Case Study 3: Managed Pressure Drilling

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

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September 2015

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

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ABBREVIATION	EXPLANATION
AID	Annular Isolation Device
ALARP	As Low As Reasonably Practicable
BHP	Bottom Hole Pressure
BOP	Blowout Preventer
BSEE	Bureau of Safety and Environmental Enforcement
CBHP	Constant Bottom Hole Pressure
CBL	Cement Bond Log
DP	Dynamic Positioning
ERP	Emergency Response Plan
FIT	Formation Integrity Test
FMECA	Failure Modes, Effects, and Criticality Analysis
GoM	Gulf of Mexico
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HC	Hydrocarbons
HPHT	High Pressure High Temperature
HSE	Health, Safety, and Environment
LCM	Lost Circulation Material
MAH(s)	Major Accident Hazard(s)
MPD	Managed Pressure Drilling
NPT	Non-Productive Time
OBM	Oil-Based mud
PMP	Preventative Maintenance Program
POOH	Pulling Out of Hole
PRV	Pressure Relief Valve
PTW	Permit to Work
QA/QC	Quality Assurance/Quality Control
RCD	Rotating Control Device
RIH	Running In Hole
RPM	Recovery Preparedness Measures
US OCS	United States Outer Continental Shelf

1. Introduction

1.1 Background

As part of the BSEE Emergent Technologies project, ABS developed a risk assessment framework to qualify new technology applications submitted to BSEE. To provide the better understanding of the risk assessment framework, ABSG Consulting 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-deepwater drilling
- Scenario 2: Deepwater Drilling with Surface BOP from a Floating Facility
- 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 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 don't reflect actual real- life projects and the studies performed for real-life project will be more comprehensive that what is provided in this document.

This document provides information on the Scenario 3: Managed Pressure Drilling.

2. Scenario Development

2.1 Scenario Basis

Managed Pressure Drilling (MPD) is an adaptive drilling process used to control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly.

In general, Managed Pressure Drilling is a drilling method that allows for greater control over the pressure in the wellbore. Additional equipment is required to achieve this, which may divide into two sections: the modified riser joint and the MPD pressure management system.

The modified riser joint consists of the top and bottom adapter, the Rotating Control Device (RCD), the Annular Isolation Device (AID) and the flowspool. The RCD is required to establish a 'closed system' in order to allow MPD and the AID is located below the RCD as another layer of protection from kicks, providing a closed seal around the drill pipe. As mud pumps down the drill pipe, it returns up the annular space to the flowspool, and directs towards the MPD pressure management system (It can also direct overboard, or to the platform's well control choke manifold).

The flowspool returns the drilling fluid to the surface through the MPD choke manifold, as opposed to conventional drilling where it returns to the surface via the riser, which is open to the atmosphere. Choke valves control the backpressure and the drilling fluid then goes through the flow meter. The flow meter provides data to allow adjustment of the backpressure, acting as an early kick detection system. Finally, the drilling fluid passes from the flow meter into the conventional mud treatment system (or directs into the Mud Gas Separator).

Figure 1 shows the components of the modified riser joint and Figure 2 is a diagram of a typical MPD system.

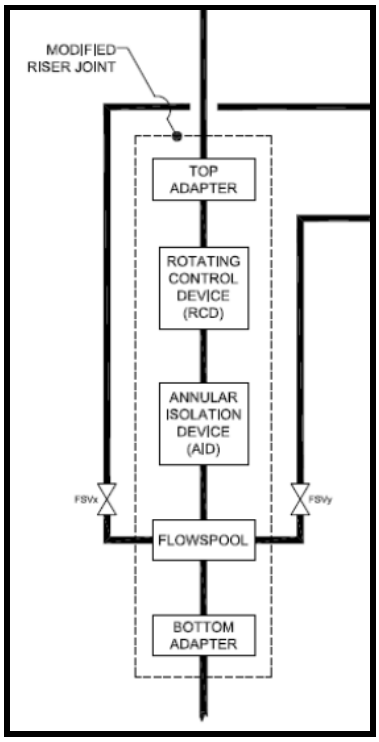

Figure 1. Components of the Modified Riser Joint

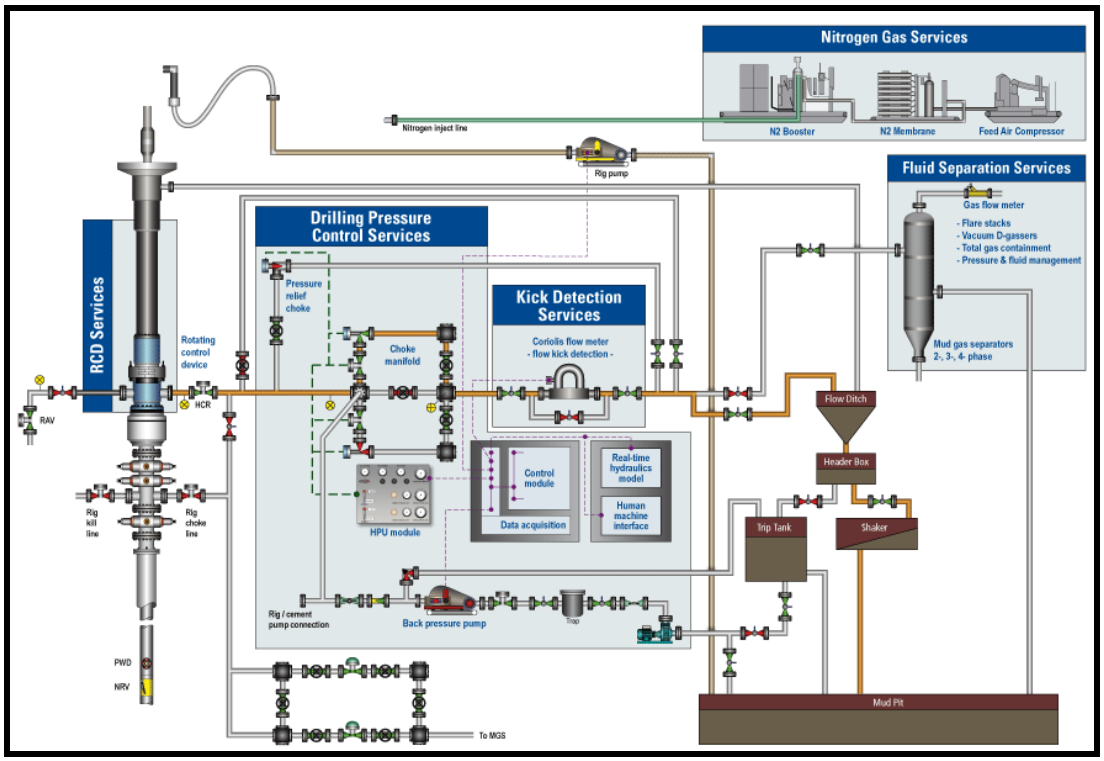

Figure 2. Diagram of Typical MPD System

Conventional well control equipment is still in place to ensure safety of the drilling operation. However, drilling operations utilizing MPD introduce additional equipment along with a different set of drilling

procedures than that of conventional drilling. In summary, MPD creates a closed system with the introduction of additional equipment, whereas conventional drilling is an open system. This additional equipment and new drilling procedures securely controls the pressure within the wellbore. The conventional drilling well control equipment remains in place as the primary and secondary well barriers.

The four basic MPD techniques are the following:

- Constant Bottom Hole Pressure Profile
- Mud Cap Drilling
- Dual Gradient
- Return Flow Control (Health, Safety, and Environment [HSE] Method)

Constant Bottom Hole Pressure (CBHP) is an MPD method where the annular pressure is kept close to constant at a given depth to eliminate cycles of kicks/losses that are common in deep wells. The typical application for this technique is for cases where there are high uncertainties on the pressure limits, a narrow mud weight window with kicks/losses and high associated non-productive time (NPT). This is typical for depleted, fractured and high pressure reservoirs.

Mud Cap Drilling is appropriate when normal techniques have difficulties to maintain circulation. Drilling fluid, together with water and cuttings, pumps sinto the wellbore and drill pipe to help to prevent and control kicks and lost circulation while drilling in fractured or layered (different pressures) formations.

Dual Gradient Drilling is an MPD technique that employs two different annulus fluid gradients to find a closer match to the natural pressure regime; one above the seabed, another beneath. This concept is the most applicable technology for deepwater drilling as the use of a duel gradient system can eliminate the heavy mud column in the marine riser. The objective is to reduce formation damage and the related fluid losses when drilling deep formations with low-fracture gradients (eliminating mud density changes (Reference 1).

Return Flow Control Drilling is an MPD method that reduces risks from drilling fluid, hazardous gases and well control incidents to the personnel and the environment. This method specifically enables drilling high-pressure, complex wells at reduced operational costs as it provides very accurate flow and pressure measurements and analysis (Reference 2). The system allows Operators to make decisions on actual data versus predicted data, resulting in safer operations.

MPD technology is increasingly being applied in reservoirs that are difficult to drill conventionally (un-drillable), deepwater, and HPHT wells to access hydrocarbon reserves, enhance operational safety and efficiency. The following table shows MPD activity in the Asia Pacific Region in June 2006.

Table 1. Asia Pacific Region MPD Activity – June 2006

MPD Type	Country	Operator	Project Duration	Formation Type	Rig Type
HSE	Vietnam	Cuu Long (ConocoPhillips)	5 year program	Fractured Granite Basement	Jack Up GALVESTON KEY & ADRIATIC 11
HSE/CBHP	Vietnam	JVPC (Japan Vietnam)	6 month program	Fractured Granite Basement	Jack Up TRIDENT 9
PMCD	Malaysia	Sarawak Shell	3 wells	Carbonate	Semi-Submersible STENA CLYDE
PMCD	Malaysia	Sarawak Shell	8 wells on 3 fields	Carbonate	Semi Tender WEST ALLIANCE
PMCD	Malaysia	Sarawak Shell	2 wells	Carbonate	Semi-Submersible OCEAN EPOCH
PMCD	Malaysia	Sarawak Shell	2 wells	Carbonate	Jack Up DEEP DRILLER 2
HSE	Malaysia	Petronas Carigali	1 well	Fractured Schist Basement	Jack Up ENSCO 52
CHBP	Malaysia	Petronas Carigali	1 well	Fractured Schist Basement	Jack Up ENSCO 52
PMCD	Indonesia	Santos	11 wells	Carbonate	Semi-Submersible SEDCO 601
PMCD	Indonesia	KNOC	1 well	Carbonate	Semi-Submersible SEDCO 601
PMCD	Indonesia	KNOC	5 + 2 wells	Carbonate	Drillship FRONTIER DUCHESS
PMCD-DDV	Indonesia	Pearl Oil	4 wells	Carbonate	Jack Up SHELF EXPLORER

The challenging hydraulics of the world's remaining prospects indicates that MPD will evolve to become a key enabling technology for developing difficult formations. Its benefits are typically:

- Adds technical, economic, and HSE viability
- High influx control
- Increases recoverable assets
- Step-change technology
- Minimum modifications for Deepwater drilling
- Less use of mud – seawater can be applied
- Increase in rate of penetration
- Reduction/elimination of stuck pipe non-productive time and lost circulation
- Enhanced formation evaluation
- Enhanced formation integrity, due to lower mud weights with lower solids content
- High cost reduction on drilling fluids

2.2 Scenario Considered for the Assessment

The scenario considered is a Deepwater drilling operation using a MPD in the Gulf of Mexico (GoM).

Table 2 below details the field characteristics considered for this study.

Table 2. Field Characteristics

Field Location	100 Miles Offshore in the Deepwater Gulf of Mexico
Water Depth:	Approximately 4,000 ft.
Reservoir /Datum Depth (MD)	25,000 ft.
Reservoir /Datum Depth (TVD)	24,500 ft.
Bottom Hole Temperature	190˚F (87.7˚C)
Wellhead flow temperature	170-200˚F (76.7 – 93.3˚C)
Reservoir Pressure	8000 psig
H_2S	Max. 2 ppm
No. of development wells	15
Design Life	20 years
Rules and Regulation:	Design and build using recognized classification rules, IMO MODU code, SOLAS and applicable rules and regulations

To evaluate the scenario using the new technology risk assessment framework, a floating production unit (Deepwater semi-submersible drilling platform) equipped with MPD, which is deployed in the Deepwater Gulf of Mexico is considered. The table below details the characteristics of the semi-submersible platform.

Table 3. Semi-Submersible Platform Description

General Description	
Dimensions	300 ft. long x 200 ft. wide x 100 ft. deep
Accommodation	150 persons
Transit Speed	Up to 3 knots
Station keeping	DP 2
Maximum Water Depth	10,000 ft. designed
Maximum Drilling Depth	30,000 ft.
Variable Drilling Load (VDL)	5,000 MT

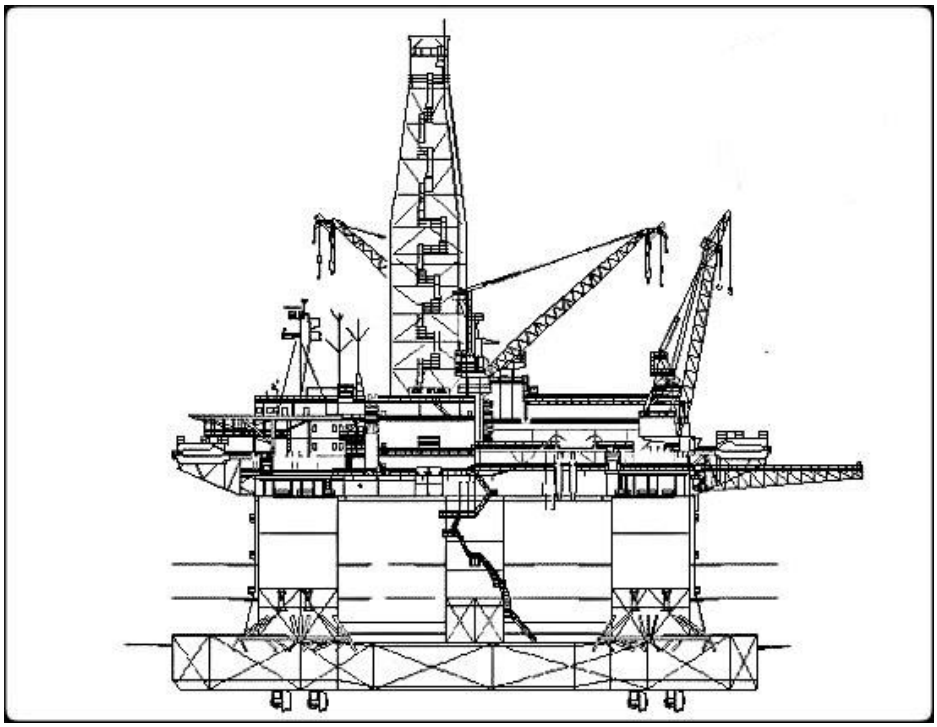

Figure 3. Typical Semi-submersible Platform

In this scenario, the focus will be on the Constant Bottom Hole Pressure variant of Managed Pressure Drilling as a new technology for controlling the pressure within the wellbore as it is considered most suitable for usage with high pressure reservoirs.

Included is the crucial equipment for performing Managed Pressure Drilling and the definitions for associated operational and physical tasks. All critical functions, elements and attributes for application will be included to highlight the unique operation of Managed Pressure Drilling.

2.3 Risk and Barrier Assessment Workflow

As wells are drilled deeper and/or are less stable, it becomes desirable to better control the pressure within the well. The more precise control of the wellbore pressure has several advantages; it allows drilling through narrow drilling windows, allows better prevention of response to well control events, and running less casing translates into deeper wells and less downtime.

The MPD system introduces additional equipment into the drilling system and while MPD has been used elsewhere in the world, there is limited or no previous use within the GoM and is therefore considered new technology. In the CBHP MPD variant considered for this scenario the pressure within the well is held constant at a specified point within the well by applying surface backpressure to the system. Changing operating mentality to a new methodology after having operated using conventional drilling procedures in the GOM for so long is one potential challenge.

The workflow described within the new technology risk assessment framework depends on the novelty of the combination of the technology and the applied conditions, and an overview of which is presented in Figure 4. In this MPD scenario, Work Flow 3 is applied, which is for new technology (MPD system) in a known condition (GoM). 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 different conditions 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 (MPD system) due to potential incompatibility or inadequate design for the different condition could lead to the realization of a major accident hazard. A barrier analysis to identify the critical success attributes for the barrier elements that constitute the barrier critical system is of extreme significance.

The Hazard Identification Study (HAZID) carried out as part of the risk assessment helps in identifying the MAHs and affected barrier functions. A Hazard and Operability Study (HAZOP) also identified the hazards related to process deviations during MPD operations. Section 3 of this report covers the risk assessment for this scenario and related findings. The barrier analysis, which involves the review of a select barrier critical system (MPD system) to understand what needs to succeed in order for it to perform its barrier function(s). For this purpose, a barrier model is developed and analyzed to determine the ways in which the barrier critical system can succeed as well as fail to perform its function. 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 application of the barrier model 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). This considers any interactions involved with the rig equipment and newly added MPD system.

The barrier model begins with the identification of the barrier function and contributing barrier critical systems. This is followed by identifying the required barrier critical system function(s) for each barrier critical system and the relevant barrier elements. For each barrier element, the identification of physical and operational tasks enable the barrier critical system function. This stage derives the performance influencing factors and attributes along with the relevant success criteria for the barrier element to perform its intended physical/operational tasks and thereby realizing the barrier function.

Note: *For further detail, refer to 1) Risk Assessment framework, refer to the "Risk Assessment framework for New Technologies in OCS", and 2) Barrier Analysis, refer to the "Barrier Analysis for New Technologies in OCS".*

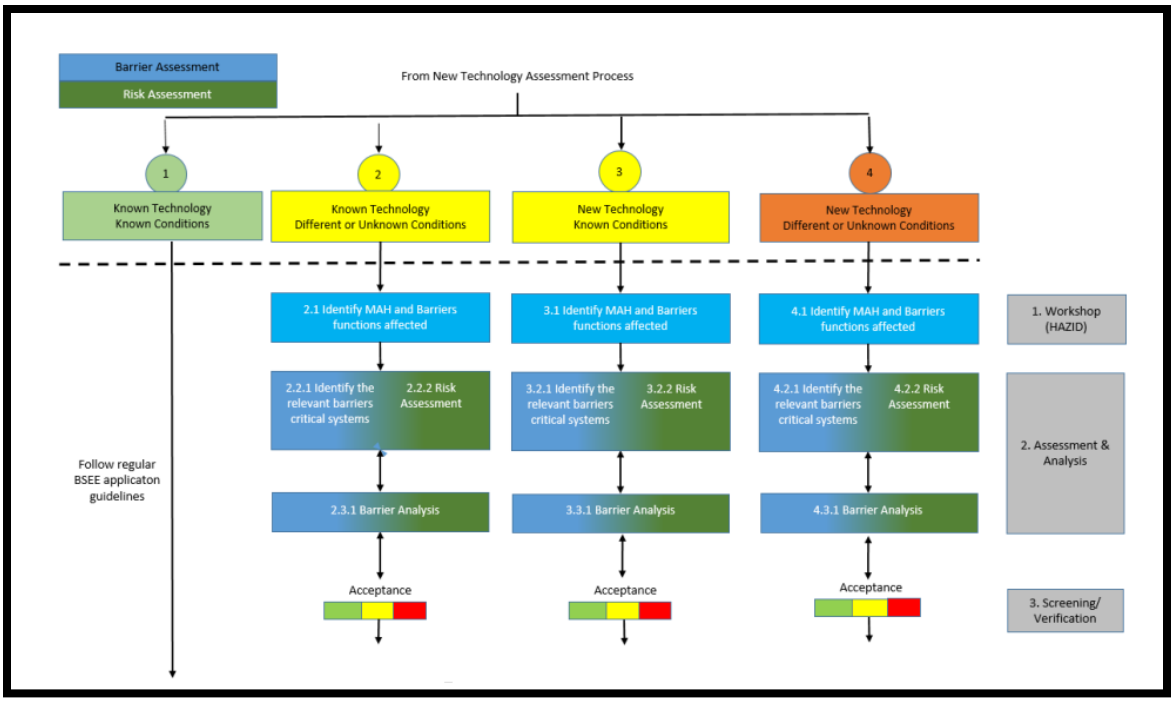

Figure 4. New Technology Assessment Framework

3. Scenario Development

3.1 Risk Management Procedure

3.1.1 Process

The project manager working with the project team and project sponsors will ensure that risks are identified, analyzed, and managed throughout the life of the project. The project manager will identify risk as early as possible in the project to minimize their impacts. Listed below are the steps to minimize impacts:

Figure 5. The 5-Step Hazard Management System

Step 1 – Identify the Hazards and Consequences

For the purpose of this study, the HAZID and HAZOP are conducted to identify the hazards associated with MPD. The consequences resulting from these hazards are also identified in the studies.

Step 2 – Determine Barriers and Recovery Preparedness Measures (RPM)

The barriers preventing the hazards from resulting into the top event and RPMs in place to mitigate consequences as a result of the top event should already be captured during the HAZID and HAZOP study.

Step 3 – Barrier and RPM Assessment

The barriers and RPMs already in place should be assessed for adequacy. The bowtie diagram is a graphical representation of the overall picture in terms of barriers and RPMs.

Step 4 – Review and Verify Hazards and Risks

Finally, the identified hazards and risks are reviewed in ord er to ensure the findings are finalized and all relevant points are captured.

3.1.2 Hazard Identification

Hazard identification will involve the project team, appropriate stakeholders, and will include an evaluation of environmental factors, organizational culture and the project management plan including the project scope. Careful attention will be given to the project deliverables, assumptions, constraints, and other key project milestones.

3.1.3 Risk Analysis

All risks identified will be assessed to determine the range of possible consequences. A qualitative risk ranking system will be used to determine categorize the identified risks. This ranking process allows the team to put a priority on mitigating the higher risk scenarios. Some of the lower ranking risks may be at an acceptable level already and no further mitigation of these will be necessary.

3.1.3.1 Qualitative Risk Analysis

The probability and impact of occurrence for each identified risk is assessed by the project team first by identifying whether the consequence will affect people, environment, assets, or reputation. The probability is then rated from A to E, and the severity from 0 to 5. Below are the definitions of the ratings.

Severity Rating - People/Environment/Assets/Reputation

0 – Zero Harm/Zero effect/Zero damage/Zero Impact

1 – Slight Harm/Slight Effect/Slight Damage/Slight Impact

2 – Minor Harm/Minor Effect/Minor Damage/Limited Impact

3 – Major Harm/Local Effect/Local Damage/Considerable Impact

4 – Single Fatality/Major Effect/Major Damage/National Impact

5 – Multiple Fatalities/Massive Effect/Extensive Damage/International Impact

Probability Rating

A – Never occurred in Industry

B – Has occurred in Industry

C – Has occurred in Company

D – Multiple occurrences per year in Company

E – Multiple occurrences per year at Location

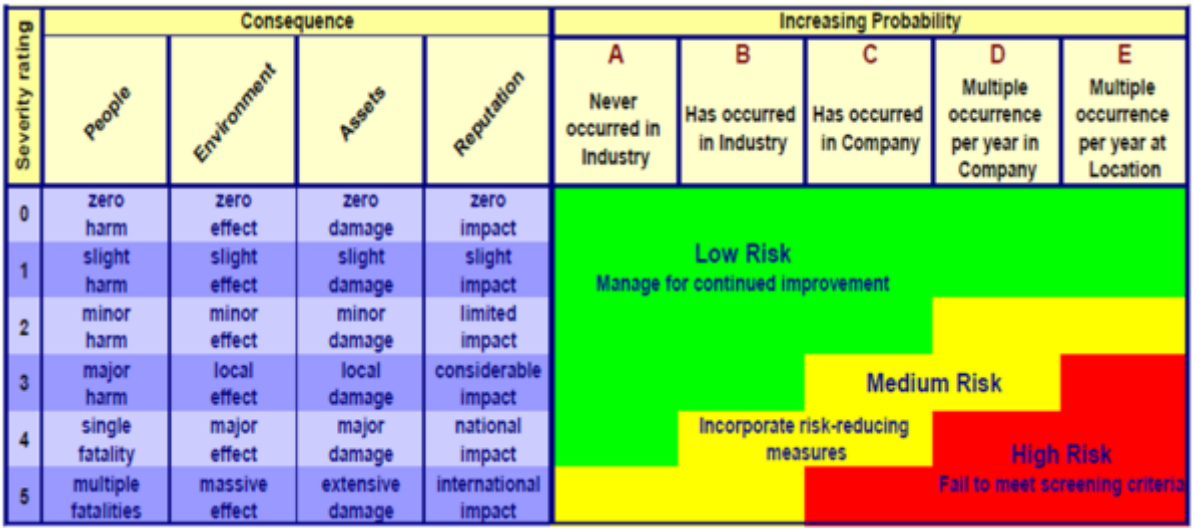

Figure 6. Risk Assessment Matrix Used in the Project (IADC HSE Case Guidelines for MODU, 2015)

3.2 Objective

Objective of the scenario is to consider a Deepwater drilling operation using MPD. The established scenario shall then be used to determine risks created by use of MPD techniques and its effects on associated barrier system functions.

3.3 HAZID Study

3.3.1 Objective of HAZID

As per the Risk Management process outlined in Section 2, the first task is to identify all major hazards resulting from the use of the technology. A HAZID is a structured way of identifying the hazards. The HAZID was conducted through a workshop involving a multidisciplinary team with knowledge of different aspects of the drilling operation using the MPD. The HAZID not only identified the major hazards but also considered the harm from these hazards if they were realized and the likelihood of such events. Using a standard qualitative risk assessment matrix, the risks from the hazards were qualitatively assessed and ranked.

3.3.2 HAZID Worksheets

Following worksheet provides the results of the HAZID performed for the MPD operation.

Table 4. HAZID Worksheets

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
H-01.01	Well fluids (which include Hydro-carbon (HC) liquid, HC gas, possible H_2S/CO_2 and water)	Well kick	Loss of hydrostatic pressure within well: • Trip of HP mud pump • Stopping of HP mud pump to make a connection • Trip of back-pressure pump when HP mud pump not operating • Control fault with MPD pressure management system (e.g., sensor, control logic, choke valve) • Erosion MPD choke (caused by high pressure drop and/or cuttings) • Operator error (wrt downhole pressure control) • High loss of drilling fluid through formation • Drilling into an unknown	• Preventive maintenance of HP mud pump, with standby HP mud pump available • Preventive maintenance of back-pressure pump • Monitoring of HP mud pump and back-pressure pump operation • MPD pressure management system, including back-pressure pump available (diagnostics, multiple sensors, multiple logic solvers, multiple choke valves), with manual operation possible • Training and competency of drilling personnel to prevent (and react to) a well kick • Operating Company drilling program based on seismic and offset well data for drilling program • Mud logging and flow measurement of drilling fluid supply and returns to identify any loss of drilling fluid, with	Well blowout with potential for: • Unignited release (HC and possible H2S/CO2) – impact on personnel • Possible oil spill to marine environment • Ignited release – with fire and explosion, causing asset damage, possible fatalities/injuries	• Training and competency of drilling personnel related to response to a kick and well control • Well control procedures, which include: ○ BOP – annular and RAMs, with ability to line up to choke manifold to circulate out a kick ○ BOP – annular and RAMs, with ability to kill well through choke & kill manifold ○ BOP – shear RAM(s) • Blowout contingency plan • Company and Operator Emergency Response Plan (ERP), which include access to safe refuge / mustering, with access to lifesaving appliances (no change required due to MPD system) • Control of ignition sources (Hazardous Area Classification) (will require consideration for MPD equipment) • Fire and gas (HC and H2S) detection system (will require consideration for MPD equipment) • Firefighting system (will require consideration for MPD equipment) • Ability to emergency disconnect and move to safe location using dynamic	**5B**	**5B**	**5B**	**5B**	**Medium**	R01 – Ensure that the material of construction for the modified riser joint and the MPD equipment (including piping, fittings, hoses, couplings, chokes and bends) includes consideration for high erosion potential caused by high-pressure drop and cuttings in the drilling fluid returns. R02 – Ensure that there are adequate/suitable safeguards are provided for the RCD design to related to the operation of the RCD bearings and also the RCD latching system (covering hydraulics and other utilities), to alert operations personnel to a potential problem that requires intervention. R03 – Due to the nature of MPD systems (a closed-loop, circulating system), the HAZID team felt that a HAZOP of the MPD system would be of benefit to assist with identifying and assessing the full

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
			high pressure formation • Loss of containment on RCD seal (due to high temperature of bearings, poor workmanship, erosion, poor materials) • Mechanical failure of riser and/or riser connections anywhere from bottom connection to LMRP / BOP up to flowspool (poor workmanship, poor materials, fatigue, loss of station-keeping) • Swabbing while pulling out of hole (POOH) • Wireline logging or other downhole intervention	reserve inventory of drilling fluid, and ability to add Lost Circulation Material (LCM) • Training and competency of personnel for implementing correct MPD pipework and valve settings • Suitable selection of material of construction of modified riser joint and MPD equipment for expected environmental conditions • Suitable inspection and maintenance program for RCD bearings and seals • Preventive maintenance for MPD piping systems (including hoses, couplings and fittings) • Design in accordance with applicable codes and standards • Quality Assurance/Quality Control (QA/QC) during fabrication, installation and commissioning • Redundancy within Dynamic Positioning System (min DP2) • Riser tensioning		positioning (DP) system • Oil spill response by Operator and local authorities • Relief well possible (takes time to mobilize and implement) • Medical Facilities and Medic /Trained First Aiders on board • Training Drills for Emergency Response						potential range of causes which would result in consequences of concern. R04 – Ensure that the addition of MPD facilities to the drilling platform includes the following considerations for extended coverage of existing Platform's safety critical elements: 1. Hazardous Area Classification coverage; 2. Fire and gas (HC and H_2S) gas detection; 3. Fire protection (both active and passive). R05 – Review and document whether the MPD back-pressure pump should be supported on the Platform's emergency power supply, to enable downhole pressure management in the event of a main power failure where the HP mud pumps will stop. R06 – Consider requiring all suppliers of equipment for modified riser joints and MPD equipment used in the United States Outer Continental Shelf (US OCS) to undertake a Failure Modes, Effects, and Criticality (FMECA)

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
				system in place • Suitable inspection program for riser system • Close monitoring and control of rate of POOH to reduce swabbing effect, with MPD providing closer control of pressure balance • Rig-up checklist in place, with hydro testing of any HP system before use • Annular Isolation Device (AID) – for isolating RCD from the riser annulus								on their equipment.
H-01.02	Well fluids (which include HC liquid, HC gas, possible H2S/CO2 and water)	Loss of integrity – well casing	• Poor cementing job (due to poor design/ workmanship/ materials) • Unforeseen formation conditions	• Design of well program casing and cement program to withstand maximum anticipated formation pressure • Competency of cementing 3rd party contractor (approved and registered with regulatory body?) – to be confirmed • Well program reviewed and approved by regulatory body (DWOP and CDWOP) – casing and cement program designed to withstand maximum anticipated formation pressure • Confirmation of	• Potential for well fluid from formation to pass into the annular, causing possible kick, ultimately leading to possible blowout (with consequences as previously described above)	• Training and competency of drilling personnel related to response to a kick and well control • Well control procedures, which include: ○ BOP – annular and RAMs, with ability to line up to choke manifold to circulate out a kick ○ BOP – annular and RAMs, with ability to kill well through choke & kill manifold ○ BOP – shear RAM(s) • Blowout contingency plan • Company and Operator ERP, which include access to safe refuge / mustering, with access to lifesaving appliances (no change required due to MPD system)	5C	5C	5C	5C	High	R07 – If not already a mandatory requirement, the GOM regulators should consider requiring all Operators to undertake a CBL, or equivalent, to confirm quality of cementing jobs for all wells. – to be confirmed

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
				cementing job by monitoring quality of lead and tail samples (Operator may require cement bond log [CBL]) • Leak – off test undertaken to ensure integrity of casing shoe (minimum expected check would be a Formation Integrity Test [FIT]) • Seismic and offset well data reviewed for drilling program • Use of MPD reduces the number of casings required to drill a well, with less potential for a poor casing job		• Control of ignition sources (Hazardous Area Classification) (will require consideration for MPD equipment) • Fire and gas (HC and H2S) detection system (will require consideration for MPD equipment) • Firefighting system (will require consideration for MPD equipment) • Ability to emergency disconnect and move to safe location using DP)system • Oil spill response by Operator and local authorities • Relief well possible (takes time to mobilize and implement) • Medical Facilities and Medic /Trained First Aiders on board • Training Drills for Emergency Response						
					• Potential for well fluid from formation to pass outside of casing to the seabed, causing marine pollution, possible scouring and increased flow of well fluids, possible impact on Platform buoyancy due to gas at surface	• Options to install plug, perforate, and squeeze cement – if extent of leakage allows for continued operation • Ability to adjust ballast condition of Platform when loss of containment known (using subsea CCTV) • Ability to emergency disconnect and move to safe location using DP system • Emergency Response – with ability to abandon • Oil spill response by	5B	5B	5B	5B	Medium	

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
						Operator and local authorities • Relief well possible (takes time to mobilize and implement) • Low likelihood that a Deepwater gas release would cause sufficient loss of buoyancy (due to drift and spread of gas as it raises to the surface)						
H-02.01	High pressure [Note – H-02.01 is included due to the majority of the modified riser joint and MPD equipment being at HP when in use]	Sudden release of high pressure (during MPD operation, or hydro testing)	Blocked/ restricted flow of drilling fluid returns : • Blocked flow (manual valve closed or fault with MPD pressure management system which closes the choke valve) • Inadequate design of modified riser joint and MPD for maximum drilling fluid flow • Blockage of MPD piping due to build-up of solids	• Training and competency of drilling personnel, with procedures to prevent inadvertent closure of valves • Suitable inspection and maintenance program of MPD pressure management system • Adequately designed modified riser joint and MPD pressure management system for maximum operating conditions • Training and competency of personnel associated with MPD connections • Training and competency of	• Potential for higher bottom hole pressure, causing potential ballooning or even fracturing of reservoir, requiring abandonment of the well	• Ballooning of reservoir should, in most cases, be recoverable (depending on nature of the formation)	0C	3C	2C	3C	Medium	

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
			(e.g., cuttings)	drilling personnel regarding pressure management (during MPD) • Drilling Operators physical checks on cuttings (e.g., size and type) • Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured • Pressure Relief Valve (PRV) on MPD around the choke valves (not applicable to several manual valves closed)	• If valve closed downstream of MPD choke valve, potential overpressure of LP side of MPD system, causing possible rupture of piping/equipment (requiring repair), potential for personnel struck by high pressure drilling fluid, water or projectile (piping/hose/couplings/fittings), potential drilling fluid spill to marine environment	• Training and competency of drilling personnel regarding pressure management (during MPD) • Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured • Medical Facilities and Medic /Trained First Aiders on board	**4B**	**4B**	**3B**	**4B**	**Medium**	R08 - Suitable management control and/or overpressure protection needs to be provided on the low pressure systems of the MPD System downstream of the choke valves. (Note – this may involve adequate design pressure for all systems on the downstream side of the MPD choke valves to the downstream side of the last isolation valve in each system.) R09 – Ensure that suitable spill containment is provided for any MPD equipment that is not located on a deck area with its own drain system – where practical.
			General mechanical failure of HP piping, fittings, couplings, hoses: • Overpressure • Poor workmanship, poor materials, damaged couplings	• Suitable pressure rated equipment in use (with test certificates for hoses) • QA/QC during equipment fabrication/construction • Suitable inspection program for MPD piping systems	• Potential for personnel harm or equipment damage struck by high pressure drilling fluid, water or projectile (piping/hose/couplings/fittings) • Possible spill of drilling fluids to the marine environment	• Segregation of people and operating equipment and/or installing barriers/cubicles during hydro testing • Use of whipline protectors on flexible joints/couplings • Medical Facilities and Medic /Trained First Aiders on board	**4C**	**2C**	**3C**	**4C**	**Medium**	R09 (Existing) – Ensure that suitable spill containment is provided for any MPD equipment that is not located on a deck area with its own drain system – where practical.

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
			• Erosion/corrosion of pipework and fittings • Improper practices during hydro testing	(including hoses, couplings and fittings) • Suitable inspection and maintenance program for modified riser joint • Suitable selection of material of construction of all modified riser joint and MPD equipment for expected environmental conditions • Training and competency of personnel involved with hydro testing	• Potential for leak of drilling fluids from HP system, causing possible loss of BHP, possible kick possible blowout (as previously advised)	• Training and competency of drilling personnel related to response to a kick and well control • Well control procedures, which include: ○ BOP – annular and RAMs, with ability to line up to choke manifold to circulate out a kick ○ BOP – annular and RAMs, with ability to kill well through choke & kill manifold ○ BOP – shear RAM(s) • Blowout contingency plan • Company and Operator ERP, which include access to safe refuge / mustering, with access to lifesaving appliances (no change required due to MPD system) • Control of ignition sources (Hazardous Area Classification) (will require consideration for MPD equipment) • Fire and gas (HC and H2S) detection system (will require consideration for MPD equipment) • Firefighting system (will require consideration for MPD equipment) • Ability to emergency disconnect and move to safe location using DP system • Oil spill response by Operator and local authorities • Relief well possible (takes	5B	5B	5B	5B	Medium	

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
						time to mobilize and implement) • Medical Facilities and Medic /Trained First Aiders on board • Training Drills for Emergency Response							
H-02.02	High pressure	Fracture of formation	• Control fault with MPD pressure management system causing high BHP • Survey of formation / investigation inadequate or unknown or unexpected formation conditions • MPD Operator error • Running in	• Preventive maintenance program for MPD pressure management system • Training and competency of drilling personnel regarding pressure management (during MPD) • Competency of 3rd party contractor used for formation survey • PRV on MPD around the choke valves (not applicable to	• Potential for excessive loss of drilling fluid and possible abandonment of well	• Ballooning of reservoir should, in most cases, be recoverable (depending on nature of the formation)	**0B**	**3B**	**2B**	**3B**	**Low**	R10 – Ensure adequate redundancy is provided for MPD pressure management system, and includes suitable control diagnostics to alert the driller to potential fault conditions. Control equipment for pressure management system should consider the need for fail-safe action.

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
			hole (RIH) at too high a rate	several manual valves closed), with set pressure adjusted for each stage of drilling well • Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured	• Potential for loss of bottom hole pressure control causing potential for kick and possible blowout (as previously described)	• Training and competency of drilling personnel related to response to a kick and well control • Well control procedures, which include: ○ BOP – annular and RAMs, with ability to line up to choke manifold to circulate out a kick ○ BOP – annular and RAMs, with ability to kill well through choke & kill manifold ○ BOP – shear RAM(s) • Blowout contingency plan • Company and Operator ERP, which include access to safe refuge / mustering, with access to lifesaving appliances (no change required due to MPD system) • Control of ignition sources (Hazardous Area Classification) (will require consideration for MPD equipment) • Fire and gas (HC and H2S) detection system (will require consideration for MPD equipment) • Firefighting system (will	**5B**	**5B**	**5B**	**5B**	Medium	C01 – NPT due to differential sticking – not a consequence of concern for this HAZID, not considered further

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
						require consideration for MPD equipment) • Ability to emergency disconnect and move to safe location using DP system • Oil spill response by Operator and local authorities • Relief well possible (takes time to mobilize and implement) • Medical Facilities and Medic /Trained First Aiders on board • Training Drills for Emergency Response						
H-03.01	Restricted Access/Egress [Note – H-03.01 is included due to the addition equipment required to implement MPD]	Exposure to restricted access/ egress	• Inadequate provision for access egress due to space constraints or poor design	• Adequate design as per applicable codes and standards (MODU) – with respect to egress, reviewed and approved by Class society • Escape, evacuation and rescue analysis for Platform updated by Owner/Operator when designing MPD equipment layout	• Potential for either delay or inability of personnel at the MPD equipment to respond to an emergency scenario, with increased risk to personnel • Potential for difficulty in routine access to equipment for operations or maintenance • Potential for poor ability to respond to an emergency scenario directly at the MPD equipment (such as removal of an injured person, firefighting, etc.)	• Operations/Maintenance review/approval of MPD equipment layout during design • Training Drills for Emergency Response – would identify design issues due to restricted egress • Medical Facilities and Medic /Trained First Aiders on board	**4C**	**3C**	**2C**	**4C**	**Medium**	R04 (Existing) – Ensure that the addition of MPD facilities to the drilling platform includes the following considerations for extended coverage of existing Platform's safety critical elements: 1. Hazardous Area Classification coverage; 2. Fire and gas (HC and H_2S) gas detection; 3. Fire protection (both active and passive). R11 – Location of MPD equipment needs to consider the potential for damage due to dropped/swinging loads, and also

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
												consider ease of access for routine maintenance/operations activities, as well as adequate provision of emergency egress.
H-04.01	Differences in height (lifting operations) [Note – H-04.01 is included due to the additional equipment associated with modified riser joint and MPD, much of which is under HP when in operation, and possibly	Dropped load/ swinging object	• Operator error • Poor communication • Equipment failure (such as: hoists; cables; crane structures; hooks) • Adverse environmental conditions (sea state, wind, poor visibility)	Control of lifting operations, which includes elements such as: • Training and certification of personnel involved with lifting; • Maintenance and inspection of all lifting equipment and lifting gear; • 3rd party certification of all lifting equipment and lifting gear; • Lifting procedures; • Supervision of lifting activities; • Use of PTW, when required, with JSA undertaken; • Restricted lifting operations during defined environmental conditions)	• Damage to components of either the MPD system or modified riser joint, possible loss of pressure control causing possible flow of well fluids to surface (possible well blowout as previously described)	• Training and competency of drilling personnel related to response to a kick and well control • Well control procedures, which include : ○ BOP – annular and RAMs, with ability to line up to choke manifold to circulate out a kick ○ BOP – annular and RAMs, with ability to kill well through choke & kill manifold ○ BOP – shear RAM(s) • Blowout contingency plan • Company and Operator ERP, which include access to safe refuge / mustering, with access to lifesaving appliances (no change required due to MPD system) • Control of ignition sources (Hazardous Area Classification) (will require consideration for MPD equipment) • Fire and gas (HC and H2S) detection system (will require consideration for	5C	5C	5C	5C	High	R11 (Existing) – Location of MPD equipment needs to consider the potential for damage due to dropped/swinging loads, and also consider ease of access for routine maintenance/operations activities, as well as adequate provision of emergency egress.

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
	vulnerable to a dropped /swinging load]					MPD equipment) • Firefighting system (will require consideration for MPD equipment) • Ability to emergency disconnect and move to safe location using DP system • Oil spill response by Operator and local authorities • Relief well possible (takes time to mobilize and implement) • Medical Facilities and Medic /Trained First Aiders on board • Training Drills for Emergency Response						
H-05.01	Oil-based mud (OBM) [Note – H-05.01 is included due to the additional equip-ment under HP pressure associated with the MPD equip-ment contain-ing drilling fluid]	Loss of contain-ment of OBM (from mod-ified riser joint / MPD system)	Mechanical failure of piping/fittings/hoses/couplings due to: • Poor workmanship /materials • Erosion / corrosion • Fatigue • Wear and tear (damaged threads or sealing surfaces) • Poor work practices/ housekeeping	• Staff training/competency • Hydrostatic testing of HP systems after any maintenance (typical industry practice) • Pre job safety meetings, with JSA • Suitable material of construction for service • Suitable inspection and maintenance program for RCD bearings and seals • Suitable inspection program for MPD piping systems (including hoses, couplings and fittings) • Design in accordance with	• Potential for spill to marine environment, or possible health/safety impact on personnel due to contact with OBM (depending on type of base oil used), limited potential for fire due to high flash point of OBM (however may contain entrained HC/H2S gas)	• Routine Operator inspection of equipment, and prompt clean-up of any spillage • Spill kits available • Oil spill response by Operator and local authorities • Safety showers and eyewash stations • Appropriate PPE for work being undertaken • Medical Facilities and Medic /Trained First Aiders on board	**3C**	**1C**	**3C**	**3C**	**Medium**	R01 (Existing) – Ensure that the material of construction for modified riser joint and MPD systems (including piping, fittings, hoses, couplings, chokes and bends) includes consideration for high erosion potential caused by cuttings in drilling fluid returns. R12 – Ensure that secondary containment is provided for the MPD equipment, which is directly above the water and not contained within other areas with drain system. (This may require provision of

HAZID Ref No.	Hazard	Top Event	Threats	Barriers Prevention/Control	Potential Consequences	Recovery Preparedness System	Risk Assessment					Comments/ Recommendations
							Risk Rating					
							P	A	E	R	RI	
DRILLING												
				applicable codes and standards • QA/QC during fabrication • Monitoring of mud properties by mud engineer								sump and pump to return any spillage to central spill collection (such as skimmer tank.)

3.3.3 Assumptions for the HAZID

- Drilling crew (including 3rd party personnel) are trained and competent in the use of the RCD and MPD System which is being used on this platform
- Equipment associated with the RCD and MPD System is designed and certified to the relevant Codes and Standards (where applicable)
- BOP Stack arrangement is suitable for the drilled well, fully compliant with the relevant Codes and Standards, and subject to a Preventative Maintenance Program (PMP) and full function testing.
- The platform has and effective programs in place for: PMP; Permit to Work (PTW); and functional testing.
- Dynamic Positioning System operational and sea state is steady
- The MPD choke system in use on the platform is fully automatic and uses a 'proven' hydraulics software model for Bottom Holes Pressure (BHP) control.
- Reservoir conditions are considered to be 'typical', HPHT not considered.

3.3.4 Summary of HAZID

This HAZID workshop identified a number of hazardous scenarios for evaluation and risk rank. The hazardous scenarios (top events) identified are summarized in Table 5. The two highest ranked scenarios were associated with (1) Loss of integrity – well casing, caused by surge of well fluids, leading to marine pollutions, scouring and impact on platform buoyancy, and (2) Dropped load / swinging object, caused by lifting operations, leading to damage of components and well blowout.

For the scenarios identified in Table 5, Table 6 presents the recommendations proposed during the workshop for further study or additional mitigation measures.

The information developed in the HAZID workshop (i.e., identified threats, barriers prevention/control, and Preparedness Measures against the consequences of the threats are further evaluated with the use of Bowtie diagrams and ALARP Demonstration presented in Section 3.5 and 3.6.

Table 5. Hazard and Effects Register

HAZID Ref No	Hazard Description	Risk Ranking
H-01.01	Well kick, caused by surge of well fluids, leading to well blowout	**Medium**
H-01.02	Loss of integrity – well casing, caused by surge of well fluids, leading to well blowout	**High**
H-01.02	Loss of integrity – well casing, caused by surge of well fluids, leading to marine pollution, scouring and impact on platform buoyancy	**Medium**
H-02.01	Sudden release of high pressure (during MPD operation or hydro testing), due to blocked /restricted flow of drilling fluid returns, leading to ballooning or fracturing of reservoir, requiring well abandonment	**Medium**
H-02.01	Sudden release of high pressure (during MPD operation or hydro testing), due to blocked /restricted flow of drilling fluid returns, leading to rupture of equipment, injury to personnel and marine pollution	**Medium**
H-02.01	Sudden release of high pressure (during MPD operation or hydro testing), due to general mechanical failure, leading to injury of personnel and marine pollution	**Medium**
H-02.01	Sudden release of high pressure (during MPD operation or hydro testing), due to general mechanical failure, leading to blowout	**Medium**
H-02.02	Fracture of formation, caused by high pressure, leading to excessive loss of drilling fluid and abandonment of well	**Low**
H-02.02	Fracture of formation, caused by high pressure, leading to well kick and well blowout	**Medium**
H-03.01	Exposure to restricted access/egress, leading to poor ability to respond to emergency scenario and difficulty in routine access to equipment	**Medium**
H-04.01	Dropped load / swinging object, caused by lifting operations, leading to damage of components and well blowout	**High**
H-05.01	Loss of containment of Oil-based mud (OBM), due to mechanical failure, leading to marine pollution and health/safety impact on personnel	**Medium**

Table 6. List of Recommendations from HAZID

No	Recommendations
R01	Ensure that the material of construction for the modified riser joint and the MPD equipment (including piping, fittings, hoses, couplings, chokes and bends) includes consideration for high erosion potential caused by high-pressure drop and cuttings in the drilling fluid returns.
R02	Ensure that adequate/suitable safeguards are provided for the RCD design related to the operation of the RCD bearings and the RCD latching system (covering hydraulics and other utilities); to alert operations personnel to potential problems requires intervention.
R03	Due to the nature of MPD systems (a closed-loop, circulating system), the HAZID team felt that a HAZOP of the MPD system would be of benefit to assist with identifying and assessing the full potential range of causes which would result in consequences of concern.
R04	Ensure that the addition of MPD facilities to the drilling platform includes the following considerations for extended coverage of existing Platform's safety critical elements: 1. Hazardous Area Classification coverage; 2. Fire and gas (HC and H2S) gas detection; 3. Fire protection (both active and passive).
R05	Review and document whether the MPD back-pressure pump should be supported on the Platform's emergency power supply, to enable downhole pressure management in the event of a main power failure where the HP mud pumps will stop.
R06	Consider requiring all suppliers of equipment for modified riser joints and MPD equipment used in the US OCS to undertake a FMECA on their equipment.
R07	R07 – If not already a mandatory requirement, the GOM regulators should consider requiring all Operators to undertake a CBL, or equivalent, to confirm quality of cementing jobs for all wells. – to be confirmed
R08	Suitable management control and/or overpressure protection needs to be provided on the low-pressure systems of the MPD System downstream of the choke valves. (Note – this may involve adequate design pressure for all systems on the downstream side of the MPD choke valves to the downstream side of the last isolation valve in each system.)
R09	Ensure that suitable spill containment is provided for any MPD equipment that is not located on a deck area with its own drain system – where practical.
R10	Ensure adequate redundancy is provided for MPD pressure management system, and includes suitable control diagnostics to alert the driller to potential fault conditions. Control equipment for pressure management system should consider the need for fail-safe action.
R11	Location of MPD equipment needs to consider the potential for damage due to dropped/swinging loads, and consider ease of access for routine maintenance/operations activities, as well as adequate provision of emergency egress.
R12	Ensure that secondary containment is provided for the MPD equipment, which is directly above the water and not contained within other areas with drain system. (This may require provision of sump and pump to return any spillage to central spill collection (such as skimmer tank.)

3.4 HAZOP

3.4.1 Objective of HAZOP

As part of the emergent technology risk assessment framework, a HAZID was performed to identify the major accident hazards and associated barriers for Deepwater drilling operations using MPD in the GoM. Due to the nature of MPD systems (a closed-loop, circulating system), one of the recommendations of the HAZID was to perform a HAZOP to assist with identifying and assessing the full potential range of causes which would result in consequences of concern. This HAZOP aims to identify any hazards originating from any deviations from the design intent that may occur from use of MPD during drilling operations. In addition, any new causes or consequences arising from the use of MPD shall be captured along with any new safeguards that come with its usage.

3.4.2 Assumptions for the HAZOP

- Bottom Hole Pressure is calculated (and controlled through MPD) by a real-time hydraulics model
- Consequences are considered without safeguards, likelihoods are considered with safeguards in place
- Well blowout has the following potential consequences:
  - Unignited release (HC and possible H_2S/CO_2) – impact on personnel
  - Possible oil spill to marine environment
  - Ignited release – with fire and explosion, causing asset damage, possible fatalities/injuries
- Reservoir conditions are considered to be 'typical', HPHT not considered

3.4.3 Summary of HAZOP

Table 7 presents the list of recommendations from the HAZOP. Note that the Recommendations from HAZOP are numbered as a continuation from HAZID Recommendations.

Table 7. List of Recommendations from HAZOP

No	Recommendations
R13	Consideration should be given to either undertaking a SIL assessment and SIL verification, or applying the same reliability philosophy for instrumented equipment performing its function when required, for the instrumented control system for MPD (including sensors, logic solvers and end devices) to cover the safety instrumented control aspects as well as operational control (as operational control relates to MPD as a safety barrier)
R14	Ensure that the modified riser joint, piping/hoses etc. on the high pressure side of MPD are of adequate design pressure for the specific anticipated maximum reservoir pressure and minimum drilling fluid specific gravity
R15	Ensure all relevant drilling personnel are suitably trained in operation of the specific modified riser joint and MPD equipment in use on platform, including relevant aspects of well control and emergency response
R16	Ensure that suitable pressure deviation alarms (from control set point) and absolute value alarms are configured for each of the pressure transmitter inputs to the MPD control system, to alert drilling personnel to a deviation from the BHP control point or pressures close to safe operating limits
R17	Ensure that suitable safeguards are provided within RCD design to alert personnel to problems with bearings and or latching system (including hydraulics and other utilities)relates to MPD as a safety barrier)

3.4.4 HAZOP Worksheets

Table 8. HAZOP Worksheets – No. 1 Normal Operations

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
1.1	Low/no flow	1. Loss of flow to suction of HP mud pump - manual valve closed or mud pit empty or low pressure (LP) mud charging pump	1. Potential damage to platform pump due to blocked suction - not a consequence of concern for the purpose of this HAZOP, MPD has no impact, not considered further						

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			3. Potential for loss of drilling fluid flow to drill string, causing possible lower BHP and potential for reservoir to backflow into drill pipe or into annulus - potential kick, potential blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 9. MPD control system - will close choke and start BP pump to maintain BHP, with standby choke available for automatic / manual use 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 13. NRV and dart sub provided on drill string to prevent backflow from well to surface through drill string 15. In event of no flow of HP mud from rotary hose to drill pipe, drill pipe is liquid filled with no open flow path to surface due to manual valve closed or reciprocating type platform pump (reverse flow through pump not credible) 16. Mitigation controls for potential blowout as detailed in HAZID	R13. Consideration should be given to either undertaking a SIL assessment and SIL verification, or applying the same reliability philosophy for instrumented equipment performing its function when required, for the instrumented control system for MPD (including sensors, logic solvers and end devices) to cover the safety instrumented control aspects as well as operational control (as operational control relates to MPD as a safety barrier) R14. Ensure that the modified riser joint, piping / hoses etc. on the high pressure side of MPD are of adequate design pressure for the specific anticipated maximum reservoir pressure and minimum drilling fluid specific gravity R15. Ensure all relevant drilling personnel are suitably trained in operation of the specific modified riser joint and MPD equipment in use on platform, including relevant aspects of well control and emergency response R16. Ensure that suitable pressure deviation alarms (from control set point) and absolute value alarms are configured for each of the pressure transmitter inputs to the MPD control system, to alert drilling personnel to a deviation from the BHP control point or pressures close to safe operating limits

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		2. HP mud pump trip /fails (mechanical, electrical or control fault)	3. Potential for loss of drilling fluid flow to drill string, causing possible lower BHP and potential for reservoir to backflow into drill pipe or into annulus - potential kick, potential blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	4. PMP for pumps and MPD equipment 5. Reliable power supply 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 9. MPD control system - will close choke and start BP pump to maintain BHP, with standby choke available for automatic / manual use 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 13. NRV and dart sub provided on drill string to prevent backflow from well to surface through drill string 15. In event of no flow of HP mud from rotary hose to drill pipe, drill pipe is liquid filled with no open flow path to surface due to manual valve closed or reciprocating type platform pump (reverse flow through pump not credible) 16. Mitigation controls for potential blowout as detailed in HAZID	
		3. Manual valve closed on discharge of HP mud pump through to rotary hose	2. Potential damage to platform pump due to operation with blocked discharge, and overpressure of discharge piping / rotary hose - not a consequence of concern for the purpose of this						

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			HAZOP, MPD has no impact, not considered further						
			3. Potential for loss of drilling fluid flow to drill string, causing possible lower BHP and potential for reservoir to backflow into drill pipe or into annulus - potential kick, potential blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 9. MPD control system - will close choke and start BP pump to maintain BHP, with standby choke available for automatic / manual use 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 13. NRV and dart sub provided on drill string to prevent backflow from well to surface through drill string 15. In event of no flow of HP mud from rotary hose to drill pipe, drill pipe is liquid filled with no open flow path to surface due to manual valve closed or reciprocating type platform pump (reverse flow through pump not credible) 16. Mitigation controls for potential blowout as detailed in HAZID	
		4. Inadvertent operation of BOP annular or pipe rams	2. Potential damage to platform pump due to operation with blocked discharge, and overpressure of discharge piping /						

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			rotary hose - not a consequence of concern for the purpose of this HAZOP, MPD has no impact, not considered further						
			4. Potential for high BHP due to blocked flow of drilling fluid returns, resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	C	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 3. Design and construction of equipment in accordance with relevant codes and standards 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump	
		5. Manual valve closed from flowspool to inlet of MPD choke valve	2. Potential damage to platform pump due to operation with blocked discharge, and overpressure of discharge piping / rotary hose - not a consequence of concern for the purpose of this HAZOP, MPD has no impact, not considered further						

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			4. Potential for high BHP due to blocked flow of drilling fluid returns, resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	C	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump	
			5. Potential for high pressure on mud return system (flowspool, piping, choke, flow meter, etc.), with potential for overpressure due to continued operation of platform pump, causing loss of containment scenario, possible injury to personnel and repair to equipment	P	4	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 11. Pressure relief	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump	
			6. Potential for high pressure on mud return system (flowspool, piping, choke, flow meter, etc.), with potential for overpressure due to continued operation of platform pump, causing loss of containment scenario, with potential for inability to maintain BHP, possible inflow of reservoir fluids causing kick and possible blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 12. Adequate design pressure for modified riser joint and MPD	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								system to downstream side of choke manifold 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump 16. Mitigation controls for potential blowout as detailed in HAZID	
		6. Control fault which closes MPD choke valve	2. Potential damage to platform pump due to operation with blocked discharge, and overpressure of discharge piping / rotary hose - not a consequence of concern for the purpose of this HAZOP, MPD has no impact, not considered further						
			4. Potential for high BHP due to blocked flow of drilling fluid returns, resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	C	Medium Risk	4. PMP for pumps and MPD equipment 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed)	
			5. Potential for high pressure on mud return system (flowspool, piping, choke, flow meter, etc.), with potential for overpressure due to continued operation of platform pump, causing loss of containment	P	4	B	Medium Risk	4. PMP for pumps and MPD equipment 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			scenario, possible injury to personnel and repair to equipment					7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 12. Adequate design pressure for modified riser joint and MPD system to downstream side of choke manifold 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump	
			6. Potential for high pressure on mud return system (flowspool, piping, choke, flow meter, etc.), with potential for overpressure due to continued operation of platform pump, causing loss of containment scenario, with potential for inability to maintain BHP, possible inflow of reservoir fluids causing kick and possible blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	4.PMP for pumps and MPD equipment 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								overpressure due to downstream valve closed) 12. Adequate design pressure for modified riser joint and MPD system to downstream side of choke manifold 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump 16. Mitigation controls for potential blowout as detailed in HAZID	
		7. Manual valve closed on discharge on MPD choke valve through to end destination (flow ditch, MGS)	2. Potential damage to platform pump due to operation with blocked discharge, and overpressure of discharge piping / rotary hose - not a consequence of concern for the purpose of this HAZOP, MPD has no impact, not considered further						
			4. Potential for high BHP due to blocked flow of drilling fluid returns, resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	C	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed)	
			5. Potential for high pressure on mud return system (flowspool, piping, choke, flow meter, etc.), with potential for overpressure due to continued operation of platform pump, causing loss of containment scenario, possible injury to personnel and repair to equipment	P	4	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 6. Monitoring of HP mud system during drilling, with checking of active mud pit levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD	
			6. Potential for high pressure on mud return system (flowspool, piping, choke, flow meter, etc.), with potential for overpressure due to continued operation of platform pump, causing loss of containment scenario, with potential for inability to maintain BHP, possible inflow of reservoir fluids causing kick and possible blowout (Refer to HAZID	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 6. Monitoring of HP mud system during drilling, with checking of active mud pit	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			for detailed description of blowout consequence)					levels 7. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 8. PWD indication on drill string 10. Multiple pressure transmitters between flowspool and mud outlet of MPD 11. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 12. Adequate design pressure for modified riser joint and MPD system to downstream side of choke manifold 14. Pressure indicator with PAH and PRV on discharge of each HP mud pump 16. Mitigation controls for potential blowout as detailed in HAZID 17. MPD pressure management system will still function if loss of containment downstream of MPD choke (lower design pressure), with ability to control a kick	
1.2	High flow	1. High pressure drilling fluid flow at higher flow rate than design basis for flowspool and MPD flow capacity (Operator oversight using wrong sized liners or fault with VFD drive if provided)	1. Potential for high BHP due to restricted flow of drilling fluid returns, resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	C	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 3. PWD indication on drill string 4. Multiple pressure transmitters between flowspool and mud	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								outlet of MPD 11. Top drive vibration monitoring	
			2. Potential for high pressure upstream of MPD choke causing potential for exceeding design pressure, potential overpressure, potential exceeding design pressure, possible rupture causing loss of BHP pressure and possible kick / blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 3. PWD indication on drill string 4. Multiple pressure transmitters between flowspool and mud outlet of MPD 5. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 6. Adequate design pressure for modified riser joint and MPD system to downstream side of choke manifold 7. Pressure indicator with PAH and PRV on discharge of each HP mud pump 10. Monitoring of high pressure (HP) mud system during drilling, with checking of active mud pit levels 12. Flow measurement of mud returns downstream of MPD choke 13. Mitigation controls	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								for potential blowout as detailed in HAZID	
		2. Control fault with MPD pressure control which starts the BP pump during normal drilling when BP pump operation not required	1. Potential for high BHP due to restricted flow of drilling fluid returns, resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	C	Medium Risk	3. PWD indication on drill string 4. Multiple pressure transmitters between flowspool and mud outlet of MPD 9. PMP for MPD equipment 11. Top drive vibration monitoring	Refer to HAZID Recommendations: R06 and R10
			2. Potential for high pressure upstream of MPD choke causing potential for exceeding design pressure, potential overpressure, potential exceeding design pressure, possible rupture causing loss of BHP pressure and possible kick / blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	3. PWD indication on drill string 4. Multiple pressure transmitters between flowspool and mud outlet of MPD 5. Pressure relief choke on upstream of MPD choke manifold (protects from overpressure due to downstream valve closed) 6. Adequate design pressure for modified riser joint and MPD system to downstream side of choke manifold 7. Pressure indicator with PAH and PRV on discharge of each HP mud pump 9. PMP for MPD equipment 10. Monitoring of high pressure (HP) mud system during drilling, with checking of active mud pit levels 12. Flow measurement	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								of mud returns downstream of MPD choke 13. Mitigation controls for potential blowout as detailed in HAZID	
1.3	Reverse flow	1. No new causes identified							
1.4	Misdirected flow	1. Inadvertent opening of choke and / or kill line valves on BOP stack - no consequences of concern anticipated, as multiple downstream valves at well control choke & kill manifolds which are normally closed (contrary to the valves shown on HAZOP PFD), not considered further							
		2. Inadvertent opening of valve on outlet of flowspool to well control choke manifold - no consequences of concern anticipated, as multiple downstream valves at well control choke manifolds which are normally closed (contrary to the valves shown on HAZOP PFD), not considered further							
		3. Manual valve opened on bypass around MPD system - not considered credible, as two valves on bypass, which should both be closed (HAZOP PFD shows one valve open)							
		4. Control fault which opens pressure relief choke when not required, or erosion of	1. Inability to provide adequate backpressure control from the MPD system, causing possible lower BHP	P	5	B	Medium Risk	4. PWD indication on drill string 7. Suitable material of	R13 (Existing). Consideration should be given to either undertaking a SIL assessment and SIL verification, or

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		choke valve	and potential for reservoir to backflow into drill pipe or into annulus - potential kick, potential blowout (Refer to HAZID for detailed description of blowout consequence)					construction for MPD choke valves for operating environment (to reduce potential for erosion caused by high pressure drop and / or cuttings) 8. Standby choke available for automatic / manual use 9. Multiple pressure transmitters between flowspool and mud outlet of MPD 10. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 11. PMP for pumps and MPD equipment 13. Mitigation controls for potential blowout as detailed in HAZID	applying the same reliability philosophy for instrumented equipment performing its function when required, for the instrumented control system for MPD (including sensors, logic solvers and end devices) to cover the safety instrumented control aspects as well as operational control (as operational control relates to MPD as a safety barrier) R16 (Existing). Ensure that suitable pressure deviation alarms (from control set point) and absolute value alarms are configured for each of the pressure transmitter inputs to the MPD control system, to alert drilling personnel to a deviation from the BHP control point or pressures close to safe operating limits Refer to HAZID Recommendations: R06 and R10
		5. Manual valve left open from inlet to outlet of MPD choke manifold	1. Inability to provide adequate backpressure control from the MPD system, causing possible lower BHP and potential for reservoir to backflow into drill pipe or into annulus - potential kick, potential blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 4. PWD indication on drill string 9. Multiple pressure transmitters between flowspool and mud outlet of MPD 10. Flow measurement of mud returns downstream of MPD choke, with flow kick detection	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								13. Mitigation controls for potential blowout as detailed in HAZID	
		6. Manual valve left open on bypass around MPD flow meter	2. Inability to measure return flow of drilling fluid, and inability for early detection of flow kick - potential blowout (Refer to HAZID for detailed description of blowout consequence)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. Standard operating procedures 12. Pressure control at MPD choke will still control BHP, reducing potential for an inflow from reservoir 13. Mitigation controls for potential blowout as detailed in HAZID	
		7. Wrong line up of mud return from outlet of MPD to either MGS or flow ditch - not a consequence of concern for the purpose of this HAZOP, MPD has no impact, not considered further							
		8. Inadvertent opening of alternate outlet valve from flowspool to overboard line - not considered credible, two valves on overboard line (one manual and one remote-actuated) which should both normally be closed (HAZOP PFD shows remote actuated valve open)							
1.5	As well as flow (unwanted input)	1. Line up of wrong mud pits to suction of HP mud pump	1. Potential for higher mud weight than intended, causing possible inaccuracy with MPD real-time hydraulics modeling, resulting in potential for higher BHP than	A	3	B	Low Risk	5. Training and competency of drilling personnel (related to equipment line up and operation of drilling	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			intended and resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well					equipment) 6. Standard operating procedures 8. Monitoring of HP mud system during drilling, with checking of active mud pit levels 10. PWD indication on drill string 13. Real-time shock and vibration monitoring system for drill string (API 16 D)	
			2. Potential for lower mud weight than intended, causing possible inaccuracy with MPD real-time hydraulics modeling, resulting in potential for lower BHP than intended and resulting in potential for inflow of reservoir fluid, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	5. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 6. Standard operating procedures 9. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 10. PWD indication on drill string 17. Mitigation controls for potential blowout as detailed in HAZID	
		2. Drilling into unknown high pressure formation due to inaccurate seismic survey	3. Potential for target BHP control point to be lower than that required for the unknown high pressure formation, resulting in potential for inflow of reservoir fluid, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	9. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 14. 3rd party seismic survey contractor competency, with review by Company reservoir engineer 15. MPD choke system available to allow	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								management of kick, including ability to line up drilling fluid returns to MGS 16. Seismic and offset well data reviewed for drilling program 17. Mitigation controls for potential blowout as detailed in HAZID	
		3. Poor cementing job of well casing	4. Potential for reservoir fluid ingress through affected casing section into annulus, causing possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	1. Design of well program casing and cement program to withstand maximum anticipated formation pressure 2. Competency of cementing 3rd party contractor 3. Well program reviewed and approved by regulatory body (DWOP and CDWOP) - casing and cement program designed to withstand maximum anticipated formation pressure 4. Confirmation of cementing job by monitoring quality of lead and tail samples (Operator may require CBL) 9. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 15. MPD choke system available to allow management of kick, including ability to line	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								up drilling fluid returns to MGS 16. Seismic and offset well data reviewed for drilling program 17. Mitigation controls for potential blowout as detailed in HAZID	
1.6	High temperature	1. No causes with any consequences, only ambient temperature change							
1.7	Low temperature	1. No causes with any consequences, only ambient temperature change							
1.8	High pressure	1. No new causes identified							
1.9	Low pressure	1. Control fault with MPD pressure control system, which opens MPD choke valve more than required	1. Potential for low BHP, possible inflow of reservoir, possible kick, possible blowout (Refer to HAZID for full description of consequences)	P	5	B	Medium Risk	1. PMP for pumps and MPD equipment 2. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 3. PWD indication on drill string 4. Multiple pressure transmitters between flowspool and mud outlet of MPD 5. MPD choke system has standby choke for manual switchover from control system, and each choke valve can be manually operated at valve 6. Mitigation controls for potential blowout as detailed in HAZID	R13 (Existing). Consideration should be given to either undertaking a SIL assessment and SIL verification, or applying the same reliability philosophy for instrumented equipment performing its function when required, for the instrumented control system for MPD (including sensors, logic solvers and end devices) to cover the safety instrumented control aspects as well as operational control (as operational control relates to MPD as a safety barrier)

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
1.10	High level	1. Not relevant to this Node							
1.11	Low level	1. LCM due to formation characteristics	1. Potential for high LCM to cause low BHP due to inability to control BHP through MPD choke, possible kick, possible blowout (Refer to HAZID for detailed description of consequences)	P	5	B	Medium Risk	1. 3rd party seismic survey contractor competency, with review by Company reservoir engineer 2. Seismic and offset well data reviewed for drilling program 3. Drilling fluid formulation will consider potential for reducing LCM based on formation characteristics 4. Multiple pressure transmitters between flowspool and mud outlet of MPD 5. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 6. MPD control system - will close choke and start BP pump to maintain BHP, with standby choke available for automatic / manual use 7. Mitigation controls for potential blowout as detailed in HAZID	
1.12	Changes in composition	1. High concentration of cuttings in drilling fluid returns due to high rate of penetration for formation	3. Potential for high cuttings concentration or poor conveying of cuttings with drilling fluid to cause stuck bit, causing disruption to drilling operations - not a consequence of concern for the MPD HAZOP, not considered further						

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			4. Potential for blockage and restricted flow through flowspool and piping systems associated with MPD causing potential for high BHP than intended and resulting in potential for fracture of formation, mud flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	B	Low Risk	2. Training and competency of drilling personnel 3. Continuous mud logging with real-time data, with routine sampling and analysis of mud returns and treated mud 4. Monitoring of rated penetration, with caution exercised at any drilling breaks 7. Multiple pressure transmitters between flowspool and mud outlet of MPD 9. Top drive vibration monitoring	
		2. Poor efficiency of mud treatment system causing high solids content in return mud downhole	5. Potential for high cuttings in drilling fluid return to cause high erosion on MPD choke valve, causing difficulty in controlling BHP, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	1. Training and competency of Mud Engineer and Mud Hand 3. Continuous mud logging with real-time data, with routine sampling and analysis of mud returns and treated mud 5. Routine monitoring of mud treatment equipment 8. PMP for MPD equipment 10. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 11. MPD choke system has standby choke for manual switchover from control system,	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								and each choke valve can be manually operated at valve 13. Mitigation controls for potential blowout as detailed in HAZID	
			6. Potential for high erosion of HP mud pumps and HP mud system through to drill string, causing potential for repair / replacement - no direct impact on MPD, not considered further						
		3. Contamination between different drilling fluids in mud pits or due to incomplete replacement of downhole drilling fluid	1. Potential for higher mud weight than intended, causing possible inaccuracy with MPD real-time hydraulics modeling, resulting in potential for higher BHP than intended and resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	B	Low Risk	1. Training and competency of Mud Engineer and Mud Hand 2. Training and competency of drilling personnel 3. Continuous mud logging with real-time data, with routine sampling and analysis of mud returns and treated mud 6. PWD indication on drill string 9. Top drive vibration monitoring	
			2. Potential for lower mud weight than intended, causing possible inaccuracy with MPD real-time hydraulics modeling, resulting in potential for lower BHP than intended and resulting in potential for inflow of reservoir fluid, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	1. Training and competency of Mud Engineer and Mud Hand 2. Training and competency of drilling personnel 3. Continuous mud logging with real-time data, with routine sampling and analysis of mud returns and treated mud 6. PWD indication on	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								drill string 10. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 12. MPD choke system available to allow management of kick, including ability to line up drilling fluid returns to MGS 13. Mitigation controls for potential blowout as detailed in HAZID	
			3. Potential for high cuttings concentration or poor conveying of cuttings with drilling fluid to cause stuck bit, causing disruption to drilling operations - not a consequence of concern for the MPD HAZOP, not considered further						
			7. Potential for stuck drill pipe due to excessive cake thickness on formation, requiring scraping and delayed drilling operation - not a consequence of concern for the MPD HAZOP, not considered further						
		4. Wrong drilling fluid formulation or error during mixing	1. Potential for higher mud weight than intended, causing possible inaccuracy with MPD real-time hydraulics modeling, resulting in potential for higher BHP than intended and resulting in potential for fracture of formation, drilling fluid flow into reservoir, possible high pressure and collapse of gas pockets resulting in high vibration on drill string, possible damage to drill string causing disruption to drilling operation, with potential for abandonment of well	A	3	B	Low Risk	1. Training and competency of Mud Engineer and Mud Hand 2. Training and competency of drilling personnel 3. Continuous mud logging with real-time data, with routine sampling and analysis of mud returns and treated mud 6. PWD indication on drill string	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								9. Top drive vibration monitoring	
			2. Potential for lower mud weight than intended, causing possible inaccuracy with MPD real-time hydraulics modeling, resulting in potential for lower BHP than intended and resulting in potential for inflow of reservoir fluid, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	1. Training and competency of Mud Engineer and Mud Hand 3. Continuous mud logging with real-time data, with routine sampling and analysis of mud returns and treated mud 6. PWD indication on drill string 10. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 12. MPD choke system available to allow management of kick, including ability to line up drilling fluid returns to MGS 13. Mitigation controls for potential blowout as detailed in HAZID	
			3. Potential for high cuttings concentration or poor conveying of cuttings with drilling fluid to cause stuck bit, causing disruption to drilling operations - not a consequence of concern for the MPD HAZOP, not considered further						
			7. Potential for stuck drill pipe due to excessive cake thickness on formation, requiring scraping and delayed drilling operation - not a consequence of concern for the MPD HAZOP, not considered further						
1.13	Leak / rupture	1. General mechanical failure of HP mud system	1. Loss of containment of HP mud or drilling fluid returns, resulting in	P	4	B	Medium Risk	1. Training and competency of	R17. Ensure that suitable safeguards are provided within RCD design to alert

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		(piping, fittings, hoses) or of the return system from subsea BOP, through riser connections, through flowspool through to MPD choke manifold	potential for injury to personnel caused by HP liquid or projectile					personnel related to integrity of equipment / piping / hoses 2. Selection of material of construction for expected environmental conditions (HP mud, modified riser joint and MPD) 3. Design in accordance with applicable codes and standards 4. QA/QC during fabrication, installation and commissioning 5. Suitable inspection program for HP mud, modified riser joint and MPD system 8. Suitable pressure rated equipment in use (with test certificates for hoses) 11. Use of whipline protectors on flexible joints / couplings	personnel to problems with bearings and / or latching system (including hydraulics and other utilities)
			2. Loss of containment of HP mud or drilling fluid returns, causing potential for inability to maintain BHP due to less mud flow through drill string, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	1. Training and competency of personnel related to integrity of equipment / piping / hoses 2. Selection of material of construction for expected environmental conditions (HP mud, modified riser joint and MPD) 3. Design in accordance with applicable codes and standards 4. QA/QC during	R17 (Existing). Ensure that suitable safeguards are provided within RCD design to alert personnel to problems with bearings and / or latching system (including hydraulics and other utilities)

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								fabrication, installation and commissioning 5. Suitable inspection program for HP mud, modified riser joint and MPD system 6. Suitable preventive maintenance / inspection program for RCD seal and RCD hydraulic latching system 7. AID provided as part of modified riser joint directly below RCD 8. Suitable pressure rated equipment in use (with test certificates for hoses) 10. Mitigation controls for potential blowout as detailed in HAZID	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
			3. Potential for leak of drilling fluid to marine environment from anywhere throughout the subsea BOP through to inlet of MPD, requiring cleanup and possible fine	E	3	B	Low Risk	1. Training and competency of personnel related to integrity of equipment / piping / hoses 2. Selection of material of construction for expected environmental conditions (HP mud, modified riser joint and MPD) 3. Design in accordance with applicable codes and standards 4. QA/QC during fabrication, installation and commissioning 5. Suitable inspection program for HP mud, modified riser joint and MPD system 6. Suitable preventive maintenance / inspection program for RCD seal and RCD hydraulic latching system 7. AID provided as part of modified riser joint directly below RCD 8. Suitable pressure rated equipment in use (with test certificates for hoses) 11. Use of whipline protectors on flexible joints / couplings	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		2. Leak on RCD seal due to general wear and tear, or fault with RCD hydraulic latching system	2. Loss of containment of HP mud or drilling fluid returns, causing potential for inability to maintain BHP due to less mud flow through drill string, possible kick, possible blowout (Refer to HAZID)	P	5	B	Medium Risk	2. Selection of material of construction for expected environmental conditions (HP mud, modified riser joint and MPD) 3. Design in accordance with applicable codes and standards 5. Suitable inspection program for HP mud, modified riser joint and MPD system 6. Suitable preventive maintenance / inspection program for RCD seal and RCD hydraulic latching system 7. AID provided as part of modified riser joint directly below RCD 9. MPD pressure management system, with BP pump available to maintain BHP (if leak not excessive) 10. Mitigation controls for potential blowout as detailed in HAZID 12. Routine inspection of RCD to identify any small leaks from seal before leak worsens	Refer to HAZID Recommendations: R02, R09 and R12
			3. Potential for leak of drilling fluid to marine environment from anywhere throughout the subsea BOP through to inlet of MPD, requiring cleanup and possible fine	E	3	B	Low Risk	2. Selection of material of construction for expected environmental conditions (HP mud, modified riser joint and MPD) 3. Design in accordance	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.						
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
								with applicable codes and standards 5. Suitable inspection program for HP mud, modified riser joint and MPD system 6. Suitable preventive maintenance / inspection program for RCD seal and RCD hydraulic latching system 7. AID provided as part of modified riser joint directly below RCD	

No.: 1	Normal Operations	Drilling ahead, high-pressure mud pump operating, MPD controlling BHP, with mud returns to mud processing system to active mud pits. Modified riser joint at the top of the riser includes the following: bottom adapter; flowspool that directs return drilling fluid to MPD or overboard (and well control choke); annular isolation device (AID); rotating control device (RCD); and top adapter.							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
1.14	Miscellaneous	1. No new issues identified (issues related to location of MPD equipment, accessibility, egress, fire and gas detection, hazardous area classification, and fire protection covered during HAZID)							

Table 9. HAZOP Worksheets – No. 2 Running-in-Hole

No.: 2	Running in hole (RIH)	During running in hole, BHP is controlled by MPD choke (with BP pump available if required), platform HP mud pump not operating, with displaced drilling fluids directed to Trip Tank (Trip Tank out of HAZOP scope as it is unaffected by operation of MPD.)							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
2.1	Low/no flow	1. No more serious than previous scenarios - Refer to Low/no flow Node 1							
2.2	High flow	1. High rate of running drill string in hole due to Operator oversight	1. Potential for low BHP due to sudden reduction of drilling fluid in wellbore (drilling fluid displaced out into trip tank), possible inflow of reservoir, possible kick, possible blowout (Refer to HAZID for full description of consequences)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. PMP for pumps and MPD equipment 3. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 4. PWD indication on drill string 5. Multiple pressure transmitters between flowspool and mud outlet of MPD 6. MPD pressure management system will still control BHP via MPD choke 7. Mitigation controls for potential blowout as detailed in HAZID	
2.3	Reverse flow	1. No causes identified							
2.4	Misdirected flow	1. No more serious than previous scenarios - Refer to Misdirected Flow in Node 1							
2.5	As well as flow (unwanted input)	1. No more serious than previous scenarios - Refer to As Well As Flow (Unwanted Input) in							

No.: 2	Running in hole (RIH)	During running in hole, BHP is controlled by MPD choke (with BP pump available if required), platform HP mud pump not operating, with displaced drilling fluids directed to Trip Tank (Trip Tank out of HAZOP scope as it is unaffected by operation of MPD.)							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		Node 1							
2.6	High level	1. Not relevant to this Node							
2.7	Low level	1. Not relevant to this Node							
2.8	High temperature	1. No causes with any consequences, only ambient temperature change							
2.9	Low temperature	1. No causes with any consequences, only ambient temperature change							
2.10	High pressure	1. No new causes identified							
2.11	Low pressure	1. No more serious than previous scenarios - Refer to Low Pressure Node 1							
2.12	Changes in composition	1. No causes identified							
2.13	Leak / rupture	1. No more serious than previous scenarios - Refer to Leak / Rupture Node 1							
2.14	Miscellaneous	1. No new issues							

Table 10. HAZOP Worksheets – No. 3 Pulling-out-of-Hole

No.: 3	Pulling out of hole (POOH)	During POOH, BHP is controlled by MPD pressure control using BP pump which takes suction from Trip Tank, platform HP mud pump not operating. (Trip Tank out of HAZOP scope as it is unaffected by operation of MPD.)							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
3.1	Low/no flow	1. BP pump trips/fails	1. Potential for low BHP - No new consequences or changes to risk ranking, not considered further (other than referring to HAZID Recommendations)						Refer to HAZID Recommendations: R05
3.2	High flow	1. Control fault with MPD pressure management system that causes higher flow through BP pump than required	1. Potential for high BHP - no new consequences or changes to risk rankings, not considered further						
3.3	Reverse flow	1. No causes identified							
3.4	Misdirected flow	1. No more serious than previous scenarios - Refer to Misdirected Flow in Node 1							
3.5	As well as flow (unwanted input)	1. No more serious than previous scenarios - Refer to As Well As Flow (Unwanted Input) in Node 1							
3.6	High level	1. Not relevant to this Node							
3.7	Low level	1. No new causes identified							
3.8	High temperature	1. No causes with any consequences, only ambient temperature							

No.: 3	Pulling out of hole (POOH)	During POOH, BHP is controlled by MPD pressure control using BP pump which takes suction from Trip Tank, platform HP mud pump not operating. (Trip Tank out of HAZOP scope as it is unaffected by operation of MPD.)							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		change							
3.9	Low temperature	1. No causes with any consequences, only ambient temperature change							
3.10	High pressure	1. No new causes identified							
3.11	Low pressure	1. No new causes identified							
3.12	Changes in composition	1. No causes identified							
3.13	Leak / rupture	1. No more serious than previous scenarios - Refer to Leak / Rupture Node 1							
3.14	Miscellaneous	1. No new issues							

Table 11. HAZOP Worksheets – No. 4 Running Casing

No.: 4	Running Casing								
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
4.1	Low/no flow	1. No more serious than previous scenarios - Refer to Low/no flow Node 1							
4.2	High flow	1. High rate of running in hole due to oversight	1. Potential for low BHP due to sudden reduction of drilling fluid in wellbore (drilling fluid displaced out into trip tank), possible inflow of reservoir, possible kick, possible blowout (Refer to HAZID for full description of consequences)	P	5	B	Medium Risk	1. Training and competency of drilling personnel (related to equipment line up and operation of drilling equipment) 2. PMP for pumps and MPD equipment 3. Flow measurement of mud returns downstream of MPD choke, with flow kick detection 4. PWD indication on drill string 5. Multiple pressure transmitters between flowspool and mud outlet of MPD 6. MPD pressure management system will still control BHP via MPD choke 7. Mitigation controls for potential blowout as detailed in HAZID	
4.3	Reverse flow	1. No causes identified							
4.4	Misdirected flow	1. No more serious than previous scenarios - Refer to Misdirected Flow in Node 1							
4.5	As well as flow (unwanted input)	1. No more serious than previous scenarios - Refer to As Well As							

No.: 4	Running Casing								
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
		Flow (Unwanted Input) in Node 1							
4.6	High level	1. Not relevant to this Node							
4.7	Low level	1. Not relevant to this Node							
4.8	High temperature	1. No causes with any consequences, only ambient temperature change							
4.9	Low temperature	1. No causes with any consequences, only ambient temperature change							
4.10	High pressure	1. No new causes identified							
4.11	Low pressure	1. No more serious than previous scenarios - Refer to Low Pressure Node 1							
4.12	Changes in composition	1. No causes identified							
4.13	Leak / rupture	1. No more serious than previous scenarios - Refer to Leak / Rupture Node 1							
4.14	Miscellaneous	1. No new issues							

Table 12. HAZOP Worksheets – No. 5 Wireline or Coiled Tubing Operation

No.: 5	Wireline or coiled tubing operation	Well intervention, when required							
Item	**Deviation**	**Causes**	**Consequences**	**Matrix**	**S**	**L**	**R**	**Safeguards**	**Action Items**
5.1	Low/no flow	Not covered during HAZOP as unsure of how wireline / coiled tubing is undertaken - requires further research, however unlikely to have any other concerns not already identified in Node 2 (Running in hole)							
5.2	High flow								
5.3	Reverse flow								
5.4	Misdirected flow								
5.5	As well as flow (unwanted input)								
5.6	High level								
5.7	Low level								
5.8	High temperature								
5.9	Low temperature								
5.10	High pressure								
5.11	Low pressure								
5.12	Changes in composition								
5.13	Leak / rupture								
5.14	Miscellaneous								

3.5 Bowtie Assessment

For the risks identified from the HAZID and HAZOP workshops, the barrier assessment has been done using Bowtie diagrams.

3.5.1 Purpose of bowties

A Bowtie model represents how a hazard can be released, escalate, and how it is controlled. It contains the elements required to effectively manage the Hazards. Bowties can also be used to support risk management of non-HSE processes. Figure 7 below illustrates the Bow-tie model for hazard management.

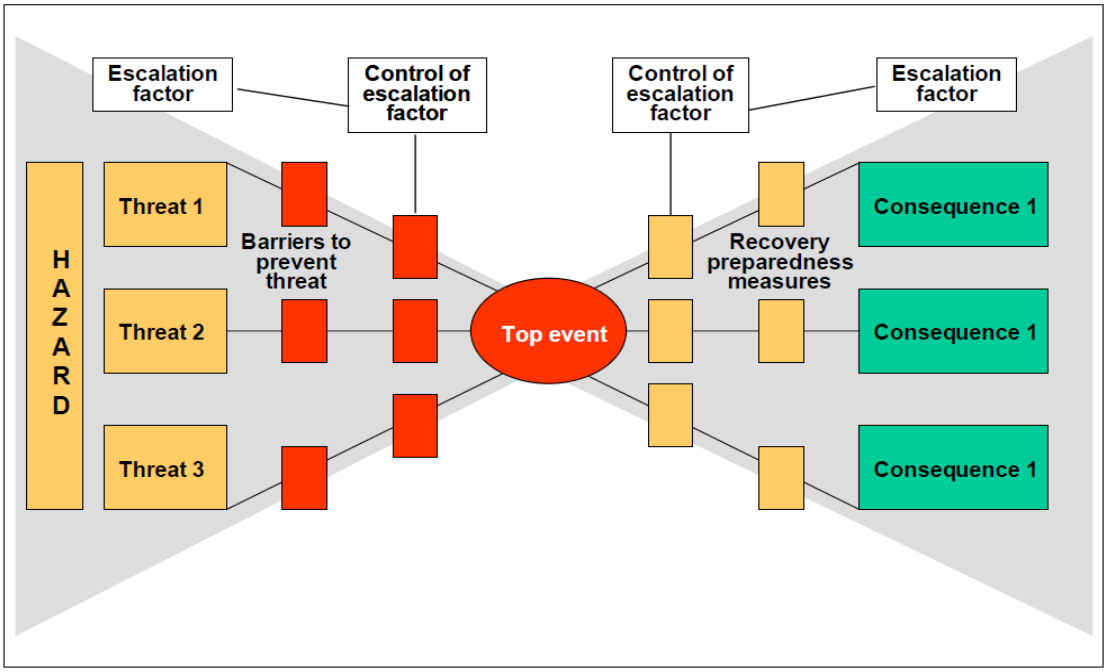

Figure 7. Hazard Analysis by the Bow–Tie Model

The model states that for a hazard at a location, there exists a number of causes (threats) that will release the hazard (top event) and that if released, there exists a number of possible outcomes (consequences). Management of the hazard fully requires suitable and sufficient control of all threats (barriers) and suitable and sufficient measures in place for all possible and foreseeable consequences (recovery preparedness measures).

The objective of this bowtie assessment is to ensure that suitable measures are in place for all hazards and consequences identified in the HAZID and HAZOP (Sections 3.3 and 3.4), and to allow visual verification of this fact. Each of the hazardous scenarios (top events) identified in the HAZID contains bowtie diagram, as presented in Section 3.5.2.

3.5.2 Bowtie diagrams

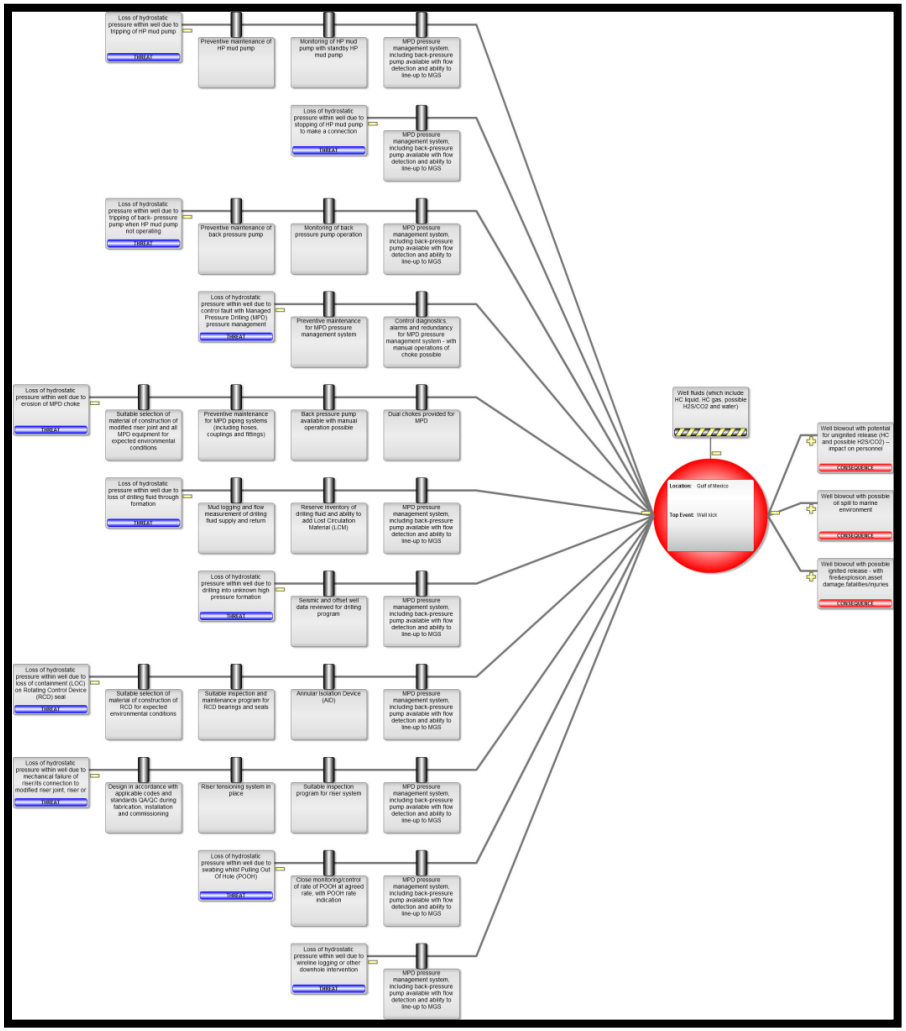

Figure 8. Bowtie Diagram H-01.01, 1 of 2

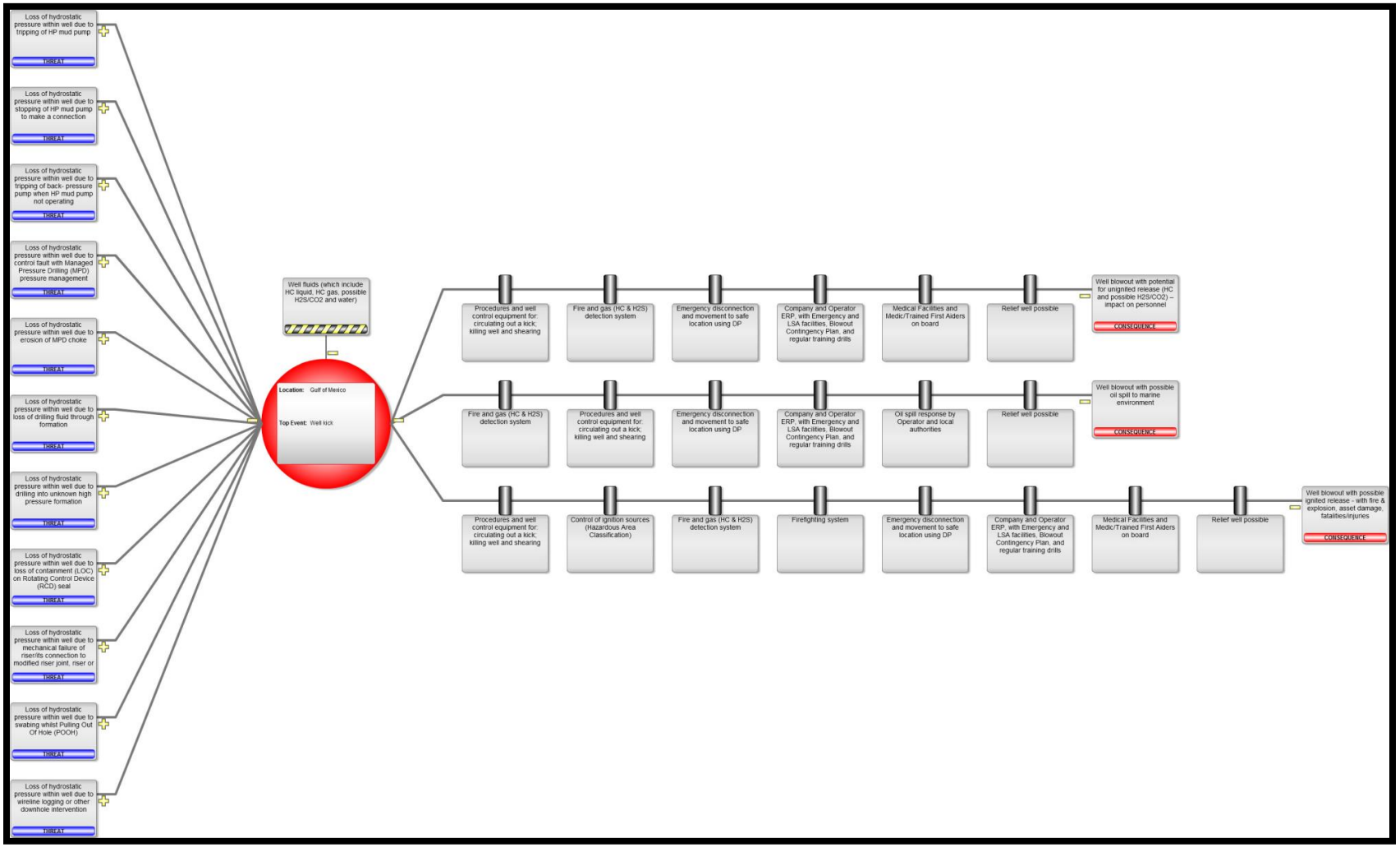

Figure 9. Bowtie Diagram H-01.01, 2 of 2

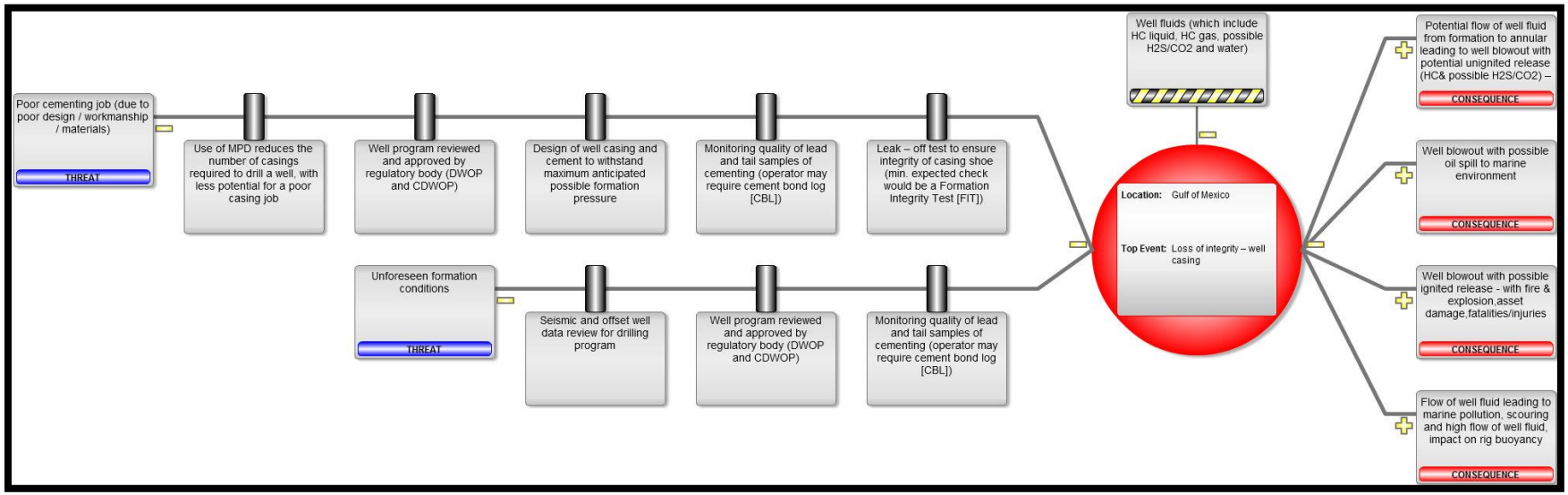

Figure 10. Bowtie Diagram H-01.02, 1 of 2

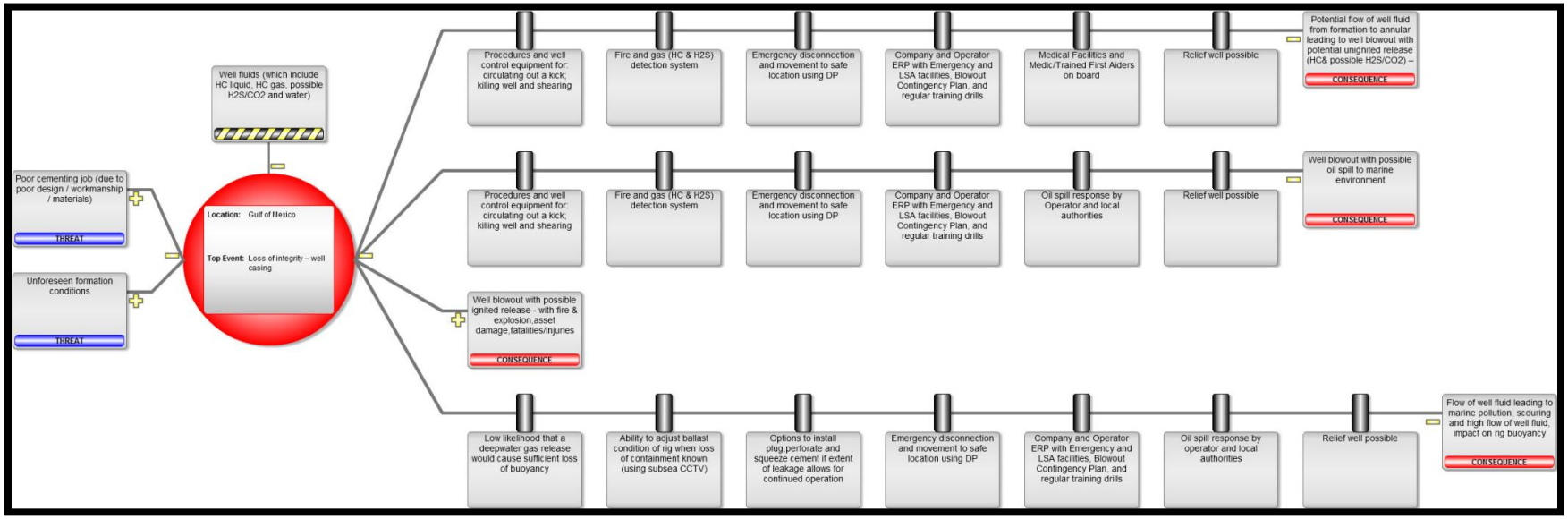

Figure 11. Bowtie Diagram H-01.02, 2 of 2

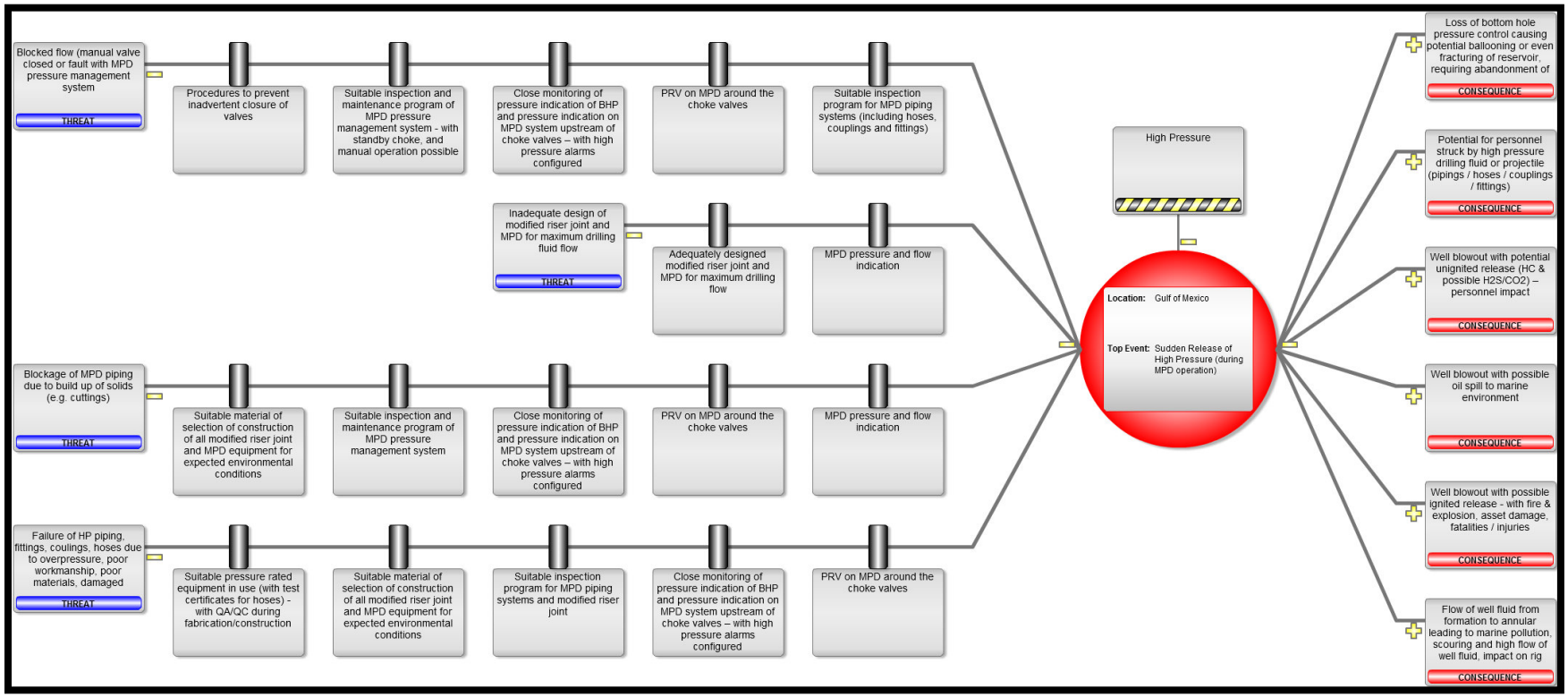

Figure 12. Bowtie Diagram H-02.01, 1 of 2

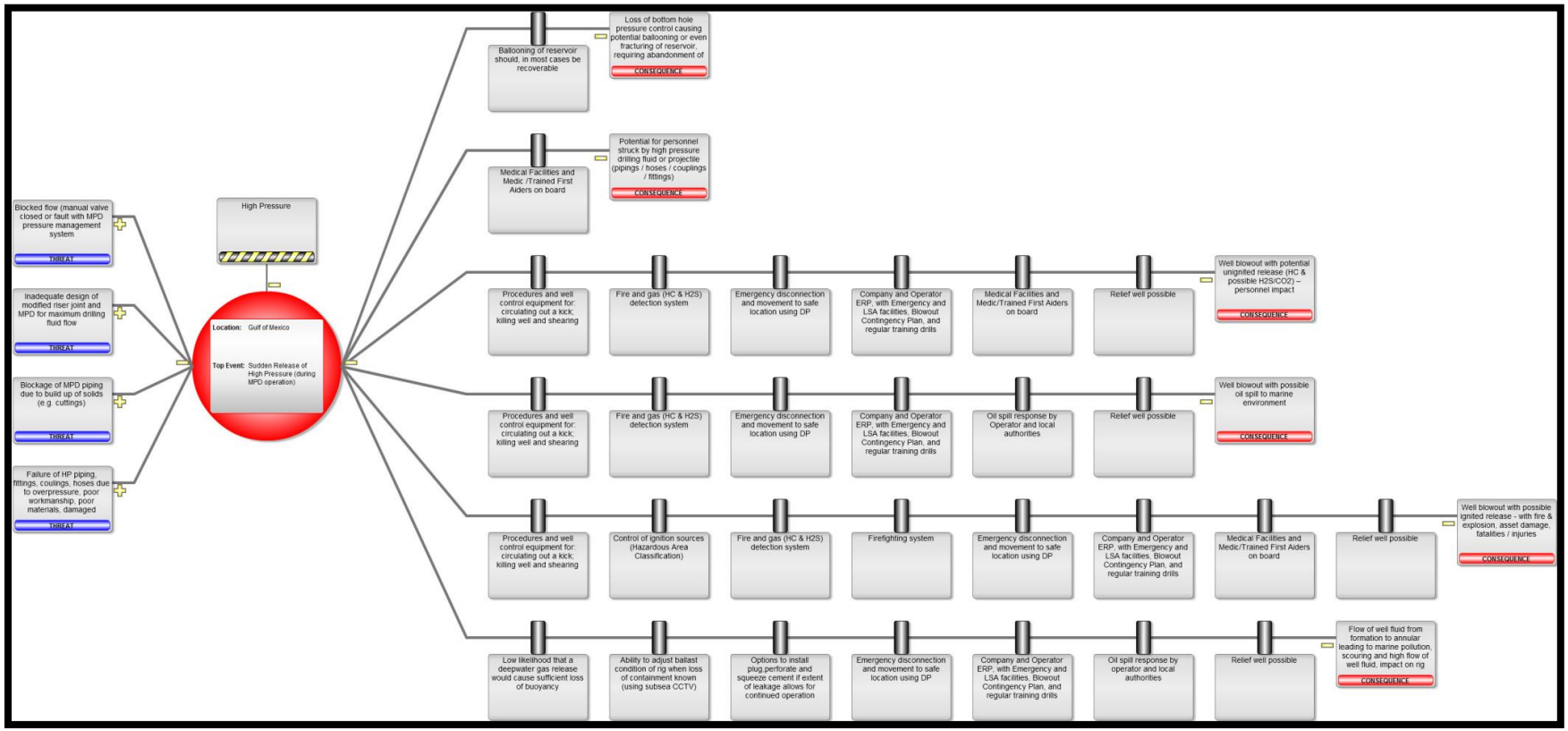

Figure 13. Bowtie Diagram H-02.01, 2 of 2

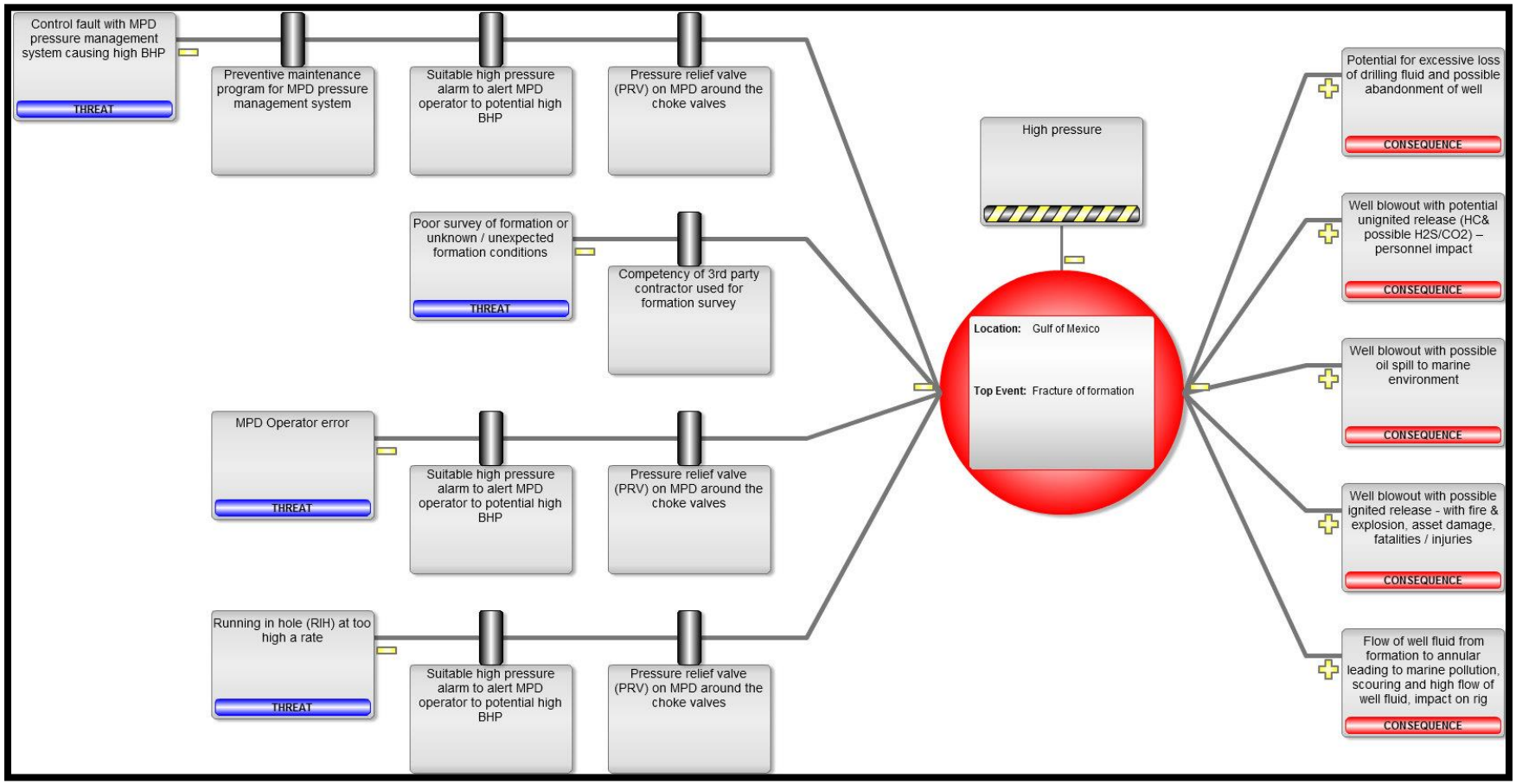

Figure 14. Bowtie Diagram H-02.02, 1 of 2

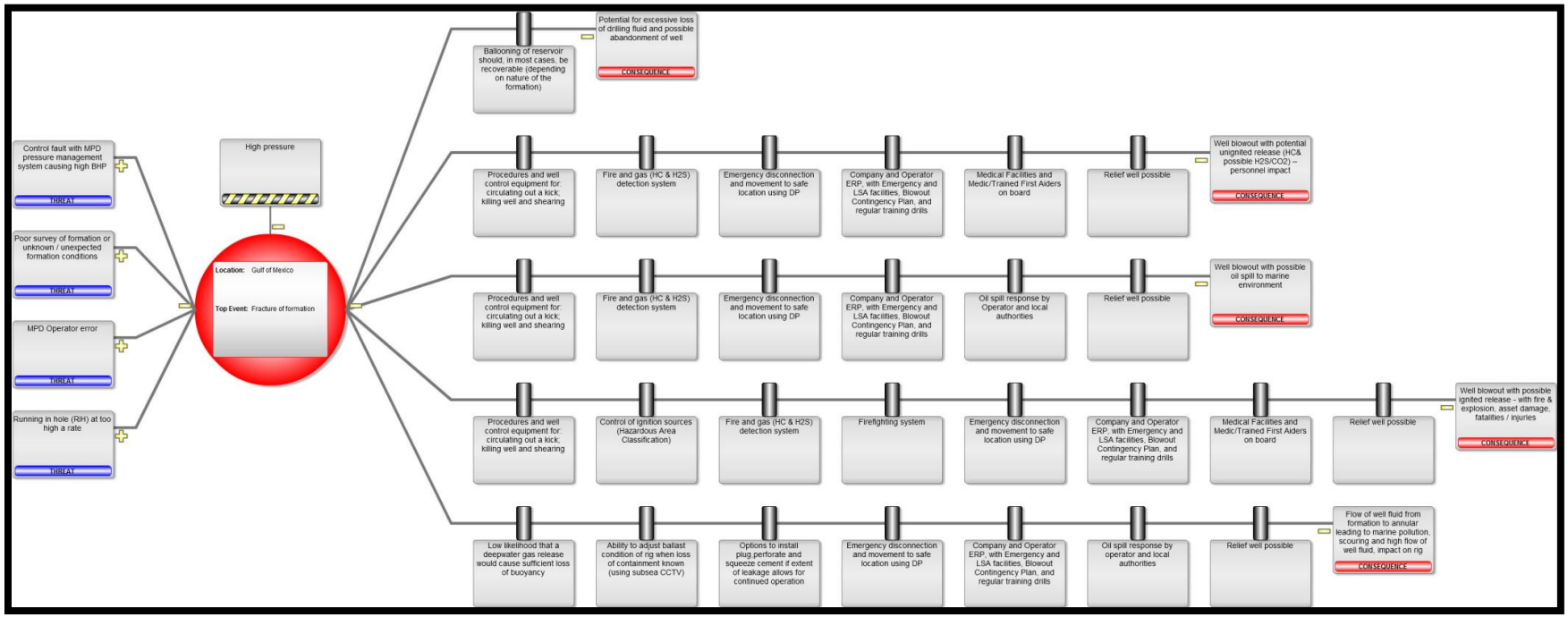

Figure 15. Bowtie Diagram H-02.02, 2 of 2

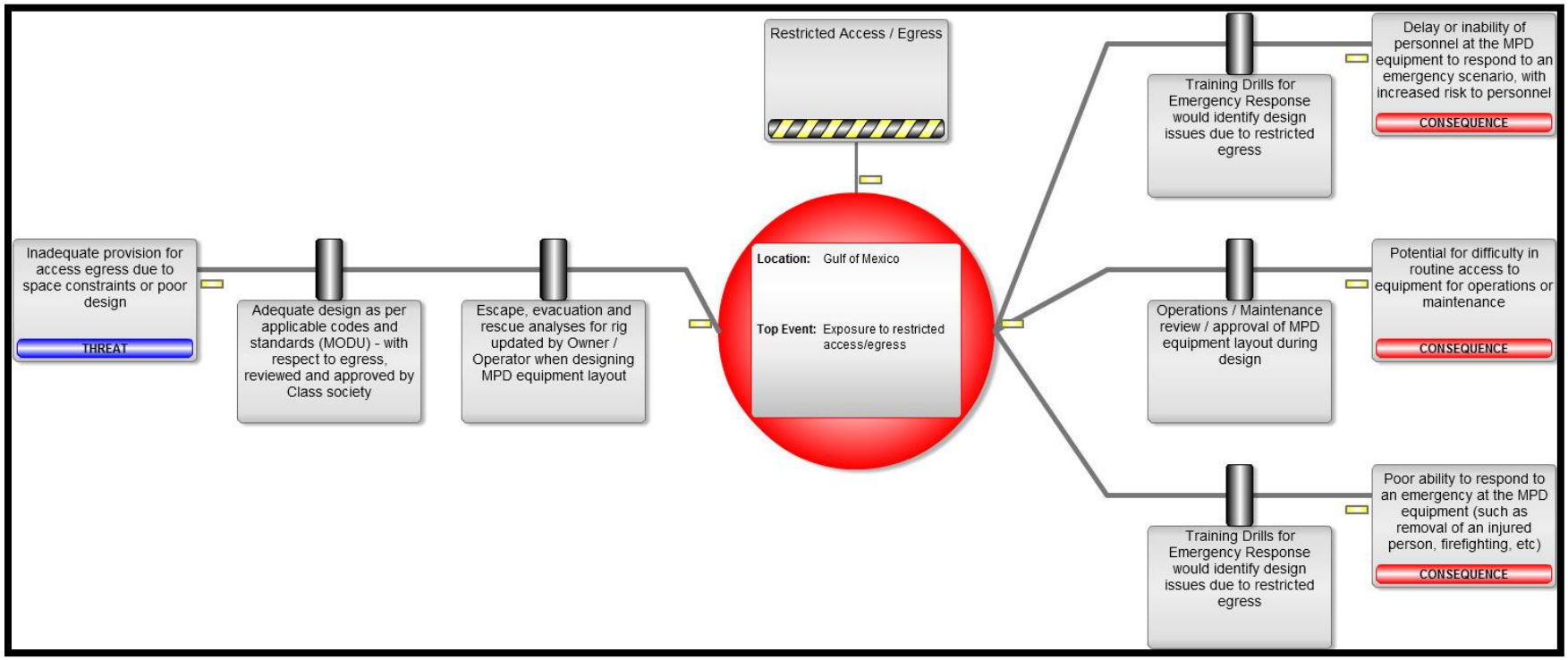

Figure 16. Bowtie Diagram H-03.01, 1 of 1

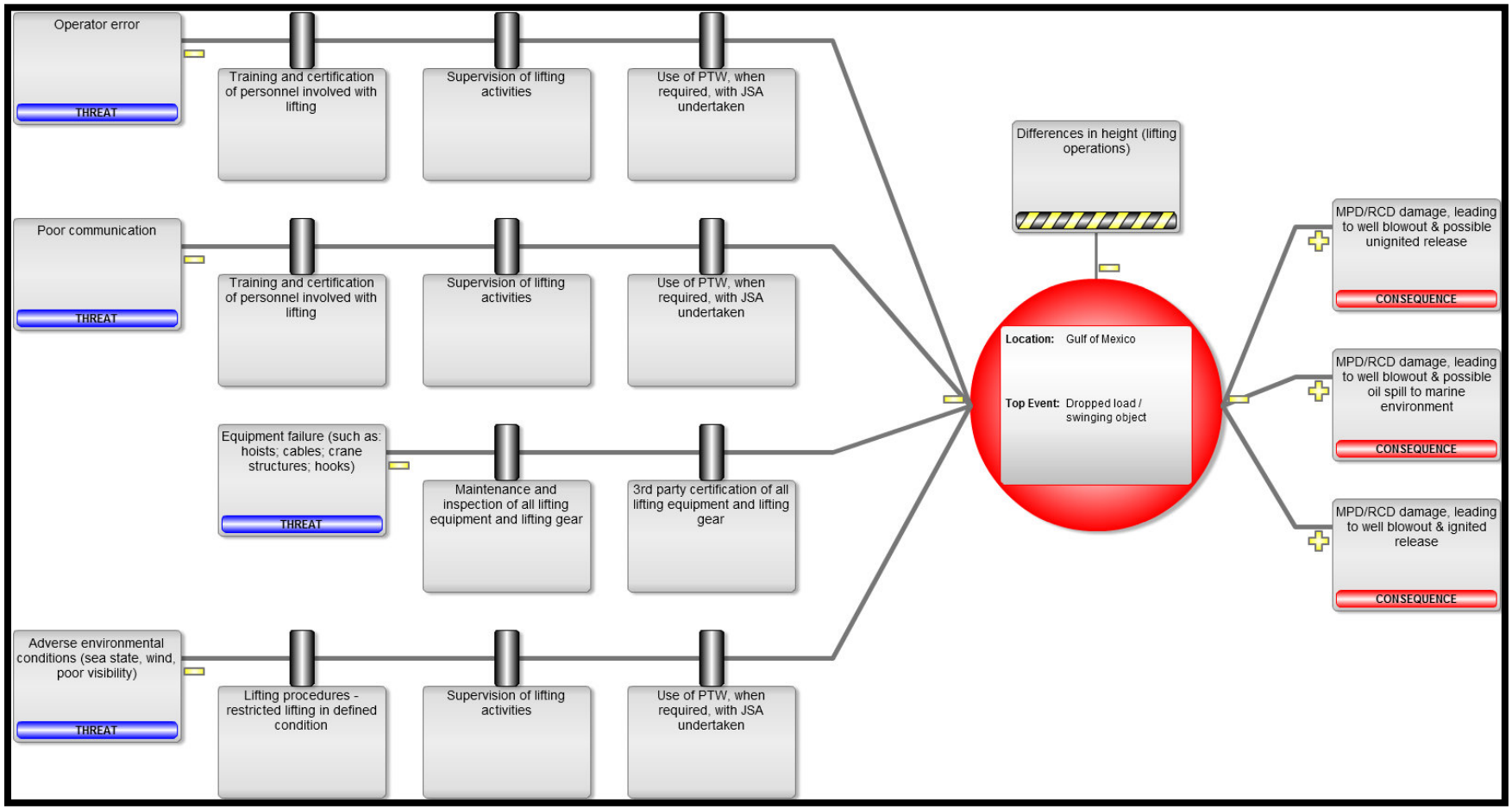

Figure 17. Bowtie Diagram H-04.01, 1 of 2

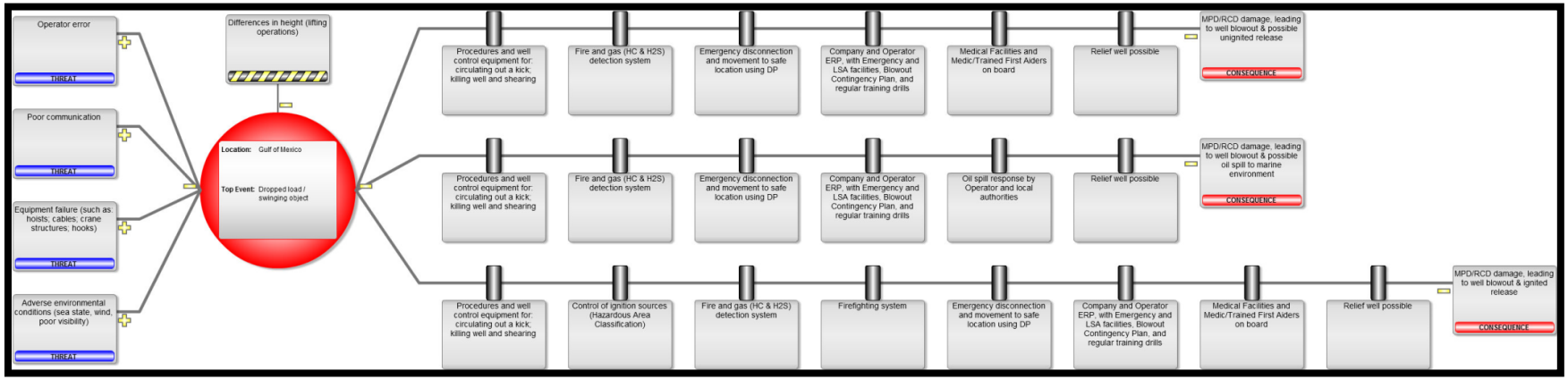

Figure 18. Bowtie Diagram H-04.01, 2 of 2

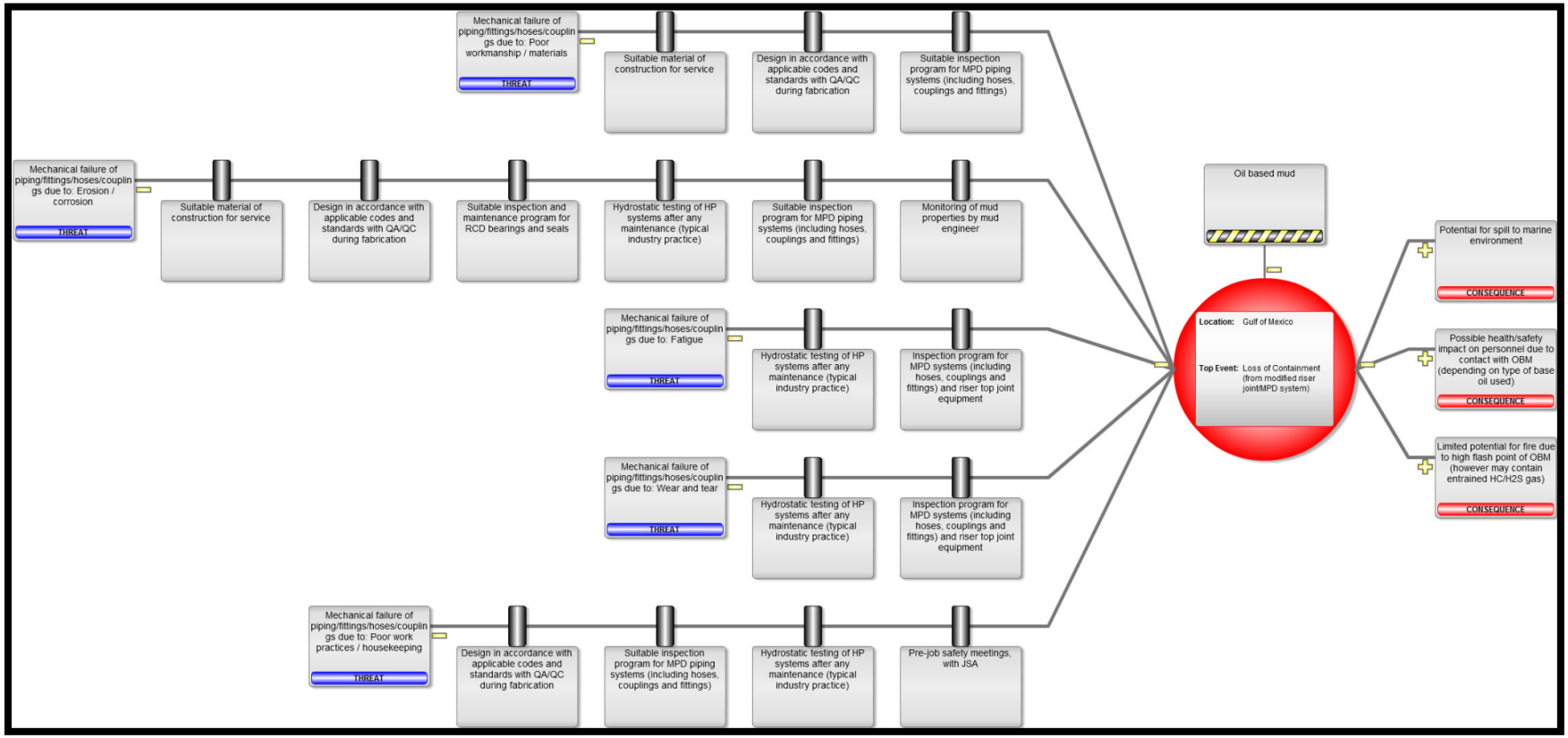

Figure 19. Bowtie Diagram H-05.01, 1 of 2

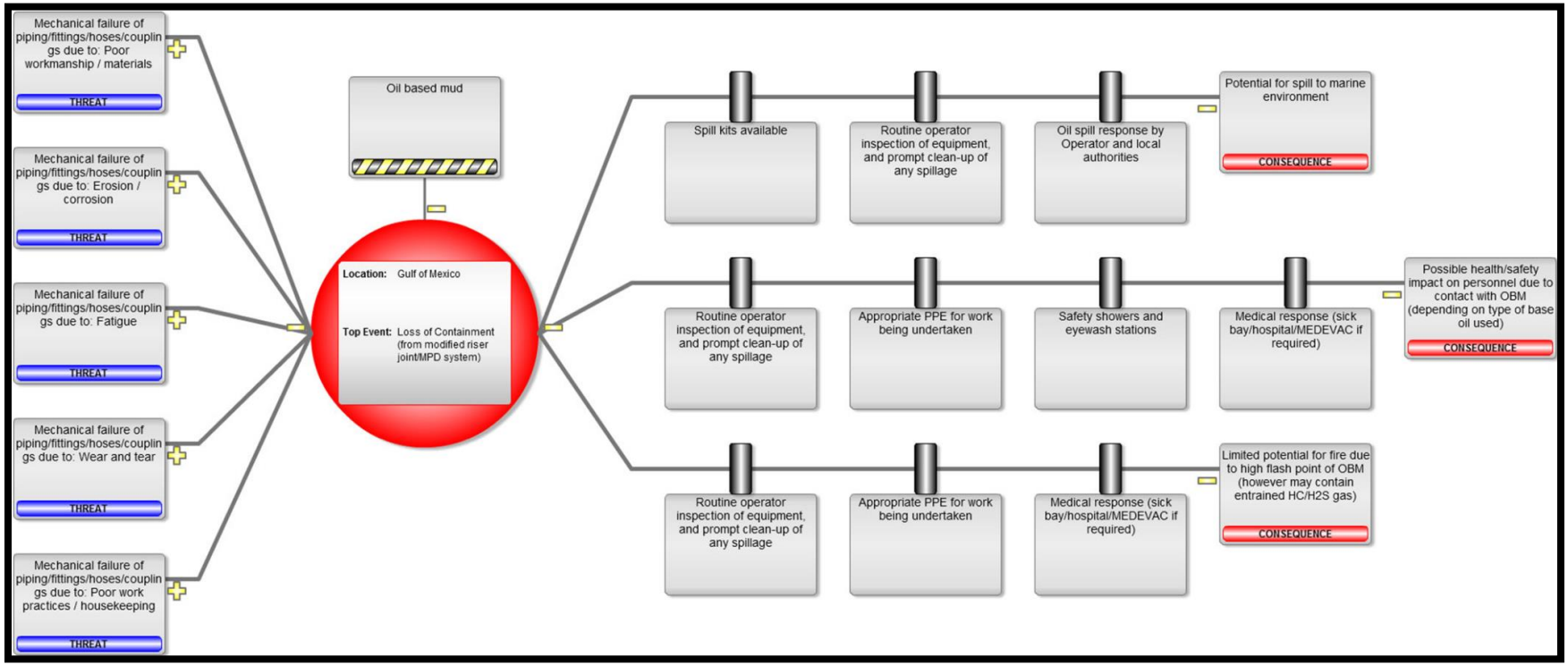

Figure 20. Bowtie Diagram H-05.01, 2 of 2

3.5.3 Summary of Bowties

Table 13 below summarizes all the identified threats and barriers to prevent realization, while Table 14 lists the recovery Preparedness Measures against for the consequences of the threats. The barriers highlighted in the bold are physical barriers.

Table 13. List of Barriers with Regards to Threats

Threats	Barriers
Adverse environmental conditions (sea state, wind, poor visibility)	Lifting procedures - restricted lifting in defined condition
	Supervision of lifting activities
	Use of PTW, when required, with JSA undertaken
Blockage of MPD piping due to build-up of solids (e.g., cuttings)	Suitable inspection and maintenance program of MPD pressure management system
	Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured
	PRV on MPD around the choke valves
	MPD pressure and flow indication
	Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions
Blocked flow (manual valve closed or fault with MPD pressure management system	Procedures to prevent inadvertent closure of valves
	Suitable inspection and maintenance program of MPD pressure management system - with standby choke, and manual operation possible
	PRV on MPD around the choke valves
	Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)
	Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured
Control fault with MPD pressure management system causing high BHP	Preventive maintenance program for MPD pressure management system
	Pressure relief valve (PRV) on MPD around the choke valves
	Suitable high pressure alarm to alert MPD Operator to potential high BHP
Equipment failure (such as: hoists; cables; crane structures; hooks)	Maintenance and inspection of all lifting equipment and lifting gear
	3rd party certification of all lifting equipment and lifting gear

Threats	Barriers
Failure of HP piping, fittings, couplings, hoses due to overpressure, poor workmanship, poor materials, damaged couplings, erosion / corrosion and improper practices during hydro testing	Suitable pressure rated equipment in use (with test certificates for hoses) - with QA/QC during fabrication/construction
	Suitable inspection program for MPD piping systems and modified riser joint
	Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions
	PRV on MPD around the choke valves
	Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured
Inadequate design of modified riser joint and MPD for maximum drilling fluid flow	Adequately designed modified riser joint and MPD for maximum drilling flow
	MPD pressure and flow indication
Inadequate provision for access egress due to space constraints or poor design	Adequate design as per applicable codes and standards (MODU) - with respect to egress, reviewed and approved by Class society
	Escape, evacuation and rescue analyses for platform updated by Owner / Operator when designing MPD equipment layout
Loss of hydrostatic pressure within well due to control fault with MPD pressure management system	Preventive maintenance for MPD pressure management system
	Control diagnostics, alarms and redundancy for MPD pressure management system - with manual operations of choke possible
Loss of hydrostatic pressure within well due to drilling into unknown high pressure formation	Seismic and offset well data reviewed for drilling program
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to erosion of MPD choke	**Back pressure pump available with manual operation possible**
	Suitable selection of material of construction of modified riser joint and all MPD equipment for expected environmental conditions
	Preventive maintenance for MPD piping systems (including hoses, couplings and fittings)
	Dual chokes provided for MPD
Loss of hydrostatic pressure within well due to loss of containment (LOC) on Rotating Control Device (RCD) seal	Suitable inspection and maintenance program for RCD bearings and seals
	Suitable selection of material of construction of RCD for expected environmental conditions
	Annular Isolation Device

Threats	Barriers
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to loss of drilling fluid through formation	Mud logging and flow measurement of drilling fluid supply and return
	Reserve inventory of drilling fluid and ability to add LCM
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to mechanical failure of riser/its connection to modified riser joint, riser or Lower Marine Riser	Design in accordance with applicable codes and standards QA/QC during fabrication, installation and commissioning
	Riser tensioning system in place
	Suitable inspection program for riser system
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to stopping of HP mud pump to make a connection	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to swabbing while POOH	Close monitoring/control of rate of POOH at agreed rate, with POOH rate indication
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to tripping of back- pressure pump when HP mud pump not operating	Preventive maintenance of back pressure pump
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
	Monitoring of back pressure pump operation
Loss of hydrostatic pressure within well due to tripping of HP mud pump	Preventive maintenance of HP mud pump
	Monitoring of HP mud pump with standby HP mud pump
	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Loss of hydrostatic pressure within well due to wireline logging or other downhole intervention	MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
Mechanical failure of piping/fittings/hoses/couplings due to: Erosion / corrosion	Hydrostatic testing of HP systems after any maintenance (typical industry practice)
	Suitable material of construction for service

Threats	Barriers
	Suitable inspection and maintenance program for RCD bearings and seals
	Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)
	Design in accordance with applicable codes and standards with QA/QC during fabrication
	Monitoring of mud properties by mud engineer
Mechanical failure of piping/fittings/hoses/couplings due to: Fatigue	Hydrostatic testing of HP systems after any maintenance (typical industry practice)
	Inspection program for MPD systems (including hoses, couplings and fittings) and riser top joint equipment
Mechanical failure of piping/fittings/hoses/couplings due to: Poor work practices / housekeeping	Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)
	Pre-job safety meetings, with JSA
	Design in accordance with applicable codes and standards with QA/QC during fabrication
	Hydrostatic testing of HP systems after any maintenance (typical industry practice)
Mechanical failure of piping/fittings/hoses/couplings due to: Poor workmanship / materials	Suitable material of construction for service
	Design in accordance with applicable codes and standards with QA/QC during fabrication
	Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)
Mechanical failure of piping/fittings/hoses/couplings due to: Wear and tear	Hydrostatic testing of HP systems after any maintenance (typical industry practice)
	Inspection program for MPD systems (including hoses, couplings and fittings) and riser top joint equipment
MPD Operator error	Suitable high pressure alarm to alert MPD Operator to potential high BHP
	Pressure relief valve on MPD around the choke valves
Operator error	Training and certification of personnel involved with lifting
	Supervision of lifting activities
	Use of PTW, when required, with JSA undertaken
Poor cementing job (due to poor design / workmanship / materials)	Well program reviewed and approved by regulatory body (DWOP and CDWOP)
	Monitoring quality of lead and tail samples of cementing

Threats	Barriers
	(Operator may require CBL)
	Leak – off test to ensure integrity of casing shoe (min. expected check would be a FIT)
	Design of well casing and cement to withstand maximum anticipated possible formation pressure
	Use of MPD reduces the number of casings required to drill a well, with less potential for a poor casing job
Poor communication	Training and certification of personnel involved with lifting
	Supervision of lifting activities
	Use of PTW, when required, with JSA undertaken
Poor survey of formation or unknown / unexpected formation conditions	Competency of 3rd party contractor used for formation survey
Running in hole (RIH) at too high a rate	Suitable high pressure alarm to alert MPD Operator to potential high BHP
	Pressure relief valve on MPD around the choke valves
Unforeseen formation conditions	Well program reviewed and approved by regulatory body (DWOP and CDWOP)
	Monitoring quality of lead and tail samples of cementing (Operator may require CBL)
	Seismic and offset well data review for drilling program

Table 14. List of Recovery Preparedness Measures with Regards to Consequences

Consequence	Recovery Preparedness Measures
Delay or inability of personnel at the MPD equipment to respond to an emergency scenario, with increased risk to personnel	Training Drills for Emergency Response would identify design issues due to restricted egress
Flow of well fluid from formation to annular leading to marine pollution, scouring and high flow of well fluid, impact on platform buoyancy	Ability to adjust ballast condition of platform when loss of containment known (using subsea CCTV)
	Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Low likelihood that a Deepwater gas release would cause sufficient loss of buoyancy
	Oil spill response by Operator and local authorities
	Options to install plug, perforate and squeeze cement if extent of leakage allows for continued operation
	Relief well possible
Flow of well fluid leading to marine pollution, scouring and high flow of well fluid, impact on platform buoyancy	Ability to adjust ballast condition of platform when loss of containment known (using subsea CCTV)
	Company and Operator ERP with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Low likelihood that a Deepwater gas release would cause sufficient loss of buoyancy
	Oil spill response by Operator and local authorities
	Options to install plug, perforate and squeeze cement if extent of leakage allows for continued operation
	Relief well possible
Limited potential for fire due to high flash point of OBM (however may contain entrained HC/H2S gas)	Appropriate PPE for work being undertaken
	Medical response (sick bay/hospital/MEDEVAC if required)
	Routine Operator inspection of equipment, and prompt clean-up of any spillage
Loss of bottom hole pressure control causing potential ballooning or even fracturing of	Ballooning of reservoir should, in most cases be recoverable

Consequence	Recovery Preparedness Measures
reservoir, requiring abandonment of well	
MPD/RCD damage, leading to well blowout and ignited release	Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Control of ignition sources (Hazardous Area Classification)
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Firefighting system
	Medical Facilities and Medic/Trained First Aiders on board
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible
MPD/RCD damage, leading to well blowout and possible oil spill to marine environment	Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Oil spill response by Operator and local authorities
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible
MPD/RCD damage, leading to well blowout and possible unignited release	Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Medical Facilities and Medic/Trained First Aiders on board
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible

Consequence	Recovery Preparedness Measures
Poor ability to respond to an emergency at the MPD equipment (such as removal of an injured person, firefighting, etc.)	Training Drills for Emergency Response would identify design issues due to restricted egress
Possible health/safety impact on personnel due to contact with OBM (depending on type of base oil used)	Appropriate PPE for work being undertaken
	Medical response (sick bay/hospital/MEDEVAC if required)
	Routine Operator inspection of equipment, and prompt clean-up of any spillage
	Safety showers and eyewash stations
Potential flow of well fluid from formation to annular leading to well blowout with potential unignited release (HC and possible H2S/CO2) – personnel impact	Company and Operator ERP with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Medical Facilities and Medic/Trained First Aiders on board
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible
Potential for difficulty in routine access to equipment for operations or maintenance	Operations / Maintenance review / approval of MPD equipment layout during design
Potential for excessive loss of drilling fluid and possible abandonment of well	Ballooning of reservoir should, in most cases, be recoverable (depending on nature of the formation)
Potential for personnel struck by high pressure drilling fluid or projectile (piping / hoses / couplings / fittings)	Medical Facilities and Medic /Trained First Aiders on board
Potential for spill to marine environment	Oil spill response by Operator and local authorities
	Routine Operator inspection of equipment, and prompt clean-up of any spillage
	Spill kits available
Well blowout with possible ignited release - with fire and explosion, asset damage, fatalities/injuries	Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Control of ignition sources (Hazardous Area Classification)

Consequence	Recovery Preparedness Measures
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Firefighting system
	Medical Facilities and Medic/Trained First Aiders on board
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible
Well blowout with possible oil spill to marine environment	Company and Operator ERP with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Oil spill response by Operator and local authorities
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible
Well blowout with potential for unignited release (HC and possible H2S/CO2) – impact on personnel	Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills
	Emergency disconnection and movement to safe location using DP
	Fire and gas (HC and H2S) detection system
	Medical Facilities and Medic/Trained First Aiders on board
	Procedures and well control equipment for: circulating out a kick; killing well and shearing
	Relief well possible

3.6 Review and Verify Hazards and Risks

3.6.1 Introduction

3.6.1.1 General

The Hazards and Effects Management Process Register is a quality record, which demonstrates that all the Hazards and Effects have been identified, are understood and are being properly controlled. It demonstrates that the platform is adequately controlled and that preparations are in place to handle any consequence that could result if control is ever lost. The HEMP Register is developed using input from all three studies discussed previously (HAZID, HAZOP, and Bowtie) and is evaluated based on the set Acceptance Criteria.

3.6.2 Methodology

Effective risk assessment requires a systematic approach to the identification of hazards and issues. The HAZID study done has managed to identify the threats, barriers, consequences and RPMs associated with the scenario. Input from the HAZID study and the bowtie diagrams has led to the development of the HEMP Register.

The HEMP Register comprises the following:

1. Hazard Number

Is the Unique hazard number for a particular identified hazard, e.g., H-01.01; Well fluids (which include HC liquid, HC gas, possible H2S/CO2 and water).

2. Hazard Group

Is the type of hazard applicable for identified hazards, e.g., hydrocarbon, elevated objects, biological hazards, toxic substances etc. See table below.

Table 15. Hazard Group Reference (ISO 17776)

Hazard Group	
Code	**Name**
H-01	Hydrocarbons
H-02	Refined Hydrocarbons
H-03	Other flammable materials
H-04	Explosives
H-05	Pressure Hazards
H-06	Hazards associated with differences in height
H-07	Objects under induced stress
H-08	Dynamic situation hazards
H-09	Environmental Hazards
H-10	Hot surfaces
H-11	Hot fluids
H-12	Cold surfaces
H-13	Cold fluids
H-14	Open flame
H-15	Electricity
H-16	Electromagnetic radiation
H-17	Ionizing radiation - open source
H-18	Ionizing radiation - closed source
H-19	Asphyxiants
H-20	Toxic gas
H-21	Toxic liquid
H-22	Toxic solid
H-23	Corrosive substances
H-24	Biological hazards
H-25	Ergonomic hazards
H-26	Psychological hazards
H-27	Security related Hazards
H-28	Use of Natural Resources

Hazard Group	
Code	**Name**
H-29	Medical
H-30	Noise
SH-01	Entrapment (Security Hazards)

3. Hazard

Hazard is a potential source of harm. Source, situation, or act with a potential to cause harm. Note that in the context of international standards, the potential harm may relate to human injury, damage to the environment, damage to property, damage to reputation, or a combination of these.

4. Activity Generating Hazard

This is the activity which will contribute in generating hazards, e.g., maintenance or equipment failure.

5. Top Event

The event or situation that represents the release of the hazard or deviation from defined control limits (continuous exposures or continuous discharges).

6. Location

This refers to the location of the facility where the hazard or effect of the hazard is present.

7. Acceptance Criteria

The Acceptance Criteria define suitable and sufficient control of threats and recovery preparedness.

In order to determine if the barriers and RPMs were sufficient for the identified hazard, and if any corrective measures were required, the following Acceptance Criteria was used:

Table 16. Acceptance Criteria

Controls	High Risk Hazards	Medium Risk Hazards	Low Risk Hazards
Threat Barriers	Minimum of three independent effective barriers to be in place for each identified threat	Minimum of two independent effective barriers to be in place for each identified threat	Minimum of one independent effective barrier to be in place for each identified threat
Recovery Preparedness Measures	Minimum of three independent effective recovery preparedness measures required for each identified	Minimum of two independent effective recovery preparedness measures required for each identified	Minimum of one independent effective recovery preparedness measures required for each identified

Controls	High Risk Hazards	Medium Risk Hazards	Low Risk Hazards
	consequence (including one to detect automatically occurrence of top event and one other to prevent automatically further escalation)	consequence (one to detect occurrence of top event and other to prevent further escalation)	consequence

It has been agreed to supply the most severe Acceptance Criteria to all identified risks. In complying with the Acceptance Criteria, the barriers and RPMs in place are considered suitable and sufficient, and the risk levels are considered to be ALARP.

8. Risk Assessment

The process of determination of risk is usually in a qualitative or semi-qualitative manner. It is an evaluation of the probability of undesired events and that of harm or damage caused together with the judgments made concerning the significance of the results. The IADC RAM is used for risk assessment (Refer to section 3.1.3.1).

9. Threats and Barriers

Identify and describe the possible causes of release of the hazard or deviation from control limits, resulting in the top event. These are threats. Hazards, threats and top events are logically related. For example:

Hazard	Threat	Top Event
‘Oil under pressure' (in piping)	'Corrosion'	'Loss of containment'
‘Elevated load’	‘Inadequate sling strength’	‘Fall to lower level’
‘Oil in effluent water’	‘Instrument failure’	‘Exceeded control limits’

Describe the likelihood or frequency that the threats realize the hazard. This may be done either quantitatively if sufficient data is available and by reference to incidents in similar facilities or operations, or based on the judgment of experienced personnel.

10. Consequences and Recovery Preparedness Measures

Consequences are the effects of the top event. RPMs in place mitigate the severity of the consequences.

11. Recommendations

Record all the recommendations with respect to management of the hazard or effect being recorded.

3.6.3 *Hazards And Effects Management Process and As Low As Reasonably Practicable Assessment*

The Hazards and Effects Registers are as follows.

Table 17. Hazards and Effects Register – H-01.01

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-01.01	**Revision**	01
1. Hazard Group	H-01		**2. Hazard**	Well fluids (which include HC liquid, HC gas, possible H_2S/CO_2 and water)	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Well kick	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barriers for every Threat, 2 RPMs for every Consequence				
7. Risk Assessment					
P	**A**	**E**	**R**	**Overall Risk Range**	
5B	**5B**	**5B**	**5B**	**Medium**	
8. Threats and Barriers					
Number of Threats			**Barriers**		
1. Loss of hydrostatic pressure within well due to trip of HP mud pump			(i) Preventive maintenance of HP mud pump (ii) Monitoring of HP mud pump with standby HP mud pump (iii) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS		
2. Loss of hydrostatic pressure within well due to stopping of HP mud pump to make a connection			(i) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS (ii) Training and competency of drilling personnel		

3. Loss of hydrostatic pressure within well due to tripping of back- pressure pump when HP mud pump not operating	(i) Preventive maintenance of back pressure pump (ii) Monitoring of back pressure pump operation (iii) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
4. Loss of hydrostatic pressure within well due to control fault with Managed Pressure Drilling (MPD) pressure management system	(i) Preventive maintenance for MPD pressure management system (ii) Control diagnostics, alarms and redundancy for MPD pressure management system - with manual operations of choke possible
5. Loss of hydrostatic pressure within well due to erosion of MPD choke	(i) Suitable selection of material of construction of modified riser joint and all MPD equipment for expected environmental conditions (ii) Preventive maintenance for MPD piping systems (including hoses, couplings and fittings) (iii) Back pressure pump available with manual operation possible (iv) Dual chokes provided for MPD
6. Loss of hydrostatic pressure within well due to loss of drilling fluid through formation	(i) Mud logging and flow measurement of drilling fluid supply and return (ii) Reserve inventory of drilling fluid and ability to add LCM (iii) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
7. Loss of hydrostatic pressure within well due to drilling into unknown high pressure formation	(i) Seismic and offset well data reviewed for drilling program (ii) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS

8. Loss of hydrostatic pressure within well due to loss of containment (LOC) on Rotating Control Device (RCD) seal	(i) Suitable selection of material of construction of RCD for expected environmental conditions (ii) Suitable inspection and maintenance program for RCD bearings and seals (iii) Annular Isolation Device (iv) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
9. Loss of hydrostatic pressure within well due to mechanical failure of riser/its connection to modified riser joint, riser or Lower Marine Riser	(i) Design in accordance with applicable codes and standards QA/QC during fabrication, installation and commissioning (ii) Riser tensioning system in place (iii) Suitable inspection program for riser system (iv) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
10. Loss of hydrostatic pressure within well due to swabbing while POOH	(i) Close monitoring/control of rate of POOH at agreed rate, with POOH rate indication (ii) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS
11. Loss of hydrostatic pressure within well due to wireline logging or other downhole intervention	(i) MPD pressure management system, including back-pressure pump available with flow detection and ability to line-up to MGS (ii) Training and competency of drilling personnel

9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Well blowout with potential for unignited release (HC and possible H_2S/CO_2) – impact on personnel	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Medical Facilities and Medic/Trained First Aiders on board (vi) Relief well possible
2. Well blowout with possible oil spill to marine environment	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Oil response by Operator and local authorities (vi) Relief well possible

3. Well blowout with possible ignited release – with fire and explosion, asset damage, fatalities / injuries	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Control of ignition sources (Hazardous Area Classification) (iii) Fire and gas (HC and H_2S) detection system (iv) Firefighting system (v) Emergency disconnection and movement to safe location using DP (vi) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (vii) Medical Facilities and Medic/Trained First Aiders on board (viii) Relief well possible

10. Recommendations

- R01 – Ensure that the material of construction for the modified riser joint and the MPD equipment (including piping, fittings, hoses, couplings, chokes and bends) includes consideration for high erosion potential caused by high-pressure drop and cuttings in the drilling fluid returns.
- R02 – Ensure that adequate/suitable safeguards are provided for the RCD design related to the operation of the RCD bearings and the RCD latching system (covering hydraulics and other utilities), to alert operations personnel to a potential problem that requires intervention.
- R03 – Due to the nature of MPD systems (a closed-loop, circulating system), the HAZID team felt that a HAZOP of the MPD system would be of benefit to assist with identifying and assessing the full potential range of causes which would result in consequences of concern.
- R04 – Ensure that the addition of MPD facilities to the drilling platform includes the following considerations for extended coverage of existing platform's safety critical elements: 1. Hazardous Area Classification coverage; 2. Fire and gas (HC and H2S) gas detection; 3. Fire protection (both active and passive).
- R05 – Review and document whether the MPD back-pressure pump should be supported on the platform's emergency power supply, to enable downhole pressure management in the event of a main power failure where the HP mud pumps will stop.
- R06 – Consider requiring all suppliers of equipment for modified riser joints and MPD equipment used in the US OCS to undertake a FMECA on their equipment.

Table 18. Hazards and Effects Register – H-01.02.A

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-01.02.A	**Revision**	01
1. Hazard Group	H-01		**2. Hazard**	Well fluids (which include HC liquid, HC gas, possible H_2S/CO_2 and water	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Loss of integrity – Well casing	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 3 Barriers for every Threat, 3 RPMs for every Consequence				
7. Risk Assessment					

P	A	E	R	Overall Risk Range
5C	5C	5C	5C	High

8. Threats and Barriers	
Number of Threats	**Barriers**
1. Poor cementing job (due to poor design / workmanship / materials)	(i) Use of MPD reduces the number of casings required to drill a well, with less potential for a poor casing job (ii) Well program reviewed and approved by regulatory body (DWOP and CDWOP) (iii) Design of well casing and cement to withstand maximum anticipated possible formation pressure (iv) Monitoring quality of lead and tail samples of cementing (Operator may require CBL) (v) Leak – off test to ensure integrity of casing shoe (min. expected check would be a FIT)
2. Unforeseen formation conditions	(i) Seismic and offset well data review for drilling program (ii) Well program reviewed and approved by regulatory body (DWOP and CDWOP) (iii) Monitoring quality of lead and tail samples of cementing (Operator may require CBL)

9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Well blowout with potential for unignited release (HC and possible H_2S/CO_2) – impact on personnel	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Medical Facilities and Medic/Trained First Aiders on board (vi) Relief well possible
2. Well blowout with possible oil spill to marine environment	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Oil response by Operator and local authorities (vi) Relief well possible

3. Well blowout with possible ignited release – with fire and explosion, asset damage, fatalities / injuries	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Control of ignition sources (Hazardous Area Classification) (iii) Fire and gas (HC and H_2S) detection system (iv) Firefighting system (v) Emergency disconnection and movement to safe location using DP (vi) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (vii) Medical Facilities and Medic/Trained First Aiders on board (viii) Relief well possible
10. Recommendations	
• R07 – If not already a mandatory requirement, the GOM regulators should consider requiring all Operators to undertake a CBL, or equivalent, to confirm quality of cementing jobs for all wells. – to be confirmed	

Table 19. Hazards and Effects Register – H-01.02.B

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-01.02.B	**Revision**	01
1. Hazard Group	H-01		**2. Hazard**	Well fluids (which include HC liquid, HC gas, possible H_2S/CO_2 and water	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Loss of integrity – Well casing	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 3 Barriers for every Threat, 3 RPMs for every Consequence				
7. Risk Assessment					

P	A	E	R	Overall Risk Range
5B	**5B**	**5B**	**5B**	**Medium**

8. Threats and Barriers	
Number of Threats	**Barriers**
1. Poor cementing job (due to poor design / workmanship / materials)	(i) Use of MPD reduces the number of casings required to drill a well, with less potential for a poor casing job (ii) Well program reviewed and approved by regulatory body (DWOP and CDWOP) (iii) Design of well casing and cement to withstand maximum anticipated possible formation pressure (iv) Monitoring quality of lead and tail samples of cementing (Operator may require CBL) (v) Leak – off test to ensure integrity of casing shoe (min. expected check would be a FIT)

2. Unforeseen formation conditions	(i) Seismic and offset well data review for drilling program (ii) Well program reviewed and approved by regulatory body (DWOP and CDWOP) (iii) Monitoring quality of lead and tail samples of cementing (Operator may require CBL)
9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Flow of well fluid leading to marine pollution, scouring and high flow of well fluid, impact on platform buoyancy	(i) Low likelihood that a deepwater gas release would cause sufficient loss of buoyancy (ii) Ability to adjust ballast condition of platform when loss of containment known (using subsea CCTV) (iii) Options to install plug, perforate and squeeze cement if extent of leakage allows for continued operation (iv) Emergency disconnection and movement to safe location using DP (v) Company and Operator ERP with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (vi) Oil spill response by Operator and local authorities (vii) Relief well possible
10. Recommendations	

Table 20. Hazards and Effects Register – H-02.01.A

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-02.01.A	**Revision**	01
1. Hazard Group	H-05		**2. Hazard**	High Pressure	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Sudden Release of High Pressure (during MPD operation)	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barriers for every Threat, 2 RPMs for every Consequence				
7. Risk Assessment					
P	**A**	**E**	**R**	**Overall Risk Range**	
0C	**3C**	**2C**	**3C**	**Medium**	
8. Threats and Barriers					
Number of Threats			**Barriers**		
1. Blocked flow (manual valve closed or fault with MPD pressure management system)			(i) Procedures to prevent inadvertent closure of valves (ii) Suitable inspection and maintenance program of MPD pressure management system - with standby choke, and manual operation possible (iii) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (iv) PRV on MPD around the choke valves (v) Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)		
2. Inadequate design of modified riser joint and MPD for maximum drilling fluid flow			(i) Adequately designed modified riser joint and MPD for maximum drilling flow (ii) MPD pressure and flow indication		

3. Blockage of MPD piping due to build-up of solids (e.g., cuttings)	(i) Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions (ii) Suitable inspection and maintenance program of MPD pressure management system (iii) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (iv) PRV on MPD around the choke valves (v) MPD pressure and flow indication
4. Failure of HP piping, fittings, couplings, hoses	(i) Suitable pressure rated equipment in use (with test certificates for hoses) - with QA/QC during fabrication/construction (ii) Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions (iii) Suitable inspection program for MPD piping systems and modified riser joint (iv) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (v) PRV on MPD around the choke valves
9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Potential for higher bottom hole pressure, causing potential ballooning, requiring abandonment of well	(i) Emergency Response Plan (ii) Training drills for Emergency Response Team
10. Recommendations	

Table 21. Hazards and Effects Register – H-02.01.B

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-02.01.B	**Revision**	01
1. Hazard Group	H-05		**2. Hazard**	High Pressure	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Sudden Release of High Pressure (during MPD operation)	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barriers for every Threat, 2 RPMs for every Consequence				
7. Risk Assessment					
P	**A**	**E**	**R**	**Overall Risk Range**	
4B	**4B**	**3B**	**4B**	**Medium**	
8. Threats and Barriers					
Number of Threats			**Barriers**		
1. Blocked flow (manual valve closed or fault with MPD pressure management system)			(i) Procedures to prevent inadvertent closure of valves (ii) Suitable inspection and maintenance program of MPD pressure management system - with standby choke, and manual operation possible (iii) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (iv) PRV on MPD around the choke valves (v) Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)		
2. Inadequate design of modified riser joint and MPD for maximum drilling fluid flow			(i) Adequately designed modified riser joint and MPD for maximum drilling flow (ii) MPD pressure and flow indication		

3. Blockage of MPD piping due to build-up of solids (e.g., cuttings)	(i) Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions (ii) Suitable inspection and maintenance program of MPD pressure management system (iii) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (iv) PRV on MPD around the choke valves (v) MPD pressure and flow indication
4. Failure of HP piping, fittings, couplings, hoses	(i) Suitable pressure rated equipment in use (with test certificates for hoses) - with QA/QC during fabrication/construction (ii) Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions (iii) Suitable inspection program for MPD piping systems and modified riser joint (iv) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (v) PRV on MPD around the choke valves
9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Potential for personnel struck by high pressure drilling fluid or projectile (piping / hoses / couplings / fittings)	(i) Medical Facilities and Medic /Trained First Aiders on board (ii) First Aid Kit
10. Recommendations	
• R08 - Suitable management control and/or overpressure protection needs to be provided on the low-pressure systems of the MPD System downstream of the choke valves. (Note – this may involve adequate design pressure for all systems on the downstream side of the MPD choke valves to the downstream side of the last isolation valve in each system.) • R09 – Ensure that suitable spill containment is provided for any MPD equipment that is not located on a deck area with its own drain system – where practical.	

Table 22. Hazards and Effects Register – H-02.01.C

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-02.01.C	**Revision**	01
1. Hazard Group	H-05		**2. Hazard**	High Pressure	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Sudden Release of High Pressure (during MPD operation)	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barriers for every Threat, 2 RPMs for every Consequence				
7. Risk Assessment					

P	A	E	R	Overall Risk Range
5B	**5B**	**5B**	**5B**	**Medium**

8. Threats and Barriers	
Number of Threats	**Barriers**
1. Blocked flow (manual valve closed or fault with MPD pressure management system)	(i) Procedures to prevent inadvertent closure of valves (ii) Suitable inspection and maintenance program of MPD pressure management system - with standby choke, and manual operation possible (iii) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (iv) PRV on MPD around the choke valves (v) Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)
2. Inadequate design of modified riser joint and MPD for maximum drilling fluid flow	(i) Adequately designed modified riser joint and MPD for maximum drilling flow (ii) MPD pressure and flow indication

3. Blockage of MPD piping due to build-up of solids (e.g., cuttings)	(i) Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions (ii) Suitable inspection and maintenance program of MPD pressure management system (iii) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (iv) PRV on MPD around the choke valves (v) MPD pressure and flow indication
4. Failure of HP piping, fittings, couplings, hoses	(i) Suitable pressure rated equipment in use (with test certificates for hoses) - with QA/QC during fabrication/construction (ii) Suitable material of selection of construction of all modified riser joint and MPD equipment for expected environmental conditions (iii) Suitable inspection program for MPD piping systems and modified riser joint (iv) Close monitoring of pressure indication of BHP and pressure indication on MPD system upstream of choke valves – with high pressure alarms configured (v) PRV on MPD around the choke valves

9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Well blowout with potential for unignited release (HC and possible H_2S/CO_2) – impact on personnel	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Medical Facilities and Medic/Trained First Aiders on board (vi) Relief well possible
2. Well blowout with possible oil spill to marine environment	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Oil response by Operator and local authorities (vi) Relief well possible

3. Well blowout with possible ignited release – with fire and explosion, asset damage, fatalities / injuries	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Control of ignition sources (Hazardous Area Classification) (iii) Fire and gas (HC and H_2S) detection system (iv) Firefighting system (v) Emergency disconnection and movement to safe location using DP (vi) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (vii) Medical Facilities and Medic/Trained First Aiders on board (viii) Relief well possible
10. Recommendations	

Table 23. Hazards and Effects Register – H-02.02.A

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-02.02.A	**Revision**	01
1. Hazard Group	H-05		**2. Hazard**	High Pressure	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Fracture of formation	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 1 Barrier for every Threat, 1 RPM for every Consequence				
7. Risk Assessment					

P	A	E	R	Overall Risk Range
0B	3B	2B	3B	Low

8. Threats and Barriers

Number of Threats	Barriers
1. Control fault with MPD pressure management system causing high BHP	(i) Preventive maintenance program for MPD pressure management system (ii) Suitable high pressure alarm to alert MPD Operator to potential high BHP (iii) Pressure relief valve on MPD around the choke valves
2. Poor survey of formation or unknown / unexpected formation conditions	(i) Competency of 3rd party contractor used for formation survey
3. MPD Operator error	(i) Suitable high pressure alarm to alert MPD Operator to potential high BHP (ii) Pressure relief valve on MPD around the choke valves
4. Running in hole (RIH) at too high a rate	(i) Suitable high pressure alarm to alert MPD Operator to potential high BHP (ii) Pressure relief valve on MPD around the choke valves

9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Potential for higher bottom hole pressure, causing potential ballooning, requiring abandonment of well	(i) Emergency Response Plan (ii) Training drills for Emergency Response Team
10. Recommendations	
• R10 – Ensure adequate redundancy is provided for MPD pressure management system, and includes suitable control diagnostics to alert the driller to potential fault conditions. Control equipment for pressure management system should consider the need for fail safe action.	

Table 24. Hazards and Effects Register – H-02.02.B

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-02.02.B	**Revision**	01
1. Hazard Group	H-05		**2. Hazard**	High Pressure	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Fracture of formation	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barrier for every Threat, 2 RPM for every Consequence				
7. Risk Assessment					

P	A	E	R	Overall Risk Range
5B	**5B**	**5B**	**5B**	**Medium**

8. Threats and Barriers	
Number of Threats	**Barriers**
1. Control fault with MPD pressure management system causing high BHP	(i) Preventive maintenance program for MPD pressure management system (ii) Suitable high pressure alarm to alert MPD Operator to potential high BHP (iii) Pressure relief valve on MPD around the choke valves
2. Poor survey of formation or unknown / unexpected formation conditions	(i) Competency of 3rd party contractor used for formation survey (ii) Suitable high pressure alarm to alert MPD Operator to potential high BHP
3. MPD Operator error	(i) Suitable high pressure alarm to alert MPD Operator to potential high BHP (ii) Pressure relief valve on MPD around the choke valves
4. Running in hole (RIH) at too high a rate	(i) Suitable high pressure alarm to alert MPD Operator to potential high BHP (ii) Pressure relief valve on MPD around the choke valves
9. Consequence and Preparedness Measures	

Number of Consequences	Recovery Preparedness Measures
1. Well blowout with potential for unignited release (HC and possible H2S/CO2) – impact on personnel	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Medical Facilities and Medic/Trained First Aiders on board (vi) Relief well possible
2. Well blowout with possible oil spill to marine environment	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Oil response by Operator and local authorities (vi) Relief well possible

3. Well blowout with possible ignited release – with fire and explosion, asset damage, fatalities / injuries	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Control of ignition sources (Hazardous Area Classification) (iii) Fire and gas (HC and H_2S) detection system (iv) Firefighting system (v) Emergency disconnection and movement to safe location using DP (vi) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (vii) Medical Facilities and Medic/Trained First Aiders on board (viii) Relief well possible
10. Recommendations	

Table 25. Hazards and Effects Register – H-03.01

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-03.01	**Revision**	01
1. Hazard Group	H-25		**2. Hazard**	Restricted Access / Egress	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Exposure to restricted access / egress	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barrier for every Threat, 2 RPM for every Consequence				
7. Risk Assessment					
P	**A**	**E**	**R**	**Overall Risk Range**	
4C	**3C**	**2C**	**4C**	**Medium**	
8. Threats and Barriers					
Number of Threats			**Barriers**		
1. Inadequate provision for access egress due to space constraints or poor design			(i) Adequate design as per applicable codes and standards (MODU) - with respect to egress, reviewed and approved by Class society (ii) Escape, evacuation and rescue analyses for platform updated by Owner / Operator when designing MPD equipment layout		
9. Consequence and Preparedness Measures					
Number of Consequences			**Recovery Preparedness Measures**		
1. Delay or inability of personnel at the MPD equipment to respond to an emergency scenario, with increased risk to personnel			(i) Emergency Response Plan (ERP) (ii) Training Drills for Emergency Response would identify design issues due to restricted egress		
2. Potential for difficulty in routine access to equipment for operations or maintenance			(i) Operations / Maintenance review / approval of MPD equipment layout during design (ii) Standard Operating Procedures		

3. Poor ability to respond to an emergency at the MPD equipment (such as removal of an injured person, firefighting, etc.)	(i) Emergency Response Plan (ERP) (ii) Training Drills for Emergency Response would identify design issues due to restricted egress

10. Recommendations

- R04 (Existing) – Ensure that the addition of MPD facilities to the drilling platform includes the following considerations for extended coverage of existing platform's safety critical elements: 1. Hazardous Area Classification coverage; 2. Fire and gas (HC and H_2S) gas detection; 3. Fire protection (both active and passive).
- R11 – Location of MPD equipment needs to consider the potential for damage due to dropped/swinging loads, and consider ease of access for routine maintenance/operations activities, as well as adequate provision of emergency egress.

Table 26. Hazards and Effects Register – H-04.01

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-04.01	**Revision**	01
1. Hazard Group	H-06		**2. Hazard**	Differences in height (lifting operations)	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Dropped load / swinging object	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 3 Barrier for every Threat, 3 RPM for every Consequence				
7. Risk Assessment					
P	**A**	**E**	**R**	**Overall Risk Range**	
5C	**5C**	**5C**	**5C**	**High**	
8. Threats and Barriers					
Number of Threats			**Barriers**		
1. Operator error			(i) Training and certification of personnel involved with lifting (ii) Supervision of lifting activities (iii) Use of PTW, when required, with JSA undertaken		
2. Poor Communication			(i) Training and certification of personnel involved with lifting (ii) Supervision of lifting activities (iii) Use of PTW, when required, with JSA undertaken		
3. Equipment failure (such as: hoists; cables; crane structures; hooks)			(i) Maintenance and inspection of all lifting equipment and lifting gear (ii) 3rd party certification of all lifting equipment and lifting gear		
4. Adverse environmental conditions			(i) Lifting procedures – restricted lifting in defined conditions (ii) Supervision of lifting activities (iii) Use of PTW, when required, with JSA undertaken		

9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. MPD/RCD damage, leading to well blowout and possible unignited release	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Medical Facilities and Medic/Trained First Aiders on board (vi) Relief well possible
2. MPD/RCD damage, leading to well blowout and possible oil spill to marine environment	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Fire and gas (HC and H_2S) detection system (iii) Emergency disconnection and movement to safe location using DP (iv) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (v) Oil response by Operator and local authorities (vi) Relief well possible

3. MPD/RCD damage, leading to well blowout and ignited release	(i) Procedures and well control equipment for circulating out a kick, killing well and shearing (ii) Control of ignition sources (Hazardous Area Classification) (iii) Fire and gas (HC and H_2S) detection system (iv) Firefighting system (v) Emergency disconnection and movement to safe location using DP (vi) Company and Operator ERP, with Emergency and LSA facilities, Blowout Contingency Plan, and regular training drills (vii) Medical Facilities and Medic/Trained First Aiders on board (viii) Relief well possible
10. Recommendations	
• R11 (Existing) – Location of MPD equipment needs to consider the potential for damage due to dropped/swinging loads, and also consider ease of access for routine maintenance/operations activities, as well as adequate provision of emergency egress.	

Table 27. Hazards and Effects Register – H-05.01

Hazards and Effects Register					
Date of Issue	10/09/15	**Hazard Number**	H-05.01	**Revision**	01
1. Hazard Group	H-03		**2. Hazard**	Oil-based mud	
3. Activity Generating Hazard	Managed Pressure Drilling		**4. Top Event**	Loss of containment of OBM (from modified riser joint / MPD system)	
5. Location	Gulf of Mexico				
6. Acceptance Criteria	Minimum 2 Barrier for every Threat, 2 RPM for every Consequence				
7. Risk Assessment					
P	**A**	**E**	**R**	**Overall Risk Range**	
3C	**1C**	**3C**	**3C**	**Medium**	
8. Threats and Barriers					
Number of Threats			**Barriers**		
1. Mechanical failure of piping/fittings/hoses/couplings due to poor workmanship / materials			(i) Suitable material of construction for service (ii) Design in accordance with applicable codes and standards with QA/QC during fabrication (iii) Suitable inspection program for MPD piping systems (including hoses, couplings and fittings)		

2. Mechanical failure of piping/fittings/hoses/couplings due to poor erosion / corrosion	(i) Suitable material of construction for service (ii) Design in accordance with applicable codes and standards with QA/QC during fabrication (iii) Suitable inspection and maintenance program for RCD bearings and seals (iv) Hydrostatic testing of HP systems after any maintenance (typical industry practice) (v) Suitable inspection program for MPD piping systems (including hoses, couplings and fittings (vi) Monitoring of mud properties by mud engineer
3. Mechanical failure of piping/fittings/hoses/couplings due to fatigue	(i) Hydrostatic testing of HP systems after any maintenance (typical industry practice) (ii) Inspection program for MPD systems (including hoses, couplings and fittings) and riser top joint equipment
4. Mechanical failure of piping/fittings/hoses/couplings due to wear and tear	(i) Hydrostatic testing of HP systems after any maintenance (typical industry practice) (ii) Inspection program for MPD systems (including hoses, couplings and fittings) and riser top joint equipment
5. Mechanical failure of piping/fittings/hoses/couplings due poor work practices / housekeeping	(i) Design in accordance with applicable codes and standards with QA/QC during fabrication (ii) Suitable inspection program for MPD piping systems (including hoses, couplings and fittings) (iii) Hydrostatic testing of HP systems after any maintenance (typical industry practice) (iv) Pre-job safety meetings, with JSA

9. Consequence and Preparedness Measures	
Number of Consequences	**Recovery Preparedness Measures**
1. Potential for spill to marine environment	(i) Spill kits available (ii) Routine Operator inspection of equipment, and prompt clean-up of any spillage (iii) Oil spill response by Operator and local authorities
2. Possible health/safety impact on personnel due to contact with OBM (depending on type of base oil used)	(i) Routine Operator inspection of equipment, and prompt clean-up of any spillage (ii) Appropriate PPE for work being undertaken (iii) Safety showers and eyewash stations (iv) Medical response (sick bay/hospital/MEDEVAC if required)
3. Limited potential for fire due to high flash point of OBM (however may contain entrained HC/H2S gas)	(i) Routine Operator inspection of equipment, and prompt clean-up of any spillage (ii) Appropriate PPE for work being undertaken (iii) Medical response (sick bay/hospital/MEDEVAC if required)
10. Recommendations	
• R01 (Existing) – Ensure that the material of construction for modified riser joint and MPD systems (including piping, fittings, hoses, couplings, chokes and bends) includes consideration for high erosion potential caused by cuttings in drilling fluid returns. • R12 – Ensure that secondary containment is provided for the MPD equipment which is directly above the water and not contained within other areas with drain system. (This may require provision of sump and pump to return any spillage to central spill collection (such as skimmer tank.)	

3.7 Conclusion

MPD is a drilling method that allows for greater control of pressure in the wellbore with the use of additional equipment. MPD technology typically applies in reservoirs that are difficult to drill conventionally (un-drillable), deep water and HPHT wells to access hydrocarbon reserves, enhance operational safety and efficiency in place of conventional drilling.

The HAZID study led to the identification of hazards and consequences associated with MPD. The MPD system has introduced several new threats and has acted as a barrier for some threats. Recommendations were made in order to further improve preexisting barriers and RPMs.

One of the recommendations from HAZID (R03) suggests conducting a HAZOP of the MPD system. This is to assist with identifying and assessing the full potential range of causes, which would result in consequences of concern. The HAZOP has identified the causes for deviation together with its safeguards. Further recommendations were made to address issues captured in the HAZOP study.

To manage the hazard fully requires that all threats are suitably and sufficiently controlled (barriers) and that suitable and sufficient measures are in place for all consequences possible and foreseeable (Recovery Preparedness Measures). The bowties were developed to ensure that suitable measures are in place for all hazards and consequences identified and to allow visual verification of this fact.

Following section provides detail on the barrier analysis of the MPD system.

4. Barrier Function and Barrier Critical Systems

4.1 Barrier Function Description in Relation to Major Accident Hazard

The major accident hazard of concern in this scenario is a blowout occurring while drilling. The barrier function selected based on relevance for this scenario and input from the risk assessment is to **"Prevent an influx by monitoring and precise dynamic control of the annular pressure profile/bottomhole pressure (BHP)".** The goal of this barrier function is to lower the risk of a blowout occurring.

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

For the barrier function "Prevent an influx by monitoring and precise dynamic control of the annular pressure profile/bottomhole pressure (BHP)", the following barrier critical systems have been identified:

1. Mud Circulation System – The mud is considered the primary well barrier by providing hydrostatic pressure to prevent formation fluids from entering into the well bore. The mud circulation system and related equipment help in establishing the hydrostatic pressure for primary well control.
2. Marine Drilling Riser System – It connects the subsea BOP to the drilling vessel and is a continuation of the wellbore from the seabed to the surface. The integrity of the Marine Drilling Riser System is crucial to ensure that no other flow paths are created other than the existing one. The Riser is part of the closed flow path. The modified riser joint that enables MPD operation also consists of the other riser joints on the riser system.
3. Managed Pressure Drilling System – Creates a closed flow path for the drilling system and introduces additional equipment to better control the pressure within the wellbore.
4. Wellhead – The wellhead needs to be intact, to ensure that the flow path is contained and thus a closed system.
5. Casing and Cementing – The integrity of the casing and cementing is crucial to zonal isolation to prevent the creation of more than the existing flow path. It provides stability and structural support for the well. It allows for deeper drilling when the wellbore pressure surpasses the drilling window.

5. Selected Barrier Critical System - Managed Pressure Drilling

5.1 System Description and Basis of Design

The Managed Pressure Drilling System is chosen as the Barrier Critical System to be assessed for this example. The operation in question for the described scenario is a drilling operation, and the MPD System is considered a key component to achieve the Barrier Function of "Prevent an influx by monitoring and precise dynamic control of the annular pressure profile/bottomhole pressure (BHP)".

The MPD System is used in conjunction with conventional drilling equipment. The System creates a closed circulation system, as opposed to the open system of conventional drilling, with the help of additional equipment items, primarily the Rotating Control Device (RCD). The RCD is a device fitted in the annular space of the drill string above the annular BOP. It isolates the column of drilling fluid from the atmosphere. As mud is pumped down the drill pipe, it returns up the annular space to the RCD. From the RCD the drilling fluid returns to the surface through choke lines, as opposed to conventional drilling where it returns to the surface via the riser, which is open to the atmosphere. By closing the system off from the atmosphere, choke valves can control the pressure and choke lines can return it to the surface.

This process proves beneficial for keeping control of the overall narrow drilling margin experienced in deepwater drilling operations and easier to handle the seawater overburden. It also introduces new equipment for maintenance and requires high degree of reliability. Figure 22 presents the MPD system configuration selected for the barrier model, which originates from a generic example of the Constant Bottom Hole Pressure variant of a MPD System, and not an actual design.

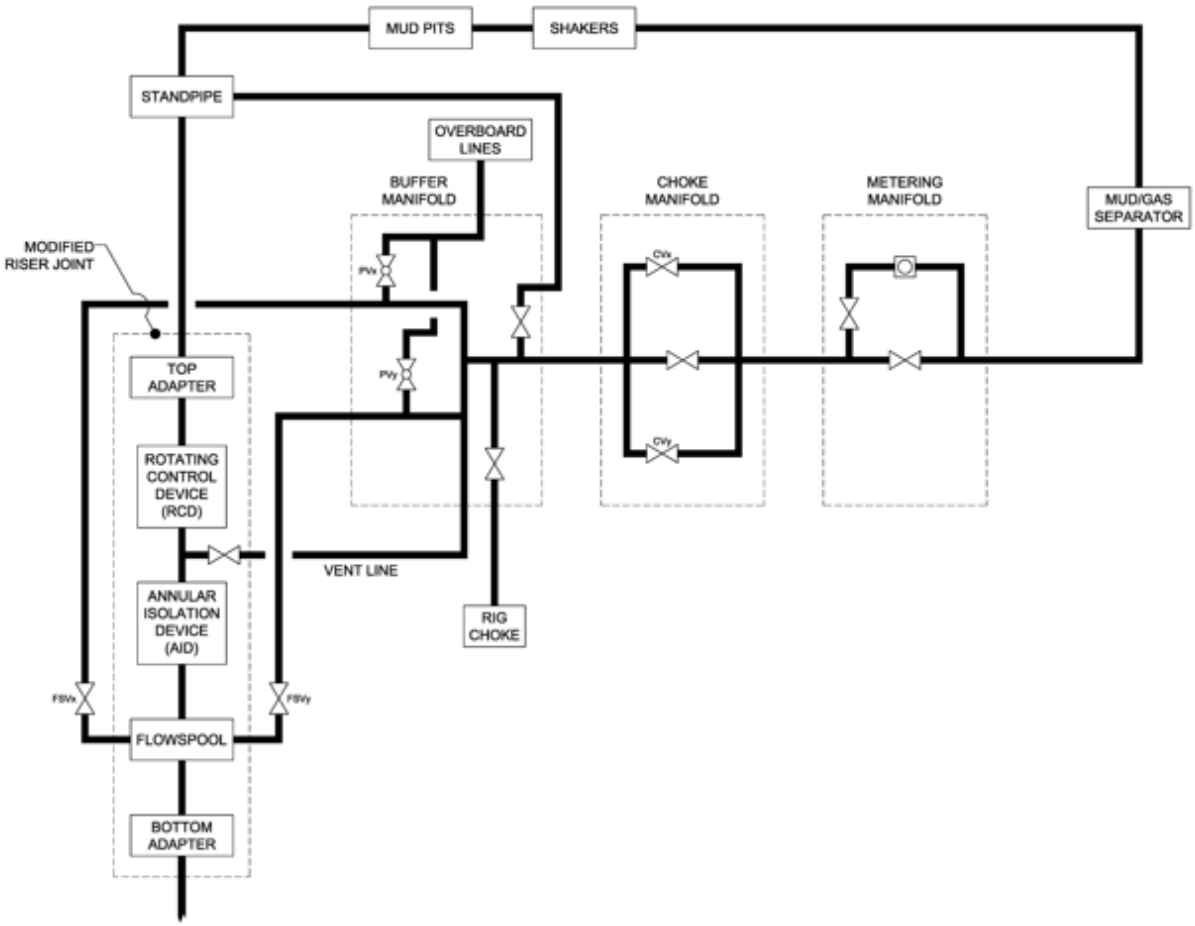

Figure 21. Example MPD System Configuration for CBHP Operations

The following barrier elements are identified as being critical for the barrier critical system to perform its intended function:

Barrier Element	Function
Rotating Control Device (RCD)	Seals the annular space between the drill string and the Riser at the modified riser joint. The trip tank is monitored for detecting a leak at the RCD.
Modified Riser Joint Control System	Allows for the latching/unlatching of the RCD and provides information about/controls the flowspool valves.
Flowspool Valve (FSV)	Redirects flow from the annulus to the Buffer Manifold (BM).
Flowspool Hose	Contains the flow between the FSVs and the BM.
Buffer Manifold Valves	Open and close to direct flow to desired flow path
MPD Control System	Provides activation signals and indicates position of valves to allow for control MPD of operations, monitors calibration of inflow/outflow measurements, provides data to detect/indication of kick/loss, and allows action to be taken in case of kick/loss.
MPD Control System Power Supply	Supplies electric/hydraulic power.

Wellbore Hydraulics Model	Receives point within wellbore where CBHP has to be maintained from the MPD control system, receives data for model calibration/update, and estimates required surface backpressure to meet desired dynamic pressure at specified point.
MPD Chokes	Open/close to control the wellbore pressure/regulate flow.
Surface Backpressure Sensor(s)	Detect/transmit surface backpressure and provides data to hydraulics model.
Data Acquisition System	Used to cross check hydraulics model, provide data for hydraulics model and provides information on control panel.
MPD Control System – Reserve Power	Supply and conditions electric/hydraulic power in case of power failure.
Inflow Rate Measurement	Measures inflow rates.
Flow Meter on Metering Manifold	Measures outflow rates.
Pressure Relief Valves (PRVs) (with Pressure Transducer)	Detect and transmit pressure to PRV and relieve pressure in case of MPD system overpressure.
PRV Control System	Controls PRV set point.
PRV Control System – Power	Supplies electric/hydraulic power to the PRVs.
Non-Return Valve (NRV)	Prevents the reversal of flow.

6. Barrier Model for MPD

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

6.1.1 Barrier Critical System Functions

The Barrier Critical System Functions (BCSFS) identified as necessary for the MPD system to perform the barrier function include the following:

- Provide a closed loop circulation system / annular seal around the drill pipe to allow for the application of surface backpressure (BCSF1)
- Direct return flow in the annulus to buffer manifold (BCSF2)
- Direct return flow to rig shakers, rig choke manifold, rig mud gas separator, overboard lines, or MPD choke manifold as necessary (BCSF3)
- Apply / control surface backpressure in the annulus to maintain desired downhole pressure (BCSF4)
- Early kick / loss detection (BCSF5)
- Prevent overpressure in the MPD System (BCSF6)
- Prevent reverse flow up to the surface through the drill pipe (BCSF7)

Provide a closed loop circulation system/annular seal around the drill pipe to allow for the application of surface backpressure (BCSF1).

The Rotating Control Device (RCD) makes this function possible. The RCD, a part of the Modified Riser Joint, closes off the annular space between the drill string and the riser. The modified riser joint control system is also required to latch the RCD bearing assembly into place.

Direct return flow in the annulus to buffer manifold (BCSF2).

The flowspool valves and hoses and the modified riser joint control system achieve this function. When drilling in MPD mode, the modified riser joint control system open the flowspool valves, directing the flow from the riser annular space through the flowspool hoses to the buffer manifold.

Direct return flow to rig shakers, rig choke manifold, rig mud gas separator, overboard lines, or MPD choke manifold as necessary (BCSF3).

The buffer manifold consists of several different valves and flow paths. The MPD Control System and the MPD Control System Power Supply control and power the Buffer Manifold Valves respectively. The buffer manifold allows control of the flow onto the MPD Manifold for MPD mode or elsewhere as needed for a specific operation.

Apply/control surface backpressure in the annulus to maintain desired downhole pressure (BCSF4).

Several items are required for the success of this barrier critical system function. A Wellbore Hydraulics Model is required in order to estimate the required surface backpressure for achieving the desired dynamic pressure at the specified point. The Wellbore Hydraulics model receives the point within the wellbore where the CBHP has to be maintained and receives data for model calibration / update. The MPD Choke Valves open and close to control the wellbore pressure and regulate flow. The MPD Control System controls the MPD Choke valves. Surface backpressure sensors indicate what the actual surface backpressure is and provide this information for the Hydraulics Model. The Data Acquisition System can be one of several sources (WITS, hard copy, etc.) and acts as a cross check for the hydraulics model and can be used to provide data for the hydraulics model if needed. The MPD Control System is powered by a standard power supply in addition to a reserve power supply.

Early kick/loss detection (BCSF5).

Early kick and loss detection is one of the attractive benefits of using Managed Pressure Drilling. To achieve this function inflow rate measurement is carried out at the suction side of the pump using a stroke counter / flow meter; and the flow out is measured using a flow meter on the metering manifold. The comparison of the flow in and flow out provides indication of a kick or a loss. These measuring devices require the MPD Control System as an interface. Power supply is also needed for the MPD Control System.

Prevent overpressure in the MPD System (BCSF6).

Since MPD creates a closed circulation system by integration of the RCD, the drilling system is now acting as a pressure vessel. As a result it is necessary to prevent the pressure within the system from getting so high that it causes failure of other components of the drilling system such as the riser or the wellbore itself. This is achieved through use of Pressure Relief Valves (with pressure transducer) which are mounted on the buffer manifold. The PRVs are controlled by the PRV control system directly or can be controlled through the MPD Control System. Power is also required for adjusting the PRVs but not for their activation.

Prevent reverse flow up to the surface through the drill pipe (BCSF7).

Given that MPD is a closed system, it is necessary to ensure that flow within the system is always in the intended direction. This is achieved by use of a Non-Return Valve (NRV).

6.1.2 *Assumptions*

When existing technology is tested in a new environment and in the process of being qualified and put into an operational setting, certain assumptions about its application will be made. There are several variations/configurations of MPD Systems. The contents of this section should be read in conjunction with the Barrier Model (presented in 6.2 below below).

Table 28 presents the assumptions applied for the barrier elements of the specific MPD System considered. It is to be noted that the barrier model for the MPD system is **an example** developed to illustrate how the barrier model template can be applied to a select system and **should not** be considered as representative of all configurations. Different MPD Systems may have different configurations than the one presented based on end user/Operator specification and selected manufacturer design. The barrier model has been developed by the project team from ABS Consulting and verified through a review workshop with industry SMEs and BSEE personnel.

Table 28. Managed Pressure Drilling Assumptions – Barrier Elements

Assumption	Barrier Element
It is assumed that two flowspool valves and hoses are present in the MPD System	Flowspool
Since this is a generic system and not an actual design, the manifold valves can either be electrically or hydraulically actuated.	MPD Control System Power Supply for Manifold Valve(s)
It is assumed that two MPD choke valves are present in the MPD System installed on the MPD Choke Manifold	MPD Chokes
It is assumed that there is only one flow meter on the metering manifold.	Flow Meter on Metering Manifold
It is assumed that the PRVs are installed on the buffer manifold	PRVs

6.2 Barrier Model

The following figures show the developed barrier model for Managed Pressure Drilling.

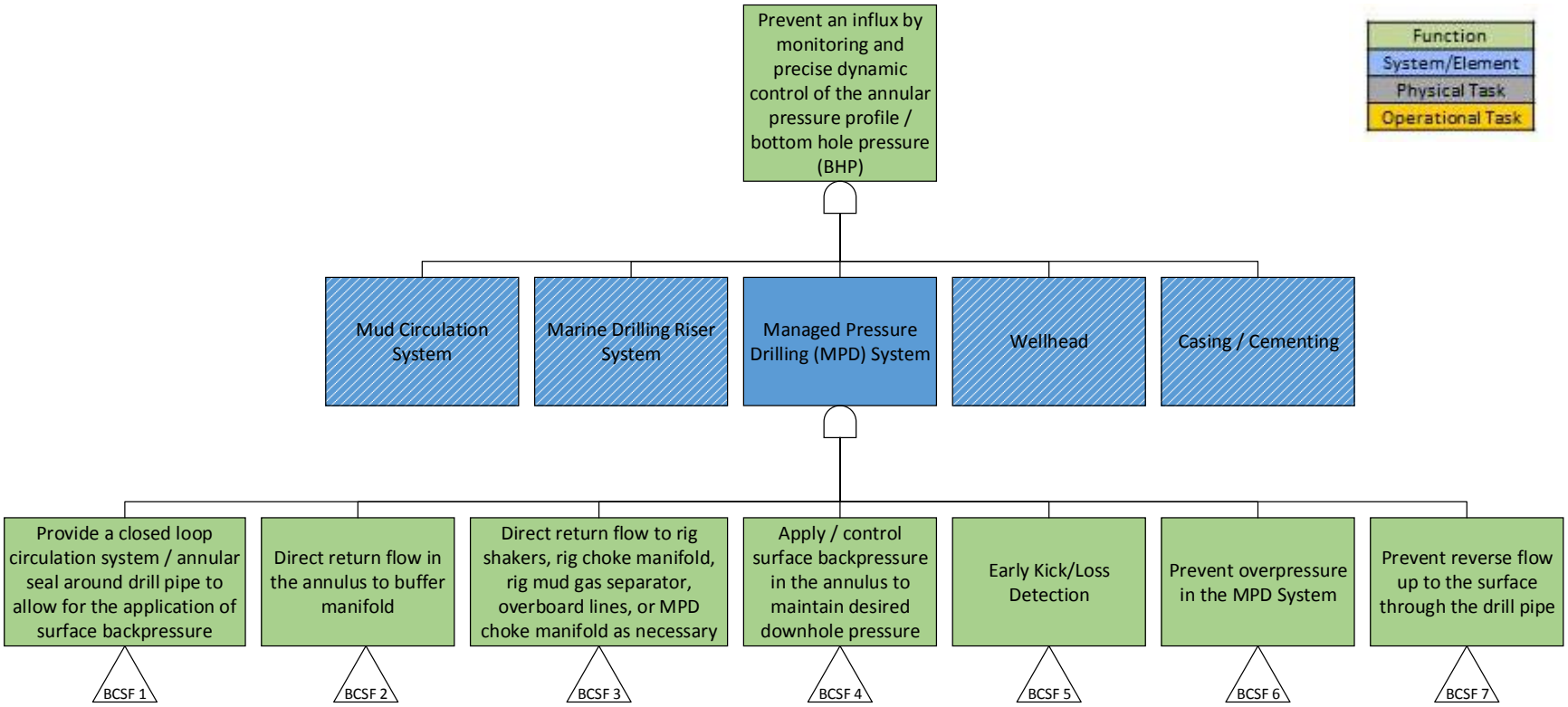

Figure 22. Barrier Function, Barrier Critical Systems and Barrier Critical System Functions

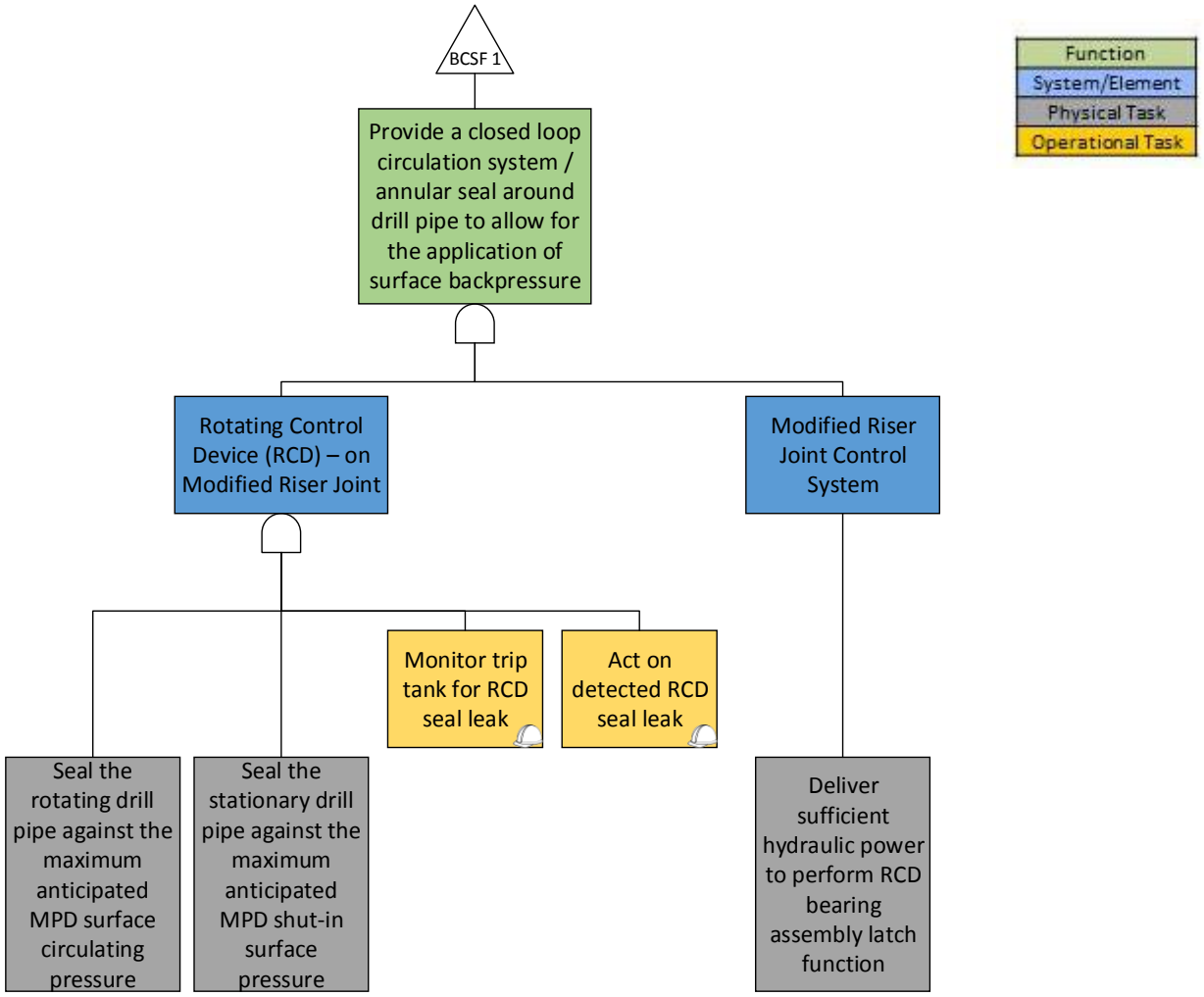

Figure 23. Barrier Critical System Function 1 – Provide a Closed Loop Circulation System/Annular Seal around Drill Pipe to Allow for the Application of Surface Backpressure

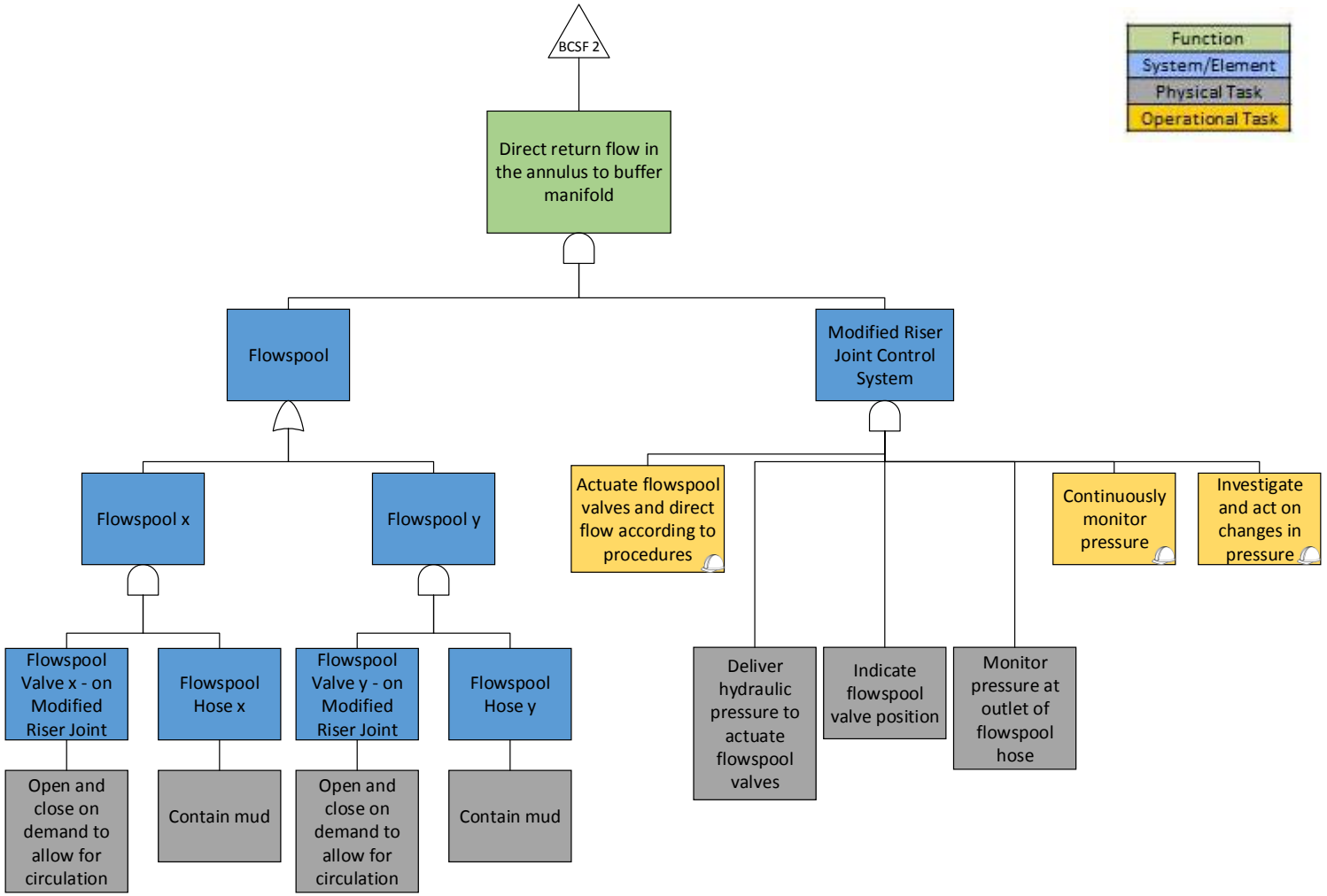

Figure 24. Barrier Critical System Function 2 – Direct Return Flow in the Annulus to the Buffer Manifold

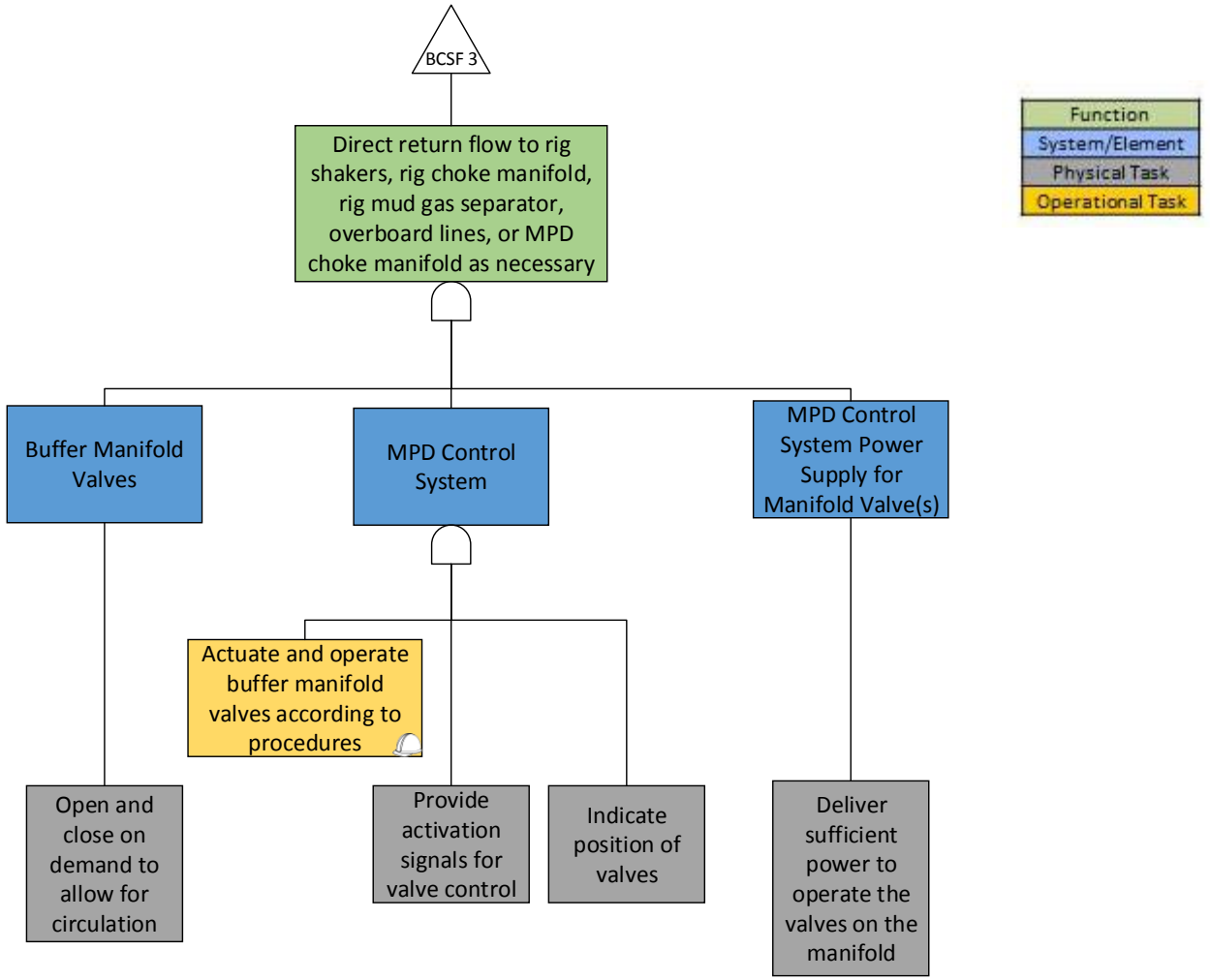

Figure 25. Barrier Critical System Function 3 – Direct Return Flow to Rig Shakers, Rig Choke Manifold, Rig Mud Gas Separator, Overboard Lines, or MPD Choke Manifold as Necessary

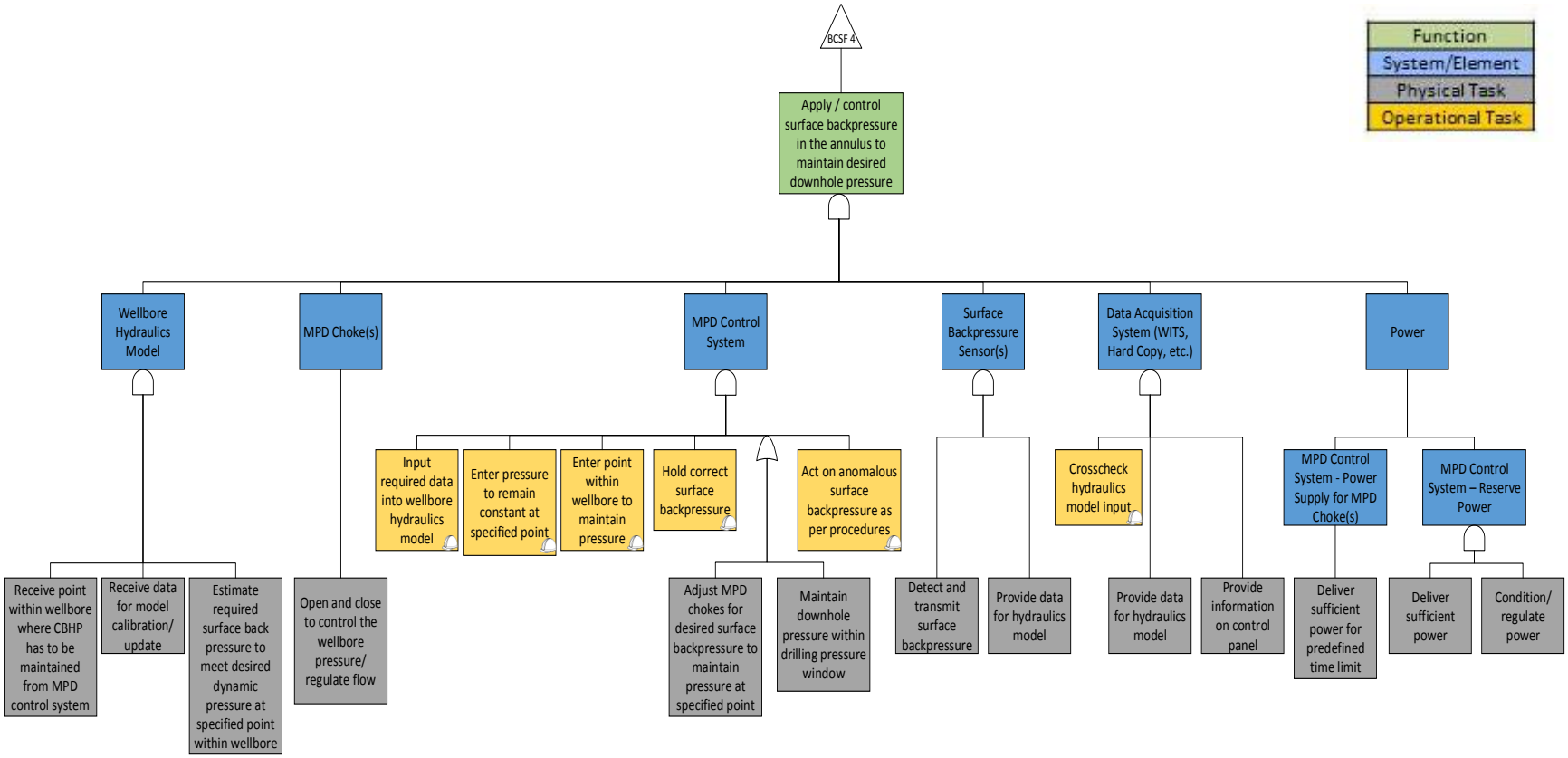

Figure 26. Barrier Critical System Function 4 – Apply / Control Surface Backpressure in the Annulus to Maintain Desired Downhole Pressure

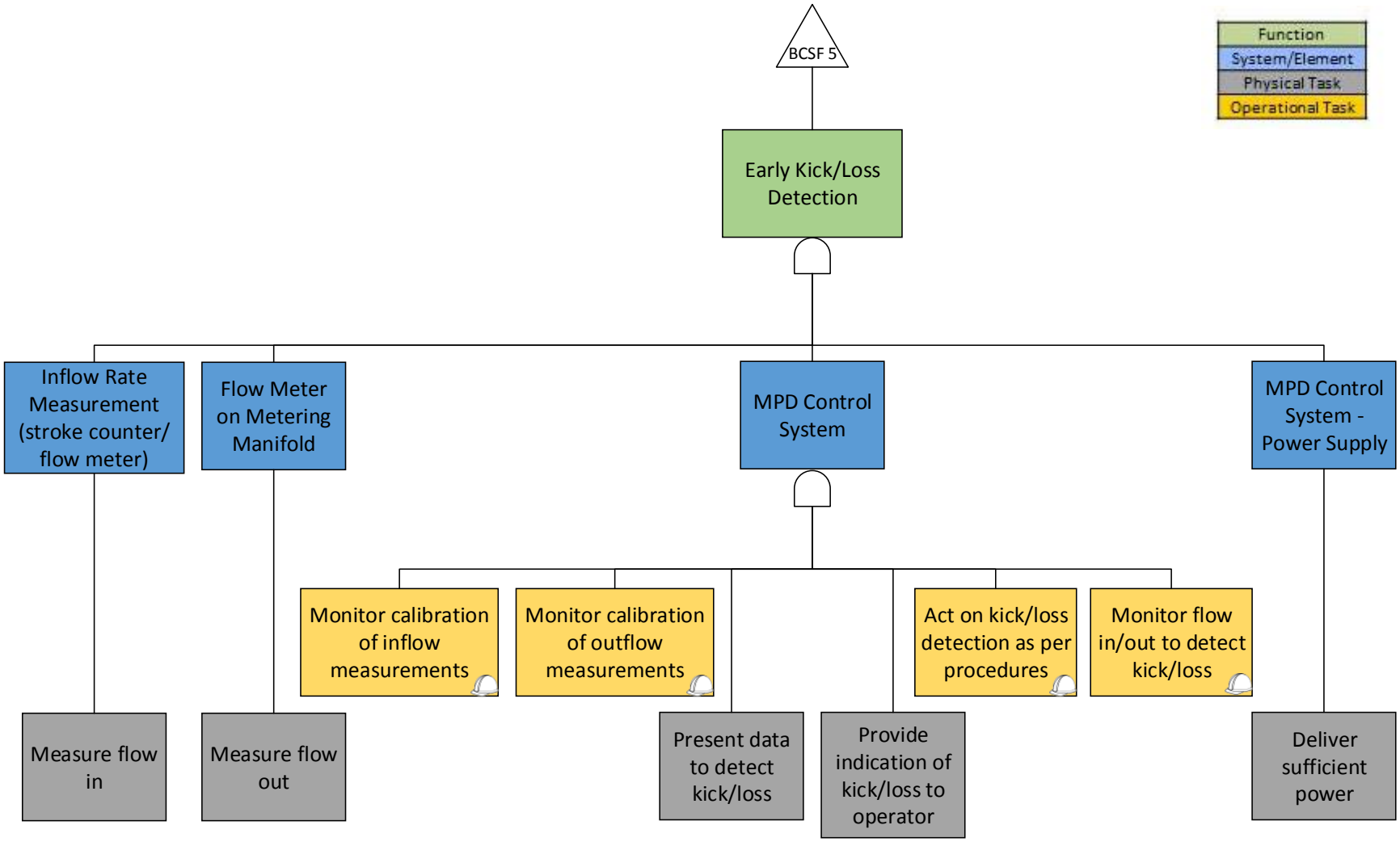

Figure 27. Barrier Critical System Function 5 – Early Kick/Loss Detection

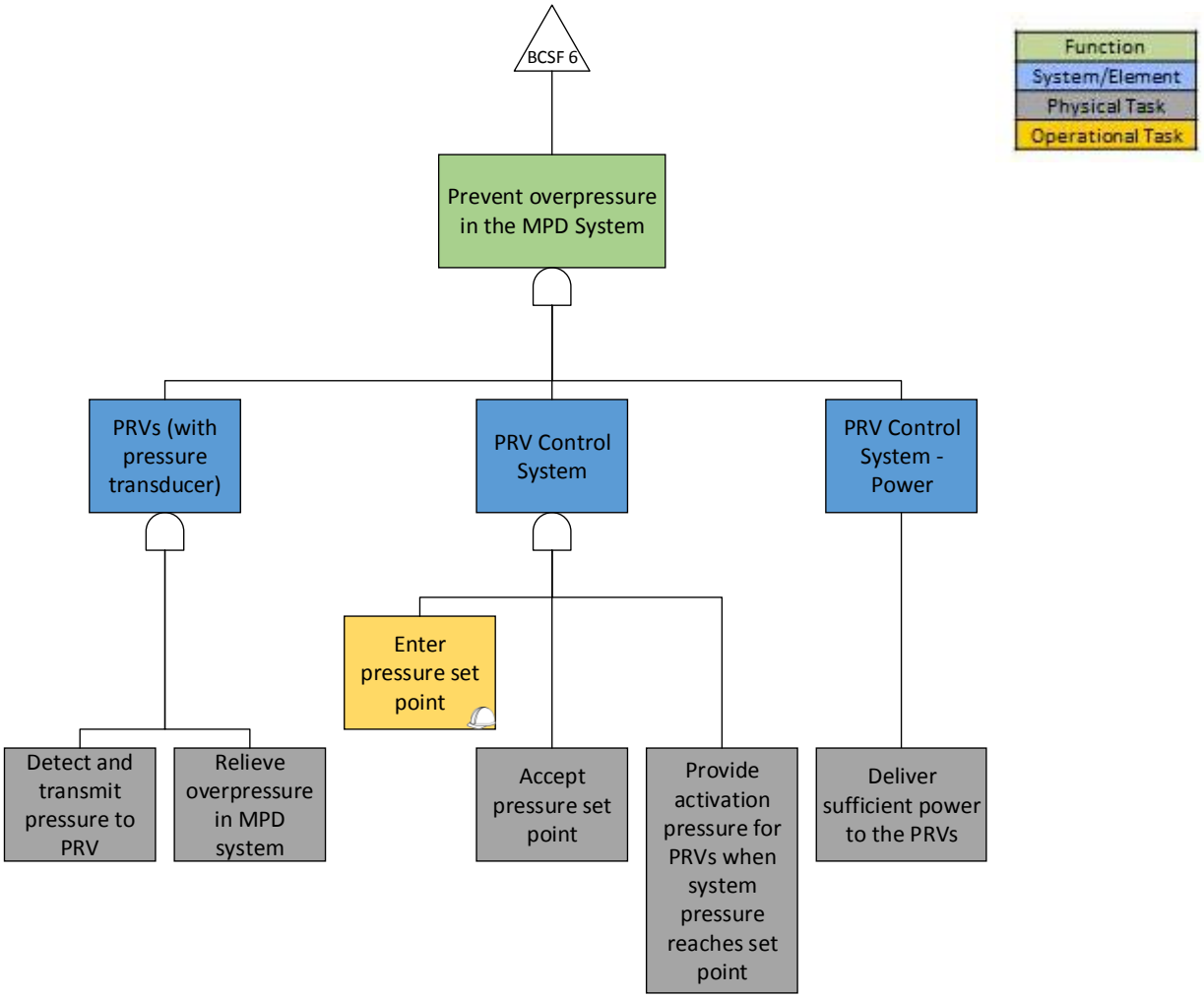

Figure 28. Barrier Critical System Function 6 – Prevent Overpressure in the MPD System

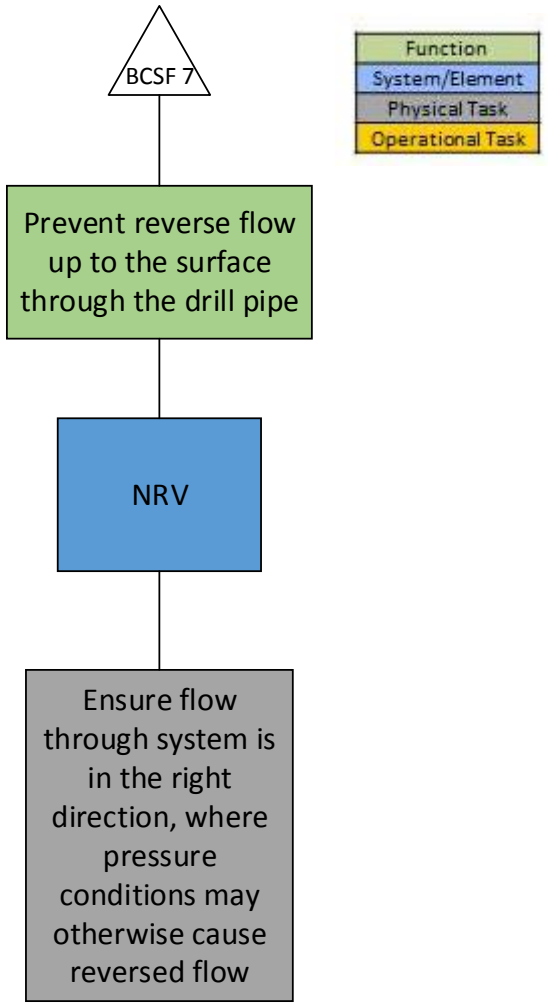

Figure 29. Barrier Critical System Function 7 – Prevent Reverse Flow Up to the Surface through the Drill Pipe

7. Barrier Element 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. Within each checklist, the attributes influencing the performance of the barrier elements are structured 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 to be assessed 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/Interdependencies
  - 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 to be complied with. 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 29 summarizes the barrier elements and the attribute checklists developed for the MPD 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.

Table 29. Barrier Element Attribute Checklist

Barrier Element	Checklist Provided (Y/N)?	Checklist (Click to open in MS Excel)
Rotating Control Device (RCD) - on Modified Riser Joint	Yes	MPD_RCD.xlsx
Modified Riser Joint Control System	Yes	MPD_Modified_Riser_Joint_Control_Syste
Flowspool Valve	Yes	MPD_Flowspool_Valves.xlsx
Flowspool Hose	Yes	MPD_Flowspool_Hoses.xlsx
Buffer Manifold Valves	No	NA
MPD Control System	Yes	MPD_MPD_Control_System.xlsx
MPD Control System Power Supply for Manifold Valves	No	NA
Wellbore Hydraulics Model	No	NA
MPD Chokes	Yes	MPD_Choke_Valves.xlsx
Surface Backpressure Sensor(s)	Yes	MPD_Surface_Pressure_Sensor.xlsx
Data Acquisition System (WITS, Hard Copy, etc.)	No	NA
MPD Control System Power Supply for MPD Chokes	No	NA
MPD Control System – Reserve Power	No	NA

Barrier Element	Checklist Provided (Y/N)?	Checklist (Click to open in MS Excel)
Inflow Rate Measurement (Stroke Counter / Flow Meter)	No	NA
Flow Meter on Metering Manifold	Yes	 MPD_Flow_Meter_on _Metering_Manifold.x
MPD Control System – Power Supply	No	NA
Pressure Relief Valves (with Pressure Transducer)	Yes	 MPD_PRV.xlsx
PRV Control System	Yes	 MPD_PRV_Control_S ystem.xlsx
PRV Control System – Power	No	NA
Non-Return Valve (NRV)	Yes	 MPD_NRV.xlsx

8. References

1. Mæland, M., and Sangesland, S., (2013). *Managed Pressure Drilling – The Solaris Prospect – HPHT Exploration Well.*
2. Rehm, B., Schubert, J., Haghshenas, A., Paknejad, A.S., and Hughes, J. (2008). *Managed Pressure Drilling.*
3. International Association of Drilling Contractors. (2015). *Health, Safety and Environment Case Guidelines for Mobile Offshore Drilling Units.*