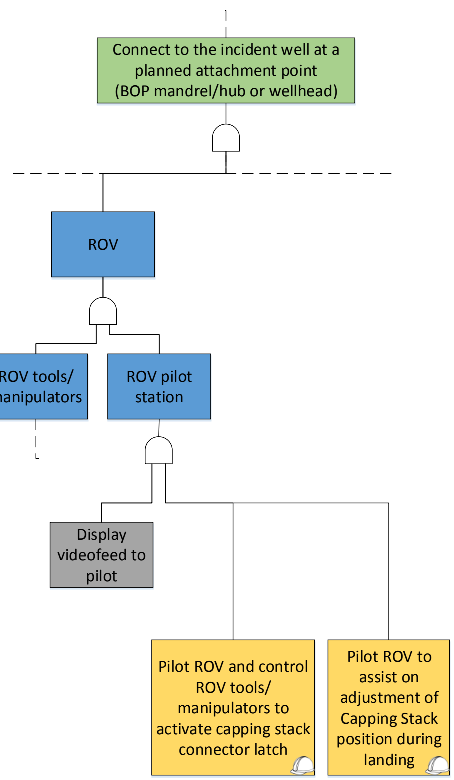

Figure 13: Operational Tasks Example – Connect to incident well at planned attachment point

The MPD barrier model includes several operational tasks in this category. Examples are "enter pressure to remain constant at specified points", "hold correct surface backpressure" and "input required data into wellbore hydraulic model".

3.6.4 *Representation of Operational Tasks in the Barrier Model*

Operational tasks may be represented at two different levels in the barrier model. In an example from the subsea BOP barrier model, Figure 14 below, operational tasks are represented at a high level. The operational task should be attached/linked to the barrier element where the operational task is performed, in this case the main control system. The operational tasks are represented in boxes with dotted lines, indicating that the barrier model also includes break down of the main control system into its corresponding barrier elements where the actual operational task is linked. The triangle under the Main Control System represents a transfer-gate that refers to another part of the model; in this case a more detailed model of the Main Control System.

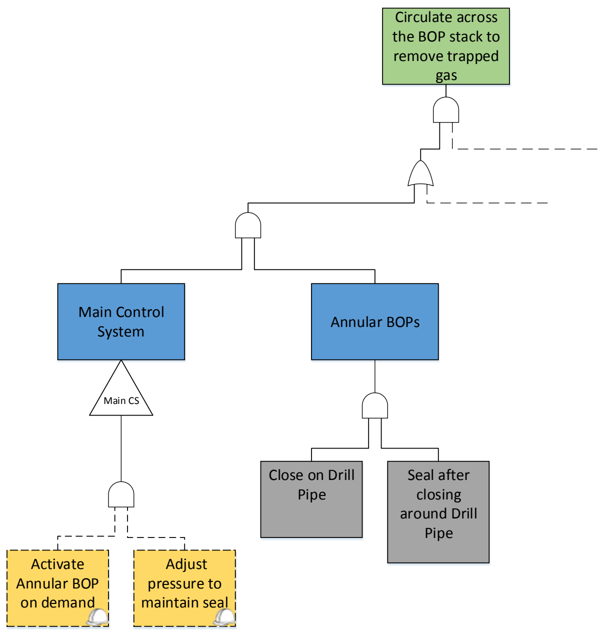

Figure 14: Subsea BOP barrier model – Operational task represented at high level

Figure 15 shows the breakdown of the main control system. In this part of the model, the operational tasks are linked to the barrier element level – the tool pusher's control panel where the button is pressed to activate the annular BOP. This will be the standard way of representing the operational barriers, but in complex barrier models such as the subsea BOP, simplified illustration is necessary for easy understanding and better overview of the model.

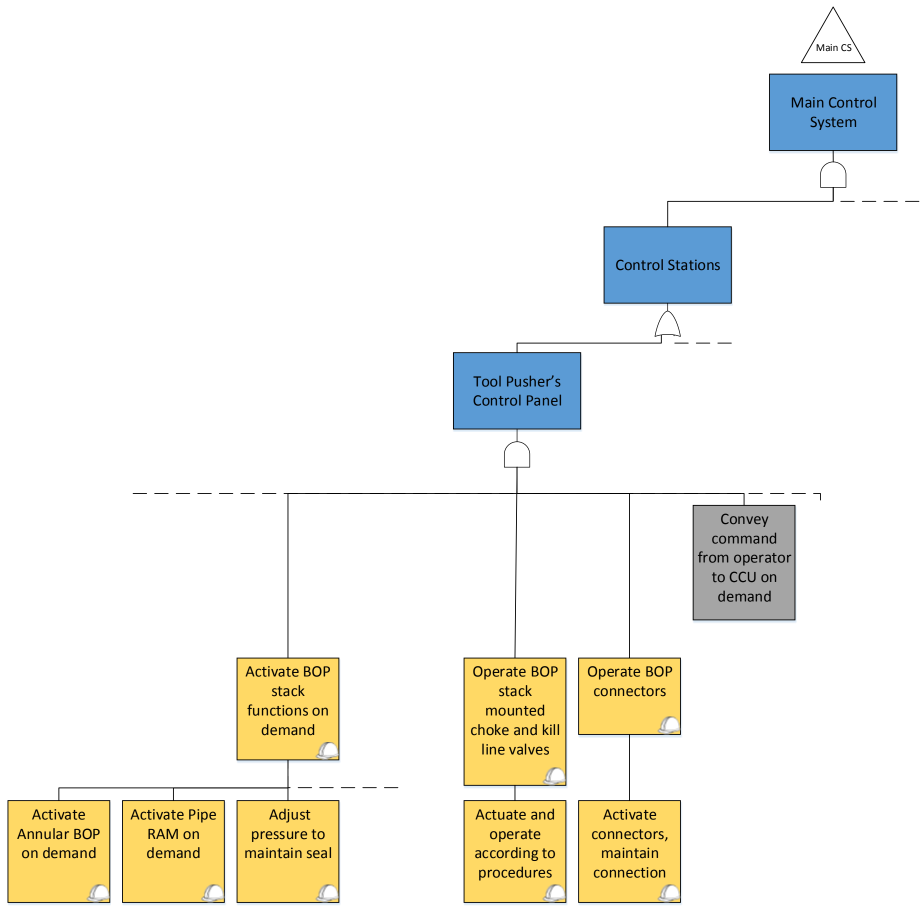

Figure 15: Subsea BOP barrier model – Operational tasks at lower lever for Main Control System

3.7 Sequence of barrier critical system functions, elements and tasks

As far as practically possible, the sequence of operations and use of barrier critical systems and their elements, should be reflected at all levels of the barrier model by presenting them **from left to right**.

For some barrier models, the operation itself will predict the sequence in which the barriers will be used. The barrier critical systems, their functions, elements and tasks should then be sequenced from left to right. In the arctic scenario (see Barrier Analysis Case Study 5) with the capping stack as the barrier critical system, the four defined Barrier critical system functions will always be used in the presented sequence:

1. Connect to the incident well at a planned attachment point (BOP mandrel/hub or wellhead)
2. Divert flow to enable closure of main bore
3. Close on open hole
4. Cap the main bore

However, in other cases, the sequence of the operation, and thereby the sequence of use of barrier critical systems, functions and tasks is fully dependent on the development of the situation at hand. This implies there is no given sequence that needs to be considered within barrier model. The scenario with the subsea BOP is an example on this, all in all nine barrier critical system functions have been defined and their order depends on the situation in which the BOP is used:

1. Close and seal on drill pipe and allow circulation
2. Close and seal on open hole and allow volumetric well control operations
3. Circulate across the BOP stack to remove trapped gas
4. Maintain BOP & LMRP connection
5. Shear drill pipe or tubing and seal wellbore - controlled operation
6. Shear drill pipe or tubing and seal wellbore - auto shear emergency operation
7. Shear drill pipe or tubing and seal wellbore - emergency disconnect sequence
8. Hang-off drill pipe
9. Strip drill string

The sequence of preferred use should be chosen if redundant systems are in place. For example, Figure 14, demonstrates the ability to activate the BOP stack functions using the driller's and tool pusher's control panels from left to right.

4. Barrier Element Attribute Checklists and Success Criteria

This section gives an overview of the minimum attribute considerations that should be made for all factors influencing the performance of barrier elements.

4.1 Attributes and their success criteria

A proposed new technology could be related to a barrier or its elements. There is need to identify and understand the relevant factors that can influence the barrier critical systems, and barrier elements ability to perform its barrier functions. The changes introduced by the new technology could introduce additional factors that were not perhaps critical in case of the conventional technology. These attributes need to succeed in accordance with a success criteria to realize the function of the barriers through the operational and physical tasks of the barrier element/barrier critical system.

The attributes should relate to the different life cycle phases of the new technology. This provides a better overview with respect to what needs to be considered and when they are of significance to the new technology.

4.2 Minimum attribute considerations

The minimum attribute considerations for factors influencing barrier performance are structured into three tiers. An overview of the attributes and their tiers which represent the lowest part of barrier model template is given in Figure 16.

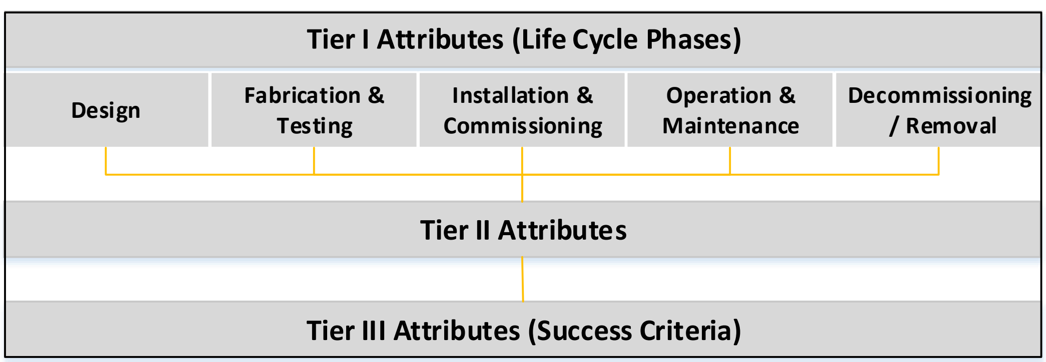

Figure 16: Three Tier Attribute Framework

The first tier covers the life cycle phases that are usually assessed during the development of a new design. The second tier breaks these down into aspects that are required to be assessed as part of each life cycle phase. The third tier provides specific detail and considerations for the BSEE reviewer to assess and typical input requirements from the applicant (the Operator/manufacturer) for each of the second tier aspects.

The main purpose of this section is to provide the user of the barrier model template with enough information to understand each tier of the model and explain how each of the attributes contribute to the success of the barrier in achieving its intended function. It should also be noted that this is not an exhaustive list of attributes and depending on the application, additional attributes may need to be considered and certain attributes may or may not apply.

4.2.1 *Tier I Attributes (Life Cycle Phases)*

The new technology is assumed to be a part of the barrier system, and the barriers prevent or mitigate major accidents from happening during the operation of a plant or installation. It is essential that during all life cycle phases, the focus is on the barrier system's or barrier element's ability to perform its intended function by enabling the physical and operational tasks.

During the life cycle of an oil and gas asset, activities are carried out to ensure that the integrity of the asset is maintained from design through to decommissioning. Similarly, the building blocks for the barrier model needs to take into consideration the different life cycle phases in order to maintain overview and control of the safety challenges and the different operations that are required during various phases of the product's life cycle. In other words, the overall success for the barrier critical system or barrier element is achieved when all attributes in each life cycle phase collectively succeed. This process can also be used to identify areas that may not successfully meet the relevant codes/ standards or the functional requirements as defined in the functional specification for the new technology.

Additionally, it is important to ensure that the safety and risk of the attributes (where applicable) have been evaluated and any potential (immediate and/or future) safety hazards or risks have been addressed and managed. For example, what are the safety hazards and risk during installation? What are the risks of injuries during installation? Can it be mitigated? These could be considered as some of the immediate safety hazards and risk that could hinder the success of installation. On the other hand, poor or improper installation could pose future safety hazards and risks that could affect other phases of life cycle like commissioning or operation (for example, damaging the shear ram during installation such that it will not fully extend).

It is equally important to understand the nature of hazards and potential risks at a given level/life cycle phase, as the severity and consequences could vary from one level to another. The potential hazard or risk may escalate if not addressed at the appropriate level. Therefore it is more advantageous to address them at the lowest level possible or during the early phases of the life cycle.

The following life cycle phases (Tier I attributes) have been derived as minimum attributes that need to be considered for a barrier critical system to achieve its barrier function:

- Design – The provision of a suitable and adequate design to meet the barrier function.

- Fabrication and Testing – Ensuring that the new technology has been procured and fabricated/constructed to meet the defined design specifications and that testing has been undertaken to confirm they have been met.
- Installation / Commissioning – Ensuring that the new technology has been installed correctly and suitable commissioning tests have been completed before the system is operated.
- Operation and Maintenance – The management of processes, procedures, operation, training, maintenance and testing to preserve the design intent and function of the barrier.
- Decommissioning – The management of the removal/decommissioning of the barrier.

4.2.2 *Design*

The first and the most important element in the barrier life cycle is the design attributes, as a well-designed new technology/barrier will contribute to the success of all other life cycle phases. The design of the barriers should be assessed in terms of identifying any weakness and limitation in the design that may influence the other attributes in the life cycle meeting the intended function, an ultimately safe operation.

The Tier II minimum attributes that have been derived for assessment within the design life cycle phase include:

- Design Parameters – These are the parameters driven by relevant Codes, Standards and Regulations and also by the location/environment of the offshore unit. For example, environmental hazards, pressure/temperature ratings, loads, corrosion/erosion allowance, strength/integrity, impacts etc.
  Within this attribute the HFE (Human Factors Engineering) program is also included. This is to ensure all aspects involving monitoring and Operator interaction is designed to reduce possibility for human error. The Operator should have the information he needs when he needs it. Operator awareness and actions shall in turn be more suitable during normal and emergency operations.
- Interactions / Dependencies – The interactions/dependencies that are required for the barrier to achieve its intended function should be identified and assessed. For example, alarms, remote indication, human actions (for instance Monitoring and Act on Alarm) and emergency power etc. For the human factors part, workplace arrangement and means of communication are included.
- Layout – The layout of the barrier needs to be assessed in terms of its ability to perform a given function at the location. This in turn has to be assessed in regards to access for maintenance, inspection and the human element and for vulnerabilities from the environment like protection from potential damage (e.g. hazardous areas and guards/covers etc.). Layout is critical for important aspects such as inspections, testing and maintenance and in turn maintainability. The need for access and ability to do inspections will of course vary, but every case must assess this need. If these factors are neglected in the design phase then it may prove difficult to maintain the barrier's ability to function as intended. The control panel layout is important for Operators to be able to perform their tasks right, attributes such as control layout, layout of displays and alarms should be included.

- Material Selection – The material selected should be robust and suitable for the purpose and assessment driven by the design specification, operational requirements, in-service conditions and applicable Codes and Standards. Considerations for material selection include function, temperature, corrosion, hardness, ductility and so forth.

4.2.3 *Fabrication and Testing*

In this particular phase of life cycle, work shall be based upon ensuring that the equipment/component for the barrier has been correctly procured and fabricated to meet the defined design specifications and that suitable testing has been undertaken by the manufacturer to confirm they have been met.

The Tier II minimum attributes that have been derived for assessment within the fabrication and testing life cycle phase include:

- Material Procurement & Quality Assurance – The procurement process must ensure that what has been ordered is what has been received. Certificates on material quality could be sought from the manufacturers with checks made into tolerance limits, protective coatings and specified design requirements etc.
- Welding and NDE – Examination should be made into any welding and NDE carried out during the fabrication of the component. Considerations include Magnetic particle examination, Ultrasonic examination, Hardness testing, Pre/post weld heat treatment and Welding and NDE procedures and related personnel qualifications etc. Validation of the production process and product quality will be directly linked to that all testing is performed correctly and will correlate to that the inspectors and welders are certified and have the right competence.
- Testing and Validation – Certification from the manufacturers should be sought for any testing and validation that is undertaken to verify that all required design specifications have been achieved. E.g. Factory Acceptance Testing such as hydrostatic test, test, load test, and other functional tests, etc. Validation of the production process and product quality will be directly linked to all testing and validation being performed correctly and will correlate to the inspectors being certified and having the right competence.

4.2.4 *Installation and Commissioning*

For the Installation and Commissioning life cycle phase it is important to assess any associated risk and hazards (where applicable) and also ensure adequate storage, installation, testing and commissioning procedures are in place such that the barrier(s) being installed and commissioned is not compromised in any way or pose any immediate or future safety hazards.

The Tier II minimum attributes that have been derived for assessment within the Installation/ Commissioning life cycle phase include:

- Inspection – This attribute relates to the inspection of all equipment that has been received from the manufacturer prior to storage/installation to ensure that it is correct and fit for purpose. Attributes to be assessed include control measures and procedures in place, special handling instructions etc.

- Storage – The equipment to be installed may require special care and handling procedures and as such attributes like labeling, controlled environment, packaging etc. should be assessed prior to installation.
- Examination Pre-installation – This attribute relates to the inspection of all equipment prior to installation to ensure it is correct and fit for purpose. Attributes to be assessed include visual inspections, layout, operating conditions etc.
- Installation – The installation of the equipment requires suitable procedures that ensure that all equipment is installed correctly and that take account of all potential hazards to personnel safety and the equipment. Considerations that should be assessed include the documentation, staffing, equipment, safety and risk etc.
- Testing and Validation Post-Installation – Certification should be sought for any testing and validation that is undertaken to verify that the equipment has been installed correctly and that the system is ready for operation, and can perform its intended function in relation to other systems/equipment. For example, system integration tests, hydrostatic testing, electric continuity tests etc.
- Commissioning – The commissioning of the equipment requires suitable procedures and tests to be undertaken in order to ensure the system is operating as intended as per the design specification. Considerations that should be assessed include the documentation, staffing, tools/equipment, scheduling, safety and risk etc.

For the points above, organizational aspects like competence, training and having the right personnel to do the job is crucial for securing a safe operation. Latent errors may be introduced into the system and may be dormant for a prolonged period of time and may in turn be root cause for a major accident.

4.2.5 *Operation and Maintenance*

For the Operation and Maintenance life cycle phase it is important to ensure that design limitations are understood, procedures are well defined and operation and maintenance activities are developed specifically to meet the design specification and procedural requirements.

The Tier II minimum attributes that have been derived for assessment within the Operation and Maintenance lifecycle phase include:

- Limits – This attribute relates to the safe operating limits of the equipment used for operation. Attributes to be assessed include design specification, performance testing, hazard identification, indicators/methods of monitoring, manufacturer's requirement and effects of external factors, and so forth. For operational tasks, stressors and environmental factors should be reflected as Limits.
- Procedures – This attribute relates to identification of the overall procedures (pre-operation, emergency and critical) required to ensure successful operation. Attributes to be assessed include testing, inspection, documentation, staffing qualifications and training, hazards identification, work instructions, environmental conditions, permits and applicable codes and standards, and so forth.

- Operation – This attribute relates to the evaluation of the required operational procedures and ensuring that adequate management and trained staff are in place to successfully operate the barrier and that proper tools and equipment are identified and are available for use during the operation. Operations should be assessed from start-up to normal operation with respect to operational and environmental conditions and limits to ensure process control and monitoring procedures are in place and performances can be measured.
- Maintenance – This attribute relates to the evaluation of the required maintenance procedures or monitoring and ensuring that adequate management and staffing are in place to successfully maintain the barrier. It also includes assessing that proper tools and equipment are identified and are available for use during the maintenance and assessing the maintenance and inspection schedules and procedures, the required spare parts, accessibility to the equipment, and so forth.

4.2.6 *Decommissioning / Removal*

In this particular phase of life cycle it is important to understand the hazards and complexities that the removal/decommissioning of the new technology/barrier will have and also the effect on the overall system. It is essential to ensure proper processes are in place for the disassembly of the barrier and interaction with other equipment are considered.

The Tier II minimum attributes that have been derived for assessment within the Decommissioning lifecycle phase include:

- Process – This attribute relates to the assessment of the process developed for removal/decommissioning and should consider operational and environmental impacts, identification of safety hazards and risk, interdependencies, changes to limits of operation, emergency scenarios, etc.
- Disassembly – This attribute involves disassembling of the barrier. Disassembly of a barrier requires suitable procedures that ensure that all related equipment are disassembled correctly and that take account of all potential safety hazards to personnel safety and the equipment. Considerations that should be assessed include documentation, proper management, supervision and staffing, equipment and tools required for disassembly, and any potential risk etc.
- Interaction / Dependencies – The interactions/dependencies should be assessed prior to decommissioning or removal of the barrier in order to ensure the barrier can be safely removed without posing any safety risk to the personal or the environment. Interaction should be identified and assessed. E.g. alarms, remote indication, human actions and emergency power, emergency shutdown systems, etc.

4.2.7 *Tier III Attributes*

A set of Tier III attributes have also been developed corresponding to each Tier II attribute within a life cycle phase. The Tier III attributes detail the list of considerations that BSEE should review as part of the assessment of each Tier II attribute. Each of the Tier III attributes themselves will be evaluated against a defined set of success criteria for realizing the physical and operational tasks for the barrier element / barrier critical system. This can also be seen as the necessary performance requirements for the barrier element. For example, the success criterion for the pressure rating attribute of a given Ram BOP could be that the Ram BOP is designed for a rated working pressure (RWP) of 15,000 psi.

Tier III also presents the potential level of information that will be expected to be submitted by the applicant/Operator for BSEE's review/evaluation of a new technology.

Figure 17 presents an example of Tier III attributes corresponding to Tier II attributes for the design phase. The Tier III attributes listed are only to highlight examples of aspects covered and not meant to be exhaustive. The attributes listed need not all apply to a given system or a new technology.

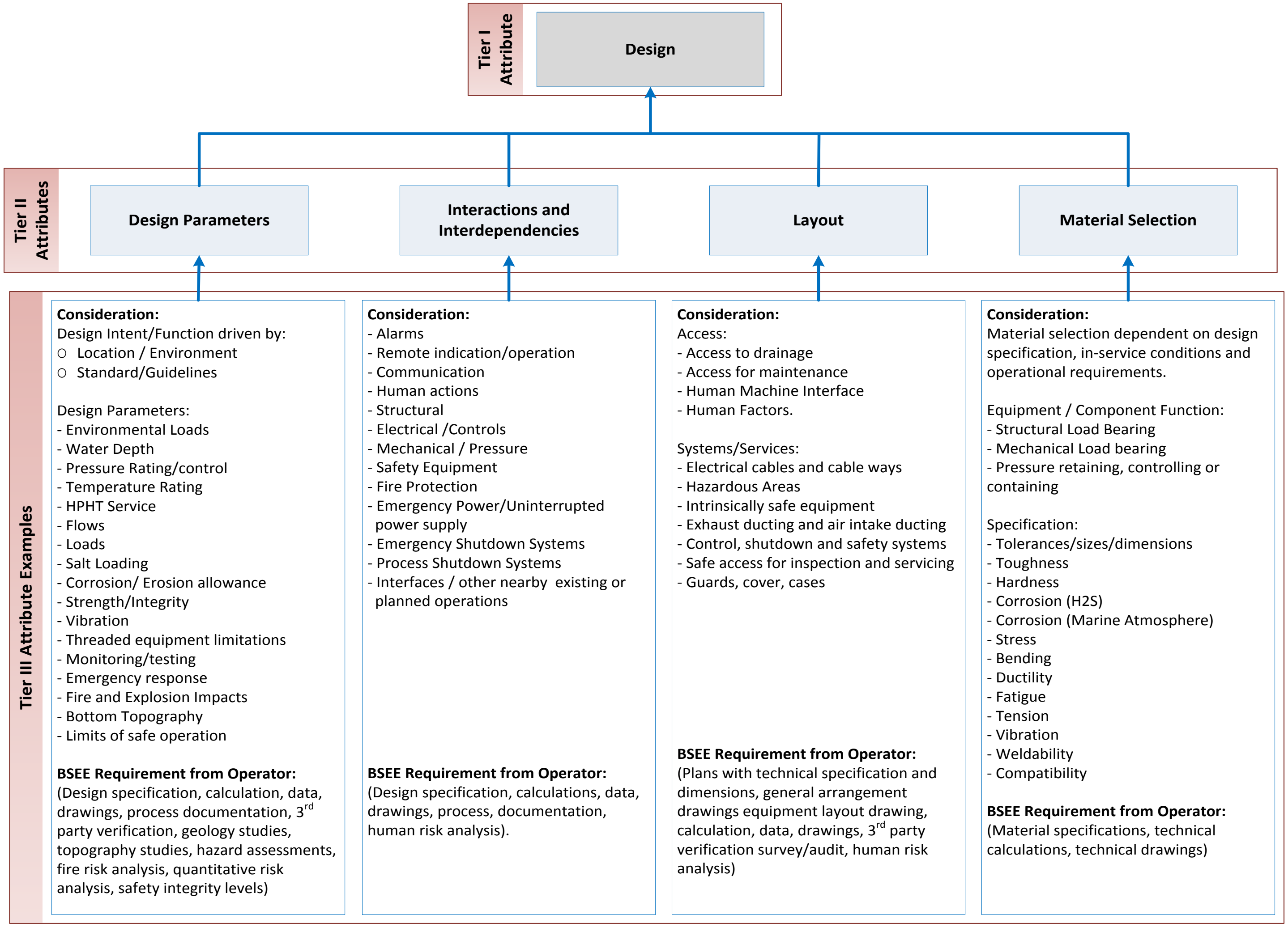

Figure 17: Design Phase Tier II and Example Tier III Attributes

4.2.8 *Linking attributes to success criteria*

A Barrier Element Attribute Checklist has to be developed to complement and link the barrier elements life cycle phase attributes (Section 4.2) to its success criteria. A snapshot of the generic template of the Barrier Element Attribute Checklist is shown in Figure 18.

Barrier Function:															
Barrier Critical System:															
Element:															
1-1 DESIGN PARAMETERS															
Checklist Ref.	**Barrier Critical System Function**	**Task Type**	**Task**	**Success Criteria**	**Success Criteria**	**Applicant Assurance**	**First Check Date**	**First Check Result (Y/N)**	**First Check ID**	**Second Check Date**	**Second Check**	**Second Check ID**	**Supervisory Check Date**	**Supervisor ID**	**Remarks**
These are the parameters driven by relevant Codes, Standards and Regulations and also by the location/environment of the offshore unit. E.g. environmental hazards, pressure/temperature ratings, loads, corrosion/erosion allowance, strength/integrity, impacts etc.															
1-2 INTERACTIONS / DEPENDENCIES															
Checklist Ref.	**Barrier Critical System Function**	**Task Type**	**Task**	**Success Criteria**	**Success Criteria**	**Applicant Assurance**	**First Check Date**	**First Check Result (Y/N)**	**First Check ID**	**Second Check Date**	**Second Check**	**Second Check ID**	**Supervisory Check Date**	**Supervisor ID**	**Remarks**
The interactions/dependencies that are required for the barrier to achieve its intended function should be identified and assessed. E.g. alarms, remote indication, human actions and emergency power etc.															

Figure 18: Snapshot of Barrier Element Success Checklist

Each checklist is separated into individual sheets for the different life cycle phases (Design, Fabrication / Testing, Installation / Commissioning, Operation / Maintenance, and Decommissioning / Removal). Each life cycle phase will consider the success criteria for each of the relevant Tier III attributes as detailed in Section 4.2.7.

Consideration has been given to barrier elements that may be part of multiple barrier critical system functions with corresponding physical and operational tasks. Therefore, the checklist developed for each barrier element considers the following:

- Barrier Critical System Function – Description of function of the barrier critical system.
- Task Type – Detail if the task required in maintaining the barrier critical system function is Operational or Physical.
- Task – Description of the Operational or Physical task required for performing the barrier critical system function
- Success Criteria – Performance requirement or success criteria for each attribute in the success path of the barrier element so that it can perform its intended function.
- Success Criteria Basis – Reference to applicable Codes and Standards, Technical or Functional Specification etc. from which the success criteria for the attribute is derived.
- Applicant Assurance – Assurance provided by the Operator verifying that each barrier element success path attribute can meet the required success criteria. This assurance could be provided by referencing other relevant design documents or test reports.

- BSEE Review Quality Assurance Processes – Processes required by BSEE to ensure all Quality Assurance requirements for the new technology review have been met.

5. Key Considerations for Barrier Element Attribute Checklist Development

This section summarizes some of the key considerations and lessons learned for the development of attributes and related success criteria for barrier elements.

The aim of developing a checklist is to allow a systematic and optimized assessment on a barrier element in achieving its barrier critical system function. Each checklist should present a defined set of success criteria for realizing the physical and operational tasks for the respective barrier element and the assurance from the Operator that each barrier element can meet the required success criteria. It is important to keep the assessor in mind when developing checklists so that all information is presented in a consistent and logical manner.

For each of the Five (5) scenarios, example attribute checklists have been developed for a variety of barrier elements to help illustrate the information required when populating a checklist. A number of checklists have been developed and are available in their respective scenario case studies (see Barrier Analysis Case Study 1-5). These can be used as guidance during the development and population of checklists.

5.1 Attribute Checklist Population

To provide a link between the barrier model and the associate attribute checklists, the information populated within the attribute checklists require to accurately reflect the information presented within the barrier model. Care should be taken to ensure that the correct details are subsumed into the checklist. For Scenario 1, the information required to be taken from the model would be:

- Barrier Function: The top level function of the barrier e.g. *Shut in Well and Control Well Bore*.
- Barrier Critical System: The critical system under assessment e.g. Blowout Preventer.
- Barrier Element: The barrier element of the system under assessment e.g. in this case the Pipe Rams of the BOP.
- Barrier Critical System Function – For the Pipe Rams – Close and Seal on Drill Pipe and Allow Circulation, Circulate across the BOP Stack to remove trapped Gas and Hang off Drill Pipe.
- Task Type – Detail if the task required in maintaining the barrier critical system function is Operational or Physical.
- Task – Description of the Operational or Physical task required for performing the barrier critical system function e.g. for the Pipe Ram a physical task is Close on Drill Pipe.

5.2 Success Criteria

Success criteria developed for each barrier element shall be ideally both measurable and demonstrable to allow the person carrying out the assessment activity to clearly understand what the requirement is and be able to validate how the criteria is being achieved through the applicant assurance (see section 5.3 below).

Measureable criteria that can be confirmed through design justifications, hazard assessments, calculations, certification, routine operations, maintenance, testing or inspections are needed. Obscure or ambiguous success criteria which cannot assure the barrier element achieves its barrier critical function can lead to confusion and a loss of confidence in the assessment.

The example, in Table 2 below from Scenario 1 of a Blind Shear Ram for a Subsea BOP stack illustrates measurable and demonstrable criteria. The criteria is measureable in so far as it provides a numerical figure against which the barrier element is ensured to be designed. The criteria are demonstrable as documentation and calculations can be provided by the Operator to the reviewer in order to prove that the design has incorporated this requirement of closing the Ram in 45 seconds or less.

Table 2: Example of Success Criteria and Applicant Assurance for Physical Task – BOP

Barrier Function: Shut in the Well and Control Wellbore						
Barrier Critical System: BOP						
Element: Blind Shear Ram						
Checklist Ref.	**Barrier Critical System Function**	**Task Type**	**Task**	**Success Criteria (Attribute)**	**Success Criteria Basis**	**Applicant Assurance**
1-2-2	Close and Seal on Open Hole and Allow Volumetric Well Control Operations	Physical	Close on open hole	Subsea power supply shall be capable of closing each ram BOP in 45 seconds or less.	API 53 (7.3.10.4)	Design specification document (reference xx) detailing subsea power design capable of supplying control system and maintain the rams closing within 45 seconds. Design certified during design review

5.2.1 *Success Criteria Basis*

When developing success criteria it is encouraged to use and reference design codes and standards where this is relevant to meet any legal/regulatory requirements. Any codes, standards and specifications used within the design of the barrier element should be identifiable within the success criteria so that the requirements can be maintained throughout the barrier element's lifecycle.

When selecting a specific code or standard to use is important to identify the most applicable to the design in question. This could be dependent on a variety of factors including regulatory body, operating parameters or the barrier critical system under assessment.

Extraction of criteria from a code or standard should identify the requirements that allow the barrier critical element to successfully perform its intended tasks to achieve the overall barrier function. It is tempting to populate an attribute checklist with any criteria that is found within a code or standard, however if criteria is not relevant to the barrier element achieving its intended function, unnecessary time and resource will be spent justifying criteria that may not be required.

Finding a relevant code and standard to use for a new technology may be difficult or not possible due to the new design not captured within current codes and standards or the new design operating within conditions that are outside the performance parameters defined by current industry codes and standards. Therefore an alternative way has to be used to derive success criteria (see section 5.2.4 below).

5.2.2 *Physical Task Success Criteria*

Physical task success criteria are identified for a specific barrier element to enable it to perform the barrier critical system function. As can be seen within the examples developed the majority of the criteria found within the checklists relate to the physical task of a barrier element. When defining success criteria for physical tasks it is important to remember to identify the requirements that allow the barrier critical system element to successfully perform its intended physical tasks to achieve the barrier critical system function.

Within the examples developed, the API codes and standards have been the main standard utilized. The APIs are particularly useful as generic criteria applicable to all of the lifecycle phases can be extracted for barrier elements. Example criteria taken from APIs are provided below for each of the lifecycle phases:

- Design
  Every installed Ram BOP shall have, as a minimum, a working pressure equal to the maximum anticipated surface pressure (MASP) - API 53 (6.1.1.1).
- Fabrication and Testing
  All welding of components exposed to wellbore fluid shall comply with the welding requirements of NACE MR0175 - API 16A (7.1) and API 53 (6.5.8.5.2).
- Installation and Commissioning
  The manufacturer shall write procedures that prepare the equipment for installation and commissioning in a manner that is effective and minimizes the risk of damage - API17F (4.6.6.2).
- Operation and Maintenance
  Manufacturer operating and maintenance documents, equipment owner PM programs, and operating experiences shall be incorporated into the site-specific procedures - API 53 (7.6.2.1.4).
- Decommissioning / Removal

If replacement parts and assemblies are acquired the parts and assemblies shall be equivalent or superior to the original equipment and fully tested, design verified, and supported by traceable documentation in accordance with relevant API specifications - API 53 (7.1.4.4/7.6.9.6.2).

It is important to note that the success criteria taken from codes and standards should be periodically reviewed at the different assessment stages for the new technology, to incorporate any lessons learnt by the Operator, industry developments or change in operating parameters. The suitability of success criteria can change over the years as new knowledge is obtained and codes and standards also change. The Operator should ensure they meet any new applicable codes and standards or demonstrate that it is not practicable to meet them. Criteria should also be reviewed when parameters in the operations on the installation change.

5.2.3 *Operational Task Success Criteria*

Most operational tasks are task being performed by an Operator in front of a control panel. The typical operational tasks will be to activate, to monitor, act on alarm and to do operation according to procedure, as described in Section 3.6. The attributes for the operational tasks will thus be covered by the control panels attribute checklists together with the identified physical tasks. Figure 19 illustrates the attributes for the operational task with reference to the different attribute tiers.

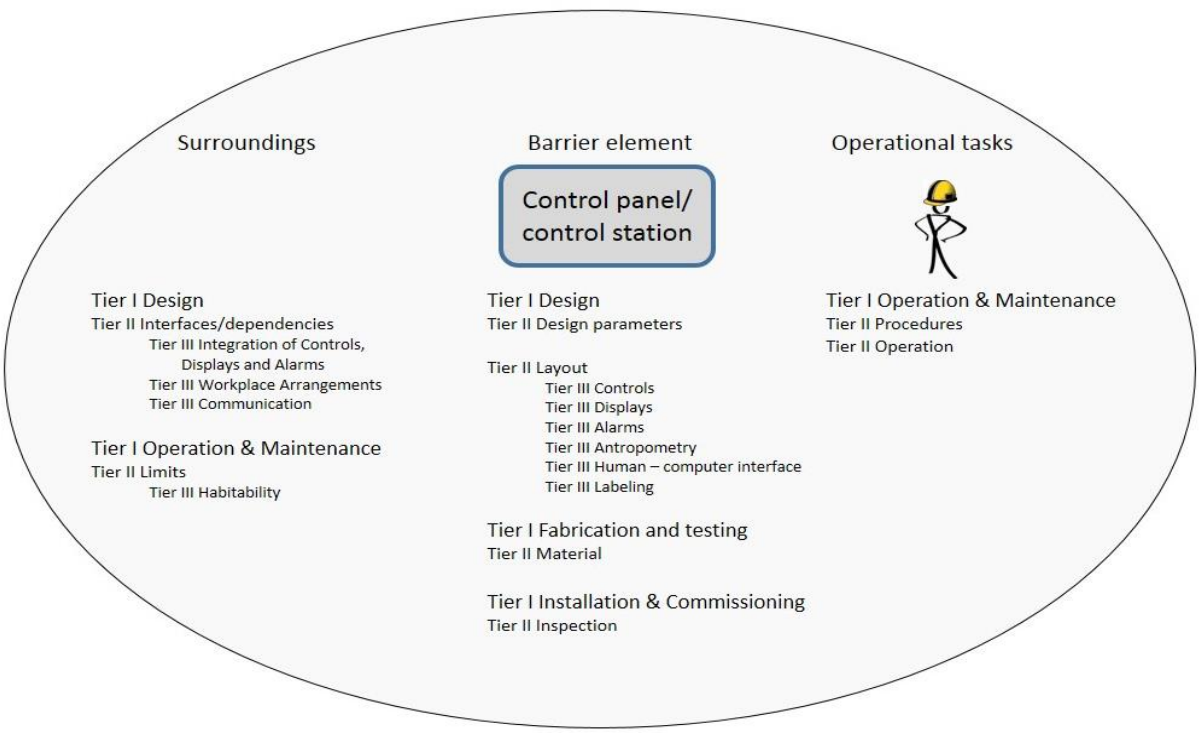

Figure 19: Overview of attributes for Operational tasks

The control panel or control station should be designed according to principles for Human Factor Engineering to minimize the likelihood of human errors in the performance of the operational tasks. I the design phase, a plan for HFE throughout the lifecycle of the panel should be written. The attributes for a successful layout need to consider the actual tasks to be performed, and the attributes will be specific according to this. Panels without alarms, do not need to consider alarm layout.

The design and layout of the control panels or stations need to be considered as part of the surroundings. Layout and locations should be studied to ensure safe operation and good accessibility.

The specified design for layout and the interaction with the surrounding, need to be followed up during the life cycle phases of Fabrication and Testing and Installation & Commissioning.

In the Operation and Maintenance phase, the operational task shall be performed according to specific procedures. Sufficient and well trained staff should be present for the operation of the barrier critical systems/barrier elements. Most of the attributes are generic, except for the layout as explained above. When it comes to the specific success criteria basis, these will be less generic especially for the Operation phase where specific procedures and competence should be referred to as far as possible.

Within the examples, the majority of the operational task criteria that have been developed are generic, applicable to all control stations derived from industry guidelines and best practice. Codes and standards used include ASTM F1166, ABS Guidance note on the implementation of human factors engineering into the design of offshore installations and API standards for specific barrier elements. These references have produced success criteria that can be applied across all control station checklists related to layout, interface/surroundings, interactions, displays, controls and environmental factors. An example from the MPD barrier model (Scenario 3) for the modified riser joint control system is provided in Table 3.

Table 3: Example of Success Criteria and Applicant Assurance for Operational Task – MPD

Barrier Function: Prevent an influx by monitoring and precise dynamic control of the annular pressure profile / bottom hole pressure (BHP)						
Barrier Critical System: Managed Pressure Drilling						
Element: Modified riser joint control system						
Check list Ref.	**Barrier Critical System Function**	**Task Type**	**Task**	**Success Criteria (Attribute)**	**Success Criteria Basis**	**Applicant Assurance**
1-2-3	Direct return flow in the annulus to buffer manifold	Operational	All	Controls, displays and alarms to be designed according to HFE design specifications	ASTM F1166 - Section 8 Integration of Controls, Displays and Alarms	HFE aspects of controls, displays and alarms to be included in manufacturer's design specification. Design verified during design review.

Specific success criteria related to operational tasks required to accomplish a barrier critical system function will be driven by the "operate according to procedure" category (Section 3.6) e.g. the barrier critical system function is realized through performing a set operating or maintenance procedure on the barrier element carried out by competent Operators.

Good practice is to align maintenance management activities directly to success criteria, ensuring that specific failure limits are defined within the routines. Table 4 demonstrates an example from Scenario 4 below.

Table 4: Example of Success Criteria and Applicant Assurance for Operational Task – SSSV

Barrier Function: Prevent Loss of Subsea Well Control						
Barrier Critical System: Subsurface Safety Valve (SSSV)						
Barrier Element Subset: Valve Control System						
Barrier Element: Emergency Shutdown (ESD) control panel						
Check-list Ref.	**Barrier Critical System Function**	**Task Type**	**Task**	**Success Criteria (Attribute)**	**Success Criteria Basis**	**Applicant Assurance**

4-2-5	Close and Shut in Flow on Commanded Closure	Operational	Activate SSSV Closure through ESD system	Operating procedures shall be prepared for use by field personnel and service technicians and should include adequate schematics and block diagrams	API 17F (4.6.6.2)	Operating manual submitted defining the following: -General description and features -General function and shutdown philosophy -System checkout -Maintenance procedures

5.2.4 *Developing Success Criteria if no basis documentation is available*

When no relevant codes or standard can be identified to be used for a new technology, success criterion has to be derived from the Operator/End User's Basis of Design document or functional specification for that particular new technology. This document will be developed by the Operator early in the field and technology design development process for discussion with relevant parties such as the Equipment Owner and Original Equipment Manufacturer (OEM) in order to specify the relevant criteria that the new technology is required to meet e.g. the largest potential loadings or the extreme pressure/temperatures that will be encountered. These scenario specific figures can form the basis of the success criteria within the checklists, with the manufacturer's technical design specifications, calculations and analysis provided as assurance that the design of the barrier element can operate at these limits. Justification will also have to be provided as to why it is tolerable to operate outside the limits set by current standards. In short, the barrier element attribute acts as a bridging document connecting the manufacturer's technical specifications and the Operator's functional specification for design verification and validation.

For some new technologies an alternative approach is to adopt existing criteria for an element that is of similar design which can be adapted to the suit the new proposed technology. For example within Scenario 2, the subsea BOP and SDS connector is of similar design to an existing BOP Stack with a LMRP. Criteria for the BOP and SDS connector was primarily taken from the IADC guidance on surface BOP configurations but also criteria for API 53 on LMRP connections was adapted for use in this scenario. In a real world application if this approach was adopted, justification and rationale would have to be provided as assurance as to why the criteria can be used.

It should also be noted that the generic criteria found within current codes and standards may still be applicable. For example, take Scenario 1 that involves ultra-deep water drilling on the outer continental shelf with a subsea BOP, the generic criteria found for a conventional Subsea BOP within API 53 will still be relevant to ultra-deep water drilling but criteria may have to be derived relating to the specific design parameters encountered during deep sea drilling that API 53 may not encompass, such as temperature, pressures and loads etc.

5.2.5 *Lessons Learnt*

The key lessons learnt through developing the example barrier element attribute checklists are presented below:

Barrier elements can be part of several barrier critical system functions, and are therefore repeated under all applicable barrier critical system functions within the barrier model. An example of this could be a control panel that is used to initiate the actuation of several barrier elements or a blind shear ram that achieves different barrier critical system functions for a BOP Stack. As most of the attributes for a barrier element will be the same for all barrier critical functions, only one checklist list should be created for each barrier element. When populating a checklist of this nature to avoid unnecessary work, rather than repeating generic success criteria the "barrier critical function" column can be completed with "All" indicating that the success criteria is applicable to all barrier critical system functions that the element helps achieve. It is important to note that care should be taken to capture all the differences between the barrier critical system functions the respective element is applicable to and specific success criteria identified for the intended barrier critical system function.

When finalizing the models it was noted that some of the barrier elements for the barrier critical system functions would produce identical attribute checklists due to the nature of the element breakdown. It was decided rather than replicate effort, checklists could be developed that encompassed more than one barrier element or alternatively cover similar type elements (such as valves) under one checklist. Examples include combining the yellow and blue control pod checklists within Scenarios 1 (Subsea BOP) and 2 (Surface BOP) into one checklist rather than creating two. Within Scenario 4 (SSSV) one valve checklist was created rather than creating individual checklists for Flowspool Valves and Buffer Manifold Valves.

5.3 Applicant Assurance

Applicant assurance is provided by the Operator to verify that each barrier element success path attribute can meet the required success criteria. The assurance is provided by referencing relevant design documents or reports such as design specification, safety justifications, hazard assessments, calculations, certification, routine operations, procedures, maintenance, testing or inspection reports to demonstrate compliance with the success criteria. As shown within the example contained within Section 5.2, design specifications and calculations can be provided by the Operator to the reviewer in order to prove that the design has incorporated the API requirement of closing the Ram in 45 seconds or less. The applicant assurance is used by the assessor to determine of the assurance submitted. The assessor will review and confirm of the criteria can be successfully met.

Within the example checklists generic assurance has been identified to compliment the criteria that has been developed. However, for real life application specific reference to documentation should be made.

Often BSEE will utilize a third party to perform the assessment of the assurance items so any assurance documentation should be auditable and the trail of assurance activities documented and tracked. On completion of the assurance review the third party should provide BSEE with a report on the status of the work completed including any recommendations, required follow-on actions or areas of concern relating to the barrier elements performing the barrier critical function.