When the Holes Align

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This paper reviews the effect of human and behavioral actions on one of the watertight Process Safety Management method in the Energy Industry, with reference to Fossil Energy (hydrocarbons). The case studies analyzed are based on breaches to the three elements of Asset Integrity Methodology of managing Process Safety, which has Integrity Leadership at its core.

From the Texas City Refinery explosion in 2005 to the Macondo well blowout in 2010, the industry has experienced various incidents that have led to loss of lives and assets, arising primarily from inadequate management of hazards and risks associated with oil and gas exploration, production and distribution. Process safety standards and regulations enacted over the years have been about keeping the hydrocarbons in containment, staying within facility operating envelopes and adequately preparing equipment for maintenance and facility restart. However, situation still occur when failures in the barriers (holes) align, creating unexpected release of hazards.

The industry uses various standards, codes and guidelines to manage potential process safety hazards from project initiation through facility operation and decommissioning. This includes the identification and generation of risk register, design of barriers and controls during project development to manage identified risks, and implementation of these barriers and controls during operation, as part of the Health, Safety & Environment (HSE) Management System. At Shell, Process Safety is managed using the Asset Integrity approach comprising of three (3) facets: Design Integrity (DI), Technical Integrity (TI) and Operating Integrity (OI) with Integrity Leadership at the core.

Three case studies, each focusing on one element of the Asset Integrity Methodology, were analyzed to determine the root causes of failure and breaches to Process Safety Management. The review outcomes show that human and behavioral actions have significant impact on process safety management. As a result, the impacts of behavioral actions should be carefully considered in design, maintenance and operation of a facility.

Key words: Process Safety, Integrity Leadership, Operating Integrity, Technical Integrity, Design Integrity, Hazard, Risks, Oil and Gas.

Introduction

Process Safety Management in the Energy Industry is about keeping the hazardous materials in the containment systems, always (keeping the tiger in the cage). It is about making sure that all physical assets are well designed, safely operated, properly maintained and securely abandoned. To achieve this over-arching objective invariably referred to as “Goal Zero” (Goal Zero = no harm to people and no leaks to the environment) in Shell, Process Safety in managed using the Asset Integrity Methodology. This includes the design and application of appropriate technical and operating standards. The principles combine design standards (design integrity) with maintenance and operating standards (technical and operating integrity), underpinned by leadership expectations (*integrity leadership*) at all levels. Hazards are identified, associated risks are evaluated and barriers are put in place to mitigate process safety events from occurring. These barriers are both hardware and human barriers, accompanied by critical business processes to manage the risks. As part of this methodology, several tools (HEMP, HAZID, HAZOP, BOWTIE, etc.) are used in identifying hazards and risks and putting mitigations in place. The overall approach is a continuous improvement in the management and robustness of hardware and human barriers.

The three main elements of the Asset Integrity Methodology are: design integrity, technical integrity and operating integrity, as shown in Figure 1.

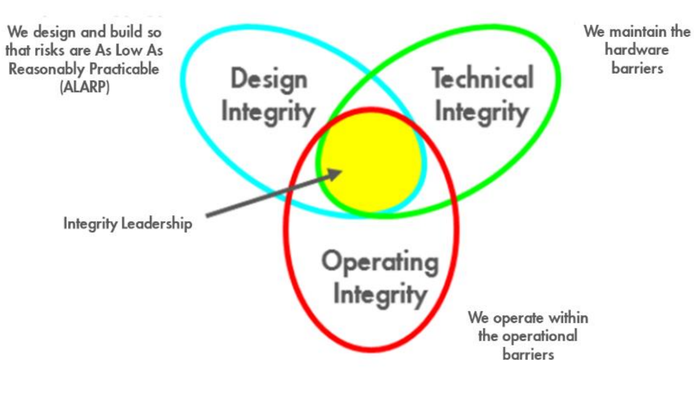

Figure 1.1: The key aspects of Asset Integrity

Design Integrity, DI

Design integrity covers all the activities necessary to establish the integrity of an asset before the first hydrocarbons are produced. Consequently, an important part of good engineering design is meeting the needs of operations and maintenance. Equally important is the communication of Operations and Maintenance needs to the design team (two-way conversation). The key elements are:

- Hazards and effects management processes (HEMP) are followed so that the chosen concept or design carries residual risk that is as low as reasonably practicable (ALARP) and tolerable.
- All safety-critical equipment (SCE), performance standards (PS) and maintenance routines are identified.

Operating Integrity, OI

Operating integrity refers to the ingrained habit of considering potential risks from cumulative hazards, changes and dynamic events. The OI process involves:

- operating all the facilities within up-to-date operating envelopes.
- rationalizing and knowing how to react to alarms and using the permit-to-work systems.
- clear, consistent and effective daily communications and shift handovers line.

Operating integrity centers primarily on compliance with procedures and standards.

Technical Integrity, TI

Technical integrity is the safeguarding of assets through effective maintenance, inspection, repair and assurance.

- When projects are handed over to operations, the HSE Case must be valid and "operationalized".
- Competent staffs are required to assess and fix the integrity-dependent elements in existing assets, starting with SCE.

Hardware barriers must be maintained and tested on a regular basis to ensure they will perform as per the performance standards when required.

At the heart of the petals (Design, Technical and Operating Integrity) is *Integrity Leadership*, which is fundamental to the success of delivering sustained asset integrity and process safety management. It focuses on leading and role-modelling the right behavior, while also providing trainings and reinforcement of the right capabilities in the right places at the right times.

From process safety improvement trends over the years (Figure 1.2), there has been a significant reduction in the cumulative recorded process safety incidents across Shell facilities. However, relative to the other Asset Integrity elements, Operating Integrity related incidents are taking more bands in the overall picture, contributing half of the total recorded incidents in 2017. A root cause analysis of these operating integrity related incidents revealed the need for a focused process safety leadership and a new approach to behavioral change at the front line, as key drivers for improvement.

Overall, analysis of all recorded incidents shows that the potential for these occurrences could have been reduced by people adhering to known good operating practices and techniques.

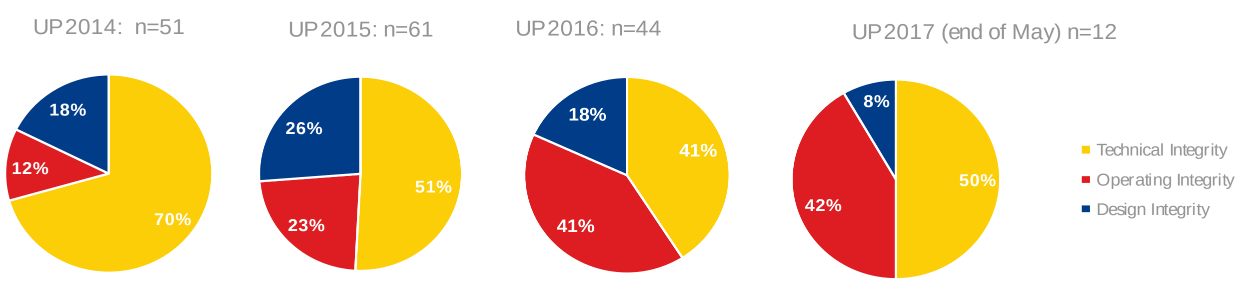

Figure 1.2: PSE distribution over the last four years

The Case Studies

Case Study #1: Design Integrity, DI

Failure of an overpressure protection system on a gas manifold

The Event

On 29th March during routine well equalization activity at a remote gas well manifold, the relief valve (RV) on the line connecting the 3rd intermediate manifold to the main manifold lifted at 129barg (below set point of 150barg). A Root Cause Analysis (RCA) into the failure and joint assessment confirmed that a similar event occurred 9 days earlier (on 20th March), with circa 3750 standard cubic feet (scf) of gas (87kg) discharged to the cold vent from the 3 RVs on the lines connecting the individual intermediate manifolds to the main manifold.

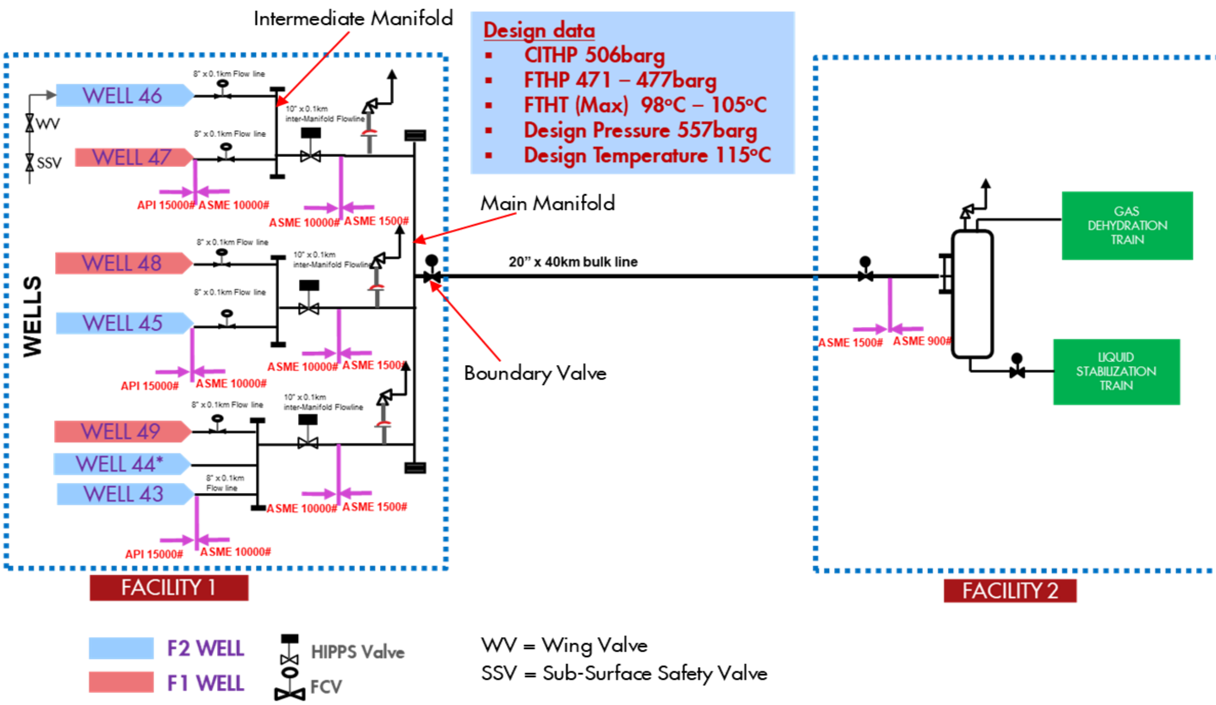

Figure 2.1: Schematic of Case Study 1

Sequence of Event

Table 2.1: Sequence of Event for Case Study 1

Time/Date	Description of Activity
04:56 hrs. 20th March	Facility-1 went down on Emergency Shutdown, ESD due to low-low instrument air on the instrument air header.
08:45 hrs. 20th March	Facility-1 was restarted and gas export resumed with no knowledge of Bursting Disc (BD) rupture and RV action.
15:09 hrs. 27th March	Facility-1 was put on ‘hot stand by’ mode due to liquid handling challenges in the Facility-2. Facility-2 inlet flow control valve (FCV) was closed.
12:47 hrs. 29th March	RV on the 3rd intermediate manifold lifted at 129barg operating pressure (below the set point of 150barg)

Key Findings

- No pressure excursions outside the operating envelope. Examination of RV (during recalibration) confirmed damage to spring.
- Historical trending on Distributed Control System (DCS) revealed unusual pressure spike on the intermediate manifold on the 20th March (153+barg).
- DCS event log confirmed plant trip on low-low instrument air pressure (ESD) @ 0456hrs on 20th March (Operations team confirmed plant trip on 20th of March).
- Pressure spike above 150barg on the 20th of March ruptured all 3 BDs on the intermediate manifold flowlines.
- PDIAs (Pressure Differential Alarm) across the BDs were found to be isolated from process (during a previous maintenance activity) and therefore did not register alarms in the DCS when BDs ruptured. – ***Failure 1 (Technical Integrity)***
- The manifold operations continued between 20th to 27th March with ruptured BDs.
- Valve closure time of Wing Valve (WV) and Sub-Surface Safety Valve (SSV) for wells is 40 - 60secs while the boundary valve on the bulk line closes in 20 secs. This resulted in rapid pressure equalization across FCV, over-pressurization of the low-pressure section of the manifold (#1500 section), rupture of BD and lifting of RVs. – ***Failure 2 (Design Integrity)***
- Process dynamics is faster than the valve dynamics hence pressure excursions beyond the High Integrity Pressure Protection System (HIPPS).
- Piping lengths upstream of FCV is longer than the piping length downstream of FCV, hence settle out of inventory across FCV on ESD/OSD results in the rapid over-pressurization of the downstream low-pressure section. – ***Failure 3 (Design Integrity)***

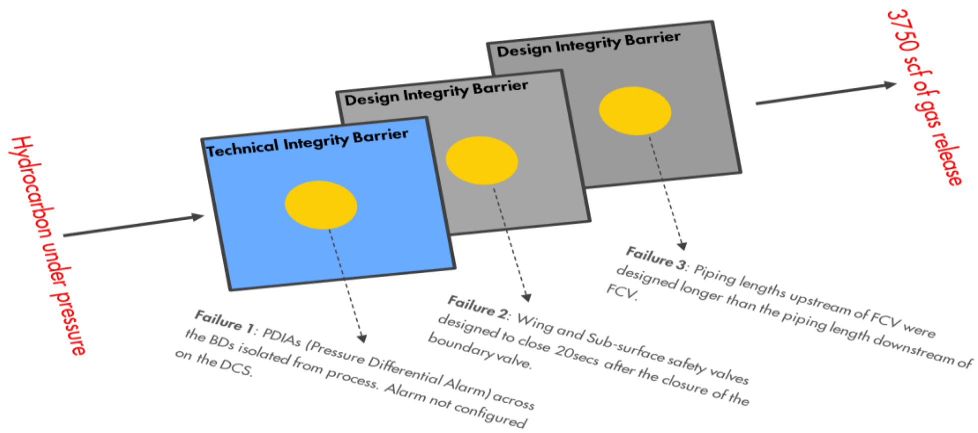

Figure 2.2: Failed Barriers for Case Study 1

Discussion

This case study identified breeches to two elements of the Asset Integrity Management System. However, the focus in this analysis is on design integrity (Figure 2.2). An important part of facility design should be the impact of piping dimensions and automated shutdown/isolation valve response times on the behavior of the process. Furthermore, dynamics behavior should be confirmed using simulators, prior to commissioning and startup. The lack of appreciation of how changes in process dynamics affect the operation of the facility, comes down to human error in design.

Case Study #2: Operating Integrity, OI

Failure of a gasket leading to loss of containment at a Gas Plant

The Event

At about 10:35hrs, an operator observed a leak from a 2" vent line flange on the standby meter Run-1 of a gas metering system. Flow was then diverted from metering system (Runs 1 and 2) to auxiliary metering system, followed by depressurization of the line to stop the leak.

Sequence of Event

Table 2.2: Sequence of Event for Case Study 2

1035hrs	Observer informs Control Room Operator (CRO) of a gas leak around the export line.
1040hrs	Emergency alarm initiated by control room for all personnel to muster.
1053hrs	CRO started ramping down production and commenced diversion of flow from the main metering system to the auxiliary metering system.
1100hrs	CRO completed flow diversion from main meter run to auxiliary metering system.
1135hrs	CRO completed depressurization of main Metering system.
1210hrs	Emergency Response Team (ERT) stood down.

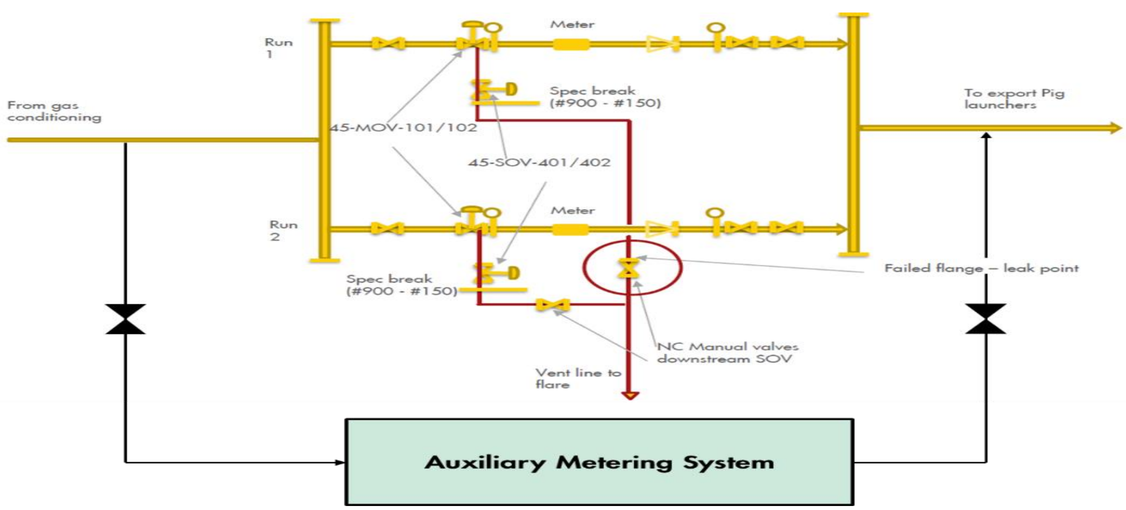

Figure 2.3: Schematic of Case Study 2

Key Findings

- The 1" solenoid valve (45-SOV-401) connected into the cavity of the 24" MOV (45-MOV-101) failed open (failed solenoid coil). However, the 2" (manual) vent valve to flare downstream 45-SOV-401 was in closed position, leading to over-pressurization and hence failure of the 150# gasket on the line.
- The 24" manual valve upstream 45-MOV-101 was passing in closed position. – ***Failure 1 (Technical Integrity)***
- As per Standard Operating Procedure (SOP), 45-MOV-101 should be in closed position when Run-1 is on standby. However, 45-MOV-101 was faulty and stuck in open position. Furthermore, Asset was yet to initiate corrective maintenance for the Safety Critical valves prior to incident. – ***Failure 2 (Operating Integrity)***
- Piping and instrumentation diagram (P & ID) indicated 2" manual (vent) valve downstream 45-SOV-401 as normally closed (NC) instead of normally open (NO), as per design guide (to guarantee open path to flare). – ***Failure 3 (Design Integrity)***

- Further checks on the “Approved for Construction” drawing indicated the 2” vent valve as NO. However, post construction update of As-built indicated 2” vent valve as NC, with no approved Change Management. – ***Failure 4 (Design Integrity)***
- Leak detection system (45-SOV-401 and 45-PIA-401) is not configured on the DCS graphics. Although found in the Asset Register, no maintenance plan was in place. 45-PIA-401 is configured only as a pressure transmitter (display only on site). – ***Failure 5 (Design Integrity)***

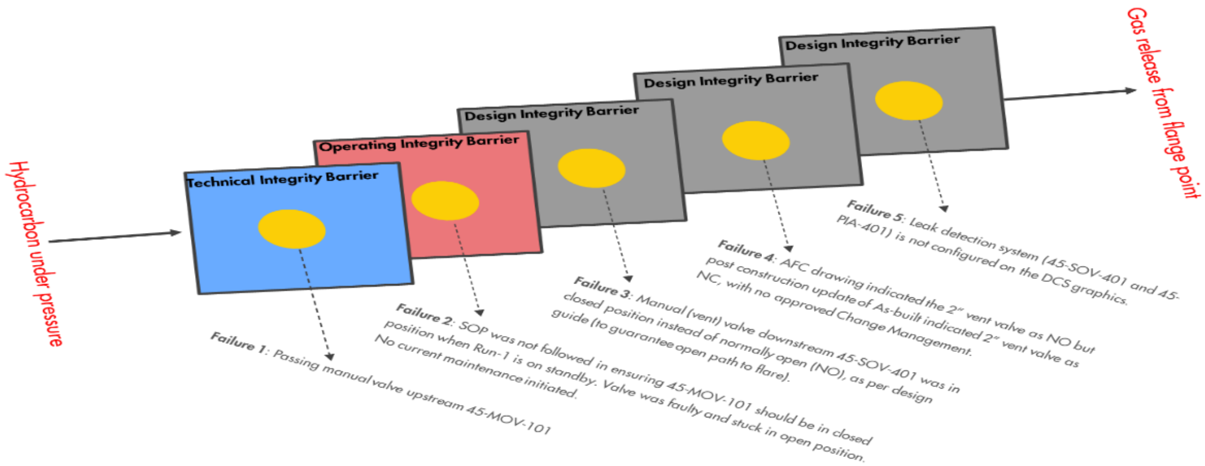

Figure 2.4: Failed Barriers for Case Study 2

Discussion

This case study identified breaches to the three elements of the Asset Integrity method to process safety management.

However, focus of this case study is on the breach to Operating Integrity (figure 2.4). There is a high likelihood that if the operators had walked the line after noticing the failure of the solenoid valve and the passing 24” ball valve, they could have observed the 2” (manual) vent valve to flare in closed position. Operating integrity centers primarily on compliance with procedures and standards, which in this case was breeched. Furthermore, connection of 45-PIA-401 to the DCS could have warned operators of the trapped high-pressure gas in Run-1, which would have prevented startup of production until the valves are fixed. There was apparently no demonstration of end-to-end appreciation of the cumulative risk of multiple failed barriers by the operators.

Case Study #3: Technical Integrity, TI

Oil spill on a Single Point Mooring, SPM system at a crude terminal

The Event

At about 05:00am on Friday 22-Dec-17, a “ship-shore” loading difference of 4,774 barrels was observed during the loading operations at a crude terminal. The control room contacted the ship operators to reconfirm the figure. The Ship Captain (Pilot) was consequently informed to stop the loading due to a suspected leak. The loading was stopped at 05:10am. An oil sheen area of approximately 187 barrels was noticed in the marine environment.

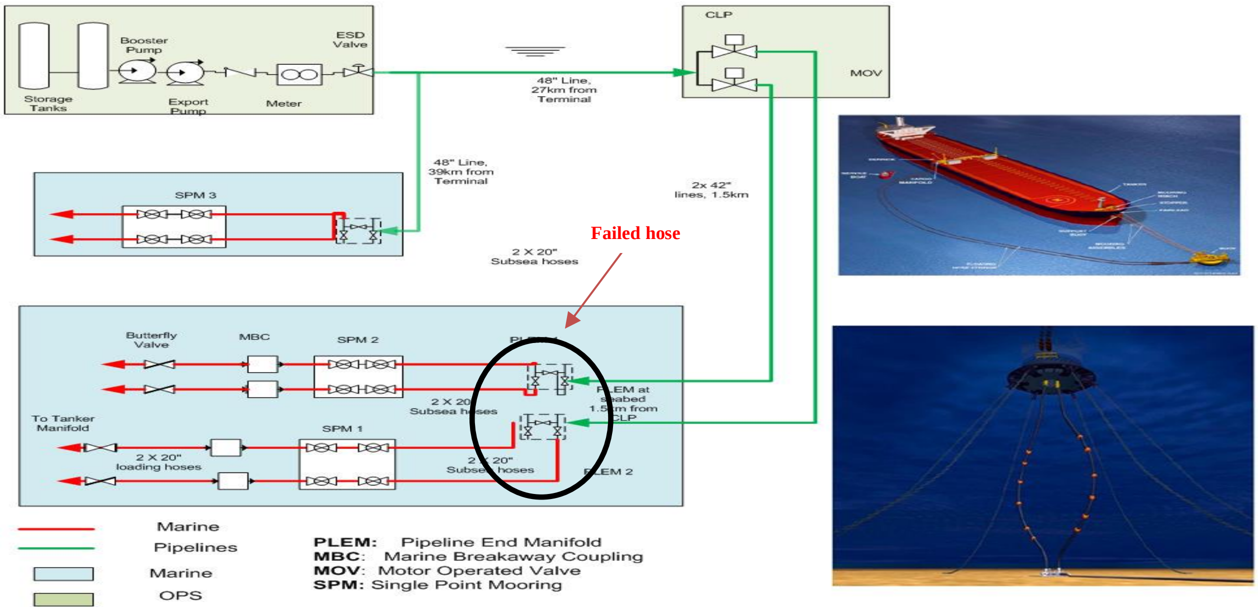

Figure 2.5: Schematic of Case Study 3

Sequence of Events

Table 2.3: Sequence of Event for Case Study 3

Date	Time	Description of Activity
21st December 2017	2318hrs	Ship (MV LIPARI) berthed for loading at SPM-1.
22nd December 2017	0118hrs	Ship completed hose connection and ready for leak test,
	0206hrs	Leak test completed, and loading commenced,
	0505hrs	Ship figure as at 0500 hrs was 131,784 bbl, while for the shore was 136,558 bbl, giving a ship-shore difference of 4,774 bbl. Central Control Room (CCR) advised ship to recalculate and reconfirm the figure, else shore will shut down.
	0510hrs	Ship to shore difference now 5139 bbl. Pilot called to inform CCR to stop loading immediately because there is a suspected leak offshore. CCR immediately stopped all export pumps.
	0522hrs	Pilot called CCR to inform they are seeing oil on water offshore but have not seen any leak point.
	0524hrs	CCR informed acting Terminal Installation Manager of the log. Terminal ERT activated

Key Findings

- Hose proof test pressure was 22.5 barg as against typical operating pressure of 15 barg
- Offtake pressure from the terminal was at average of 18barg, while the pressure at the subsea hose (delivery point) was 15.9barg – ***Failure 1 (Operating Integrity)***
- Hose minimum burst pressure is 75 barg and design life is 5 years from installation date. Hose was installed on 1-Dec-10 and due for change-out 1-Dec-15. Changeout was originally scheduled for 10-Jul-16, and *then extended twice* without a change management approval. – ***Failure 2 (Technical Integrity)***
- A tear of approximately 500mm x 80mm (although not deep) was observed on the first subsea hose attached to the string from the PLEM take off arm connection during April 2016 inspection. There was no evidence of close monitoring for further deterioration of the hose as the anomaly was not found in the corrective maintenance download from SAP. – ***Failure 3 (Technical Integrity)***

- The leak occurred on 22-Dec-17 and Diver's inspection on 27-Dec-17 revealed a damaged section of the hose in question from the PLEM1 (which happens to be around the same section of deterioration identified during April 2016 inspection).

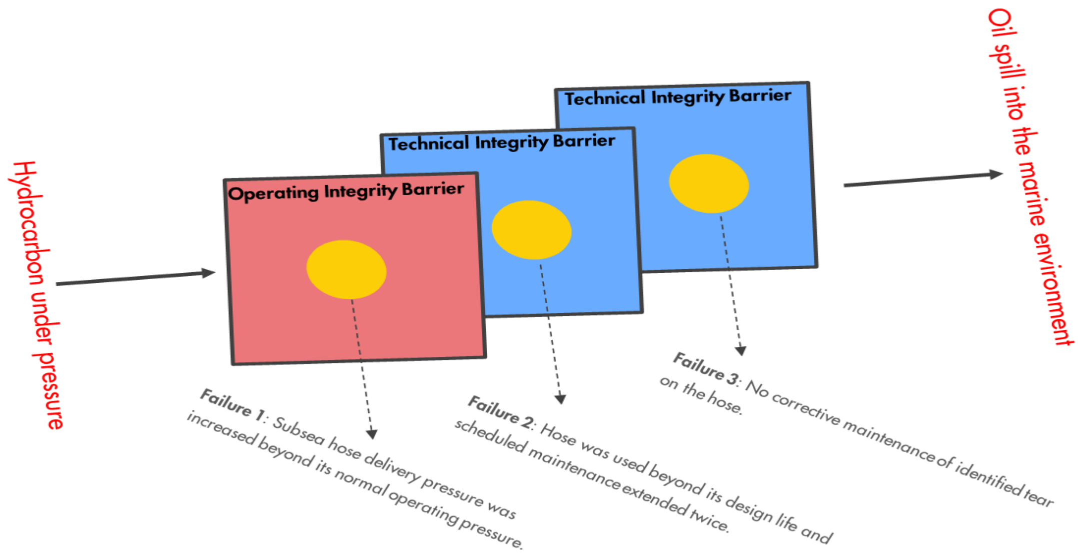

Figure 2.6: Failed Barriers for Case Study 3

Discussion

This case study identified breaches to two elements of the Asset Integrity method to process safety management.

However, focus of this case study is on the breach to Technical Integrity (Figure 2.6). Scheduled change out of hose was extended twice over a period of 2 years without a change approval, despite the observed failure from inspection. A performance standard was set for maintenance and replacement of the hose, but this was not followed through leading to the incident. The human and behavioral barrier in the maintenance chain failed in this incident.

Conclusion

Process safety incident cannot be prevented just because there are a set of good enough process safety standards, procedures and guidelines. Incidents could be minimised and prevented by having people with the right mindset, attitude and consciousness to dynamic changes to risks, backed by the right leadership. The behavioural impediments required is operational discipline where everyone is seeking and seeing the risks (zero risk normalization) from design to operation and maintenance.

One of the critical success factors for effective roll out and implementation of any process safety management program is ownership and visibility by the Assets. At Shell, the Process Safety Fundamentals, PSFs, was launched in 2017 to keep emphasis on good operating practices and behaviours as the key enabler to getting it right 100% of the time (goal zero). Other suggestions include:

- Careful consideration of human and behavioural impact on process safety during safety studies (HAZOP, HAZID, Process Safety Review (PSR) etc.) in project design and operation phase of the asset life.
- Trainings for frontline operators and technicians on human psychology and responsiveness during facility operation (zero risk normalisation).
- Digitalization - use of Virtual Reality (VR) in safety and operator training for a close-to-reality simulation of process safety incidents.

The energy industry has made significant step changes in how process safety is managed over the years. Focus has been on crafting the best standards, writing procedures, and ensuring compliance. However, if we must prevent incidents from occurring, increasing focus should be placed on the human and behavioural elements of Process Safety Management.

References

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2. Shell Sustainability Report – (2012 – 2017)