Case Study 4: Production Operation in HPHT and Sour Environment

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

Submitted by
ABSG CONSULTING INC.
1525 Wilson Blvd., Suite 625
Arlington, VA 22209
(703) 351-3700

September 2015

BPA Contract # E13PA00008
Task Order # E14PB00078
TDL #001, Deliverable D

Table of Contents

List of Figures

List of Tables

ABBREVIATION	EXPLANATION
API	American Petroleum Institute
BSEE	Bureau of Safety and Environmental Enforcement
CFD	Computational Fluid Dynamics
DP	Dynamic Positioning
ESD	Emergency Shutdown
FMECA	Failure Mode and Effect and Criticality Analysis
FPSO	Floating Production Storage and Offloading
GoM	Gulf of Mexico
HAZID	Hazard Identification Study
HPHT	High Pressure High Temperature
HSE	Health, Safety, and Environment
MAH	Major Accident Hazard
PLETs	Pipeline End Terminations
QA/QC	Quality Assurance/Quality Control
SSCSV	Subsurface-Controlled Safety Valves
SCSSV	Surface Controlled Subsurface Safety Valve
UTA	Standard Operating Procedures

1. Introduction

1.1 Background

As part of the Bureau of Safety and Environmental Enforcement (BSEE) Emergent Technologies project, ABSG Consulting Inc. developed a risk assessment framework to qualify new technology applications submitted to BSEE. To provide a better understanding of the risk assessment framework, ABSG Consulting Inc. selected the following five scenarios to test the proposed framework. The results of the five risk assessment scenarios will guide BSEE during the review of new technology applications using the proposed methodology.

- Scenario 1: Ultra-deep water drilling
- Scenario 2: Floating production installation with a surface BOP
- Scenario 3: Managed Pressure Drilling
- Scenario 4: Production in HPHT and sour Environment
- Scenario 5: Drilling from a semi-sub in the Arctic

It is important to consider when reviewing this document, that the subject scenario background information and risk assessment were developed and tested based on publicly available information. Therefore, due to this limitation the provided studies or assessment do not reflect actual real-life projects and the studies performed for real-life project will be more comprehensive than what is provided in this document.

This document provides information on the Scenario 4: Production in High Pressure High Temperature (HPHT) and sour environment.

2. Scenario Development

2.1 Scenario Descriptions

The scenario is based on establishing production operations on ultra-deep waters in the Gulf of Mexico (GoM) within HPHT environments. Another assumption surrounds the premise that the wells in the area are sour wells, with relatively high concentrations of H_2S and other contaminants that will introduce challenges concerning corrosion and equipment detrition. The basic principle of well construction, drilling and production in an HPHT and sour environment is not different compared to conventional environments, but challenges arise in selecting suitable materials and designing equipment that can withstand the HPHT and sour conditions. This scenario will review the use of a Surface Controlled Sub-Surface Safety Valve (SCSSV) for well control in an emergency 'last resort' situation that functions to close and shut in the flow (see Section 5).

As per 30 CFR 250.807(b), HPHT environment means when one or more of the following well conditions exist:

1. The completion of the well requires completion equipment or well control equipment assigned a pressure rating greater than 15,000 psi or a temperature rating greater than 350 degrees Fahrenheit (°F).
2. The maximum anticipated surface pressure or shut-in tubing pressure is greater than 15,000 psi on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead.
3. The flowing temperature is equal to or greater than 350°F on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead.

Current BSEE regulations and American Petroleum Institute (API) design specification standards do not address completion and well control equipment for subsea wells with pressure ratings greater than 15,000 psi or for surface wells with pressure ratings greater than 20,000 psi. There is currently a need for the development of 20,000-psi subsea well equipment. High temperature generally equates to anything over 350°F.

To evaluate the scenario using the new technology risk assessment framework, production operations from a floating production unit in Gulf of Mexico (GoM) is considered.

Table 1 lists the characteristics of this scenario.

Table 1. Scenario 4 - Characteristics

Field Location	100 Miles Offshore in the Deep Water Gulf of Mexico
Water Depth:	Approximately 6,000 ft.
Facility type	Floating production storage and offloading (FPSO) unit
Reservoir/Datum Depth (MD)	25, 000 ft.
Reservoir/Datum Depth (TVD)	24, 500 ft.
Bottom Hole Temperature	300 F
Wellhead flow temperature	350-400 ^{o}F

Field Location	100 Miles Offshore in the Deep Water Gulf of Mexico
Reservoir Pressure	15,000 – 20,000 PSIG
No. of development wells	15
Design Life	20 years
Rules and Regulation:	
Design and build using recognized classification rules	
IMO MODU code	
SOLAS	
Applicable rules and regulation, where applicable	
NACE MR- 0175 complied systems design	

It is imperative to note that not all the design basis information is included here. It is expected that actual new technology application submissions should include, but not limited to, the following supporting documentation:

Engineering/Design Documents

- Design basis document providing, but not limited to, the following information:
    - Design Life
    - Operating Envelope
    - Working Environment
- Functional specification of all the major systems and associated interfaces
- General arrangement/layout drawings

2.2 Risk and Barrier Assessment Workflow

There has been limited development of HPHT wells in the GoM. Thus, meaning there is little experience and data relating to the equipment used for these types of operations in this environment.

The new technology risk assessment framework follows a workflow that depends on the novelty of the combination of the technology and the applied conditions. Figure 1 presents an overview of workflow options. This scenario will apply Workflow 2 (WF2), which is for “Known Technology (SCSSV) in a Different or Unknown Condition” (HPHT and Sour Environment). The risk assessment will focus on the identification of Major Accident Hazards (MAHs) and associated consequences. As part to the risk assessment, the team will identify the barrier critical systems that can prevent MAHs or provide mitigation against the consequence resulting from MAHs.

Operation in a different or unknown condition using the known technology/barrier critical system would require a greater focus on the consequence effects from the identified MAHs. In addition, failure of the barrier critical system due to potential incompatibility or inadequate design for the unknown condition could lead to the realization of a Major Accident Hazard (MAH). A barrier analysis to identify the critical success attributes for the barrier elements that constitute the barrier critical system is of extreme importance.

The Hazard Identification Study (HAZID) carried out as part of the risk assessment helps in identifying the MAHs and affected barrier functions. A FMECA conducted will identify failure modes and mechanisms for the SCSSV in HPHT-sour service. Section 3 of this report covers the risk assessments for this scenario and related findings.

The barrier analysis is covered in Section 4, which includes a review of the select barrier critical system (The SCSSV in this scenario) to understand what subsystems/components need to succeed in order for it to perform its barrier function(s). The barrier analysis will determine the ways in which the barrier critical system can succeed. A good understanding of the success logic is critical in determining the requirements and related activities for ensuring the integrity of the barrier critical system.

The barrier analysis also provides insight about other barrier critical system(s)/barrier element(s) that interface with the proposed barrier critical system and contribute to the realization of the barrier function(s). The barrier model begins with the identification of the barrier function and contributing barrier critical systems. The subsequent step involves identifying the required barrier critical system function(s) for each barrier critical system and the relevant barrier elements. Each barrier element contains physical and operational tasks that enable the barrier critical system function. Performance influencing factors and attributes along with the relevant success criteria originate at this stage for the barrier element to perform its intended physical/operational tasks, thereby realizing the barrier function.

Note: For further detail on risk assessments, refer to the "Risk Assessment for New Technologies Technical Note". For more information on barrier analysis, refer to the "Barrier Analysis for New Technologies Technical Note".

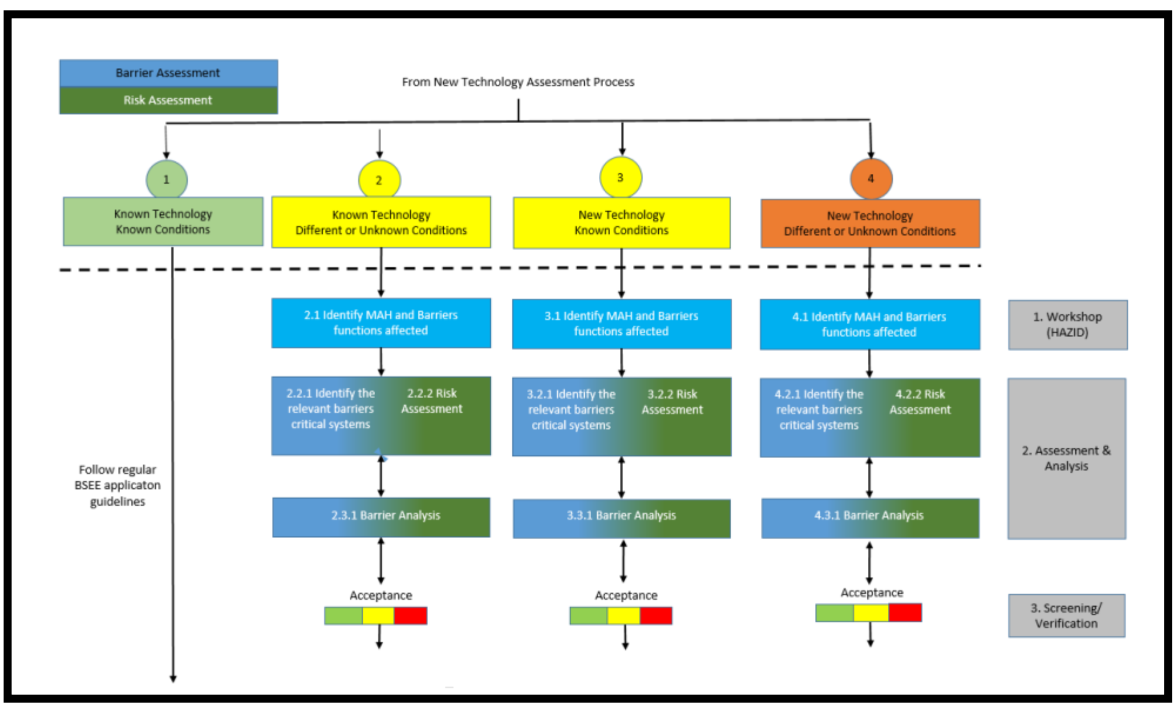


Figure 1. New Technology Assessment Framework

3. Scenario Risk Assessment

3.1 Subsea HAZID – HPHT and Sour Environment

3.1.1 Introduction

Scenarios have been developed in order to test and verify the assessment process for evaluating and premiering emergent technology. The first step in the process is to perform a HAZID, which will support the subsequent emergent technology, barrier analyses, and risk assessments.

3.1.2 Background

To evaluate the scenario using the new technology risk assessment framework, a floating production unit is considered. It is designed for operations in the Gulf of Mexico environments.

This scenario considers the field characteristic as provided in Section 2.1.

The following comprises the production facilities for subject field:

- Subsea systems
- Floating Production Storage and Offloading (FPSO) Process Facilities

Hydrocarbons from the reservoir will be produced via high-rate subsea wells through a subsea production system connected to a spread moored FPSO.

3.1.3 Objectives

A HAZID was conducted to identify hazards associated with the routine operation of the subsea development including production and facility operation. The HAZID will document the qualitative risk levels of each of the hazards identified and record risk elimination or reduction measures. Section 3.1.7 contains the results of the HAZID.

This HAZID aims to identify any impact on MAHs from new technology and/or changed conditions as discussed during the pre-planning conference with BSEE. The focus is to identify any impact on barriers in place to control the actual MAH and possible changes in consequences from the same hazards.

For this scenario, a MAH is defined as any incident or event that can lead to safety or environmental consequence of 4 or higher (i.e., major or critical) without considering any safeguards as indicated in the risk matrix in **Figure 2**.

Category	Consequence Severity				
Asset	No shutdown, costs less than $10,000 to repair	No shutdown, costs less than $100,000 to repair	Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $1,000,000	Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $10,000,000	Operations shutdown, loss of day rate for more than 28 days and/or repair more than $100,000,000
Environmental Effects	No lasting effect. Low level impacts on biological or physical environment. Limited damage to minimal area of low significance.	Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance.	Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts e.g. oil spill causing impacts on shoreline.	Serious environmental effects with some impairment of ecosystem function e.g. displacement of species. Relatively widespread medium-long term impacts.	Very serious effects with impairment of ecosystem function. Long term widespread effects on significant environment e.g. unique habitat, national park.
Community/ Government/ Media/ Reputation	Public concern restricted to local complaints. Ongoing scrutiny/ attention from regulator.	Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected with a small number of site focused people.	Attention from media and/or heightened concern by local community. Criticism by NGO's. Significant difficulties in gaining approvals. Environmental credentials moderately affected.	Significant adverse national media/public/ NGO attention. May lose license to operate or not gain approval. Environment/ management credentials are significantly tarnished.	Serious public or media outcry (international coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected.
Injury and Disease	Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment required.	Objective but reversible disability/impairment and/or medical treatment, injuries requiring hospitalization.	Moderate irreversible disability or impairment (<30%) to one or more persons.	Single fatality and/or severe irreversible disability or impairment (>30%) to one or more persons.	Short or long term health effects leading to multiple fatalities, or significant irreversible health effects to >50 persons.
	Low (1)	Minor (2)	Moderate (3)	Major (4)	Critical (5)
Likelihood: Almost Certain (E) Occurs 1 or more times a year	High	High	Extreme	Extreme	Extreme
Likelihood: Likely (D) Occurs once every 1-10 years	Moderate	High	High	Extreme	Extreme
Likelihood: Possible (C) Occurs once every 10-100 years	Low	Moderate	High	Extreme	Extreme
Likelihood: Unlikely (B) Occurs once every 100-1000 years	Low	Low	Moderate	High	Extreme
Likelihood: Rare (A) Occurs once every 1000-10000 years	Low	Low	Moderate	High	High

Figure 2. Risk Matrix

The following questions should require an answer during the HAZID related to *New Conditions* and *New Technology*:

1. Do the changed / unknown conditions directly impair or weaken or increase demand on any barrier function(s) in place to control the MAH in question? Are any new barriers introduced?
2. Do the changed / unknown conditions give potential for increased or new consequences related to the MAH in question?

The objective of the assessment is to:

- Review the selected subsea systems process functionality, specifications and operability.
- Identify major hazards associated with the design and operations of the systems.
- Develop hazard scenarios and identify potential consequences, causes, protection, detection, and indicating mechanisms.
- Surface opportunities of alternative options towards an inherently safe design or identify risk mitigation measures to reduce the estimated risk.

3.1.4 Scope

The scope of the study included all subsea facilities covering:

- All Subsea Trees / Subsea Well Center.
- All Subsea architecture including infield flow lines, umbilical, manifolds, jumpers and risers.

The Subsea HAZID covered the generic hazards associated with the overall subsea layout and associated systems. Table 2 depicts the Subsea HAZID study nodes:

Table 2. Subsea HAZID Node List

Node #	System
1	Overall Field Layouts
2	Subsea Production System

3.1.5 Methodology

The HAZID technique, as shown in **Figure 3**, is a brainstorming activity to consider hazards of system using guidewords to assist with hazard recognition. The guideword list contains a mixture of hazard sources and factors that may help control and/or help reduce damage recovery from exposure to those hazards.

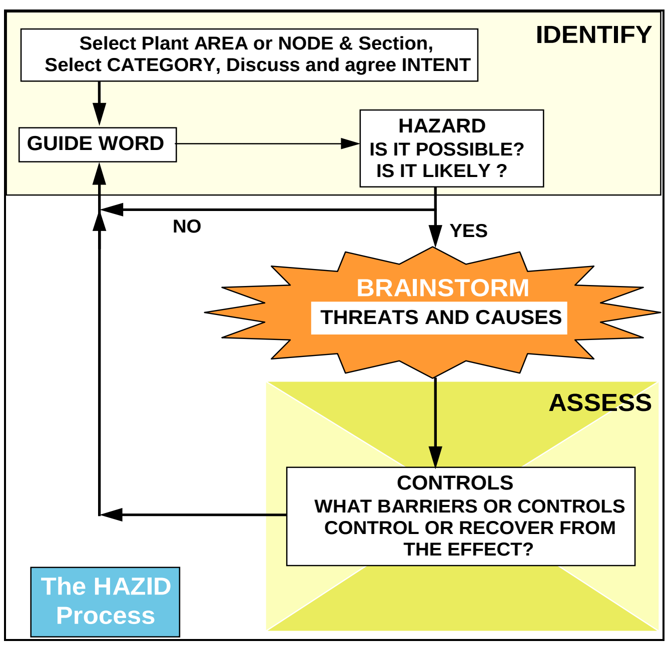


Figure 3. HAZID Study Process

Table 3 lists the HAZID guidewords that would be applicable to the systems under consideration. Feedback from the subject matter experts on the HAZID team during the workshop session have modified the list.

Table 3. Subsea HAZID Guidewords

Hazard Category	Guideword
Node 1: Overall field Layout	
Operations Hazards (hydrocarbon under pressure	• Flow Assurance (including incorrect operations) • Thermal growth • Hydrocarbon release (internal corrosion, external corrosion, cracking, erosion, etc.) • Manufacturing defects (seam, pipe ,weld, threads) • Equipment failure (flange, valve, seal, pressure relief, gauge, trap door, non-metallic degradation) • Dissimilar material • Fluid commingling / compatibility • Start-up / shutdown • Unplanned events • Pigging
Field Layout - Dropped Objects / Clashing	• Approach points (escarpments, etc.) • Accessibility (limitation due to existing infrastructure) • Existing infrastructure - phasing • Interference (with existing equipment) • Trees interference
HPHT Condition	• Well Construction
Field Layout – Environmental Hazards	• Sea floor stability and Bathymetry • Pipeline spans • Umbilical spans • Sea floor currents, waves, extreme events • Hydrocarbon release (isolation valves PLEMs/ Pipeline End Terminations [PLETs]) • Cutting • Exclusion/expulsion zones • Weather
Maintenance/Repair (future impacts)- Ergonomics	• 3rd party damage (impact - anchor, trawling, marine life) • Dropped Objects (change out of damaged Umbilical Termination Assembly [UTA], flying lead etc. in the future)
Node: 2. Subsea Production System - Surface Controlled Subsurface Valve (SCSSV) on each Production Well; Top of production riser at hang-off elevation;	
Dropped Objects/Clashing	• Existing infrastructure - phasing
Field Layout- Environmental Hazards	• High flow
Flex joint location	• Existing infrastructure - phasing

The system under examination is broken down into sections (called nodes). Credible causes of a hazardous scenario are identified for each hazardous scenario. The potential consequences that could result are discussed, assessed and recorded along with proposed protection, detection, and indicating mechanisms. The HAZID team can propose actions or requests for further considerations to mitigate/reduce the identified risk.

The basic study approach for the HAZID involves:

- The assembly of an appropriate team of experienced personnel, including representatives of all disciplines involved in the area being reviewed and (as needed) interfaces with adjacent systems.
- Short presentations detailing the scope of the study.
- Application of the relevant guidewords to identify hazards and other health, safety, and environmental (HSE) concerns.
- Recording the discussions on worksheets summarizing the nature of the hazard, its consequences, threats, the safeguards in place, risk ranking, and recommendations for any actions required.

3.1.6 Assumptions

Assumptions made at the start of the workshop for HAZID study include the following:

- Subsea system is designed in accordance with recognized standards.
- Equipment is delivered and ready to use.
- Contractor is aware of Safe Work Practices.
- Approved operating procedures will be in place before the start of operation.

3.1.7 Results and Conclusion

3.1.7.1 Results

During the HAZID, it was concluded that production in the HPHT condition does not generate any new major accident hazard but the exposure of the equipment to the HPHT condition can lead to faster degradation of the critical barriers than what will be experienced in the normal or known conditions and will require further evaluations. **Table 4** provides the list of recommendations generated during the HAZID.

Table 4. HAZID Recommendations

Recommendations (HAZID)	Place(s) Used
1. Ensure that the material of construction of the SSSV and subsea system are in accordance with HPHT environment. Also, perform a FMECA to determine if any component failure of the SCSSV will result in the complete loss of control or other unsafe situation.	(HAZID Worksheet – see Section 3.1.9)
2. Consider providing corrosion allowance in accordance with the HPHT environment	(HAZID Worksheet – see Section 3.1.9)
3. Ensure shock loads are considered in the well construction and design	(HAZID Worksheet – see Section 3.1.9)
4. Ensure wellhead and production packer seals are suitable for HPHT environment	(HAZID Worksheet – see Section 3.1.9)
5. Ensure the wellhead bay is designed to accommodate the rise of wellhead in accordance with the expected HPHT conditions	(HAZID Worksheet – see Section 3.1.9)

Recommendations (HAZID)	Place(s) Used
6. Ensure that well tubular are suitable for HPHT environment	(HAZID Worksheet – see Section 3.1.9)

3.1.7.2 MAH Identification

This HAZID aims to identify any impact on MAHs from new technology and/or changed conditions. The focus is to identify any impact on barriers in place to control the actual MAH and possible changes in consequences from the same hazards.

For this scenario, MAH is defined as, any incident or event that can lead to safety or environmental consequence of 4 or higher without considering any safeguards in place as indicated in the risk matrix (see **Figure 2**). During this HAZID, the identified MAH was a subsea release during production operation in the HPHT conditions. There were no new MAHs identified that were unique to HPHT conditions.

3.1.7.3 Barrier Critical System Identification

The review of the HAZID led to the identification of a list of the critical barriers, which can either prevent the MAHs from occurring or mitigate the consequence of the MAH. See **Table 5**.

Table 5. Critical Barriers to Prevent MAHs

Barrier Critical System	Description
Hydrocarbon Containment Systems	Pressure containment systems and equipment whose failure can lead to a loss of containment event. This includes the following: • Sub-Surface Safety Valve • Subsea System ○ Trees and Tree Valves ○ Subsea Jumpers ○ Subsea Production Manifolds ○ Subsea Flow line Connection System ○ Subsea Flow lines • Risers • Flex Joint
Subsea Controls	Control system components that help with the actuation and control of subsea equipment to facilitate safety critical functions.
Emergency Shutdown (ESD) System	All ESD measures that could minimize the risk by isolating hydrocarbon inventories to minimize release durations and escalation potential.

During development, the Barrier model will follow the guidelines provided in the barrier model template guide for all identified critical barriers. As a representation of the barrier model template, this project will only contain a subsurface safety valve barrier model.

3.1.8 Additional Risk Assessment Work

The initial HAZID led to the conclusion that production operation in the HPHT environment does not introduce any additional potential consequence vs. consequence potentially experienced during production operation in the conventional deepwater production operations.

There were multiple scenarios where consequence related to loss of containment were identified but it is imperative to note here that production operation in the HPHT environment will not lead to any additional risk to the facility or the environment than what will be experienced in the normal conditions.

The following table provides information on the various studies that can be performed as part of the general engineering practice and in most cases recommended by Operators. **Table 6** also provides the information on if HPHT environment can affect the study outcomes. If HPHT condition affects the study, it will require conductance and submittal for review and acceptance. For this case study, the studies affected by HPHT condition (i.e., Riser release risk analysis, system reliability assessment) were not performed due to limitation on the information availability.

Table 6. Additional Studies

Study	Comment
Failure Mode and Effect and Criticality Analysis for the SCSSV	Provide information on the failure modes of SCSSV while operation in the HPHT environment
System Reliability Assessment	Provide information on the system reliability while operation in the HPHT environment
Escape Evacuation and Rescue Analysis	Provide information on impairment of escape routes and evacuation means. Focus on exposure of escape routes and evacuation means to fire loads. The Escape Evacuation and Rescue Analysis Study will be not be dependent on or influenced by the operation in the HPHT environment.
Dropped Objects Study	Assess exposure of the subsea system to dropped object. The Study will be not be dependent on or influenced by the operation in the HPHT environment.
Collision Risk Assessment	Will provide information on potential collision risk, but the study will be not be dependent on or influenced by the operation in the HPHT environment.
Helicopter Risk Assessment	Will only provide information on risk contribution to personnel, but the study will be not be dependent on or influenced by the operation in the HPHT environment.
Environmental Risk Analysis	Important, provides consequences of release to the environment. No separate study will be performed, but the environmental consequences will be discussed as part of the risk analysis.
Explosion Risk Assessment	Exposure of physical barriers to explosion loads, and subsequent exposure from fires but the study will be not be dependent on or influenced by the operation in the HPHT environment. Operation in the HPHT environment will not affect the study outcome.
Riser Release Risk Analysis	Provides information on risk contribution from riser releases; should especially investigate possibility of exposure to HPHT environment.

Surface controlled subsurface safety valve was identified as a critical barrier in multiple scenarios during the HAZID. The application of the SCSSV in the HPHT environment warrants a detailed analysis of the SCSSV to ensure its performance does not degrade while working under HPHT conditions. A Failure

Modes and Effects and Criticality Analysis (FMECA) for the SCSSV was performed in addition to the HAZID and its details are provided in the Section 4.

3.1.9 HAZID Worksheet

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
1. Operations - Crude Oil Under Pressure	1. Flow assurance (including incorrect operations)	1. Leak in the Subsea System	1. Leaking connector due to incompatible materials with HPHT and sour environment	1. Ingress of sea water into the subsea system leading to hydrate formation considering sub ambient system 2. Release of production fluids to the environment (environ-mental and reputation ranking)considering system pressure above ambient subsea pressure	1. Leak test should be conducted during commissioning 2. Subsea systems should be designed for at least SITP(shut in tubing pressure) 3. Primary and secondary seals on connectors 4. Pressure and temperature sensors on subsea and topsides would be able to detect the leak 5. Ability to shut in the well using SCSSV and Subsea Tree Valves 6. NACE MR- 0175 complied systems design	Environmental	4	B	High	1. Ensure that the material of construction of the SSSV and subsea systems are in accordance with HPHT environment. Also, perform a FMECA to determine if any component failure of the SCSSV will result in the complete loss of control, or other unsafe situation.
			2. Leaking valve	1. Ingress of sea water into the subsea system leading to hydrate formation considering sub ambient system 2. Release of production fluids to the environment (environmental and reputation ranking)considering system pressure above ambient subsea pressure	1. Double barrier provided or valve and cap arrangement 2. Subsea systems are designed for at least SITP 3. Elastomer/soft goods need to be suitable for HPHT environment 4. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	5	B	Extreme	

ABS Consulting

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks CAT	S	L	RR	Recommendation
			3. Corrosion and/or erosion	1. Ingress of sea water into the subsea system leading to hydrate formation considering sub ambient system	1. Fluid velocities are controlled by operating procedures	Environmental	5	B	Extreme	2. Consider providing corrosion allowance in accordance with the HPHT environment
				2. Release of production fluids to the environment (environmental and reputation ranking)considering system pressure above ambient subsea pressure	2. Corrosion inhibitor connection points					
					3. Design in accordance with NACE MR175					
					4. Internal cladding on subsea jumpers and manifolds					
					5. Intelligent pigging operation					
					6. Acoustic Sand Detectors					
					7. Corrosion coupons/probes monitoring management on topsides					
					8. Sand controlled completions					
			4. Excessive movement of sea bed (faults) leading to cracks on subsea systems	1. Ingress of sea water into the subsea system leading to hydrate formation considering sub ambient system	1. Subsea manifolds will be installed using piles	Environmental	4	B	High	
				2. Release of production fluids to the environment (environmental and reputation ranking)considering system pressure above ambient subsea pressure	2. Jumpers will be installed such that it will not cross the fault lines					
					3. Geohazard study will be conducted for the project					
					4. Ability to shut in the well using SCSSV and Subsea Tree Valves					
	2. Flow assurance (including incorrect	2. Hydrate formation (worst-case in the flow line)	1. Leak when operating on sub ambient conditions	1. No flow through the affected item resulting in loss of or deferred production	1. Subsea equipment is fitted with Hot Water Hydrate Remediation	Financial	5	D	Extreme	
					2. Multiple hydrate inhibitors (Methanol) injection points					

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks CAT	S	L	RR	Recommendation
	operations)		resulting in water ingress into the system		3. Subsea systems are designed for at least SITP					
			2. Low temperature transients during startup / shutdown or other operating modes	1. No flow through the affected item resulting in loss of or deferred production	1. Subsea equipment is fitted with Hot Water Hydrate Remediation 2. Multiple hydrate inhibitors (Methanol) injection points 3. Subsea systems are insulated 4. Multiple pressure and temperature sensors on the wellheads with Safe Operating Procedures 5. Operating procedures and flow assurance strategies include steps to prevent hydrate formation	Financial	5	E	Extreme	
	3. Flow assurance (including incorrect operations)	3. Water collection in low spots on Lazy S production risers	1. Extended shutdown or high amounts of water entrained in process fluids	1. High rates of corrosion in the risers potentially leading to loss of contain-ment	1. Conducting dead oil displacement during shutdowns 2. Chemical injection 3. Corrosion allowance 4. Baseline and In service inline Inspection	Environmental	4	B	High	
	4. Thermal growth	4. Non identified (system is designed for maximum thermal range for wellhead temperatures)								
	5. Hydro-carbon release (internal corrosion,	5. Subsea Release	1. Erosion/ Corrosion	1. Loss of containment	1. Internal erosion monitoring system 2. Downhole completion design 3. Material selection	Environmental	4	B	High	

ABS Consulting

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks CAT	S	L	RR	Recommendation
	external corrosion, cracking, erosion, etc.)				4. Acoustic and intrusive sand detectors					
					5. CFD modeling					
					6. 7" piping downstream of choke on tree for to reduce the flow velocity					
					7. Corrosion Resistant Alloy materials					
					8. Insulation / coating					
					9. Chemical inhibitor chemical injection					
					10. NACE MR- 0175 complied systems design					
			2. Loss of well control	1. Fire hazard, environmental impact, release of toxics (H2S)	1. BOP during well intervention	Safety	5	B	Extreme	
					2. Ability to shut in the well using SCSSV and Subsea Tree Valves					
					3. Emergency Shutdown System (ESD)					
	6. Manufacturing defects (seam, pipe ,weld, threads)	6. Subsea release	1. Improper welding	1. Loss of containment, potential for fire/explosion resulting in personnel injury/fatalities	1. On loss of control system will go to fail safe mode	Safety	5	B	Extreme	
				2. Loss of control	2. Specified NDT based on the equipment requirements					
				3. Equipment replacement	3. Regular inspection					
					4. Quality Assurance/Quality Control (QA/QC) procedures					
					5. Manufacturer selection					
			2. Improper material selection		1. QA/QC procedures					
					2. Manufacturer selection					
			3. Improper		1. QA/QC procedures					

ABS Consulting

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
			machining		2. Manufacturer selection					
	7. Equipment failure (flange, valve, seal, pressure relief, gauge, trap door, non-metallic degradation)	7. Inability to control/shut-in the field	1. Marine growth 2. H2S exposure/corrosive environment	1. Inability to isolate during an emergency event 2. Loss of containment, potential for fire/explosion resulting in personnel injury/fatalities 3. Not being able to use future hubs	1. Ability to shut in the well using SCSSV and Subsea Tree Valves 2. NACE MR- 0175 complied systems design	Safety	5	B	Extreme	
	8. Dissimilar materials	8. Internal Corrosion that leads to a leak	1. Galvanic action between clad and non-clad boundaries	1. See small leak events #1	1. Corrosion inhibitor is designed to prevent this scenario	Environmental	5	B	Extreme	
	9. Dissimilar materials	9. External Corrosion that leads to a leak	1. Thermal paste used in hot water remediation system contains graphite which may cause a galvanic action	1. See small leak events #1	1. Cathodic Protection Monitoring system 2. Multi-layer coating around pipes and thermal paste	Environmental	5	B	Extreme	
	10. Fluid commingling / compatibility	10. See hydrate formation Scenario #2	1 .	1. No HSE consequences identified; operational issues only						
	11. Start-up/ shutdown	11. See hydrate Scenario #2								
	12. Unplanned events	12. Uncontrolled drive off or Drift off during work over	1. Dynamic Positioning (DP) malfunction/ failure on the	1. Damage to the tree or other subsea equipment (jumpers, etc.) 2. Potential loss of	1. Marine vessel verification (minimum DP-2 requirement) 2. Weak point analysis	Environmental	4	B	High	

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks: CAT	S	L	RR	Recommendation
			drill rig/loss of power	containment due to contact between the riser or LMRP and subsea equipment	3. Subsea infrastructure is designed to minimize elevation of components to avoid contact with risers and other subsea infrastructures 4. LMRP emergency disconnect 5. BOP stack 6. Ability to shut in the well using SCSSV and Subsea Tree Valves					
				3. Drilling rig drifting towards FPSO leading to allision with FPSO	7. FPSO moored via disconnectable turret buoy 8. Semiannual function test of turret buoy 9. Defined watch circle for emergency disconnect 10. Subsea safety valves will be closed before disconnect	Safety	5	A	High	
	13. Unplanned events	13. Controlled Drive off in response to an emergency	1. Emergency on the Drilling rig	1. Potential loss of containment due to contact between the riser or LMRP and subsea equipment 2. Damage to the tree or other subsea equipment (jumpers, etc.)	1. Weak point analysis 2. Subsea infrastructure is designed to minimize elevation and location of components to avoid contact with risers and other subsea infrastructures 3. LMRP emergency disconnect 4. BOP stack 5. Drill rig has the ability to shut-in other wells in the same drill center 6. Ability to shut in the well using SCSSV and Subsea Tree Valves	Safety	4	B	High	

ABS Consulting

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
	14.Pigging	14. Stuck pig	1. Wax, paraffin, piping arrangements	1. Deferred production	1. 5D bends on subsea systems 2. Inside Diameter matching 3. QA/QC on pigging tests 4. Barred tees 5. Pigging procedures	Financial	5	D	Extreme	
2. Field Layout - Dropped Objects / Clashing	1. Approach points (escarpments, etc.)	1.	1. Non identified							
	2. Accessibility (limitation due to existing infrastructure)	2.	1. Non identified							
	3. Existing infrastructure - phasing	3. Dropped object over subsea systems	1. Work over, installation of future equipment, maintenance / OSV activities at the host	1. Deferred production 2. Damage to subsea equipment resulting in hydrocarbon release	1. Dropped object analysis 2. Dropped object shutdown system on the drill rig 3. Pre-defined lifting zones will be determined based on dropped object analysis 4. Design incorporates shielding of sensitive equipment 5. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	
	4. Interference (with existing equipment)	4. See drive off hazards above								

ABS Consulting

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
	5. Trees interference	5.	1. Non identified							
3. HPHT conditions	1. Well Constructions	1. Failure of well tubular and hangers	1. Incompatible materials	1. Potential damage to well tubular, seals and well equipment leading to loss of containment	1. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	6. Ensure that well tubular are suitable for HPHT environment
	2. Well Constructions	2. Failure of sealing elements	1. Incompatible materials	1. Potential loss of seals a leading to loss of containment	1. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	4. Ensure wellhead and production packer seals are suitable for HPHT environment
	3. Well Constructions	3. Rise of wellhead	1. Heating up of the well construction/Shock loads	1. Potential damage to well tubular, seals and well equipment leading to loss of containment	1. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	3. Ensure shock loads are considered in the well construction and design 5. Ensure the wellhead bay is designed to accommodate the rise of wellhead in accordance with the expected HPHT conditions
4. Field Layout – Environ-mental Hazards	1. Sea floor stability and Bathymetry	1. Refer to scenario 1.1.5 movements on sea bed								
	2. Pipeline spans	2. Overstressed pipes	1. Bathymetry	1. Possible deformation to pipes	1. Conducted extensive survey of field and span analysis	Financial	3	B	Moderate	
	3. Umbilical spans	3. VIV (vortex induced vibration)	1. Umbilical span	1. Possible umbilical damage / fatigue	1. Conducted extensive survey of field and span analysis	Financial	3	B	Moderate	

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
	4. Sea floor currents, waves, extreme events	4. Lazy wave configuration on 20" export oil riser maybe subject to fatigue failures	1. Fatigue due to VIV (vortex induced vibration), wave, VIM	1. Early replacement of riser 2. Potential loss of containment with release of oil (leak/crack). Potential failure likely to occur at the touch down point away from the host	1. CFD evaluations 2. Flex joints on risers 3. In-service performance monitoring of the risers 4. The risers are fully straked except at the buoyancy elements	Environmental	3	B	Moderate	
	5. Sea floor currents, waves, extreme events	5. Lazy wave configuration on 9" production riser maybe subject to fatigue failures	1. Fatigue due to VIV (vortex induced vibration), wave, VIM, slugging	1. Early replacement of riser 2. Potential loss of containment with release of production fluid (leak/crack). Potential failure likely to occur at the touch down point away from the host	1. CFD evaluations 2. Flex joints on risers 3. In-service performance monitoring of the risers 4. The risers are fully straked except at the buoyancy elements 5. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	
	6. Sea floor currents, waves, extreme events	6. Lazy wave configuration on 12" gas export riser maybe subject to fatigue failures	1. Fatigue due to VIV vortex induced vibration, wave, VIM	1. Early replacement of riser 2. Potential loss of containment with release of gas (leak/crack). Potential failure likely to occur at the touch down point away from the host	1. CFD evaluations 2. Flex joints on risers 3. In-service performance monitoring of the risers 4. The risers are fully straked except at the buoyancy elements	Environmental	4	B	High	
	7.Hydrocarbon release (isolation valves PLEMs/ PLETs)	7. Movement of PLEMs/PLETs	1. Seismic activities, seabed movement	1. Connection damage / rigid jumper damage leading to subsea release	1. Seismic analysis 2. Adequate flexibility in jumper and PLET design 3. Routine inspection 4. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	

Node: 1. Overall Field Layouts - Drill Centers;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
	8. Cutting	8. No hazardous scenario identified - wells will be pre-jetted to avoid debris from cuttings								
	9.Exclusion/expulsion zones	9. No hazardous scenario identified								
	10. Weather	10. Emergency disconnect during well work over	1. Adverse weather	1. Damage to the well jumper, potential for loss of containment	1. Field shut-in 2. Ability to shut in the well using SCSSV and Subsea Tree Valves	Environmental	4	B	High	
5. Maintenance /Repair (future impacts) - Ergonomics	1. 3rd party damage (impact - anchor, trawling, marine life)	1. No new hazards identified - see dropped objects								
	2. Dropped Objects (change out of damaged UTA, flying lead etc. in the future)	2. Dropped object over subsea systems	1. Dropped Objects	1. Damage to the tree or other subsea equipment (jumpers, etc.) 2. Potential loss of containment due to contact between the riser or LMRP and subsea equipment	1. Marine vessel verification (minimum DP-2 requirement) 2. Subsea infrastructure is designed to minimize elevation of components to avoid contact with risers and other subsea infrastructures 3. LMRP emergency disconnect 4. Ability to shut in the well using SCSSV and Subsea Tree Valves 5. Weak point analysis	Environmental	4	B	High	

ABS Consulting

Node: 2. Subsea Production System - Surface Controlled Subsurface Valve (SCSSV) on each Production Well; Top of Production Riser At Hang-OFF Elevation;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
1. Dropped Objects / Clashing	1. Existing infrastructure - phasing	1. Dropped object contacts the pontoon riser tie-in spool below the RIV	1. OSV / lifting activities at the host	1. Deferred production	1. Dropped object analysis	Safety	2	B	Low	
				2. Damage to tie-in spool resulting in loss of containment and potential fire/explosion affecting the host	2. FPSO gas detection system alarm triggering personnel evacuation					
				3. Potential escalation if ignited jet plume impinges adjacent riser	3. Accommodation is approx. 300 ft. from the potential release point					
2. Field Layout - Environmental Hazards	1. High flow	1. High gas flow rates through gas lift flexible riser	1. Flow induced pulsation	1. Early replacement of riser	1. Project is conducting flow induce pulsation study	Environmental	4	B	High	
				2. Damage to the gas lift riser Potential loss of containment with release of gas near the host	2. Topsides gas detection will shut down the gas lift compressor					
				3. Potential oil flow back from the well/production flow line through the leak	3. Flow safety valve in the ILS, between the riser and gas lift injection flow line					
					4. PSHL on topsides					
					5. GLIV on the ILS will isolate flow from the production flow line if a shutdown is triggered					
3. Flex joint location	1. Existing infrastructure - phasing	1. Releases from flex joints	1. Damage during installation	1. Subsea release resulting in environment impact	1. Hydro testing of flex joints after installation	Safety	4	B	High	
				2. Vapor cloud formation near	2. Flex joints designed for 30 years					

ABS Consulting

Node: 2. Subsea Production System - Surface Controlled Subsurface Valve (SCSSV) on each Production Well; Top of Production Riser At Hang-OFF Elevation;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
				FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	3. Protective installation tool 4. SSIV to reduce the inventory released 5. Proper installation procedures 6. Regular inspection					
			2. Pressure swings due to daily nomination of gas	1. Subsea release resulting in environment impact 2. Vapor cloud formation near FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	1. Proto type testing to confirm design 2. Designed with a safety factor of 10 3. Standard Operating Procedures	Safety	4	B	High	
			3. Blowing down / pressuring up to fast	1. Subsea release resulting in environment impact 2. Vapor cloud formation near FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	1. Standard Operating Procedures 2. Restrictive Orifice on topsides to maintain the blowdown flowrate 3. Bypass valve across SSIV for pressure equalization	Safety	4	B	High	

ABS Consulting

Node: 2. Subsea Production System - Surface Controlled Subsurface Valve (SCSSV) on each Production Well; Top of Production Riser At Hang-OFF Elevation;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
			4. Excessive vessel motion	1. Subsea release resulting in environment impact	1. Location and orientation of FPSO is such that to minimize the excessive fatigue and stress on the flex joints	Safety	4	B	High	
				2. Vapor cloud formation near FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	2. Mooring inspection program 3. Tension monitoring of the FPSO mooring lines					
			5. Incompatible materials	1. Subsea release resulting in environment impact	1. Proper design (compatibility testing)	Safety	4	B	High	
				2. Vapor cloud formation near FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	2. Use of bellows to isolate production from elastomers of the flex joints					
			6. Operating temperature of the incoming fluids outside of	1. Subsea release resulting in environment impact	1. Proper design	Safety	4	B	High	
				2. Vapor cloud formation near	2. Top of the riser temperature monitoring					

Node: 2. Subsea Production System - Surface Controlled Subsurface Valve (SCSSV) on each Production Well; Top of Production Riser At Hang-OFF Elevation;

Hazard	Guide Word	Hazardous Scenario	Causes	Consequence	Safeguards	Existing Risks				Recommendation
						CAT	S	L	RR	
			the design	FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	3. Bypass valve across SSIV for pressure equalization					
			7. Ship collision with the attendant vessel	1. Subsea release resulting in environment impact	1. Loading/unloading are on the opposite side of the riser location	Safety	4	B	High	
				2. Vapor cloud formation near FPSO, possibly leading to explosion/fire, resulting in personnel injury and fatalities, damage to equipment	2. Exclusion zone around the riser location					

3.2 Failure Mode and Effect and Criticality Analysis (FMECA) – Surface Controlled Subsurface Safety Valve (SCSSV)

3.2.1 Introduction and Scope

3.2.1.1 General Information

As part of the emergent technology risk assessment framework a HAZID was performed to identify the major accident hazard and associated barriers for production operation in the High Pressure High Temperature GoM offshore well. One of the recommendations from the HAZID was to perform the FMECA to determine if any component failure of the SCSSV will result in the complete loss of control or other unsafe situation.

This study will help in early identification of any single point failures in the system design and associated risks during operations, thereby leading to a more proactive risk management approach.

3.2.1.2 Scope

The scope of the FMECA was to review the SCSSV and its components and evaluate their operation to identify potential failures and address if adequate safeguards are in place to contain or minimize the risk of failure.

The focus of the study will be on the use of SCSSV in the HPHT environment. It's assumed that all the failures related to operation of SCSSV in the normal operation are identified and accounted for in the design of the SCSSV.

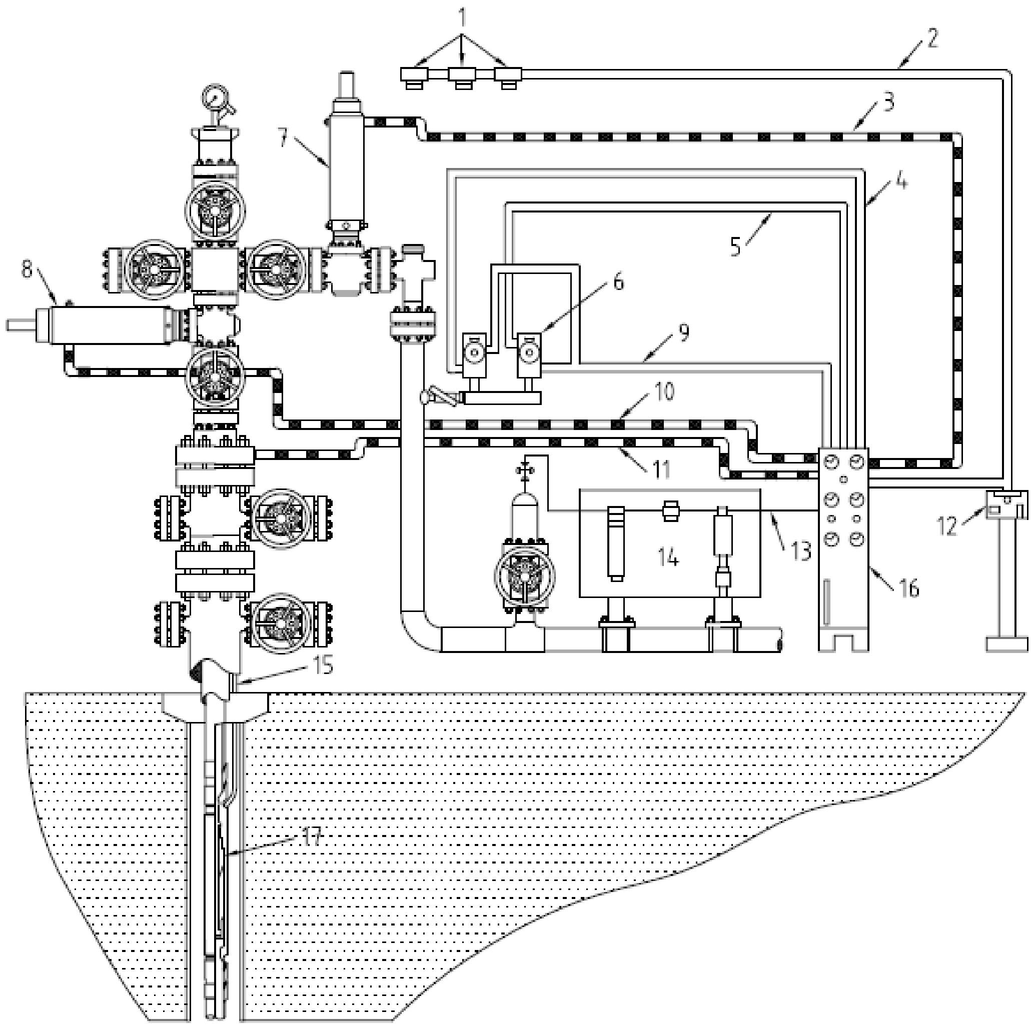
Downhole safety valves act as a last line of defense during the emergency events such as well head failure to shut-off the well flow to avoid a catastrophic event. There are two basic types of downhole safety valves:

- Subsurface-Controlled Safety Valves (SSCSV)
- Surface- Controlled Subsurface Safety Valves (SCSSV)

This study focuses on the Surface – Controlled Subsurface Safety Valves.

3.2.2 System Description

The Surface Controlled Subsurface Safety Valve system as prescribed in the API RP 14B is being considered for the FMECA study and is shown in the Figure 4 below.



1 fusible plugs
2 ESD pressure line [207 kPa to 345 kPa (30 psi to 50 psi)]
3 hydraulic/pneumatic pressure line to wing valve
4 high pilot signal
5 low pilot signal
6 pilot box
7 wing SSV hydraulic or pneumatic actuator
8 master SSV hydraulic or pneumatic actuator
9 supply to pilots [172 kPa (25 psi)]
10 hydraulic/pneumatic pressure to master valve
11 hydraulic pressure line to SCSSV
12 manual remote emergency shutdown station
13 supply line
14 flowline scrubber assembly
15 hydraulic pressure line to the SCSSV
16 hydraulic/pneumatic control panel
17 surface-controlled subsurface safety valve (SCSSV)

Figure 4. Surface Controlled Subsurface Safety Valve System[1]

[1] API RP 14B

3.2.3 Surface-controlled Subsurface Safety Valves[2]

The tubing string below the surface tubing hanger also contains the SCSSVs . Hydraulic pressure through a capillary (control) line that connects to a surface control panel (Figure 5) controls them. Most SCSSV designs today use a flapper to form a seal. Both elastomeric and metal-to-metal seal designs are available.

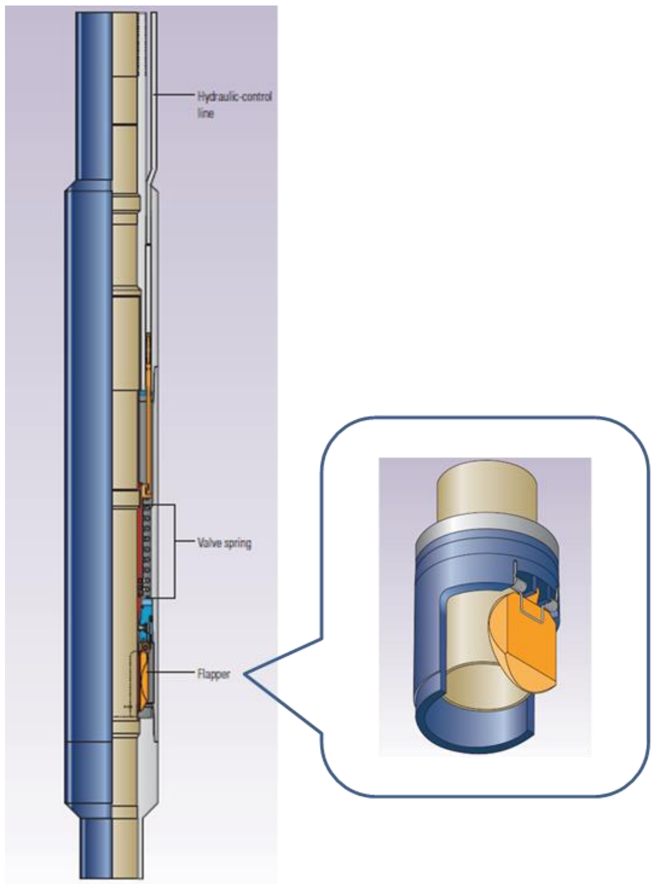


Figure 5. Surface-controlled Safety Valve[3]

The SCSSV is a normally closed (failsafe) valve and requires continuous hydraulic pressure on the control line to keep it open. The pressure acts upon an internal piston in the valve, which pushes against a spring. When the hydraulic pressure is relieved, the internal spring moves a flow tube upward and uncovers the flapper. The flapper then swings closed, shutting the well in. Ball valves work similarly. The surface control panel, because of a change in flowing characteristics that exceed predetermined operating limits, generally initiates the closing sequence. However, any failure of the system that results in loss of control-line pressure should result in the valve shutting in the well.

[2] http://petrowiki.org/Completion_flow_control_accessories#Flow_couplings

[3] At the ready: Subsurface Safety Valve, Oil field Review

To open the SCSSV, the pressure above it must be equalized (usually by pressuring up on the tubing string), and hydraulic pressure must be reapplied to the control line. Some models have a self-equalizing feature and for reopening without the aid of pressuring up on the tubing. Whether the valve is working or not, most models have a pump-through kill feature that allow the pumping of fluids down the tubing to regain control of the well.

The SCSSV is available in a tubing-retrievable model and a wireline-retrievable type. The wireline-retrievable SCSSV is installed in a special ported safety-valve nipple. The capillary line is connected from the surface control panel to the ported nipple. The hydraulic pressure applied at the surface communicates to the valve through the ported nipple. The wireline-retrievable SCSSV can be pulled and serviced without pulling the tubing string out of the hole. Because of the design and the use of elastomeric seals, they are somewhat less reliable than the tubing-retrievable version. The wireline-retrievable valve has a smaller inside diameter, and reduces flow area for production to pass through. The reduction in inside diameter can create a pressure drop across the valve and turbulence in the tubing above it. In high-flow-rate wells, the turbulence can lead to erosion of the valve or tubing string. When installed, the wireline-retrievable SCSSV restricts access to the tubing string below the valve. The valve must be removed before performing any through-tubing workover or wireline operations below the valve.

The tubing-retrievable model is more robust and offers a larger internal flow diameter. This helps eliminate turbulence and increases production capabilities. It also allows full-bore access to the tubing string below the valve. One disadvantage, in some instances, is the large outside diameter. This may limit the size of tubing that can run into certain sizes of casing. To service the tubing-retrievable SCSSV, the tubing string must be retrieved. To avoid this and extend the life of the completion, it is possible to disable the valve permanently by locking it open. A new wireline-retrievable SCSSV can be inserted into the sealbore of the retrievable valve, enabling the well to continue production without interruption.

3.2.4 Methodology

Identification of the critical failures that could disrupt the SCSSV operation resulted from a risk assessment methodology known as FMECA. The FMECA tool can evaluate the ways equipment can fail (or be improperly operated) and the effects of these failures on a system. FMECA can identify local and global effects of component failures and, if carefully done, systemic failures with undesirable and/or harmful impacts on the system as well as on those entities interfacing or relying upon it.

The FMECA provides a basis for determining where to make changes to improve a system design. Each individual failure exists as an independent occurrence with no relation to other failures in the system, except for the subsequent effects that it might produce. In addition, common cause failures of more than one system component will be considered. Human/Operator errors are not considered as cause of the functional or equipment failure.

The FMECA technique (1) considers how the failure mode of each system component can result in system performance problems, (2) identifies single point failures that can cause system failure, and (3) highlights if appropriate safeguards against such problems are in in place or if there is need for defining further safeguards. The criticality rating of the consequences and the failure event will be based on the risk ranking matrix as provided in the HAZID.

If the analysis indicated that the undesirable HSE consequence could result from a single failure, a corrective action item was suggested to demonstrate compliance with class design philosophy (assuming existing safeguards are found to be inadequate). It will be the responsibility of entity engaged on the contract with classification to follow through on the corrective actions needed to comply with classification requirements. Figure 6 graphically presents the proposed FMECA.

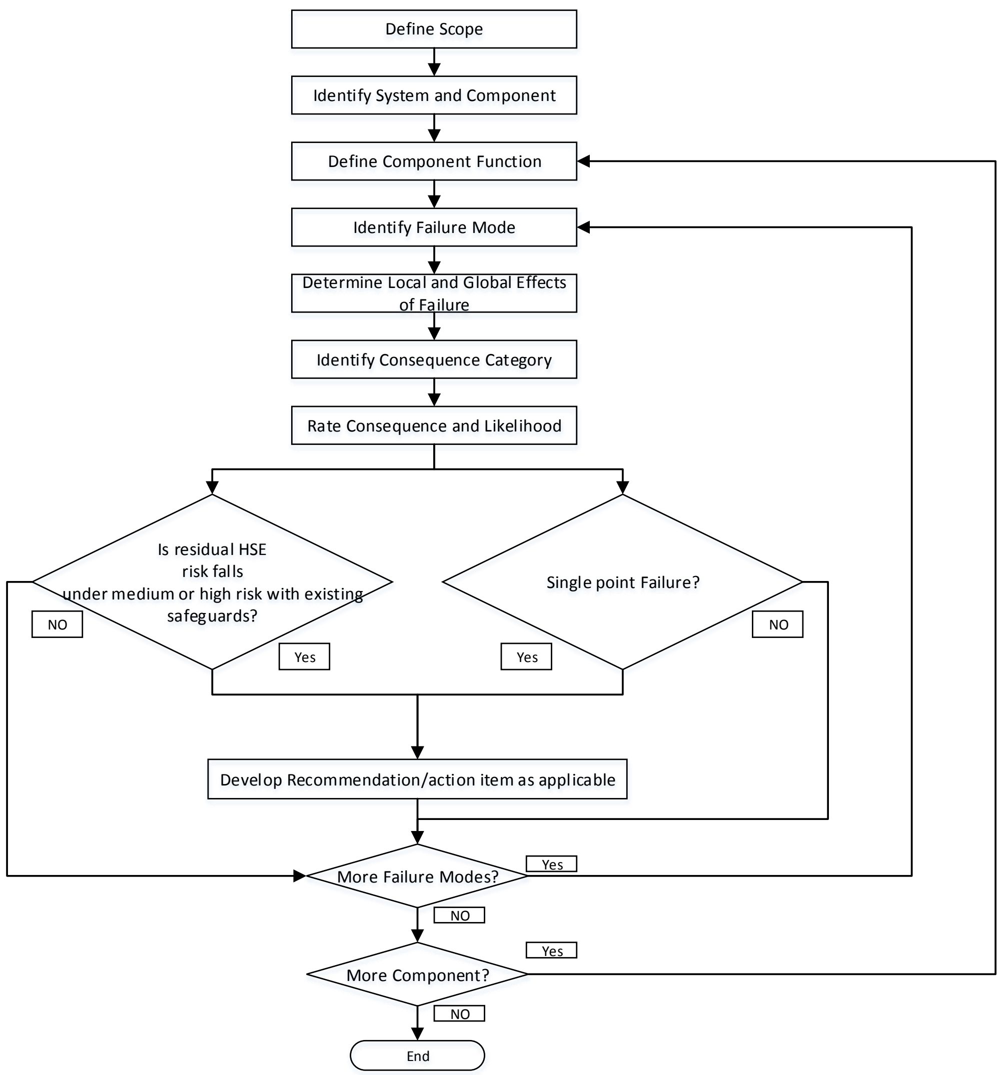


Figure 6. FMECA Flowchart

The FMECA was documented by a systematic tabulation of the effects of equipment failures within a system. **Table 7** describes the worksheet fields used to describe equipment failure modes in the FMECA.

Table 7. Description of FMECA Worksheet Fields

Worksheet Field	Description
Equipment/Component	A group of components that performs a function necessary for the success of the major function.
Function/Description	Concise statement of the function performed by the item.
Failure Mode	The predictable failure mode for the item at the analyzed functional level.
Potential Cause / Mechanism of Failure	Identification and description of the most probable causes associated with the listed failure mode.
Effect – Local	Local effects concentrate specifically on the impact an identified failure mode has on the operation and function of the item at the next higher level under consideration.
Effect – Global	System effects evaluate and define the total effect an identified failure has on the operation, function, or status of the main system relative to the analyzed consequence.
Effective Safeguard	Existing safeguard design to respond to the failure mode so that the function performed by the failed equipment is not lost.
Risk Ranking	Each Failure mode was risk ranked against applicable consequence category (i.e., Safety, Environment, Production, Financial)
Recommendations	List of any ideas presented by the team for improving the system against the failure mode for which the residual risk with existing safeguards falls under the medium of high risk

3.2.5 Results of FMECA

Section 4.1.4 provides the results of the FMECA study performed for the SCSSV. During the study, one recommendation was developed to ensure that the SCSSV components are suitable for the intended environment, e.g., considering corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), high pressure, flow rates, loads and high temperature. The operation on the HPHT environment should place focus on performing further studies to evaluate how the SCSSV component performs under such conditions. Examples of the studies include performing Computational Fluid Dynamics (CFD), water hammer analysis, thermal stress analysis, and Finite Element Analysis.

3.2.6 FMECA Worksheets

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
Close on demand	1. Fail to close on Demand	1. Flapper spring damage due to prolonged exposure to HPHT condition Mechanical Component Damage due to prolonged exposure to HPHT condition Seat/ Locking mechanism Damage	1. Flow through well when not required	1. Possible loss of containment during the emergency situation as the SCSSV are considered as a last line of defense to shutoff the well flow	1. Valve unable to close	1. Regular/periodic testing and calibration 2. Before installation, qualified personnel will test SSCSVs in accordance with the manufacturer's operating manual to verify mechanical actuation and closure-mechanism pressure integrity. 3. Opening and closing hydraulic pressures, mechanical actuation, closure-mechanism integrity and other features shall be verified according to the manufacturer's operating manual prior to valve installation	Yes	Environment	5	B	Extreme	1. Ensure the SCSSV component is suitable for the intended environment, e.g., corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), pressure, flow rates, loads and temperature.	
		2. Control valve line plug or			1. Valve unable to close	1.Control Line Protectors to prevent the control damage						2. Ensure casing pressure is maintained	

ABS Consulting

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
		damaged			2. Valve unable to closed due to the casing pressure increased higher than designed pressure	2. Regular/periodic testing and calibration						to ensure the closure of SCSSV	
		3. Scale, paraffin and hydrate deposition			1. Valve unable to close	1. Scale, paraffin and hydrate deposition are considered in the setting depth						1. Ensure the SCSSV component is suitable for the intended environment, e.g., corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), pressure, flow rates, loads and temperature.	

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
		4. Automatic Reset			1. Valve unable to maintain the close position	1. No automatic reset is provided in the control system to ensure inadvertent reopening of the SCSSV							
	2. Fail to open on demand	1. Flapper spring damage due to prolonged exposure to HPHT condition Mechanical Component Damage due to prolonged exposure to HPHT condition Seat/ Locking mechanism Damage	1. No well flow when required	1. No well flow when required - delay in production - no safety or environmental consequences	1. Pressure drop during normal operation	1. Regular/periodic testing and calibration							
					2. No well flow	2. Before installation, qualified personnel will test SSCSVs in accordance with the manufacturer's operating manual to verify mechanical actuation and closure-mechanism pressure integrity.							
						3. Opening and closing hydraulic pressures, mechanical actuation, closure-mechanism integrity and other features shall be verified according to the manufacturer's operating manual prior to valve installation							
		2. Control valve line			1. No well flow	1. Control Line Protectors to prevent the control damage							

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
		plug				2. Regular/periodic testing and calibration							
		3. Scale, paraffin and hydrate deposition			1. No well flow	1. Scale, paraffin and hydrate deposition are considered in the setting depth						1. Ensure the SCSSV component is suitable for the intended environment, e.g., corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), pressure, flow rates, loads and temperature.	
Stay in the close position when	1. Leakage through valve in closed	1. Flapper spring damage due to	1. Flow through well when not	1. Restricted well flow but well will not be fully	1. Valve unable to maintain the close	1. Regular/periodic testing and calibration		Environment	3	B	Moderate	1. Ensure the SCSSV component is suitable	

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
required	position	prolonged exposure to HPHT condition Mechanical Component Damage due to prolonged exposure to HPHT condition Seat/ Locking mechanism Damage	required	shut-off	position	2. Before installation, qualified personnel will test SSCSVs in accordance with the manufacturer's operating manual to verify mechanical actuation and closure-mechanism pressure integrity.						for the intended environment, e.g., corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), pressure, flow rates, loads and temperature.	
						3. Opening and closing hydraulic pressures, mechanical actuation, closure-mechanism integrity and other features shall be verified according to the manufacturer's operating manual prior to valve installation							
		2. Control valve line plug			1. Valve unable to maintain the close position	1. Control Line Protectors to prevent the control damage							
						2. Regular/periodic testing and calibration							

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
		3. Scale, paraffin and hydrate deposition			1. Valve unable to maintain the close position	1. Scale, paraffin and hydrate deposition are considering in the setting depth						Ensure the SCSSV component is suitable for the intended environment, e.g., corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), pressure, flow rates, loads and temperature.	
Remain open on demand	1. Fail to open on demand	1. Flapper spring damage due to prolonged exposure to	1. No well flow when required	1. No well flow when required - delay in production - no safety or	1. Pressure drop during normal operation	1. Regular/periodic testing and calibration							

ABS Consulting

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
		HPHT condition Mechanical Component Damage due to prolonged exposure to HPHT condition Seat/ Locking mechanism Damage		environmental consequences	2. No well flow	2. Before installation, qualified personnel will test SSCSVs in accordance with the manufacturer's operating manual to verify mechanical actuation and closure-mechanism pressure integrity.							
						3. Opening and closing hydraulic pressures, mechanical actuation, closure-mechanism integrity and other features shall be verified according to the manufacturer's operating manual prior to valve installation							
		2. Control valve line plug			1. No well flow	1. Control Line Protectors to prevent the control damage							
						2. Regular/periodic testing and calibration							

ABS Consulting

System: 1. SCSSV System

Subsystem: 1. SCSSV

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
		3. Scale, paraffin and hydrate deposition			1. No well flow	1. Scale, paraffin and hydrate deposition are considering in the setting depth						1. Ensure the SCSSV component is suitable for the intended environment, e.g., corrosion, stress-cracking (see ISO 10432 for SSSV class of service applications), pressure, flow rates, loads and temperature.	

ABS Consulting

System: 1. SCSSV System

Subsystem: 2. Hydraulic Supply System

Function Description	Failure Mode	Cause	Local Effect	Global Effect	Detection Method	Preventive or Mitigating Safeguards	Single Point of Failure?	CAT	S	L	RR	Action Items	Remarks
Provides hydraulic supply to SCSSV	1. Unavailability of hydraulic system when needed	1. Hydraulic line Failure Hydraulic control Panel Failure	1. SCSSV will go to close position	1. No well flow when required - delay in production - no safety or environmental consequences	1. Pressure drop during normal operation	1. Regular/periodic testing and calibration							1. No additional hazards or failure modes identified in respect to operation of SCSSV in HPHT conditions
					2. No well flow	2. Before installation, qualified personnel will test SSCSVs in accordance with the manufacturer's operating manual to verify mechanical actuation and closure-mechanism pressure integrity.							
						3. Opening and closing hydraulic pressures, mechanical actuation, closure-mechanism integrity and other features shall be verified according to the manufacturer's operating manual prior to valve installation							
						4. Control Line Protectors to prevent the control damage							
						5. Regular/periodic testing and calibration							
						6. Scale, paraffin and hydrate deposition are considering in the setting depth							

4. Barrier Function and Barrier Critical Systems

4.1 Barrier Function Description in Relation to Major Accident

During the HAZID, subsea release was identified as a Major accident hazard that can lead to undesirable consequence. Hence, the barrier function chosen for further assessment in this example is **“Prevent Loss of Subsea Well Control”**. This barrier function provides a layer of safety for topside events that can cause uncontrolled well flow, subsea and topside releases, and loss of risers due to marine events or dropped objects, which can lead to spills to the environment.

This barrier function is established to stop flow from the well upon such events as described above, by sealing the well within the production tubing in the well.

4.2 Relevant Barrier Critical Systems and Brief Summary of Their Role in Realizing the Barrier Function

Barrier critical systems considered relevant for the barrier function “Prevent Loss of Subsea Well Control” include the followint. Barrier critical systems identified during this phase will also include additional systems that may have a direct or indirect effect on the barrier critical system identified during the HAZID or contribute to barrier function.

1. Electrical Power Unit (EPU) – The EPU provides power to the control system and umbilical, which sends a signal to the solenoid valve controlling the subsea quick-dump valve within the SCM.
2. Hydraulic Power Unit (HPU) – The main function of the HPU for this barrier function is to trip and thereby stop the supply of hydraulic power to the SCSSV.
3. Subsea Control Module (SCM) - The SCM controls the flow of hydraulic fluid to the SCSSV. The SCM has the task of actuating the solenoid valve and bleeding off hydraulic pressure on demand.
4. Emergency Shutdown (ESD) System - The ESD System is tasked with signaling the SCM to bleed off hydraulic pressure, in order for the SCSSV to close.
5. Surface Controlled Subsurface Safety Valve – The SCSSV is tasked with stopping the flow of hydrocarbons and is the main barrier critical system in this barrier function.
6. Production Tubing - The Production Tubing is required to contain the hydrocarbons, both during normal operation, and while the SCSSV is closed. It is also to be noted that for a tubing retrievable SCSSV, the valve body is located between the production tubing joints and undergoes same service conditions (loads and duty cycles).
7. X-mas Tree (XT) - The XT has a support function only for the current barrier critical element. The XT houses the SCM, Underwater Safety Valves (USVs) and hydraulic pressure and return line going to the downhole SCSSV. Note that the XT also houses other redundant functions to the closure of the SCSSV.
8. Production Casing System – The production casing system (including production packers) is required to provide the structural protection to ensure production tubing and SCSSV integrity.
9. Wellhead – The wellhead provides a means of attaching the X-mass tree equipment for production operations.

10. Boarding Shut-Down Valve – The boarding shut-down valve isolates the facility from the riser.
11. Cementing – The cementing helps with zonal isolation and maintains integrity of the casing and well structure.

5. Selected Barrier Critical Systems - SCSSV

5.1 System Description and Basis of Design

The barrier critical system chosen for this example is the SCSSV. The SCSSV is a fail-safe valve, designed for placement inside the production tubing to stop the flow from the well on demand. There are several types of SCSSVs, but the selected type for this assessment is a surface controlled, tubing retrievable, flapper mechanism type SCSSV which is held open by hydraulic pressure (illustrated example in Figure 5). When the hydraulic pressure is relieved, the piston and spring retract and the flapper mechanism closes the tubing bore.

The SCSSV will be open during normal production and other operations and is installed as part of the production tubing. It is located subsurface, meaning that it is placed downstream of the wellhead and X-mas tree. Normal activation of the SCSSV is through the ESD system. The general design of the SCSSV is not changed compared to what is used for a normal well. However, due to HPHT and Sour Well conditions, the material selection and requirements regarding pressure and corrosion resistance may change.

The barrier elements considered necessary for the SCSSV to perform its intended functions include the following.

- Spring and Piston
  - Spring/piston will automatically retract allowing the flapper to close and seal the tubing bore upon loss of hydraulic pressure.
- Flapper
  - Mechanical flapper mechanism automatically closes, sealing the tubing bore when hydraulic power is lost to shut-in the flow.

In addition, there exists a valve control system consisting of the following components:

- Topside HPU Control Panel
  - Topside HPU Control Panel provides visual indication of the hydraulic pressure. The Operator will monitor and act on pressure loss as per relevant procedure.
- Topside Bleed-Off Valve
  - Valve that allows the hydraulic fluid in the hydraulic control line to the SCSSV to bleed-off manually upon pressure loss in the control system. This allows closure of the SCSSV. Operator, who should receive an alert following pressure loss on Topside HPU Control Panel, will manually open the Bleed-off valve.
- Hydraulic Control Tubing
  - Hydraulic control tubing provides the necessary means of venting the hydraulic pressure to either air or sea when the relevant valve is manually or electrically commanded open.

- ESD Control Panel
  - Topside ESD Control Panel is used by the Operator to activate SCSSV closure by sending an electrical command signal to the solenoid controlled valve in the Subsea Control Module (SCM).
- Umbilical
  - Umbilical provides the necessary means of transmitting the command signal from the ESD Control Station to the SCM.
- Subsea Control Module (SCM)
  - SCM houses the electrically controlled solenoid Subsea Quick-Dump Valve.
- Subsea Quick-Dump Valve
  - Subsea Quick-Dump Valve provides the necessary means of bleeding the hydraulic pressure in the chamber upon command signal. The ESD Control Panel sends an electric command signal to the solenoid to initiate the bleed-off.

6. Barrier Model for SCSSV

6.1 Barrier Model Scope (Interfaces and Barrier Elements) and Key Assumptions

Read the contents of this section in conjunction to the Barrier Model (presented in Section 6.2).

6.1.1 Barrier Critical System Functions

The following Barrier Critical System Functions (BCSFs) are identified for the SCSSV as sufficient to realize the barrier function **"Prevent Loss of Subsea Well Control"**:

- Close and Shut in Flow Upon Loss of Hydraulic Power (BCSF 1).
- Close and Shut in Flow on Commanded Closure (BCSF 2).

<u>Close and Shut in Flow upon Loss of Hydraulic Power (BCSF 1)</u>

Operator monitors the hydraulic pressure at the HPU Control Panel and upon loss of hydraulic power, the Operator will act to manually bleed-off the hydraulic pressure topside by opening the Topside Bleed-Off Valve. This will result in no hydraulic pressure being exerted on the piston, which will cause the spring to retract and allow the flapper to close. Hence, the SCSSV is considered a fail-safe closed valve.

<u>Close and Shut in Flow on Commanded Closure (BCSF 2)</u>

This function is in place to close the SCSSV on demand through ESD command. If a demand occurs that causes the Operator to initiate an ESD, a command signal is sent from the ESD Control Panel to the SCM to initiate bleed-off at the solenoid controlled Subsea Quick-Dump Valve. Hydraulic pressure is vented from the Quick-Dump Valve via a Hydraulic Control Tubing, which will cause the hydraulic pressure exerted on the piston to decrease, enabling the spring to retract and the flapper to close.

6.1.2 Assumptions

Different SCSSV designs exist, such as ball valves or flapper valves, which can be either surface or subsurface controlled. The barrier model for the SCSSV shown in this case study is **<u>an example</u>** developed to illustrate how the barrier model template can be applied to a selected SCSSV (as specified above and illustrated in Figure 7, Figure 8, and Figure 9) and **<u>should not</u>** be considered as representative of all SCSSV designs and configurations. The barrier model was developed by the ABSG Consulting project team and verified through a review workshop with industry BSEE Subject Matter Experts (SMEs).

For the purpose of this example, Table 8 represents the main assumptions relevant to the barrier elements.

Table 8. SCSSV System Assumptions – Barrier Elements

Assumption	Barrier Element
• The SCSSV is assumed to be a Category 1 HPHT Primary Barrier Pressure Containing and Pressure Controlling equipment.	SCSSV
• Upon loss of hydraulic pressure, the piston will retract. This retracts the spring holding the flapper in an open position. • The Spring and Piston will not be exposed to Wellbore fluids/HPHT conditions.	Spring and Piston
• The Flapper is a mechanical component that will be positioned downwards into the well flow. When the flapper closes, it will seal tubing bore and shut-in the flow.	Flapper
• The HPU Control Panel includes visual indications that allow the Operator to monitor hydraulic pressure.	HPU Control Panel
• The Topside Bleed-Off Valve is designed to be manually opened to bleed hydraulic pressure if necessary.	Topside Bleed-Off Valve
• There is hydraulic control tubing that allows for the hydraulic fluid bleed-off topsides for manual closure of the SCSSV by means of the Topside Bleed-Off Valve (BCSF 1). • There is hydraulic control tubing that connects the chamber to the Subsea Quick-Dump Valve that enables the venting to sea of hydraulic fluid in the chamber (BCSF 2).	Hydraulic Control Tubing
• The ESD Control Panel includes the push-button and ESD systems topside that provides the interface for the Operator to communicate with the SCM for commanded closure of the SCSSV.	ESD Control Panel
• Transmits the command signals from the ESD Control Panel to the SCM, which houses the Subsea Quick-Dump Valve.	Umbilical
• The SCM houses the Subsea Quick-Dump Valve and all subsea electronics required to communicate via topsides.	SCM
• Subsea Quick-Dump Valve is controlled via an electrical solenoid. The ESD system sends a command signal. This is the only method to close the SCSSV on commanded closure.	Subsea Quick-Dump Valve

6.1.3 Independent Third Party Review Requirement

There is a requirement from BSEE that an independent third party must review and accept Category 1 HPHT equipment material selection/qualification, design verification and design validation. The independent third party must provide their own review reports relating to the following:

- Basis of Design, Loads and Environment including the hazard and failure mode analysis (HAZID/HAZOP and/or FMEA/FMECA).
- Material Selection, Qualification and Testing.
- Design Verification Analysis.
- Design Validation Testing.
- Load Monitoring.
- Fabrication processes, quality control/quality assurance process and inspections process of the final product.

The lessee/Operator must nominate and receive BSEE acceptance of the independent third party reviewer.

6.2 Barrier Model

The following figures show the developed barrier model for the SCSSC.

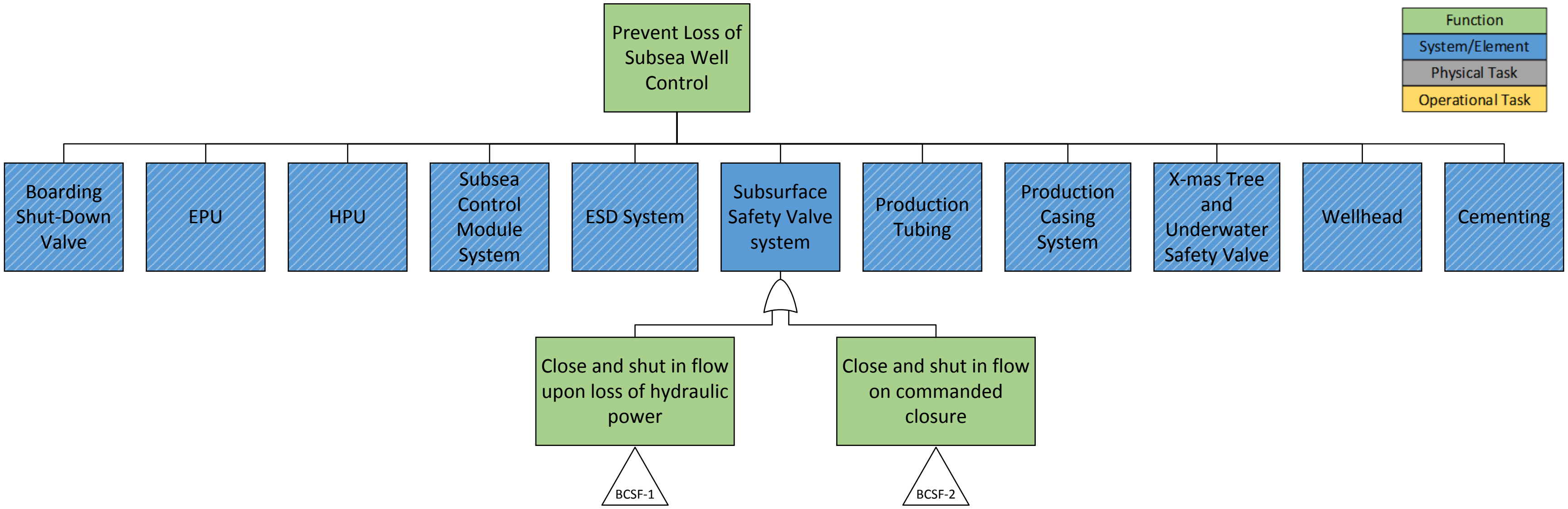


Figure 7. Barrier Function, Barrier Critical Systems, and Barrier Critical System Functions

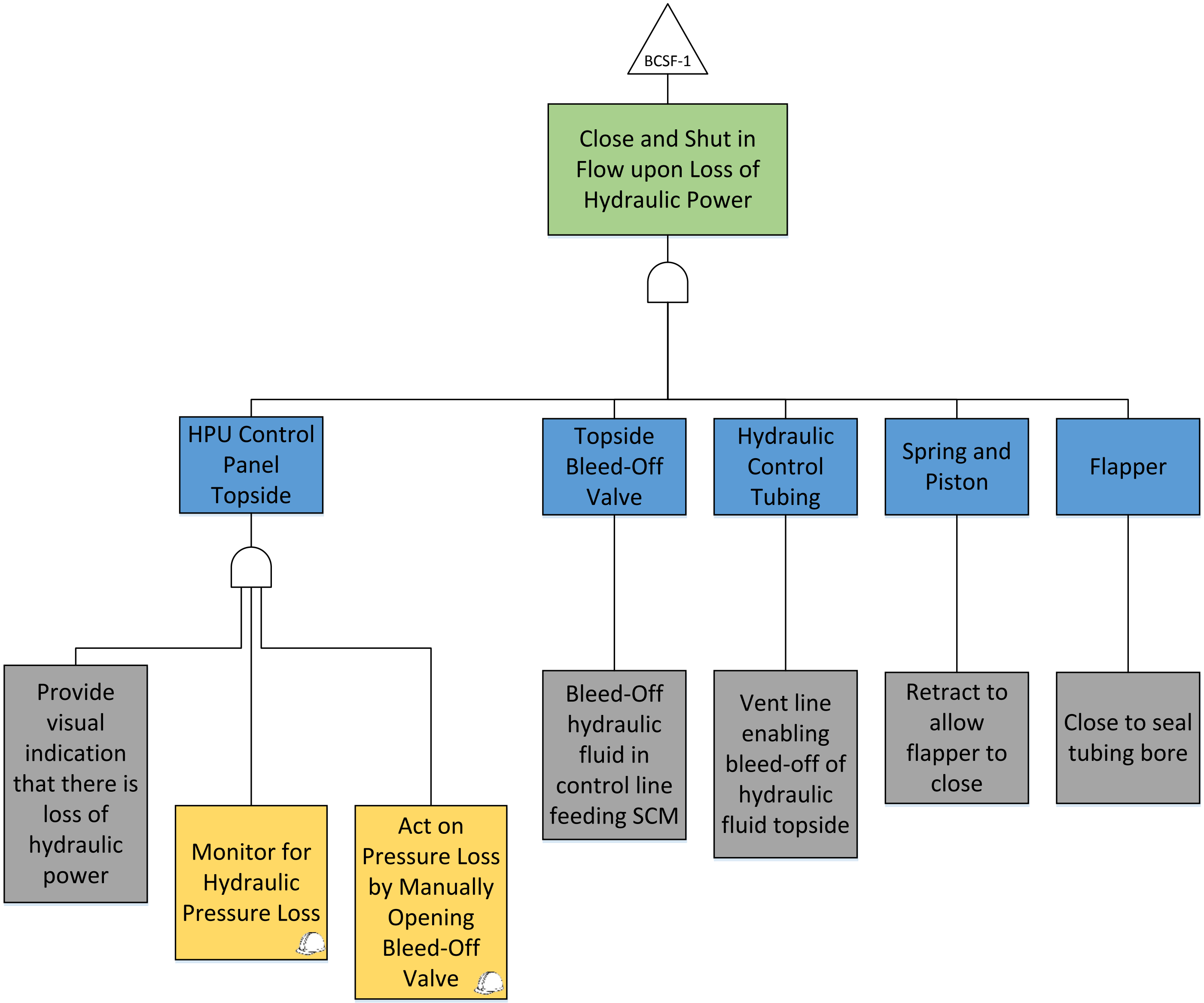


Figure 8. Barrier Critical System Function 1 – Close and Shut in Flow upon Loss of Hydraulic Power

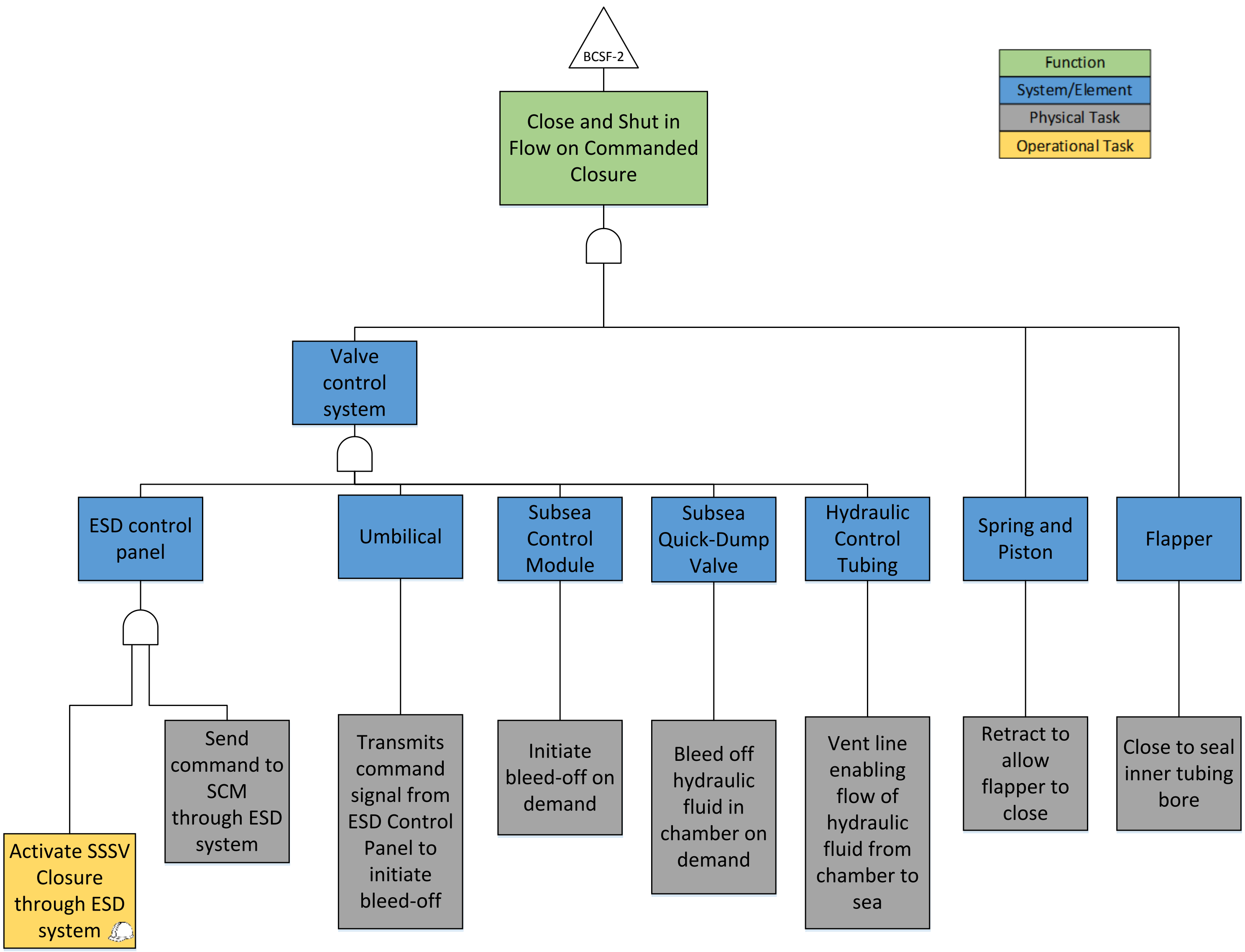


Figure 9. Barrier Critical System Function 2 – Close and Shut in Flow on Commanded Closure

7. Barrier Element Attribute Checklist

Checklists highlighting attributes and related success criteria for the barrier elements have been developed to ensure that they can perform the required physical/operational task(s) to meet their intended barrier critical system function(s). The checklists have been developed as MS Excel™ workbooks. Each checklist structures the attributes influencing the performance of the barrier elements into three tiers:

- Tier I – Covers the life cycle phases that need to be assessed
  - Design;
  - Fabrication and Testing;
  - Installation and Commissioning;
  - Operation and Maintenance;
  - Decommissioning and Removal.

  These are indicated by the worksheet labels.

- Tier II – Specific aspects that are required for assessment as part of each lifecycle phase. As an example, corresponding to the Tier I Design worksheet, there are four Tier II attributes indicated by headers in green with each worksheet:
  - 1-1 Design Parameters
  - 1-2 Interactions/Dependencies
  - 1-3 Layout
  - 1-4 Material

- Tier III – Provides specific detail and consideration for the BSEE reviewer to assess and validate. These are developed in rows under each corresponding Tier II header.

It is important to note that the success attributes provided for the barrier elements are **only examples** to illustrate the development of typical attributes based on available design standards/codes and **should not** be interpreted as prescriptive requirements for compliance. For each proposed new technology, attributes will have to be developed based on the barrier model by the Operator in conjunction with relevant parties such as the equipment manufacturers.

Table 9 summarizes the barrier elements and the attribute checklists developed for the SCSSV used in a HPHT and Sour environment scenario. Each barrier element checklist developed is provided as an individual MS Excel workbook, which can be accessed by clicking on the icon within the table.

The Applicant Assurance column currently includes information on general documentation for validating that the attributes meet its success criteria. With the third party review requirement from BSEE, the Applicant Assurance column could be modified to refer to the relevant section of the third party review report which confirms the same.

Table 9. Barrier Element Attribute Checklists

Barrier Element	Checklist Provided (Yes(Y)/No(N))	Checklist (Double Click to open in MS Excel)
SCSSV		
Spring and Piston	Y	HPHT_SSSV_Checklist_Spring_Piston.xlsx
Flapper	Y	HPHT_SSSV_Checklist_Flapper.xlsx
Topside HPU Control Panel	N	N/A
Topside Bleed-Off Valve	N	N/A
Hydraulic Control Tubing	Y	HPHT_SSSV_Checklist_Hydraulic Control T
ESD Control Panel	Y	HPHT_SSSV_Checklist_ESD Control Panel.:
Umbilical	N	N/A
Subsea Control Module	Y	HPHT_SSSV_Checklist_SCM.xlsx
Subsea Quick-Dump Valve	Y	HPHT_SSSV_Checklist_Subsea Quick Dump

8. Reference

1 – API RP 14B, Design, Installation, Repair and Operation of Subsurface Safety Valve Systems

2 - http://petrowiki.org/Completion_flow_control_accessories#Flow_couplings

3 - http://petrowiki.org/Completion_flow_control_accessories#Flow_couplings

4 - At the ready: Subsurface Safety Valve, Oil field Review