Alvheim

Kneler A Workover Project

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Skandi Arctic Port Bell Investigation Report

MARATHON DOCUMENT NO.

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Investigation Report

Alvheim – Kneler A Workover Project

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Rev. No.		Date	Section(s)	Page(s)	Reason
CLIENT	TECHNIP				
A	0	22.08.2013	ALL	ALL	Evaluation and implementation of feedback and comments from Operators, Safety Delegates, RCDD, Group Diving Manager, T-MOS, DSV Skandi Arctic, Technip Norge and investigation team. The changes are not marked.

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1. EXECUTIVE SUMMARY

On the evening of 22nd of June, while the DSV Skandi Arctic conducted diving operations for Marathon at the Kneler A worksite, the port diving bell had two uncontrolled descents whilst being lowered into the moonpool. During the second uncontrolled descent the umbilical was damaged causing gas from the bell interior to leak out.

The divers in the bell experienced a pressure drop equivalent to approximately 18 meters of depth. To stop the leaks they had to close all internal umbilical related penetration valves and to re-pressurize back to a living depth equivalent to 110 meters using the bell's on-board emergency gas. The bell was subsequently recovered and re-connected to the ship's saturation system and the divers returned to their living quarters.

The port bell umbilical was damaged and could not be used. The potential existed for damage to the bell and launch system though these have now been thoroughly examined and confirmed as not damaged. Under Marathon's management control and Technip risk assessment, the ship continued to make a series of further dives using the identical starboard bell and related control system.

The Petroleum Safety Authority has notified Technip's clients of the incident and the police have visited the ship to collect evidence.

The events leading to and during the incident have been investigated by a combined Technip and Marathon team.

Findings

This incident occurred because the Programmable Logic Controller (PLC) based system that controls the bell during launch and recovery had been inadvertently placed in an unsafe state because the system allowed two separate operating errors to be made. The subsequent attempts to understand the failure and recover from the bell pressure loss, although ultimately successful, have revealed a need to learn lessons in a number of areas.

During the investigation the Root Cause Analysis focused on 2 main areas:

- The bell made 2 uncontrolled descents in the moonpool
  Establishing the design, engineering, organisational, procedural and competence failings that led to the uncontrolled movements of the bell.

- As a consequence of the second uncontrolled descent the bell lost gas pressure
  Establishing the design, engineering, organisational, procedural and competence failings that hindered a rapid arrest of the bell pressure loss.

Potential Consequences

Without code modifications to the bell control systems the incident has a limited possibility of repeating. There was a potential for multiple fatalities and further damage to the diving system. It should be noted however that several safety barriers remained intact and the bell's on-board gas reserves would have remained available to support life for a further 1½ hours.

Principal Conclusions

The principal conclusions are drawn from the root cause analysis and are summarized as follows:

- During the construction of Skandi Arctic the bell launch control systems were given a low hazard rating and therefore lacked the level of technical safety scrutiny given to other, more highly rated systems.

- Although there are organisations and systems for conducting audit and correction of non-compliances, these have not detected or corrected the deviations identified by the investigation team in diving technical risk management, diving procedures, and related systems.

- The implications of introducing PLC technology to the diving industry might not have been fully understood, and the related roles, responsibilities & competencies of both technical and operational personnel are not sufficiently well clarified.

- The diving organization has not sufficiently defined the emergency response to reasonably foreseeable hazard conditions, and not optimized equipment, checklists, training or drills for effective use. Furthermore emergency related processes are not audited for effectiveness or for feedback to improve related technical, procedural or competency systems.

- There was insufficient supervisory understanding of both the bell launch and recovery control system and the situational awareness needed to understand and control the human and equipment response to a complex hazardous situation.

2. METHOD OF INVESTIGATION

2.1 The Investigation Team

An investigation team was appointed by Company and Contractor, boarding the vessel on Wednesday 26th June. Provisional Terms of Reference (ToR) were issued in the evening of the 25th June. There have been additional personnel appointed to the investigation team from Company and Contractors marine operations division. ToR was re-issued on June 28th. In addition the investigation team was strengthened with an independent 3rd Party functional safety specialist on Friday July 5th and a diving operations and compliance specialist from 12th July.

Name	Position	Company	Role
Øyvind Loennechen	Diving Manager	Technip Norge AS	Investigation Leader
Hamish Payne	Project Engineer	Technip Norge AS	Team Member
Einar Wold Svendsen	Diving Advisor	Technip Norge AS	Team Member
John Nortcliffe	Systems Engineer	Technip Norge AS	Team Member
Aksel Nesse	HES Advisor	Marathon Oil Norge As	Team Member
Justin Kooij	Project Engineer	Marathon Oil Norge As	Team Member
John Cramb	Asset Technical Capex Manager	Technip Marine Operations Services	Team Member
Edward Gardyne	Technical Director	Safe Well Solutions	Independent 3rd Party Team Member

Table 2-1: Investigation team members

The team was able to co-opt other personnel as required for assistance or special knowledge. The following were specifically available for advice and governance.

Name	Position	Company	Role
Jahn Erling Nakkestad	Diving Technical Manager	Technip Norge AS	Technical
Chris Solheim-Allen	QHSES Director	Technip Norge AS	Governance
Mikal Sjur Lothe	Group Diving Manager	Technip Group	Diving

Table 2-2: Supplementary personnel

2.2 Interface with PSA and Police

Marathon notified the PSA of the incident without delay.

The PSA and management from Company and Contractor were present in the opening meeting on-board Skandi Arctic on Wed 26th June. The PSA also visited the diving system. Three PSA representatives were present.

The PSA notified the Rogaland Police District of the incident because of the potential to cause 3 fatalities. On Thursday 27th June the PSA and the police visited Skandi Arctic to collect information on the incident and the ship's diving systems. To date there have been no further requests from the police for assistance in their enquiry.

PSA have also notified the Oil & Energy Department in the Norwegian Government, and have notified all interested parties through a public statement on their internet site.

2.3 Investigation Process

The investigation team have worked both on-board Skandi Arctic and from Technip Stavanger's office. Safety Delegates were involved on-board the vessel. Every interviewed person was given the option of being accompanied by a Safety Delegate or other person during their interview. Safety Delegates, Technip and Marathon have been notified of investigation progress at key points.

The investigation team have conducted the investigation by examining the following;

- Gathering witness statements from all parties involved directly and indirectly.
- Conducting interviews with persons directly involved in the incident.
- Visiting the incident site and developing an understanding with the help of vessel crew.
- Taking photographs of the diving system and damaged diving bells.
- Recovery and review of HMCS, LARS PLC and LARS Drives data.
- Recovery of black box recording from the port and starboard bells.
- Processing the recovered video and sound
- Transcribing the speech from the video recordings.
- Review of internal procedures and documentation.
- Visiting T-MOS to understand governance, management and safety management systems.

2.3.1 Investigation into the following incident:

Uncontrolled Movement of the Skandi Arctic Port Side Submersible Diving Chamber (SDC), on Sat 22nd June 2013. Synergi Case number 279688.

2.3.2 Investigation Methodology (TOPSET)

Kelvin TOP-SET is the Incident Investigation and Analysis system used by Technip and was used in this incident investigation. Please visit the company website for more information. www.kelvintopset.com

2.3.3 Investigation Remit

- Describe the incident.
- Determine the sequence of events leading up to the incident.
- Evaluate the response during and after the incident, including notification and actions taken to depart the worksite in a safe manner.
- Determine the actual Incident potential according to both Technip and Marathon incident potential criteria.
- Identify immediate, underlying and root causes.
- Make suitable recommendations to prevent the same or similar events occurring again.
- Review the incident on 24th June 2013 when the starboard bell lift wires came out of synchronization and to determine whether the 2 incidents are related.
- Maintain a relationship with the ship's elected safety delegates during the investigation.

The investigation should include review of engineered systems & operating procedures, inspection of the worksite, and interviews with the parties involved. The following shall be considered:

- Design and engineering of relevant systems.
- Knowledge and competence of operating, diving and technical personnel.
- Compliance with operational and technical standards.
- Barriers in place and their effectiveness.
- Management influence.
- Standards of communication.
- Similar incidents.

3. DESCRIPTION OF THE INCIDENT

3.1 General Introduction

A serious incident occurred on the Dive Support Vessel (DSV), Skandi Arctic on Saturday, June 22 evening while performing diving operations on the Alvheim Field in the North Sea.

During a normal launch of the port diving bell, with a three man diving team, the Launch & Recovery System (LARS) lowered the bell in an uncontrolled manner within the moonpool. The diving bell umbilical gas hoses were dislocated from the termination plate resulting in loss of pressure in the diving bell equivalent to an approximate depth of 18 msw.

The divers responded to the situation, shut off the leaks by means of the internal shut off valves and re-pressurized the bell back to living depth using onboard gas.

After having eliminated the apparent fault and re-instigated the LARS functionality, the diving bell was recovered and mated to the saturation chamber system for transfer of the divers. The divers underwent thorough neurological checks performed under the supervision of the onboard nurse in consultation with the Duty Diving Doctor.

Descriptions of the incident as experienced by the divers in the bell are listed in the evidence log, Appendix C, EVID 008

3.2 Persons Involved

The following people (names removed for confidentiality) were involved in the incident. Full POB lists are available at the bottom of the daily progress reports (DPRs) listed in the evidence log, EVID 063. Shift list for the period of the incident is listed in the evidence log, EVID 068. The evidence log is found in Appendix C.

Position	Company	Relevant Experience	Days On-Board	Shift Pattern
OCM				
Captain				
AOCM				
Dive Supervisor				
Dive Tech Supervisor				
PLC Tech				
Mech Tech				
Elec Tech 1				
Elec Tech 2				
Trainee Dive Supervisor				
Standby Diver				
Launch Crew				
Dive Supervisor				
Junior Project Engineer				
Client Tech Rep				
Project Engineer				
Hyperbaric Nurse				
Client Dive Rep				
Client Senior Dive Rep				
Diver 1				
Diver 2				
Diver 3				
2nd Officer				
Life Support Supervisor				

Table 3-1: Position, Company, Experience and Shift Pattern of the Persons Involved

3.3 Incident Statement

The Skandi Arctic had an uncontrolled descent of the port diving bell, causing significant damage to the main umbilical and a drop in the internal bell pressure.

3.4 Notification

The Captain of the vessel was notified at 21:20 and took command on the bridge. At 21:45 he revoked the green light and the permit to dive. The on shift Company representative was notified at 21:30. Alvheim FPSO was notified at 22:01.

Company and Contractors organisations ashore were notified of the incident without delay. Company immediately notified PSA duty manager via telephone and followed up with a written notification on 23.06.13 at 01:48.

3.5 Actual Consequences

3.5.1 Personnel

None of the divers reported any symptoms of decompression sickness or other injuries. This was confirmed by the on-board nurse after running the divers through neurological checks while in consultation with the Duty Diving Doctor on-shore.

3.5.2 Material Damage

Gas and water hoses in the bell umbilical were severed, causing the internal pressure drop in the bell. The umbilical requires re-termination as well as checks to ensure integrity.

The umbilical termination plate and fittings on the bell hull were damaged. All connection points, gas, water, electrical and signal cables need thorough inspection, testing and repairs.

Initial inspection of the LARS shows signs of overloading on the umbilical chute (nodding donkey). The umbilical chute requires thorough inspection, testing and repairs.

The entire LARS has been subjected to unexpected loading and requires thorough checks to ensure system integrity.

3.5.3 Project Work Scope

The project work scope was disrupted. The work site was made safe prior to departure from the field. The work scope was to disconnect spools from two live wells and cap them to allow for well workover.

3.6 Potential Consequences

The potential consequences of the incident are, Multiple fatalities and further damage to the diving system. Note that a number of barriers remained intact and the possibility of fatality is believed to be low. (Appendix F).

3.7 Assessment of Depressurisation and Repressurisation Phase

The barriers left to prevent such an outcome, were:

- The availability of check valves on gas and hot water supply lines
- The availability of internal hull stop valves on all through hull fittings
- The availability of external hull stop valves on all through hull fittings

- The availability of a considerable amount (approx. 160 m^3) of on-board gas (10% O_2/90% He) suitable for maintaining/regaining the bell internal pressure.

The bell internal pressure dropped from 111 msw to 93 msw in a time span of 4 minutes and 15 seconds. The leak rate (volume) was approx. 2960 l/min, the average pressure loss (decreases with decreasing differential pressure), expressed in msw, was 4.24 msw/min. At this point in time, the divers in the bell had closed most of the leaking valves and had started to regain the internal depth of the bell through pressurizing by means of the on-board bell gas reserves.

The last leak was stopped 11 minutes and 19 seconds after the initial leaks occurred. Living depth of 110 msw was regained 15 minutes and 29 seconds after the leaks started.

14,2 % of the available on-board gas (10/90) was used to compensate for leaks and to regain living depth in the bell. This means that, at the actual usage rate, there was still gas left for another 95 minutes of compensating for the leaks.

Three of the barriers, i.e. check valves, closing internal valves and pressurizing using on-board gas, were activated and actually stopped escalation of the situation. The last barrier, closing external valves was not used because access to the bell exterior was complicated with the bell positioned inside the moon pool. If the divers had not been successful in closing the internal valves, surface personnel (i.e. the contingency diver) would have attempted to close the corresponding external valves. It is considered unlikely that these barriers, one by one or in combinations, would not have been effective in time.

It is also considered unlikely that the divers could have become incapacitated due to hypoxia if the leak continued reducing the pressure of the bell. The PO_2 in the bell as the leak started was 400 mbar (3,3 % O_2). With no introduction of gas into the bell, the depth at which they would reach 210 mbar would be 54 msw. The lowest PO_2 at which they would be functional could be as low as 160 mbar, which would be reached at 38 msw.

The divers started compensating the pressure loss soon after the leak occurred, using 10/90 O_2/He from the on-board gas. They had, at the start approximately 160 m^3 of this mix available for use. The bell has an internal volume of 7 m^3. If all available gas had been used to compensate for the leak, which it would have been if the leaks had not been stopped, the oxygen percentage in the bell would have ended up at approximately 8%. With 8% O_2 in the bell, a PO_2 of 210 mbar would be reached at a depth of 16 msw, and 160 mbar at a depth of 10 msw. It is reasonable to believe that other symptoms of being subjected to a major pressure loss from being saturated at 110 msw, would take effect before reaching these depths. See RCDD evaluation below.

3.8 RCDD Evaluation

The investigation team has contacted the RCDD for an evaluation of the potential medical consequences of not being able to stop/contain the leak at all. The response is given in the evidence log, Appendix C, EVID 088 with an extract below;

"A continued drop in pressure would at some depth have given serious Decompression Sickness with involvement of the central nervous system. The literature does not give us sufficient data to in any way try to model at what depth and what symptoms. If no intervention could be made, and a decompression took place at a speed of 4msw/min from 110msw to surface, it would be considered incompatible with the sustainment of life."

4. SEQUENCE OF EVENTS

4.1 Background – LARS Development

The main items of equipment involved in the incident were the port diving bell (including stand-off frame and cursor) and the Port Launch and Recovery System (LARS). The physical system is described in detail at Appendix A and the control system development cycle at Appendix B.

The LARS, along with the rest of the dive system was designed and built to Lloyd's Register Rules and Regulations for the Construction and Classification of Submersibles and Underwater Systems. This vessel was the first saturation diving system to extensively use programmed logic controller (PLC) and supervisory control and data acquisition (SCADA) technology.

Early HAZOP reports led to a safety integrity level (SIL) assignment report which concluded that:
'*no SIL requirements exist for the control system*'. This meant that it was considered not necessary to implement safety related systems beyond those already identified, to protect against the functional hazards identified for this system. As a result of this assignment the LARS control system was designed and developed in house by the dive system manufacturer and not by the control and safety specialists that were subcontracted to develop the SIL 1 rated Hyperbaric Monitoring and Control System (HMCS) which comprises the majority of the computer, PLC and software systems implemented on-board The investigation team, under advice from an independent safety systems specialist have concluded that the normal rigour that may be applied to developing such a system might have been relaxed because of the lack of SIL rating. Appendix B discusses this in more detail.

Following through the design process and associated documentation it is clear that the failure mode that caused this incident was indirectly identified at HAZOP. The system was not designed to protect against incorrectly being placed into a mode used for maintenance activities while diving operations were happening.

4.2 Events- Immediately Prior to the Incident

Prior to the incident DSV Skandi Arctic was conducting diving operations at the Alvheim field on the Norwegian continental shelf. Divers were at a living depth of 110 msw and transferred from the chamber system to the port bell in preparation for an 'on bottom bell turn around'. All three divers were committed to saturation on the 19.06.2013 at hrs. 16:00.

4.3 Events - During the Incident

This section of the timeline covers the immediate incident on the 22nd June 2013 from when the divers entered the bell until they return to the living chambers after the incident. A detailed timeline of the incident can be found at Appendix D.

Abbreviations	
AOCM	Assistant OCM
D1, D2, D3	Divers 1,2,3
DSP	Dive Supervisor Port
DSS	Dive Supervisor Starboard
DTS	Dive Technician Supervisor
ETD	Electrical Technician Day
ETN	Electrical Technician Night
LC	Launch Crew
MTD	Mechanical Technician Day
MTN	Mechanical Technician Night
OCM	Offshore Construction Manager
PE	Project Engineer
PLC	PLC Technician
SBD	Standy Diver
TDS	Trainee Dive Supervisor

Figure 4-1: Key to Personnel Job Titles

21:00:00
21:13:54

Preparing for an on the bottom turn around. Normal diving operations.

The dive team were conducting normal diving operations with the relevant personnel located in the positions shown in Figure 4-1. The trainee Dive Supervisor was operating the LARS control panel under the direct supervision of the AOCM who normally carries out this function. In the process of isolating the bell from the TUP, bell pressure was increased to the equivalent of 111msw. The launch procedure during this phase progressed as normal, with the bell being unmated from the TUP, raised to and locked into the trolley hooks, traversed to the moonpool position and the stand-off frame raised and locked in place. (Appendix A contains a description of the system).

Winch mode was then selected and the bell, cursor and stand-off frame were raised and disengaged from the trolley hooks in preparation for lowering through the moonpool to the work site.

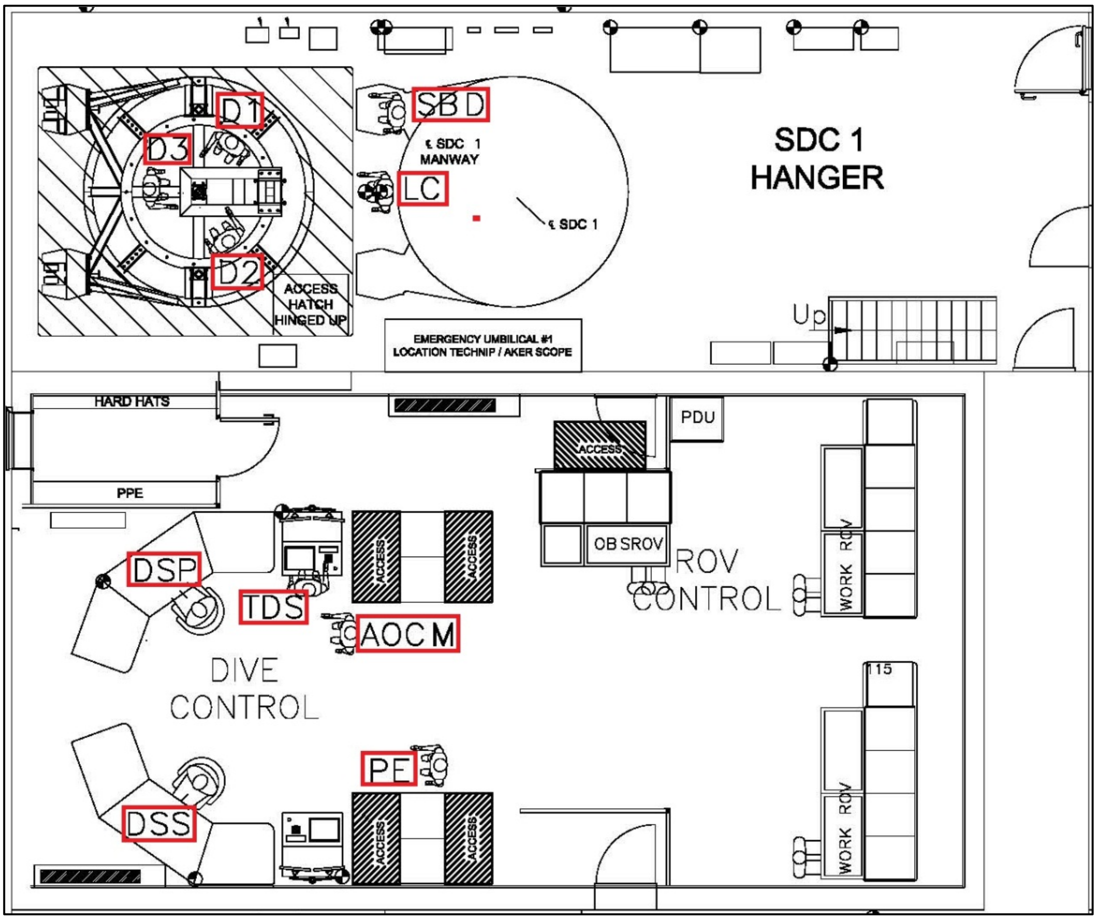


Figure 4-1: Dive control personnel movements prior to the incident

21:13:55
21:21:12

From starting to lower the bell until the start of the first uncontrolled descent.

While the trainee Dive Supervisor was lowering the bell using the port LARS control panel in winch mode, the vertical locking pin1 proximity sensor sent a system alarm and the bell automatically stopped. The AOCM took over the port LARS control panel and called for the night Mechanical and Electrical Technicians to investigate.

NOTE: The reliability of the proximity sensors (See 11.2.3) has been poor from commissioning with some 50 sensors within the system suffering from a variety of problems such as too small an activation range (3mm) or corrosion of the connections leading to premature failure. There are two vertical locking pin sensors of which only the lower one became faulty. The upper one was fully operational throughout the incident. Though the fault with this sensor was the trigger for incident it played no further part in the proceedings.

The HMCS Trends database (Black box) indicates that traverse mode was selected at 21:17:02. It is not known who selected this mode or if it was system initiated (which is very unlikely). Though the LARS control panel HMI indicated that traverse mode was selected, system safety interlocks would have prevented any action to initiate traversing and the winch drive motors were still configured for lowering the bell safely.

After visual confirmation of the vertical locking pin engagement, the Electrical Technician selected maintenance mode and overrode the faulty proximity sensor. The selection of maintenance mode changed the critical winches from Speed Control (SP) mode to Constant Tension (CT) mode and thus they were configured to manage the load of their wires/umbilical but not a weight of 24 Te of the bell, stand-off frame and cursor. In Traverse Mode the bell is expected to be secured in the trolley hooks and the maximum load (tension) each wire winch is designed to manage is set to 1.5 Te and the umbilical winch 0.5 Te (Total system load of 5 Te). Thus in this unsafe configuration there was an extra 19 Te (24 – 5 Te) that the combined winches were not designed to manage. This load was being held by the wire winch brakes of which there are 2 x 8 Te for each winch. See Appendix A Sect 12.2.2 for further detail.

Selection of maintenance mode overrode all safety interlocks and effectively locked the winches into an incorrect and unsafe configuration. The Electrical Technician does not know why he activated maintenance mode in order to override the faulty locking pin sensor as the override could have been selected without the activation of maintenance mode.

It was a combination of the two actions in that specific order that placed the system in an unsafe configuration. No winch was configured to take its normal part of the full bell/stand-off frame/cursor weight present during normal launch and recovery winch operations. Because maintenance mode was active the selection of either winch or traverse mode on the LARS HMI Trolley & TUP screen had no effect on the actual configuration of the winches.

There is no clear guidance that maintenance mode should not be used when carrying out manned underwater operations. It has been used in the past to recover the bell to the trolley hooks when the bell has been out of alignment and all hooks would not engage. It is worth noting that in these previous situations the winches would have been in their correct modes for winch operations. Relevant personnel in dive control were aware that maintenance and override modes were active but not of the implications of multiple safety interlocks being disabled.

The Electrical Technician passed the controls back to the AOCM for continuation of the lowering operation.

Figure 4-2 highlights the location of the personnel during this phase of the incident.

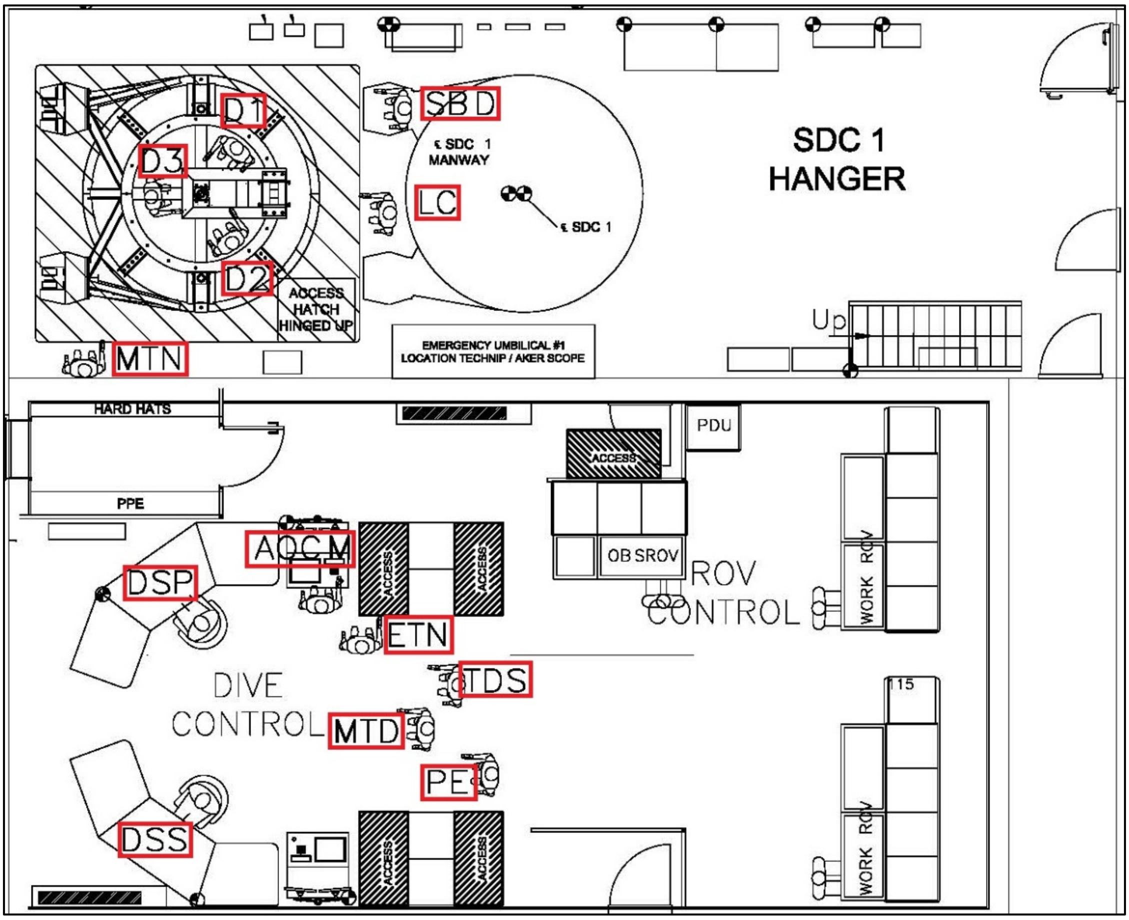


Figure 4-2: Dive control personnel movements when the vertical pin sensor sent an alarm signal to the LARS HMI

21:21:13
21:24:05

From the first uncontrolled descent until just before the second uncontrolled descent

The AOCM depressed the deadman's trigger on the port LARS control joystick (Figure 0-10) and the bell began the first uncontrolled descent. The bell descended because all four winches were in constant tension mode and thus configured to pay out wire & umbilical when the weight of the bell exceeded the constant tension maximum setting.

The AOCM released the deadman's trigger and the Electrical Technician activated the emergency stop and simultaneously winch motor over speed alarms initiated the braking sequence. The umbilical chute (nodding donkey) collapsed (this expression means that the device has been fully compressed) and alarms were sent to the port LARS control panel. Umbilical load warnings were also sent to the port LARS control panel. The first uncontrolled descent of the bell was stopped after 10 seconds and approximately 3 meters of movement. The bell stopped with approximately 1 m of cursor frame above the level of the moonpool deck. From the HMCS Trends database (Black box) it can be estimated that the bell reached a speed of at least 3 times the normal speed when descending through the moonpool. Normal maximum speed in the moonpool is 12 meters/min.

After the first uncontrolled descent the decision was made to recover the bell. The main safety relay and emergency stop were reset and the hydraulic power unit (HPU) was reset/restarted. The HMCS Trends database (Black box) indicates that winch mode was selected at 21:22:47. This was probably selected by the Electrical Technician though statements and interviews do not confirm this. However, because maintenance mode was still active this had no effect on the actual operating mode of the winches despite the HMI Trolley & TUP Screen displaying an indication that winch mode is selected. The Electrical Technician handed the controls back to the AOCM in preparation for recovery of the bell. This is supported by statements from several personnel involved including the vessels DP Officer who had been instructed by the Master to record a log of the incident. Figure 4-3 highlights the location of the personnel during this phase of the incident.

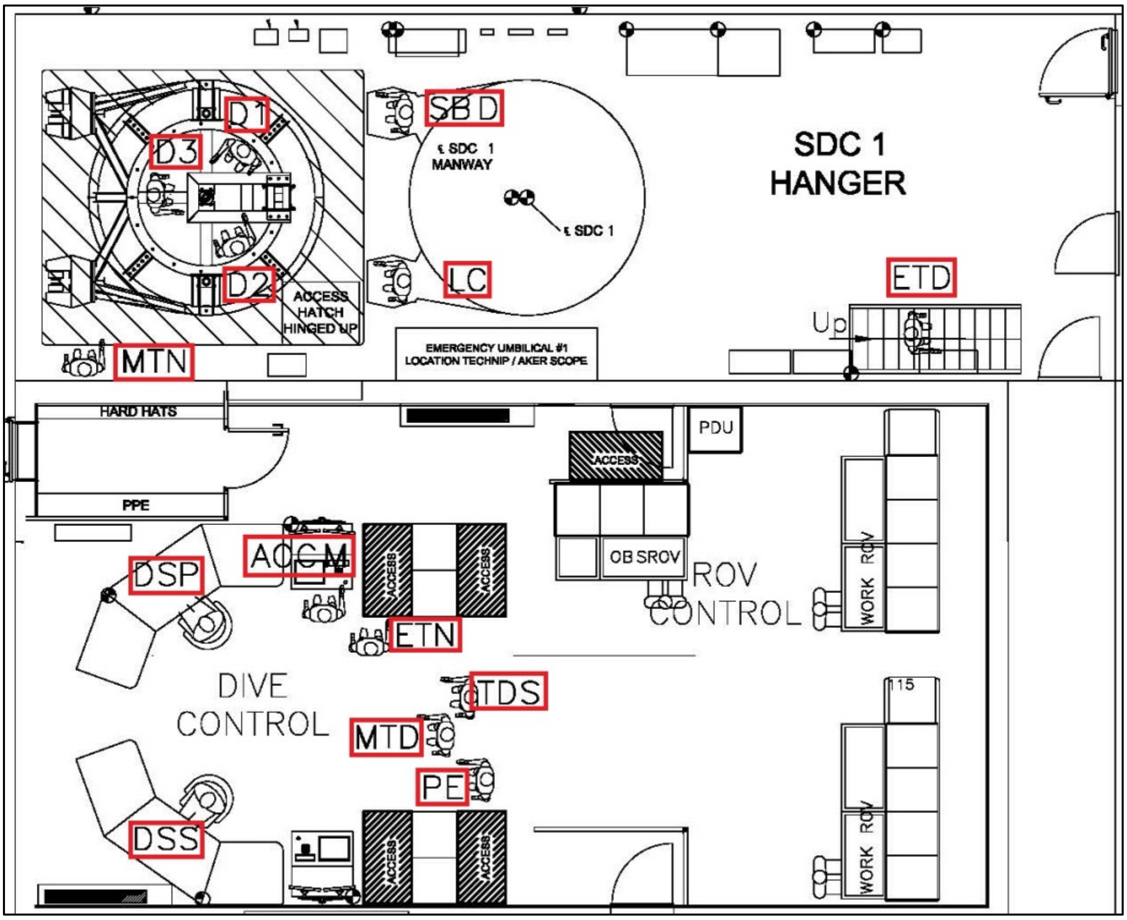


Figure 4-3: Dive control personnel movements during the 1st uncontrolled lowering

21:24:06
21:30:10

From the second uncontrolled descent until the beginning of the recovery phase

The Electrical Technician placed his hand over the emergency stop and the AOCM depressed the deadman's trigger on the port LARS control joystick (Figure 0-10) in order to recover the bell. The bell began the second uncontrolled descent. This was because the relevant winches were still in the same, incorrect mode as for the first uncontrolled descent. The AOCM released the deadman's trigger and the Electrical Technician activated the emergency stop and simultaneously the winch motor over speed alarms initiated the braking sequence.

The umbilical chute (nodding donkey) collapsed ("collapsed" refers to a relatively normal condition where the device is fully compressed and hence can not take up any more umbilical tension) or was already fully collapsed and alarms were sent to the port LARS control panel. Umbilical load warnings were also sent to the port LARS control panel. The umbilical was over tensioned resulting in breaking of the chinese finger securing system which was intended to take a normal load of 0.5 Te and a maximum design load of 1.5 Te. Once the chinese finger had failed, gas connections at the umbilical termination plate were ripped off. A hot water supply hose was also broken off at its bell hull penetration point. The bell began to lose pressure through the open ended connections. The second uncontrolled descent of the bell stopped after 6 seconds with a movement of approximately 4 meters. Once again the bell accelerated to at least 3 times the normal speed when descending through the moonpool.

The bell descended at much higher than normal speeds during the uncontrolled descents. The umbilical winch motors are significantly less powerful than the wire winch motors as they are designed to manage a much smaller load. It is probable that as the umbilical winch has a much larger rotational inertia compared to the wire winches, combined with the significantly less powerful motors it was not able to pay out the umbilical fast enough and maintain the nominal 0.5 Te tension. Consequently the maximum design load was exceeded leading to failure of the chinese finger and main umbilical connections.

The divers were instructed to close all valves and to re-pressurise (blow down) the bell using on-board gas to maintain internal pressure. The bell was stationary in the moonpool with all brakes on and clear of the water. The bell continued to lose internal pressure as the divers isolated the leaks. The bell de-pressurised to the shallowest depth of 93 msw from its initial depth of 111 msw in 4mins 15 sec. The re-pressurisation continued, returning the bell to a depth of 101 msw where a stop was called to check for remaining leaks. The final leak was isolated after 11 minutes and the re-pressurisation back to 110 msw continued. Figure 4-4 highlights the location of the personnel during this phase of the incident.

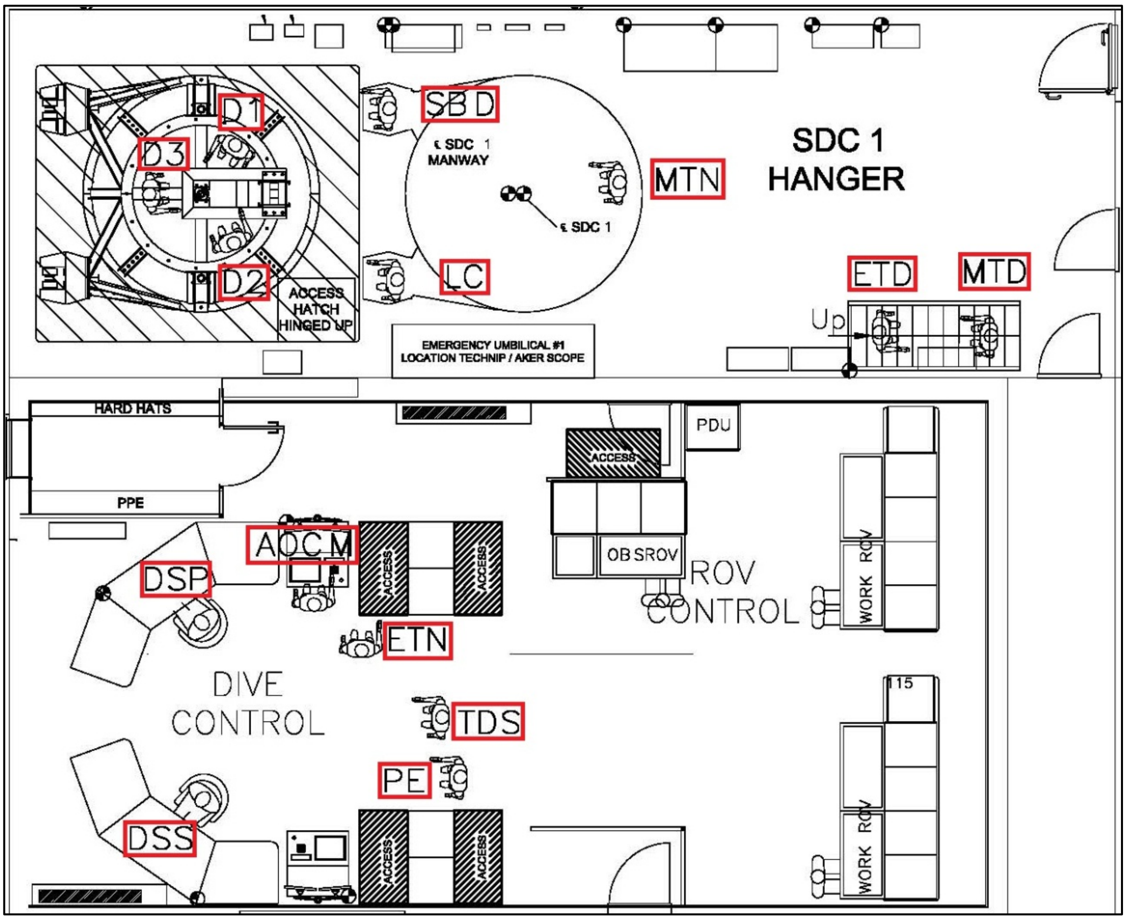


Figure 4-4: Dive control personnel movements during the second uncontrolled drop

21:30:11
22:10:00

The recovery phase

The PLC Technician and Dive Chief Engineer were called to dive control and the PLC technician identified that because the system was in maintenance mode all winches were still in constant tension mode, thus not able to take the weight of the bell. He de-activated maintenance mode and the system returned to the mode selected on the HMI Trolley & TUP Screen which already had winch mode selected. The critical winches were switched back to speed control mode and thus the system was restored to a safe operating configuration for lowering and recovering the bell. The main safety relay and emergency stop were reset and the HPU was reset/restarted. At the same time the divers isolated the final leak and re-pressurised the bell back to 110 msw.

After the PLC Technician confirmed that the port LARS control and winches were in the correct operating mode for recovery to the trolley hooks, the bell was recovered back to and locked onto the TUP in a normal operational manner. The only non-standard selection was the continued need to override the vertical locking pin No. 1 sensor which was still faulty. The divers were transferred to the saturation chamber system where they underwent thorough neurological checks performed under the supervision of the onboard nurse in consultation with the Duty Diving Doctor.

Figure 4-5 highlights the location of the personnel during this phase of the incident.

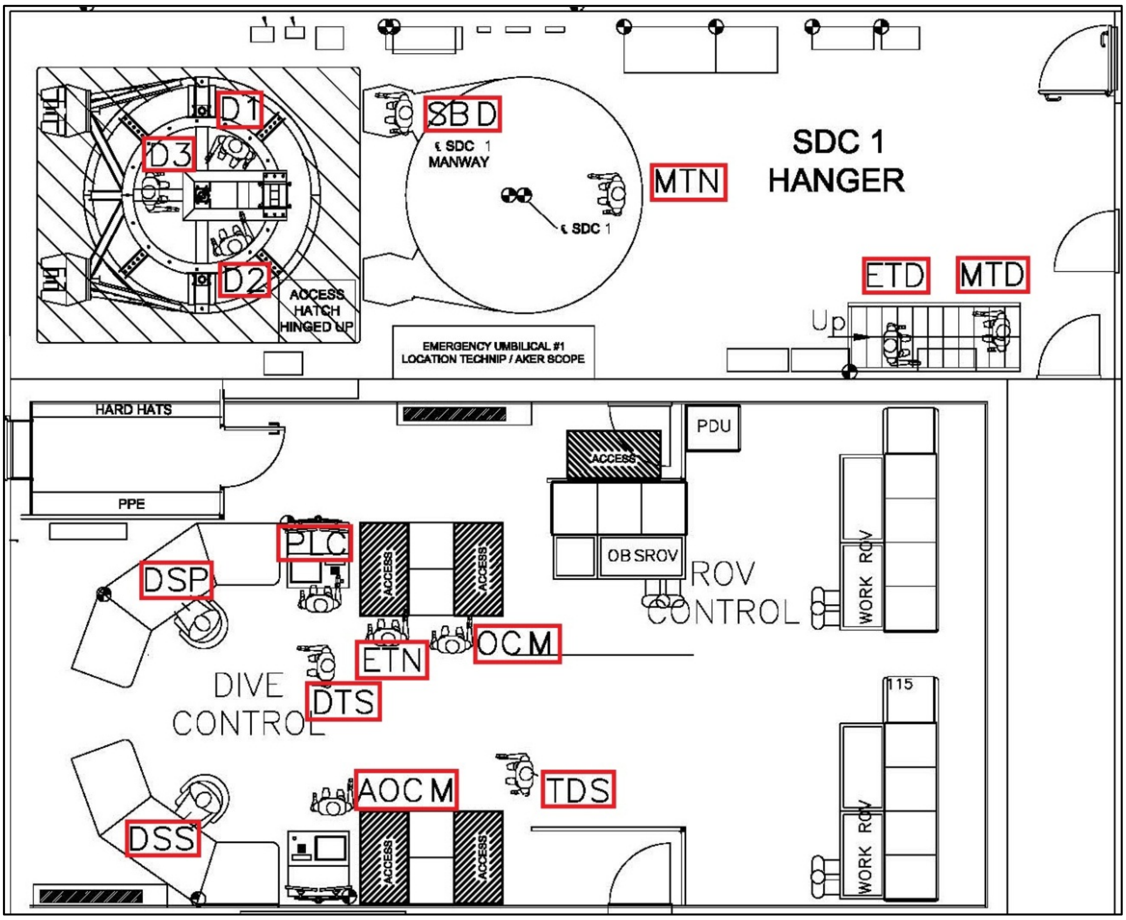


Figure 4-5: Dive control personnel movements during the recovery phase

4.4 Events after the Incident

4.4.1 Decision to secure the work site by continuing diving using the starboard bell only.

In the aftermath of the incident, a “Time out for Safety” session was conducted from hrs. 23:00 on the 22.06.2013, lasting until past midnight. At around midnight Marathon instructed via their Client Representative, after consultation within onshore management, that diving should be suspended until a formal risk assessment had been conducted and approved by Marathon onshore management. Furthermore, all required actions to avoid reoccurrence should be implemented. Marathon instructed Technip to suspend diving until a formal authorization to recommence was issued by Marathon.

Offshore discussions were held about completing the barrier test and making the work area safe before departing the field. All parties seem to have agreed that it would be preferable if the work site could be made safe. It is the investigation team’s understanding that there was a single barrier isolation between live hydrocarbons and the environment, and that Marathon wanted confirmation of the integrity of this barrier, and the implementation of a second barrier.

This would require a one bell operation, without the contingency to use the port bell in emergency situations. NORSOK U-100, section 9.3 allows for this providing a ROV is available, capable of connecting the emergency umbilical to the bell and as long as another, operational DSV is within range to rescue the divers if need be.

It would also require using a LARS, identical to the port LARS, which had just caused an incident with a potential for multiple fatalities. However the Diving Chief Engineer issued a Standing Order (early on 23rd June 2013) prior to these further operations with the starboard bell restricting use of over-rides and maintenance mode and requiring the approval of the Diving Chief Engineer and PLC Technician to use anything other than normal operating modes. The way the problem of 24th June (Sect 4.4.2) was handled is also good evidence that Skandi Arctic now had a clear understanding that maintenance mode was neither necessary nor acceptable to use whenever diver safety was dependent on LARS.

The agreement from the “Time out for Safety” session was to explore the possibilities for making safe the work site.

On-board the vessel Job Risk Assessments were conducted assessing “Diving Operations with single operational SDC”. The assessments concluded that risks were low (H-3C-LOW to H-2A-LOW) with respect to the function of LARS and the ability to recover the SDC. Risk is H-5A-MED with respect to the lack of a second SDC to assist if through water transfer from a lost bell is required. The divers in saturation, one of them a Safety Delegate, were consulted on whether they were content to carry on diving to secure the worksite or not. They all agreed to this but commented that they had to depend on the judgement of the surface crew and the dive management with respect to whether the LARS fault was 100% understood and mitigated for. It was not discussed how many dives would be necessary to secure the worksite.

Further action on board was to verify the readiness of the emergency umbilical, which can be connected to the bell in situations where the main umbilical is damaged and through which communications, verbal and visual, as well as gas and hot water supplies are restored. Also all ROV crew and diving crew on surface were familiarised with the procedures of connecting and using the emergency umbilical.

Technip onshore management made inquiries to establish whether a DSV was in operation within acceptable distance from the Kneler A work site and confirmed that the DSV Seven Falcon was performing diving operations at the Ekofisk field and could assist if necessary.

07:45 23.06.2013 Technip onshore management were informed of above mitigating actions and of the results of the Job Risk Assessment. This had also been presented to Marathon offshore representatives with assurances that the Technip offshore management considered that it would be safe to recommence diving in order to make safe the worksite.

Marathon Filter Group Meeting

As part of Marathon's procedure for incident management a group of relevant managers shall meet after an incident to agree further actions and level of investigation. The following positions participated in this meeting (Filter Group Meeting) at 09:30 on the 23rd of June: Managing Director, Operated Assets Manager, HESQ Manager, Subsea Manager (via phone), Subsea Project Engineer and Compliance Superintendent (who also was Emergency Response Duty Manager at the time).

The Filter Group got a briefing on the incident's latest status by the Duty Manager. Actual and potential consequences were discussed and investigation approach (mandate, participants etc.) was agreed.

The Filter Group members also participated in the morning call with the vessel and Technip Management at 10:00. Technip Management was represented by the Technip Group Diving Manager, Technip Norge Diving Manager and Technip Norge Project Manager. After the morning call the Filter Group continued their discussion but now also with the participation from the above mentioned members from Technip.

In this meeting the risk assessment was reviewed and it was agreed that the risk assessment needed a revision by Technip offshore. Different options for making the work site safe were also discussed. The number of bell runs required was discussed and it was clear that more than more than one bell run was required to make the site safe. The conclusion was that either it was safe to perform a one bell operation – or it was not. The decision was that as long as the requirements for such an operation were met, and corrective actions from the risk assessment put in place, diving could commence. An exact number of runs required to make the site safe was difficult to estimate but there was however a clear understanding that the dive operations should be limited to the scope of making the site safe. Comments to the risk assessment were provided and it was agreed that Technip should revert with an updated risk assessment and confirmation of actions being implemented.

A revised Risk Assessment was forwarded from OCM Skandi Arctic to Marathon representatives on-board and to Technip onshore management at 13:30 on 23.06.2013. It was forwarded to Marathon onshore management soon after and reviewed by Marathon and Technip onshore management

At 13:55 on 23.06.2013 an e-mail from Marathon onshore management confirms that the vessel is cleared to recommence diving.

Investigation team Evaluation.

The overall process leading to the decision to recommence diving is considered to be sound. They considered whether leaving the worksite "as is" would be safe and concluded that the hydro-carbon barrier situation was not optimal and that it ought to be improved. The challenge of diving with a LARS identical to the port LARS that failed, was risk assessed as was diving with only one operative diving bell. Mitigating actions were implemented, the divers were consulted and agreed to dive and Technip and Marathon onshore organisations agreed to proceed after having evaluated available information.

However the investigation team have some comments with regards formality of the process, the quality of the risk assessments, the extent of the mitigating actions and the fact that the risk assessments seem to have focused on assessing the risks involved in making a short dive. Also the need for revising the risk assessment, and what that revision entailed, seems unclear based on the available documentation.

The investigation team consider that a Management of Change process should have been initiated to deal with the changed situation and the changes in scope and procedures that resulted from the incident. A

Change Request Form, CRF 09, (EVID 22) was written on 23.06.2013, to cover abandonment of the work site without completing the work scope. CRF 09 is however not registered on subsequent DPR`s and there is no trace of a signed and approved document.

Two Job Risk Assessment Reports are documented, assessing "Diving Operations with single operation SDC". Attendees on one assessment (JRAR1) (EVID 022) are reported to have been: OCM (Job Supervisor), Captain, Dive Technical Supervisor, Project Engineer, two Marathon representatives, Technip Stavanger Office and Marathon Stavanger office. This assessment Report has no signatures. The scope of this assessment was: *"This JRA has been carried out for diving with the starboard SDC as the port SDC has a major mechanical breakdown and is unable to support us during a short dive"*. This is the risk assessment that was submitted as the revised assessment at 13:30 on 23.06.2013.

Attendees on the other assessment, is noted as: Senior Dive Supervisor, Gas Diver (Stand by diver) and AOCM (Job Supervisor). This assessment report (JRAR2) (EVID 22) is signed by all 3 attendees. The scope of this assessment was: "*This JRA has been carried out for diving with the starboard SDC as the port SDC has a major mechanical breakdown and is unable to support us during a short dive, while we stabilise the work site prior to departing the Field*". It is unclear if this was the first risk assessment that was sent in at 07:45 the same day, and that needed revision, but these are the only two assessments that are documented.

The difference in scope is significant in that JRAR1 does not consider the dive in question to have a scope limited to "*stabilising the work site prior to departing the Field*". Both reports, however, base their assessment and conclusions on "*performing a (one) short dive*".

The conclusions/HAZARD scores are identical on both assessments. Both assessments concludes that risks are low (H-3C-LOW to H-2A-LOW) with respect to the function of LARS and the ability to recover the SDC. Risk is H-5A-MED with respect to the lack of a second SDC to assist if through water transfer from a lost bell is required.

The quality of the risk assessment suffers through lack of attendance by specialised personnel such as the PLC technician, divers as well as the elected Safety Delegates. Also, the fact that the two LARS control systems potentially share a common failure mode might have been underestimated based on the written evidence. It is known, however, that by this stage the crew had the utmost respect for the failure that could ensue from use of maintenance mode, although they may not have formulated this well in the written word.

The Standing Order issued early 23.06.2013 to restrict the use of overrides and the use of maintenance mode would probably effectively have prevented an identical incident, but one could not be sure that there were no other combinations of faults that could lead to other incidents.

The fact that it took longer than could be expected to close the critical valves in the port bell during the first incident does not seem to have led to any mitigating actions prior to recommencement. It would have been appropriate to ensure that the Valve isolation checklist (Ruptured umbilical) was corrected and available, that the critical valves were identified and marked and that the divers were drilled on the "Loss of bell pressure emergency procedure".

Further, the investigation team is of the opinion that a new Job Risk Assessment should have been performed when it became evident that the job to make safe the work site would take more than one dive to complete. Several bell runs under the prevailing circumstances will have led to more risk exposure than one short dive.

4.4.2 Starboard Bell Recovery to Trolley Hooks Misalignment 24th June 2013

At approximately 04:00 during recovery of the Starboard Bell to the overhead trolley hooks a slight misalignment of the winch wires mean that one of the hooks would not engage. This is something that happens occasionally and historically maintenance mode would have been used to adjust the out of alignment winch to allow closure of the hook. In such instances the winches would have been in the correct configuration for winch operations and not traverse mode as was the case for the incident of the 22nd.

Consultation between El Tech, PLC Tech, AOCM, Dive Supervisor and Client Rep carried out and in this case the PLC Technician advised recovering the bell to the hooks using an alternative method that did not involve the activation of maintenance mode. (EVID-031 – Stbd Bell Recovery 24/06/2013)(EVID-033 – PLC_DAILY_Reoprt_22-24/06/2013)(EVID-034 – 24/06/13 Stbd Bell Wires Misalignment)(EVID-068 – DPR010).

This method involved overriding the ‘high’ sensor to allow further upwards movement of the bell to allow engagement of all 4 hooks. The system was still protected by the ‘high high’ sensor and alarm. This method worked. This evolution was carried out several times to verify operation with the divers out of the bell, at the request of the Client Rep.

It is confirmed that this procedure did not involve the use of maintenance mode and that the two incidents were not related. The Investigation Team is satisfied that at all times the system was in a safe configuration.

5. BARRIER ANALYSIS -

This barrier analysis has been constructed by the investigation team from the significant findings in this report. It is intended as an aid to understanding the physical, procedural and cultural barriers available during this incident.

Barrier	Status during incident	Comment
LARS HMI control integrity to prevent critical winches in Constant Tension mode whilst over moonpool.	Failed	LARS not subject to rigorous safety assessment. Maintenance mode active during diving not considered.
LARS HMI password protected to prevent maintenance mode access.	Failed	Technician has the password and it is the same as for activating an override which is what he intended to do.
Procedure to prevent maintenance mode selection with divers in the bell.	Failed	Not present.
Emergency stop.	Intact	Immediate stop using the brakes.
Deadman's trigger.	Intact	But perceived as failed by operators because it is a slow acting 'soft stop' and not immediate.
Winch motor over speed trip.	Intact	Soft stop using electronic braking of the winch motors.
Umbilical winch load out of range.	Intact	Soft stop using electronic braking of the winch motors.
Umbilical chute collapsed.	Intact	Soft stop using electronic braking of the winch motors.
Operator systems knowledge.	Failed	
Technician operational awareness.	Failed	
Supervisor caution after 1st uncontrolled descent.	Failed	
Emergency checklist for LARS failure.	Failed	Does not exist.
Umbilical main supply check valves.	Intact	Hot water check valve ripped off but internal hull valve was closed.
Management of Change procedure - MOC.	Failed	Unauthorised modification to hot water supply. No MOC.
Emergency drills for internal pressure loss in bell.	Failed	Drill not practiced. Physical drills not on Skandi Arctic training matrix.
Emergency checklist for uncontrolled bell depressurization.	Failed	Not immediately available to dive control personnel.
Basic Saturation diver training for isolating a leaking bell.	Succeeded, but needs improvement	Closing the valves took too long.
Internal hull stop valves.	Intact	Ergonomically inadequate. Should be grouped and marked to stand out from multiple other valves.
Bell gas reserves.	Intact	Gas available for a further 95 minutes at the average rate of depressurization during incident.
External hull stop valves.	Not used	Would have required personnel to enter moonpool. Barrier missing - equipment to allow standby diver access to the bell when in the moonpool.

Table 5-1: Barrier analysis during the incident

6. FINDINGS

6.1 Technology

1. The trigger for the sequence of events that led to the incident was a faulty vertical locking pin proximity sensor. The reliability of these sensors has been a recurring problem since commissioning and most, including the one in question have been changed for more reliable ones.
2. Traverse mode was selected by someone (unknown) soon after the bell descent was automatically stopped. The LARS HMI screen is a touch screen and without appropriate confirmation checks allows for these kind of errors.
3. The Electrical Technician selected and activated maintenance mode in order to override the vertical locking pin sensor. It is not necessary to use maintenance mode in order to override a sensor. By doing so he over-rode all safety interlocks in the system.
4. The ability to override individual faulty sensors is a functional requirement for the system design. It is a password protected operation and is only carried out by Technicians (Electrical, PLC).
5. The Electrical Technician entered a password as part of the procedure to activate maintenance mode.
6. The password is the same as for using the override function and only requires entering once (in a 15 minute period) in order to gain access to all access protected HMI screens.
7. The password was available in shift handover notes. It should have had restricted availability.
8. The Electrical Technician had used maintenance mode previously with divers in the bell to carry out an unrelated task of recovering the bell to the trolley hooks. The Dive Supervisor, LARS operator/AOCM and Electrical Technician did not realise the hazards of using maintenance mode while divers were in the bell.
9. When maintenance mode was activated the system read the mode selected on the Trolley and TUP screen and reconfigured the critical winches into constant tension mode. When in this mode the winches are not configured to take the weight of the bell.
10. The sequence of first selecting traverse mode on the Trolley & TUP screen and then activating maintenance mode were required in order to put the system into the unsafe configuration that allowed the uncontrolled descents to occur.
11. Both the Trolley & TUP and the Dashboard screens indicated that the system was in an operating mode that it was not. Because maintenance mode was active it had effectively locked the system so that it did not respond to selections made from the Trolley & TUP screen.
12. The indications on the Dashboard screen of the actual winch status of constant tension or speed modes was correct but the two characters “CT” or “SP” are normal text size and not highlighted. These indications are very easy to miss.
13. Inadequacies in the LARS PLC coding allowed the inboard and outboard wire winches to be in constant tension mode when the bell was over the moonpool (or TUP) and out of the trolley hooks.
14. Maintenance mode was not deselected by the LARS operator /AOCM or the Electrical Technician after the vertical pin sensor was overridden prior to the first uncontrolled descent. There are warning text boxes on all LARS HMI screen headers displaying “MAINTENANCE ACTIVE”. These warnings are not sufficiently highlighted.
15. If the LARS control system was not in maintenance mode, the safety interlocks would have remained in place. If the safety interlocks were in place, constant tension mode on the winches could not have been activated and the bell would have remained stationary when the deadman’s trigger was pressed
16. It is probable that the Electrical Technician selected winch mode on the Trolley & TUP screen but this had no effect on the actual winch configuration because maintenance mode had effectively locked out

actions carried out on this screen. The system remained in an unsafe configuration leading to the second uncontrolled descent.

17. The LARS HMI has gone through many code revisions during development and commissioning and the interface is not intuitive, the investigation team could not find supporting evidence for control over the software revisions in the first few years of LARS operations. Since the introduction of the MAF management of change system in 2011 there is a much better controlled system. Note that this finding is specific to the LARS control system only and not the main HMCS system which was under much more rigorous control from inception. In the investigation team's opinion the human factor evaluation could have been better and there is no evidence that the LARS control system went through a FAT.
18. The LARS HMI does not reinforce the LARS operating procedures by prompting or screen switching and relies on users to follow this elaborate, detailed written procedure.
19. During the second uncontrolled descent the brakes did not stop the diving bell in sufficient time before the main umbilical was over tensioned and severely damaged.
20. When the LARS operator/AOCM released the deadman's trigger, this activates a "soft stop" braking sequence designed to protect the system from mechanical damage. The investigation team consider this to be a reasonable functional requirement due to the inertia in the system.
21. The over speed on the wire winches tripped and activated a "soft stop" braking sequence as above. The investigation team consider this to be a reasonable functional requirement due to the inertia in the system.
22. The emergency stop button activates a rapid stop sequence by immediately applying the mechanical brakes but the bell did not stop before over tensioning the umbilical because it was descending faster than the braking system was designed for. The reason for this faster than normal motion was that the system allowed traverse mode to be active when in maintenance mode and out of the hooks. The investigation team consider this to be a flaw in the PLC design.
23. The Chinese finger, which secures the main umbilical to the bell and takes any load away from the umbilical connections was overloaded and broke. Neither the Chinese finger nor the umbilical are designed to take the weight of the bell. The umbilical winch has a lower power and greater inertia than the wire winches and thus did not pay out quickly enough at the higher than normal speed with which the bell descended. An umbilical chute designed to compensate for wave action, could not compensate for the rapid over-tensioning of the umbilical. The umbilical was already under tension, with the hydraulic dampers supporting the chute depressed, after the first uncontrolled descent.
24. Gas hoses in the main umbilical were severed at the termination plate. The umbilical connection points are not designed to take the load of a rapidly descending bell.
25. One umbilical hot water hose was terminated directly into the hull penetrator and was ripped from this fitting. The penetration fitting and the check valve was damaged. This was the result of an unauthorised change to the system. The change was made to minimize pipework heat loss.
26. The critical (leaking) internal hull stop valves were not closed as quickly as could be expected. The instructions from the dive supervisors was to close all valves. There are over 80 valves in the bell.
27. Sampling lines and pneumo lines from the bell are required to provide feedback to the surface; these lines cannot have check valves and began leaking gas.
28. The critical internal hull isolation valves were not grouped in a logical way.
29. The critical internal hull valves were not sufficiently marked or coloured to stand out from all other valves (about 80 in total).
30. The external hull stop valves were not closed because it was not safe for the standby diver to reach them. He was making preparations to enter the moonpool but the Dive Supervisor instructed him to

not enter due to inherent risks as no personal protection equipment was readily available for working at height.

31. The Starboard LARS control system runs the same PLC code and shares the common failure mode that caused this incident.

6.2 Organisation

32. LARS training is part of the Skandi Arctic dive system skills assessment program, but is considered insufficient (by the investigation team). In particular LARS operators and Dive Technicians have inadequate understanding of the LARS HMI and the control system logic.

33. It is not documented that Dive Technicians in any of the categories on-board have receive general training in saturation and bell diving techniques' to enable them to fully understand the relation between their own job performance and the health and safety of the diver.

34. The Dive Supervisor and the LARS operator/AOCM do not fully understand their roles, tasks and responsibilities and those of the electrical technician in a situation where the system is operated in a non-standard configuration.

35. The investigation team could find no checklist or procedure for checking or resetting the system after the emergency stop button has been activated.

36. Standing orders did exist for the situation at hand and could have prevented the incident if used (OOS-DIV-133, "Supervisor Technicians Standing order – Skandi Arctic, 31.08.2009). They were not widely known about amongst the diving technicians or on-board dive management. Presumably the standing order was established during the commissioning phase of the dive system and not revised / removed after the commissioning phase was completed. There is no formal procedure or guideline for evaluation, setup, approval and maintenance of Standing Orders for the vessel construction crew (non-Marine discipline).

37. There was an unofficial LARS launch and recovery "aide memoir" attached to the LARS HMI which does not contain critical points contained in the official LARS launch and recovery procedure.

38. Although the divers were calm and collected, it took more than 11 minutes to close the (4 of) leaking valves.

39. The OOS-DIV-C-248 Internal Valve Isolation Checklist (Ruptured or Loss of Umbilical) - Skandi Arctic was not available in dive control or in the bell and the Dive Supervisor and the Divers were not familiar with it.

40. Faults in numbering and functional descriptions were found on MOS-DIV-C-208 - "Port SDC internal check list (full) SLS equipped - Skandi Arctic" and on OOS-DIV-C-248 Internal Valve Isolation Checklist (Ruptured or Loss of Umbilical) - Skandi Arctic. Other checklists and procedures might have similar faults.

41. The hull stop valves, internal and external, are not marked as per "as-built drawing" (drawing no SDC 100101201S1 - SY113, Rev R03B, Port & Starboard SDC`s Overall Gas and Fluid Schematic) available for reference in dive control, rendering reference ineffective.

42. The valve closing sequence given in the Skandi Arctic specific valve isolation checklist (OOS-DIV-C-248 Internal Valve Isolation Checklist (Ruptured or Loss of Umbilical) - Skandi Arctic) is not optimized with regards to the leak potentials and possible leak rate.

43. The investigation team have requested, but are not made aware of the existence of any management of change procedure for the hot water umbilical termination into the bell hull as opposed to the termination plate.

44. The Skandi Arctic internal bell checklist (intermediate) that was used does not include confirmation of valve status.

45. Some procedures and checklists contain discrepancies in valve function and numbering, i.e. MOS-DIV-C-208 - "Port SDC internal check list (full) SLS equipped - Skandi Arctic". In general, procedures and checklists seem to be written more with the aim to ensure full compliance rather than as practical tools to aide skilled professionals in performing their work correctly.
46. There is no formal procedure or guideline for setup of dive system drills on-board or any clear expectations from the management of what training and drills are to be performed, their minimum frequency for repetition or what documentation they shall be based on. Management and discipline responsibilities for training, drills content, execution, performance evaluation and continuous improvement are not stated neither for the operational nor technical disciplines.
47. On the job training and drilling that require use of operational equipment/systems will conflict with project execution and progress. “Live” training should be complemented by simulator training to be effective.
48. Doc no OOS-DIV-067 - "Dive System Operations and Emergency Manual - Skandi Arctic" is in revision A, dated 31.November 2009, and described as Initial Proposed Manual. It is in use offshore and seems to be the only document that includes operational and emergency procedures for all or most relevant operational and emergency scenarios. Some of the procedures found in the manual, are revised and replaced by standalone procedures, without being removed from the manual.
49. FMECA`s and HAZID Reports (EVI 076, 077, 078 and 080) are available and have been used as basis for defining hazards and emergency situations. Findings have been used to dimension emergency preparedness as documented in Doc no OOS-DIV-067 - "Dive System Operations and Emergency Manual - Skandi Arctic". Some of the emergency scenarios covered in above referenced documentation have not been implemented on-board in the form of available emergency procedures/checklists and as routine emergency drills, amongst other “loss of pressure from the bell due to ruptured umbilical”.
50. The Safety Delegate system and the Work Environment committee do not seem to have been active in this case. There is no evidence that the Safety Delegates participated in the “Time out for safety (TOFS)” meeting or any of the two Job Risk Assessments held subsequent to the accident to evaluate eventual risks of recommencing diving. The saturation diver/safety delegate that was in saturation at the time, was consulted as a diver on whether he (and the other divers) were comfortable to continue diving. Offshore management does not seem to have consulted any of the safety delegates as such. On the other hand, there are no indications that the safety delegates took any initiative towards management either.
51. The investigation team has found information that indicates that Diving technicians, mainly Electrical Dive Technicians, are extensively used for project related work, sometimes to the extent where they consider it could compromise their work on the diving systems and equipment.

6.3 People

52. Traverse mode was incorrectly selected while the bell was supported by the winch brakes and out of the hooks. The investigation team is not able to establish who specifically made this operating error. However this was probably caused by modern touch screen technology: an operator may have pointed to an item on the screen, and changed its status without realising.
53. The LARS PLC does not reinforce the LARS operating procedure by prompting or page switching and relies on users to follow this elaborate, detailed written procedure. It is the opinion and experience of the investigation team that such elaborate procedures will not be used.
54. PLC Technician and Dive Technician Supervisor whom had the in depth LARS HMI & PLC knowledge was not present during either of the uncontrolled descents. They were not called to dive control until after the second uncontrolled descent. The PLC Technician was off shift but was on call.

55. There was tension left in the umbilical after the first uncontrolled descent which was not alleviated before the second uncontrolled descent. The AOCM had identified that the umbilical tension was above the allowable but did not act on his concerns.

56. The brakes were released prior to the second uncontrolled descent because the AOCM had witnessed the electrical technician working on the system after the first uncontrolled descent and believed the system had been made safe. The LARS operator/AOCM trusts the team and believes the electrical technician is competent. The Diving Supervisor accepted the decision of the LARS operator/AOCM.

57. There was no time out for safety during the incident.

58. The Divers did not close the internal bell hull valves quickly as could be expected, or in the most efficient manner.

6.4 Similar Events

59. On 22nd August 2010, the DSV Skandi Arctic was involved in Diving Operations when the starboard diving bell stand-off frame came into contact with the seabed. The bell was secured and successfully recovered to the vessel without harm to personnel. The decision was then taken to return to port to mobilise a team to carry out a full investigation. The investigation team does not consider that this incident has a direct relationship to the incident on 22nd June 2013.

60. On 31st October 2011 whilst the port diving bell was being recovered within the moonpool in good weather. The main bell cursor dropped down and impacted the drop head which was located on top of the bell. Three divers were in the bell and one received a minor impact to his head. No treatment was required. The investigation team does not consider that this incident has a direct relationship to the incident on 22nd June 2013.

6.5 Environment

61. Dive control was not noisy or overcrowded at the time of the incident

62. The incident took place during daylight hours, with a low sea state, light wind and good visibility. The investigation team does not consider the physical environment played a significant part in this incident.

63. The diving bell interior did not experience reduced visibility due to condensation caused by leaking gas.

64. Communications between the Dive Supervisor, Divers and the Launch Crew were not unduly disturbed by the noise of leaking gas.

65. The dive hangar was noisy when gas began escaping from the bell and main umbilical. Personnel were wearing ear defenders with clearcomms communications.

6.6 Other observations

66. Where a risk analysis report limits the scope of the analysis, there is not necessarily a complementary risk analysis that covers the omitted aspect.

67. Many of the risk analyses, FMECA`s in particular, does not consider operator error as a risk factor. There is not always another analysis covering this risk factor.

68. Not all risk analyses are routinely updated based on changing conditions, equipment, assumptions, knowledge etc. Feedback from updated risk analysis into improvement of the emergency preparedness is therefore not always forthcoming.

69. The Skandi Arctic Dive System FMECA and HAZID reports are not available on Agility (BMS) for regular review and updating.

70. Depending on the route chosen to enter Agility Diving Management documentation the user will get different results, as follows:

- T-MOS > T-MOS Vessels > Skandi Arctic > Dive Management System (188 documents whereof 20 manuals, 90 Procedures and 73 checklists) will only result in the old version of the Group Diving Manuals without any hint of them being superseded (also when exported to Excel the document list is repeated twice and does look like double the quantity at first glance).
- Diving Management System > Technip Group Diving Manuals (64 documents whereof 43 valid Group Diving manuals and 21 Superseded Diving Manuals). The superseded Group Diving Manuals only marked in the Agility header and not on each document (watermark etc.).
- Diving Management System > Vessels > Skandi Arctic (172 documents) being a mixture of procedures, checklists, drawings and UKBU project template documents, MOS-HR- documents without the same Agility header setup as for the above searches. Hence there is a great risk that user of Agility will not be able to retrieve the correct and valid documentation when required.

71. Searching Agility brings up both current and voided documentation and there is no distinction between them.

7. REVIEW OF DIVING OPERATIONS & REGULATIONS

7.1 Introduction

The incident occurred on the Norwegian Continental Shelf and during a diving operation, expected to be in compliance with Norwegian Petroleum and Working Environment Law, at the Marathon operated Alvheim field.

The investigation remit includes a review of findings measured against Norwegian regulatory requirements and relevant standards. Some of the findings reveal that, in spite of all efforts made to ensure full compliance, shortcomings' and/or deviations have been identified related to the incident involving launch and recovery operations on-board the Skandi Arctic.

The Findings as listed in the following are repetition of selected findings from Section 6 which reveal deviations from the regulations and standards. Deviations as listed in the following gives a status of compliance with same regulations and standards as found during the investigation of this specific incident, and are not necessarily representative for contractors other assets or operations".

Marathon has carried out comprehensive verification activities prior to start of operations, including audits on the Technip organisation and on the Skandi Artic. This is also the case for other Operators on the Norwegian Continental Shelf.

In this particular incident, we have focused on compliance towards the following regulations and standards:

PSA regulations:

- Frame regulation
- Management regulation
- Facilities regulation
- Activities regulations
- Work Environment Act (where applicable).

Standards:

- NORSOK U – 100 Manned Underwater Operations, edition 3, April 2009

7.2 Organisation, Responsibility and Authority

- Working Environment Act, Section 2.2 and 2.3
- Management Regulations, Section 14 and Section 19
- Activities regulations, Section 31
- Framework Regulations, Section 7, Section 10, Section 13
- NORSOK U – 100, Section 5.3, Section 6.37, Section 8, 8.1.2.3 and 8.1.2.5.

7.2.1 Findings

It was not ascertained that all equipment (the LARS) was safe to operate prior to commencing diving operations after the technician had overridden the faulty proximity sensor and after the first uncontrolled descent.

Appropriate precautions and actions were not taken prior to the second uncontrolled descent. With the warnings, alarms and system status information available to them from the LARS control system, all available expertise should have been called upon prior to attempting to recover the bell. The bell was at this stage locked in a safe position, and they could have used several hours to make a decision.

A Working Environment Committee and a Safety Delegate regime is in place on-board the Skandi Arctic. There were three Safety Delegates on-board at the time, one Main Safety Delegate and two Safety Delegates. One of the Safety Delegates is a saturation diver and was in saturation at the time.

The safety delegate/diver in saturation confirms that he and the other divers were asked if they agreed to recommence diving to secure the worksite, using the starboard bell only, and that they agreed to do so. There is, however, no formal documentation to support that the divers and the safety delegate in saturation were satisfactorily informed of the causes for the incident, and of the full implications of the decision to carry on, to be able to form a qualified and independent view on the issue.

There is no documentation to support that safety delegates were formally involved in “Time out for Safety” sessions, job risk analyses or the decision process leading up to recommencement of diving using the starboard SDC only.

There is no documentation to support that the safety delegates/safety committee took any initiatives towards on-board management in order to be included in the Job risk assessments, the evaluations of the incident or the decision to recommence diving after the incident.

7.2.2 Deviations

- The operation and shift management have not at all times ensured that they knew the status of the plant and equipment in use.
- Although a significant safety culture exists, the responsible party has not fully succeeded in achieving a climate where middle management and supervisors instinctively utilise the available resources and knowledge to ensure a safe outcome.
- Safety Delegates were consulted in the decision to recommence diving subsequent to the incident, but they should have formally participated in Time Out for Safety & JRAs, and formally agreed to the decision to recommence diving.
- Safety Delegates seem, in this case, not to have duly participated in critical safety evaluations and decision processes.

7.3 Emergency preparedness

- Activities Regulations, section 73
- Management regulations, section 16 and section 17
- NORSOK U – 100, Section 5.3 and 9.1

7.3.1 Findings

The responsible party has actively used risk analyses, FMECAs, HAZIDs and Design Reviews in the process of identifying hazard and accident situations and have to a large extent used findings from these in the effort to establish comprehensive and efficient emergency preparedness on board Skandi Arctic.

Where a risk analysis report limits the scope of the analysis, there is not necessarily a complementary risk analysis that covers the omitted aspect.

Some risk analyses, FMECAs in particular, do not consider operator error as a risk factor. There is not always another analysis covering this risk factor.

Not all risk analyses are routinely updated based on changing conditions, equipment, assumptions, knowledge or operational experience. Feedback from updated risk analysis into improvement of emergency preparedness is therefore not always forthcoming. FMECA`s are reviewed yearly and have a major revision every 5 years.

Emergency procedures and checklists based on the defined hazard and accident situations found in the risk assessment processes are, as a rule, made and implemented. Document no. OOS-DIV 067: Diving operation and emergency manual – Skandi Arctic, section 24 contains 43 equipment specific diving emergency procedures. Not all of these emergency procedures have been implemented on-board as part of the vessel/equipment emergency preparedness (for instance Section 24.25 Loss of Main Umbilical and OOS-DIV-C-248 Internal Valve Isolation Checklist ruptured/loss of umbilical).

A safety integrity level (SIL) assignment report concluded that no SIL requirements exist for the LARS control system. This was despite the fact that the initial HAZOP study identified safety critical risks closely related to the incident.

7.3.2 Deviations

- Necessary consistencies between risk analyses are not always present.
- There is not always a risk analysis covering human interaction as a risk factor.
- Not all risk analyses are routinely updated, and findings are thus not made available for improvement of emergency preparedness.
- Not all findings in FMECAs, HAZIDs and other analyses have been successfully mitigated for, through either design changes, operational measures or emergency preparedness.

7.4 Technology - Early Warning of Unsafe Equipment Status

- Facilities Regulations, Section 8, Section 10, Section 21
- NORSOK U-100, section 7.0 and 7.3, 7.3.1 General

7.4.1 Findings

The LARS control system allowed entering “Traverse mode” while the full weight of the bell was on the winches.

The LARS control system allowed entering maintenance mode during a live diving operation.

The LARS did not automatically warn the operator that it was in an unsafe state prior to the first and second uncontrolled descents.

The internal bell shut off valves for the umbilical connections were not grouped and marked to facilitate easy identification and prompt closing to stop the internal bell pressure loss.

7.4.2 Deviations

- The LARS control system was not equipped to prevent, detect or to limit the effect of the winches being in an unsafe state (constant tension while SDC was supported by the wires/winches/brakes).

- The LARS control system was not equipped to warn the operator of the unsafe state.

- The LARS control system design has not adequately limited the possibility of human error.

- Operating devices (critical internal shut down valves in the bell) were not designed, placed and grouped for simple and quick receipt of necessary information and implementation of necessary actions.

7.5 Competence, Training and Emergency Drills

- Activities regulations, Section 21 and Section 23
- Management Regulations, Section 14
- NORSOK U-100, Section 6.1 and section 6.3, point 6.3.7

7.5.1 Findings

There is a comprehensive training and familiarisation program with an associated skills assessment system in place for the diving crew on-board the Skandi Arctic. Yet the incident shows that both operators and technicians failed to understand the LARS control system sufficiently to handle the unexpected combinations of faults experienced prior to and during the incident.

The wrong mode (maintenance mode) was used for overriding a sensor during diving operations.

A comprehensive, documented emergency drill routine is available on-board the Skandi Arctic but does not encompass drills for a loss of pressure from the SDC due to ruptured main umbilical.

7.5.2 Deviations

- It is not documented that diving technical personnel have sufficient knowledge of or experience with diving operations/systems enabling them to understand the relation between their own job performance and the safety of the divers.
- Technical personnel have not always shown sufficient knowledge of applicable procedures.
- The responsible party has not adequately ensured that personnel at all times have the competence necessary to carry out the activities in accordance with the health, safety and environment legislation and were able to handle hazard and accident situations.
- The responsible party has not ensured that necessary training and necessary drills are conducted, so that the personnel are always able to handle operational disturbances and hazard and accident situations in an effective manner

7.6 Procedures and Documentation

- Activities regulations, Section 24 and 93
- NORSOK U-100, Section 4.2

7.6.1 Findings

Procedures and checklists in use have a format and a content that are not optimised as practical aids for skilled workers in doing their job correctly. Nor are they easily accessible when immediately required and there is therefore no instinct by operators to use them.

A procedure and checklist for use in case of loss of pressure caused by umbilical rupture was not in place while the incident occurred.

No contingency procedure was in place that covered the situation were the LARS stopped due to a proximity sensor alarm during an operational dive.

The Management of Change procedure was not used when altering the main umbilical connection points of the hot water supply hoses to the SDC.

7.6.2 Deviations

- Vessel specific procedures and checklists do not have a sufficiently user-friendly, simple and straightforward lay-out.

- Detailed emergency procedures covering all emergency scenarios were not available.
- The responsible party has not made available procedures covering all normal and emergency operation of the equipment.
- Personnel have not always adhered to the procedures for approval of alterations of the plant and equipment.

8. CONCLUSIONS

1. Incident Potential This is a serious incident which had the potential to fatally injure 3 divers. Although several safety barriers were breached, sufficient barriers remained intact and there is no evidence that injury occurred. On completion of the incident, 85% of the bell's onboard gas reserves remained available, sufficient to sustain life for an estimated further 1½ hours of gas leakage. The divers were able to isolate the bell leaks in 11 minutes.

2. Causation This incident occurred because the Programmable Logic Controller (PLC) based system that controls the bell during launch and recovery had been inadvertently placed in an unsafe state because the system allowed two separate operating errors to be made.

3. Introduction of PLC Technology The implications of introducing PLC technology to the diving industry might not have been fully understood, and the related roles, responsibilities & competencies of both technical and operational personnel are not sufficiently well clarified. The means of controlling software changes in safety critical PLC controlled systems are now satisfactory with the introduction of the MAF system.

4. Technical Risk Management Processes Although the risk management documentation for Skandi Arctic's diving systems is unusually advanced for a DSV, there is evidence that it lacks continuity and integrity. The FMECA and HAZIDs cover certain aspects of the equipment suite, but not all of them, and they do not consider operator error as a risk factor.

5. Emergency Procedures The diving organization has not sufficiently defined the emergency response for reasonably foreseeable hazard conditions, and not optimized ergonomic layout, checklists, training or drills for the most effective use. Furthermore emergency related processes are not audited for effectiveness or for feedback to improve related technical, procedural or competency systems.

6. Situational Awareness There was insufficient supervisory understanding of both the LARS system and the situational awareness needed to understand and control the human and equipment response to a complex hazardous situation.
At the end of the 1st uncontrolled descent it would have shown better judgment to leave the bell and divers in a temporary safe condition (all winch brakes were applied) and carefully consider the safest means of resolving the problem through discussion with the available expertise.

7. LARS SIL Rating The LARS was not given a SIL Rating by the sub-contractor tasked with developing the Technical Risk Analyses for the Diving Systems. This appears not to have been challenged by the Technip organization overseeing the procurement and construction of Skandi Arctic.

8. Operational Risk Management The decision to dive after the incident in order to make the worksite safe is understandable. Marathon had a clear responsibility to ensure the integrity of barriers between live hydrocarbons in the Alvheim subsea infrastructure and the environment. Hence Marathon permitted diving on advice from Technip that the starboard LARS had sufficient reliability and risk mitigation for manned use. Marathon and Technip, onshore and offshore, engaged in an appropriate decision making process, but should ensure a sound auditable trail is made when giving such consents.

9. Compliance, Audit, Inspection and Operational Feedback The investigation team has identified a number of deviations within the disciplines of diving equipment, operation, configuration control, documentation, competency, understanding, training & drills. Technip's compliance and audit organisations have not been able to detect these same deviations.

10. Responsibility Note that the legal responsibility for the safe conduct of a dive rests with the Dive Supervisor. He must therefore ensure that he understands and controls any interactions with the diving systems by technical personnel.

9. RECOMMENDATIONS

9.1 Immediate Recommendations issued to T-MOS on 19th July 2013

These recommendations were considered by the investigation team to be the minimum necessary to resume safe diving operation.

No	Summary	Action	Verification
TECHNICAL			
1	Modify the LARS PLC code to eliminate possibility of incorrect bell movement mode selection	Modify the LARS PLC code to ensure that it is not possible to place the system into Traverse Mode when the bell is not locked into the trolley hooks. This should not be affected by any other modes being active (such as Maintenance).	Review of code modifications. Trial onboard to demonstrate that Traverse Mode can't be accessed when bell out of hooks.
2	Replace Maintenance Mode requirement during Manned Underwater Operations with alternative function	If, during Manned Underwater Operations, a particular function is needed that is currently only available by activating Maintenance Mode (specifically when the bell is not level and a winch has to be adjusted to recover it to the hooks) this should be made available as a separate function. Furthermore the design should ensure that only essential interlocks (to accomplish said function) are overridden and that such overrides do not put the system into an unsafe state.	Review of code modifications. Trial onboard to demonstrate that alternative functions are available and work correctly instead of Maintenance Mode during MUO.
3	Remove Maintenance Mode from use during Manned Underwater Operations	Modify the LARS PLC code to ensure that Maintenance Mode can't be activated during Manned Underwater Operations. It should only be used for maintenance purposes when there are no divers in the bell.	Review of code modifications. Trial onboard to demonstrate that Maintenance Mode can't be activated during MUO. Risk review of implications of removing maintenance mode functionality during MUO, including EOPs.
4	Remove non-essential functions from the Maintenance Mode screen	Review the Maintenance Mode screen and remove any functions that are not required. It has been suggested that the right hand side of this screen that allows winches to be switched between Traverse and Winch Mode was written for commissioning purposes only and is no longer needed.	Review of code modifications. Trial onboard to demonstrate that Maintenance Mode is still able to meet its intended purpose.
5	Eliminate false positive indications on the HMI screens.	Modify the PLC code so that the HMI can only display the mode that the system is actually in (not the mode requested). Eliminate the ability for the Trolley & TUP and Dashboard screen to display that the system is in Traverse Mode when it is actually in Winch Mode (and vice versa). Review the HMI to ensure that there are no other instances of false indications.	Trial onboard to demonstrate that the correct indications are present for Winch and Traverse Modes.
6	Review the effectiveness of the LARS HMI screen header warnings	Review the LARS HMI screen header with respect to the clarity and effectiveness of the warnings indications for 'Overrides Active' , 'Maintenance Active' and any other messages displayed. Though these display as expected they do not convey the importance of such modes being active	Trial onboard to demonstrate effectiveness of displayed warning.

No	Summary	Action	Verification
7	Review of the LARS HMI screens to identify any other unsafe configurations that the system could be placed in.	Review the LARS HMI screens for operator selectable overrides and modes that could place the system into a similar unsafe operating state. In particular it is possible to make multiple selections from Overrides Screens 1, 2 and 3 which might allow the system to operate in the incorrect mode.	
8	Review the passwords to the LARS HMI protected levels	Review the password protection to the system ensuring that there is not a common password. It was reported that there were separate passwords for Maintenance Mode and Overrides but that they are now the same. Note that the LARS HMI Detailed Design Specification claims that there is only a single password level.	
9	Third party verification of the above code changes and actual operation.	Involve third party Functional Safety specialists to both review the changes to the code and witness proving trials onboard the vessel.	
PROCEDURAL			
1	SDC Emergency Procedures & Checklists	Go through and verify numbering and function of all valves, internally and externally, in both SDC`s.	
2	«	Update all internal and external SDC checklists for both SDC`s in accordance with above	
3	«	Consider to mark valves on copy of drawing no SDC 100101201S1 - SY113, Rev R03B, Port & Starboard SDC`s Overall Gas and Fluid Schematic available in Dive Control according to above numbering, in addition to Divex original numbering system. This would ease reference to drawings if and when necessary.	
4	«	Revise OOS-DIV-C-248 Internal Valve Isolation Checklist (Ruptured or Loss of Umbilical) - Skandi Arctic, in accordance with above. Prioritize valves to be closed immediately in accordance with criticality i.e.: 1. Related to umbilical and not equipped with check valves and open ended inside the bell, 2. Related to umbilical and equipped with check valves (in case check valves leak), 3. Related to umbilical and not equipped with check valves and NOT open ended inside the bell(If leak continues). When the leak is under control, a checklist preparing for receiving an emergency umbilical can be initiated, observing caution if having to operate any of the critical valves. Also, an effort should be made to reconfigure valves so that same category valves are grouped together on the hull penetrations, i.e. pneumo`s with pneumos, sample lines with other sample lines etc. This would further ease the identification of critical valves in an emergency situation.	

No	Summary	Action	Verification
5	«	Mark the critical valves, ref above, internally and externally in a manner rendering them easily recognisable both in light and darkness and standing out from other, less critical valves.	
6	«	Make OOS-DIV-C-248 Internal Valve Isolation Checklist (Ruptured or Loss of Umbilical) - Skandi Arctic(see above) available for easy reference in dive control and in both SDC`s.	
7	LARS Operational Procedures	During Normal Launch and recovery of the SDC`s using LARS, the operators are referring to an "Aide Memoire" to guide them through the actions needed. This "Aide Memoire" is taped on the LARS operating console for easy reference. The "Aide Memoire" does not have status as a procedure and has no place in the Technip document system. Further, it differs on several crucial points when compared to the approved documents, i.e. MOS-DIV-116- SDC Launch - LARS Normal Procedure - Skandi Arctic and MOS-DIV-117 - SDC Recovery - LARS Normal Procedure – Skandi Arctic respectively. If the "Aide Memoire" is followed to the letter, it circumvents important steps to confirm, amongst other, actual winch modes, CT or SP, which played a role in this incident. These steps are taken consistently throughout the launch sequence when using the official document/launch procedure. All "unofficial" and unverified documents, "Aide Memoirs", check lists and other should be removed asap and replaced with proper, verified and approved procedures and/or checklists. A systematic means of correct document control has to be implemented.	
8	«	LARS Normal Operational Procedures are described in Doc no OOS-DIV-067 - "Dive System Operations and Emergency Manual - Skandi Arctic", Section 23. These should be reviewed and revised to reflect current situation and to include limitations to which repair-, override- and/or maintenance- actions that are allowed in an operational situation with divers in the SDC`s. It should also reflect the fact that it is the Diving Supervisor, and nobody else, who carries the full responsibility for the safety of the divers regardless. The same manual also contains Recovery procedure for LARS in Emergency Situations, ref section 24.7. These should also be reviewed/revised to ensure that they reflect current situation and that suitably qualified personnel (PLC Engineer/technician) are involved in all stages of an eventual emergency recovery operation.	
9	Group Diving Management System	Doc no OOS-DIV-067 - "Dive System Operations and Emergency Manual - Skandi Arctic" is in revision A, dated 31.November 2009, and described as Initial Proposed Manual. It is in use offshore and seems to be	

No	Summary	Action	Verification
		the only document that gives operational and emergency procedures for all or most relevant operational and emergency scenarios. Step by step procedures, operating instructions and checklists contained in this manual should be extracted, verified for relevance and correctness and re-issued as stand-alone documents within the Technip Diving Management System, to facilitate revisions in accordance with future modifications/changes. Only a reference to these stand-alone documents should remain at the appropriate place in the manual itself. The rest of the manual should be revised to reflect current status as per DIVEX and/or internal modifications performed during and after commissioning. Emergency scenarios described should be linked to relevant FMECA`s and Hazid performed and should reflect findings and mitigating actions resulting from these. The manual should then be reissued as a vessel specific procedure within the Diving Management System. Examples: 1.:"MOS-DIV-116 SDC Launch - LARS Normal Procedure - Skandi Arctic" differs from OOS-DIV-Dive System Operation and Emergency Manual - Skandi Arctic, Section 23, 23.2.1 SDC Launch - Normal SDC Launch Procedure. Presumably the stand alone document is the correct one, because it was issued 11 Jan. 2012 as opposed to the manual which was issued in 2009. 2.: OOS-DIV-Dive System Operation and Emergency Manual - Skandi Arctic, Section 24, 24.25 Loss of Main Umbilical refers under "SDC Actions" to a Valve Isolation Checklist without further identification. The reference should be to: OOS-DIV-C-248 Internal Valve Isolation Checklist (Ruptured or Loss of Umbilical) - Skandi Arctic which contains the relevant checklist.	
TRAINING			
1	LARS Control System in training syllabus	There is a training system for operators in Skandi Arctic (detailed in MOS-HR-006 Rev 4 2011 Skandi Arctic Dive System – Skills Assessment & Verification). This is for Dive Supervisors, OCM/AOCM, Gas Supt, LSS, LST & Gasman. The LARS control system has not been included in this programme. The LARS control system is recommended to be part of the above training system.	
2	Training of technicians	The Mechanical, Electrical and PLC dive technicians are required to maintain the entire system and operate parts of it. They need to be	

No	Summary	Action	Verification
		included in the above group of personnel and be suitably integrated into appropriate parts of the training programme.	
3	Emergency Drills	Drills shall be based on the Skandi Arctic Operation and Emergency Manual and are to be conducted, paying particular attention to use of checklists and operation/incident control by the Dive Supervisor and Bellman.	
SAFETY MANAGEMENT			
1	Maintenance and update of FMECA	Start the review process for the FMECA. The links from Hazid, to FMECA, to design and operating documents, and back to the FMECA need to be reviewed and updated as a continuous process taking into account modifications and operational experience. This is unlikely to be completed prior to diving again, but needs to be commenced as soon as possible and shortfalls identified.	

9.2 Additional Immediate Recommendations

These are recommendations additional to those above issued on 19th July 2013, that should be implemented prior to a return to manned underwater operations.

No	Summary	Action	Verification
1	Potential damage to structure.	Carry out inspection of the structural integrity of the Bell & LARS load path.	Lloyds Register
2	Umbilical terminations.	Ensure that all main umbilical hoses terminate via a termination plate and not directly at the hull penetrator. The external isolation check valve should be positioned to afford them maximum protection.	Inspection by Technip Norge Diving Technical Manager.
3	Ergonomy of critical valves.	Identify and mark critical through hull skin valves so that they stand out and are easy to identify both in darkness and light.	Inspection by Technip Norge Diving Technical Manager.
4	Diving Supervisor responsibility.	Enforce the fact that it is the Diving Supervisor who is responsible for diver safety during a bell run. If repairs are required with divers in the bell, the responsibility remains his. He must actively satisfy himself that operational status is re-instigated prior to carrying on the bell run. Statements to this effect could be included in Dive Supervisor's job description.	Review of standing orders and DS understanding by Technip Norge Diving Technical Manager.
5	Compliance with Working Environment Law.	Reinforce the use of the Safety Delegate system on-board. The employer has a legal obligation to ensure that the employees are consulted and heard in matters regarding safety, health and working environment. Elected safety delegates on their side also have a legal obligation to participate in activities to improve safety, health and the working environment, and to stop	Review of working environment arrangements by Technip Norge Diving Technical Manager.

No	Summary	Action	Verification
		unsafe practices. A well functioning safety delegate system can assist management in creating a culture where one utilise the available resources and knowledge to ensure a safe outcome. To ensure understanding and respect, it is recommended that T-MOS onshore management are also trained in working environment law, at the level that supervises and audits Skandi Arctic diving activity.	
6	Situational Awareness	De-brief Skandi Arctic supervisory personnel on this incident, with particular emphasis that when faced with a crisis situation the supervisor in charge is to use all available information to establish the fault condition, and if time permits the available expertise is to be consulted before committing to a course of action.	Briefing by Diving Technical Manager.
7	Diving Approvals post incident	Onshore management in Marathon and Technip are to ensure they have an auditable process that demonstrates foreseeable risks have been accounted for and that safety delegates have been properly consulted when consenting to dive after an incident.	Diving Manager for Technip. Compliance Manager for Marathon.

9.3 Long Term Recommendations to Prevent Other Similar Incidents

1 Technician Training Formalize and document a Dive Technician training program focusing on diving methods, Diver safety and the relation between the work of the Technicians and the safety of the Divers. Technicians also need to achieve a consistent knowledge of the system (including PLC) functions and limitations.

2 OMT and Supervisor Training OCMs, AOCMs and Dive Supervisors should receive sufficient training in the dive control systems to understand the operational and safety implications of the selection of differing operating modes, maintenance modes and over-ride functions. The training is to emphasise the Dive Supervisor’s responsibility to remain in full control of Technician actions at all times that divers are exposed to system hazards.

3 Risk Management and Procedures The technical risk analyses (FMECA, FMEA, HAZID) for Skandi Arctic should be reviewed, re-written and re-issued such that there is a single consistent top-down approach for all diving related risks, to ensure there are no gaps in the suite of risk documentation, to ensure that human interaction and operator error risks are accounted for, and to ensure that there are proper emergency operating procedures or checklists covering all reasonably foreseeable hazard conditions. Specifically the SIL rating for LARS has to be reviewed. The technical risk analyses should be regularly reviewed and updated to reflect changes in conditions, equipment and knowledge gained from operational experience, incidents and accidents.

4 Emergency Checklists Checklists for operating and supervisory personnel should be re-written in an easy to read format based on practice in safety critical industries such as aviation. They also need to be instantly available to operating and supervisory personnel. As an example, Appendix G contains an assessment and suggestion from a consulting firm engaged by the investigation team.

5 Emergency Drills The emergency checklists need to be exercised with drills, either on the dive systems themselves under controlled supervision, or on a simulator such as is available for saturation

control. The performance of the team and Dive Supervisor conducting the drills needs to be periodically evaluated.

6 Ergonomic Arrangements Bell through hull penetrations for the umbilical gas, hot water, and signal/sensor lines should be positioned together in a logical way for easy identification and operation under normal and emergency conditions.

7 Contingency Diver Clarify the role of the contingency (stand-by) diver and his ability to access the bell exterior whilst in the moonpool in order to conduct emergency operations. If he is needed to enter the moonpool then appropriate protective equipment and training has to be identified and provided. This clarification can be based on technical risk assessment of the need to enter the moonpool for bell accident conditions.

8 Situational Awareness Training A modern DSV has complex multi-disciplinary safety critical systems that require Supervisors to have good Situational Awareness. T-MOS has initiated a programme that develops these skills. This incident is a good example of why this programme is essential. See the Note 1 below on Situational Awareness.

9 Repairs during Operations The Standing Orders need to clarify the types of repairs that can be done by Technicians on shift, and which of these need to be referred to the Dive Technician Supervisor for permission to proceed.

10 Modification Control The management of change system needs to be rigorously enforced for diving systems changes, and should be regularly audited as part of the compliance process.

11 Compliance, Audit, Inspection and Operational Feedback A compliance function exists within T-MOS and TNorge which covers whole ship safety issues such as classification & marine assurance, general HSE management and competency assurance. This compliance function needs to be enhanced towards diving systems, diving operations, diving technical risk assessment, diving operating documentation (normal and emergency conditions) and diving drills.

12 Procurement of DSVs and the Intelligent Customer Function Technip New Marine Builds needs to ensure that it has learned from this investigation and for safety critical systems (ie where human life is totally dependent on technology), that it has sufficient knowledge of the technologies being purchased, and sufficient influence over contractors to ensure that new DSVs are commissioned with optimal safety and operability built in. Please see Note 2 below on Intelligent Customer.

Note 1 Situational Awareness Situational awareness (SA) involves being aware of what is happening in the vicinity, in order to understand how information, events, and one's own actions will impact goals and objectives, both immediately and in the near future. Lacking or inadequate situation awareness has been identified as one of the primary factors in accidents attributed to human error. Thus, situation awareness is especially important in work domains where the information flow can be quite high and poor decisions may lead to serious consequences.

Situational Awareness is essential where technological and situational complexity on the human decision-maker are a concern. Situation awareness has been recognized as a critical, yet often elusive, foundation for successful decision-making across a broad range of complex and dynamic systems, including aviation and air traffic control, emergency response and military command and control operations, offshore oil and nuclear power plant management.

Note 2 Intelligent Customer The UK Nuclear Installations Inspectorate defines the "Intelligent Customer" function as follows: Intelligent Customer Function is an in-house capability within an organisation which assists the organisation in the procurement of outsourced services. The 'Intelligent Customer' retains sufficient technical knowledge of the services being provided by a third party to competently specify requirements and manage delivery of the services.

The Nuclear Installations Inspectorate (NII) of the Health and Safety Executive (HSE) developed the concept of the 'Intelligent Customer' in relation to licensee use of contractors and it has gained international acceptance.

10. ABREVIATIONS TERMINOLOGY & REFERENCES

10.1 Abbreviations & Terminology

Company	:	Marathon Oil Norge AS
Contractor	:	Technip Norge AS
Contingency Diver	:	For the purpose of this report reference to Stand-by diver actually means the Contingency Diver as defined by NORSOK U-100
Responsible Parties as defined in PSA regulations:		Operator, contractor and others participating in the activities

AOCM	Assistant Offshore Construction Manager
BE	Bridge Engineer
BMS	Business Management System
CRF	Change Request Form
CT	Constant Tension (winches)
DNV	Det Norske Veritas
DP	Dynamic Positioning System
DPR	Daily Progress Report
DS	Diving Superintendent
DSV	Dive Support Vessel
Elec	Electrical
EVID	Evidence
EVP/COO	Executive Vice President Chief Operating Officer
FAT	Factory Acceptance Test
FMECA	Failure Modes, Effects & Criticality Analysis
HAZID	Hazard Identification Study
He	Helium
HMCS	Hyperbaric Monitoring & Control System
HMI	Human Machine Interface
HPU	Hydraulic Power Unit
HSE	Health, Safety and Environment
IMCA	The International Marine Contractors Association
IV	Installation Vessel
JHA	Job Hazard Analysis
JRA	Job Risk Assessment
LARS	Launch And Recovery System
MAF	Modification Approval Form
mbar	Millibar
Mech	Mechanical
MoC	Management of Change
MOC	Management Of Change (process)
MONAS	Marathon Oil Norge AS
msw	Meters of Sea Water

mtrs	Meters
MWS	Marine Warranty Surveyor
NCR	Non Conformance Report
OCM	Offshore Construction Manager
OIM	Offshore Installation Manager
OMT	Offshore Management Team (OCM, Master, Chief Eng)
PE	Project Engineer
PLC	Programmable Logic Controller
PO_2	Partial Pressure Oxygen
POB	Persons On Board
PSA	Petroleum Safety Authority
PTil	Petroleumstilsynet
PTW	Permit To Work
RCA	Root Cause Analysis
RCDD	Responsible Competent Diving Doctor
Rep	Representative
ROV	Remote Operated Vehicle
SC	Speed Control (winches)
SCADA	Supervisory Control And Data Acquisition
SD	Safety Delegate (Working Environment Law)
SDC	Submersible Decompression Chamber (Bell)
SIL	Safety Integrity Level
SJA	Safe Job Analysis
SMART	Specific Measurable Achievable Relevant Time
TBT	Tool Box Talk
Te	Metric Tonne
Tech	Technician
T-MOS	Technip Marine Operations Services
TNOR	Technip Norge AS
TOFS	Time Out For Safety
TOR	Terms of Reference
TUP	Transfer Under Pressure
VOM	Vessel Operations Manager (TMOS)

10.2 A Note on the Technip Organisation

Technip Norge (TNOR) is part of Technip's North Sea Canada (NSC) Region, one of 7 regions that engage in project execution and engineering in client contracts worldwide for subsea, offshore and onshore work scopes.

The NSC Region reports to the EVP/COO Subsea in Paris.

Technip Marine Operations Services (TMOS) is based at Aberdeen in the United Kingdom and is part of the Technip Group Subsea Division, reporting to the EVP/COO Subsea in Paris. T-MOS is an internal contractor to TNOR, in this case responsible for providing the Skandi Arctic DSV and crew competent and compliant for manned underwater operations in Norway. Technip Norge's single point of contact within T-MOS for the DSV is it's Vessel Operations Manager (VOM) in the T-MOS Asset Delivery department.

Technip Norge operates at 4 sites in Norway: Oslo, Stavanger, Haugesund and Orkanger. Technip Stavanger has a diving discipline function. This does not have direct responsibility for manned underwater operations, but is in place as an interface function (for diving related planning, logistics & organisation) between Technip Norge projects that utilise diving services and T-MOS. Additionally it is a compliance function to ensure that the T-MOS DSV is qualified for diving in Norway. Technip Stavanger also has a health service that provides medical control of the diving operation, an RCDD, Duty Doctor and on-board Hyperbaric Nurse.

10.3 References

The evidence log contains the majority of the referenced documents, Appendix C. Any documents not directly referenced as evidence have been included in the list below.

	Document Number	Document Title
Diving Documentation		
/1/	-	Technip Group Diving Manuals January 2013
/2/	U100	Manned Under Water Operations
/3/	MOS-GM-DIV-12122 rev.2	Group Diving Manuals Bell Emergency
Vessel Specific References		
/4/		
Dive System Specific References		
/5/	OOS-DIV-067 Rev.A	Dive System Operations & Emergency Manual Skandi Arctic
General Documentation		
/6/	GOPS – 10009	HSE Incidents classification, notification, investigation & reporting
/7/	NR033560 – 10006_0	Skandi Arctic Emergency Notification Flowchart
/8/	NR033560-10005	Skandi Arctic Emergency Preparedness Plan
/9/	NR033560-10003	Skandi Arctic Emergency Response Manual

11. APPENDICES

Appendix Number	Contents
Appendix A	Information on vessel organisation and dive system
Appendix B	LARS Control System
Appendix C	Evidence Log
Appendix D	Detailed Timeline
Appendix E	Root Cause Analysis
Appendix F	Potential Consequences Analysis
Appendix G	Human Factor Evaluation

APPENDIX A – INFORMATION ON VESSEL ORGANISATION AND DIVE SYSTEM

11.1 Organisation Chart

The following extract is from QMS and demonstrates the onshore and offshore diving organisation. Detailed job descriptions are available for each position and have been examined by the investigation team. Where relevant these job descriptions have been included in the evidence log, Appendix C.

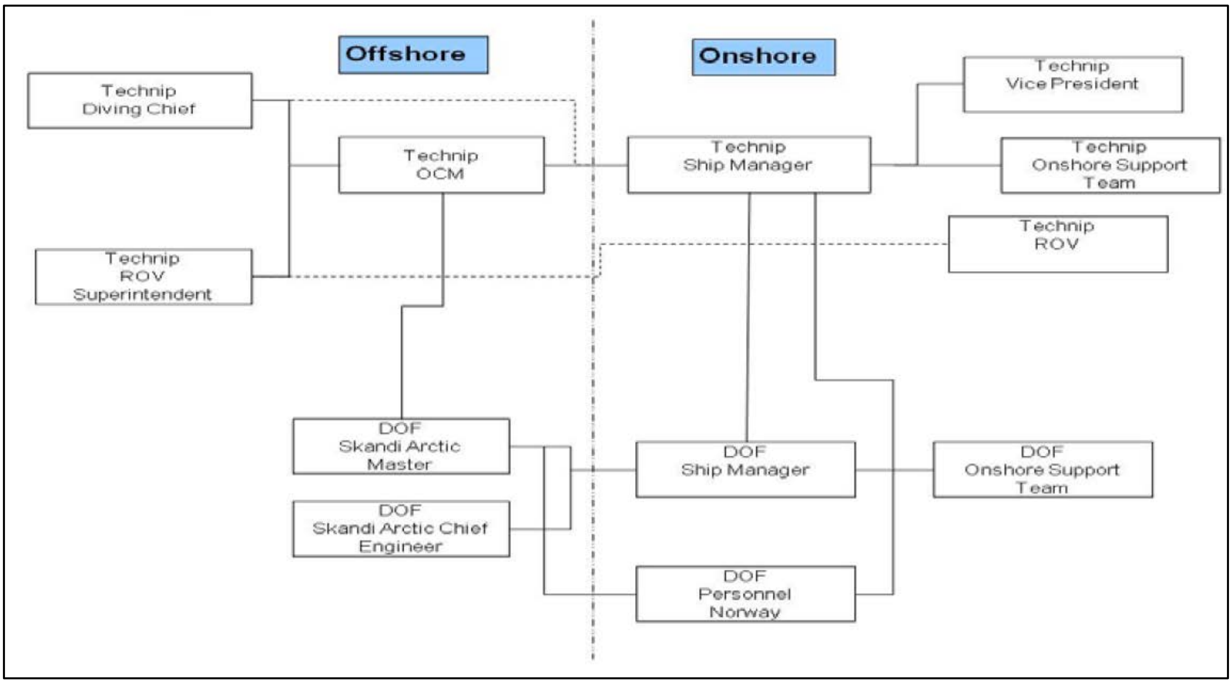


Figure 0-1: Technip DOF Onshore/Offshore Communication Lines – Skandi Arctic – Extract From MOS-HSE-040

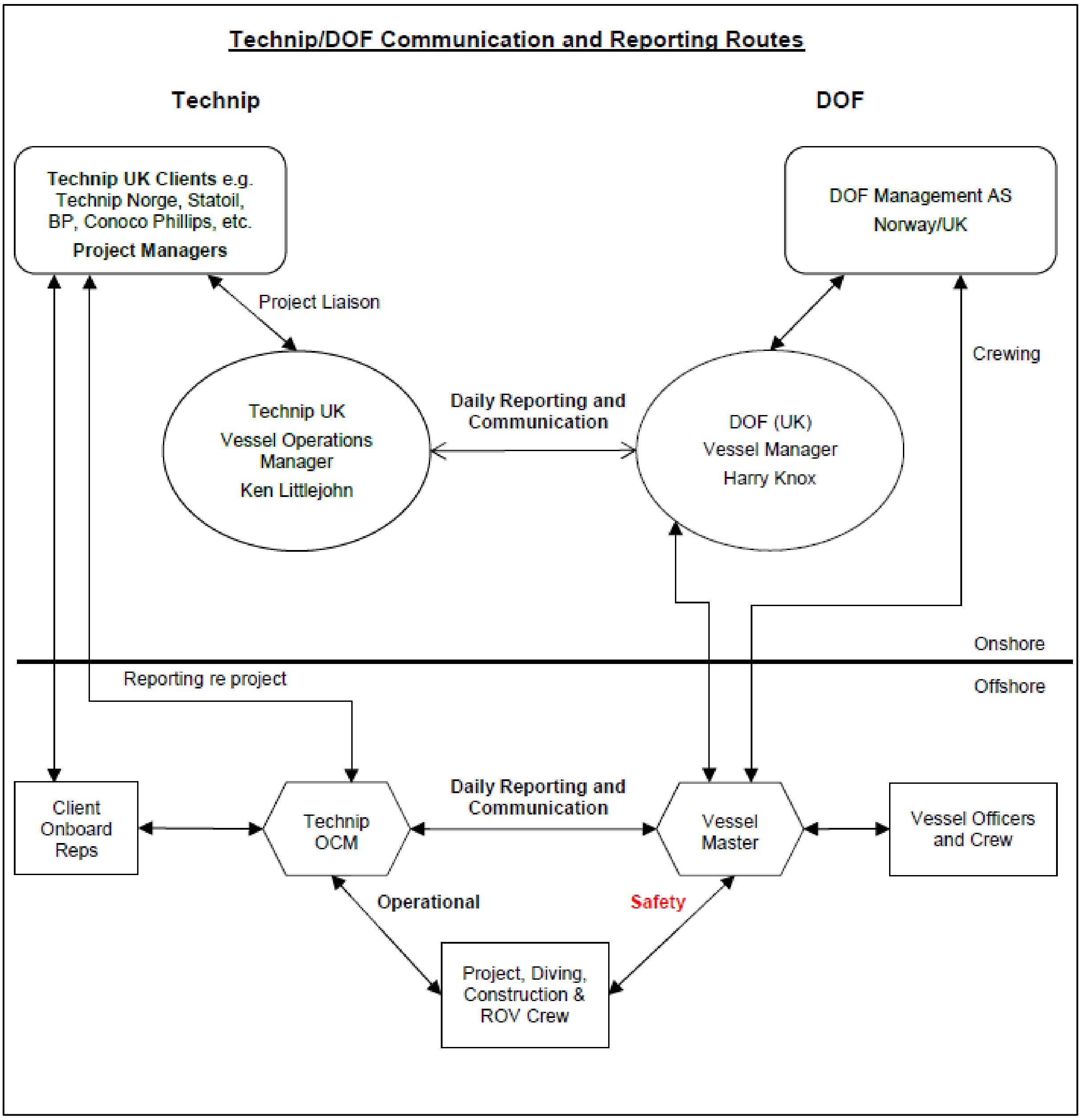


Figure 0-2: Technip DOF Communications and Reporting Routes – Extract From MOS-HSE-040

11.2 Dive System Details

11.2.1 System Overview

The system provides saturation diving services and has an integrated 24 man saturation diving complex which is rated to 350msw. The system comprises 2 x 6 man and 4 x 3 man living chambers as well as 2 x 3 man diving bells (port and starboard). This is supported by 2 x 18 man hyperbaric lifeboats and is fully compliant with Norwegian NORSOK standards.

The dive system was designed and built to Lloyd's Register Rules and Regulations for the Construction and Classification of Submersibles and Underwater Systems.

Each bell is deployed and recovered through its own moonpool with its own launch and recovery system (LARS). The LARS is a 3 wire system whose winches are synchronised and provide redundancy for emergency recovery.

Figure 0-2 is a representation of the Skandi Arctic saturation diving system. Three areas of interest have been highlighted on this model;

- 3 x wire winches & 1 x umbilical winch (Figure 0-4)
- The vertical pin and guide rails (Figure 0-5)
- The umbilical entry point on the bell and umbilical termination panel. (Figure 0-6)

Pictures from these three areas have been presented in Figure 0-4, Figure 0-5 & Figure 0-6. Where appropriate these pictures have been accompanied by a short description.

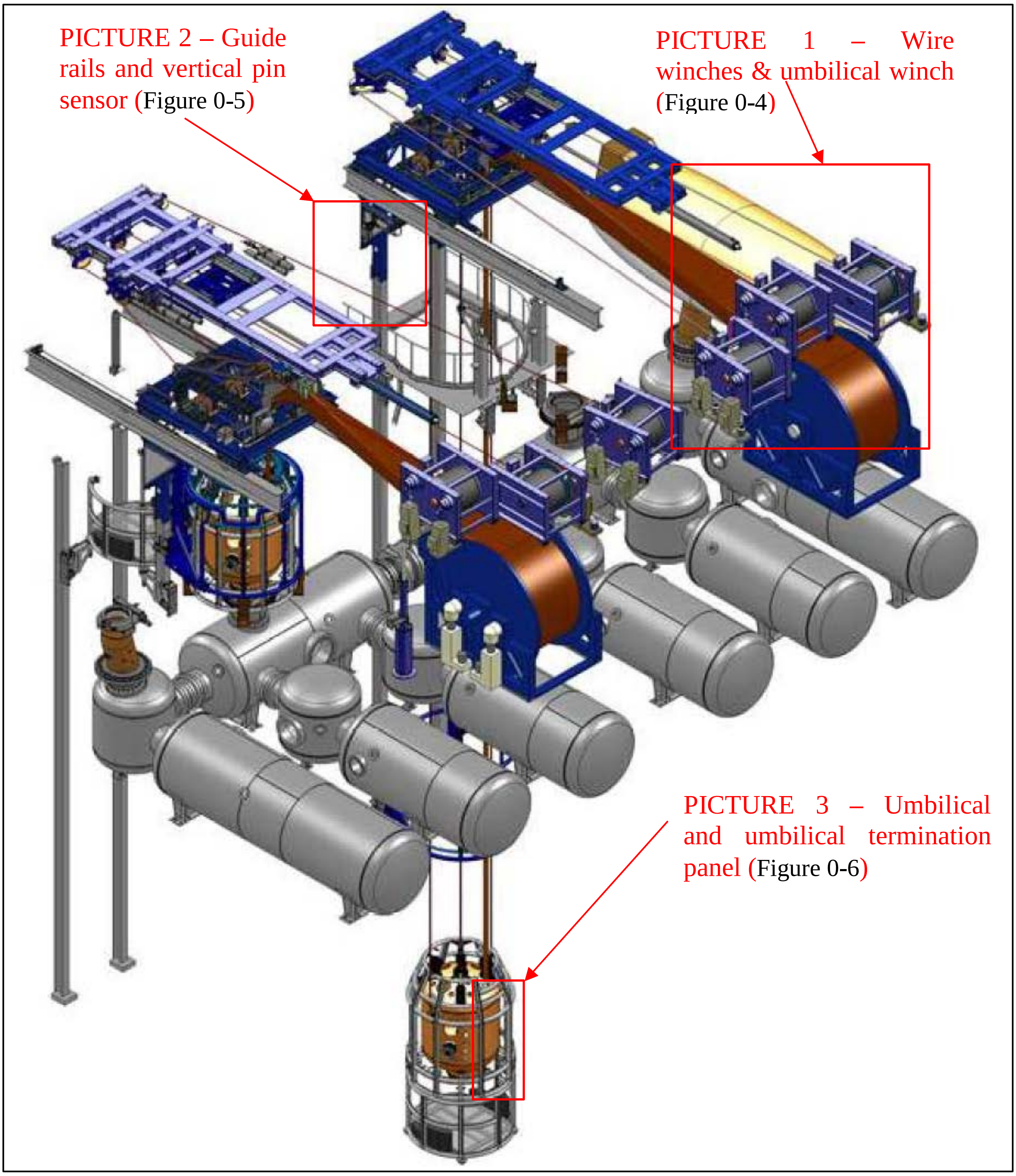


Figure 0-2: Skandi Arctic Dive System

11.2.2 Winch System Overview

Figure 0-3 shows the basic winch arrangement. There are three main winches (Inboard, centre and outboard) and one umbilical winch.

Normally, the system will be operating in one of the two defined operating modes, Winch mode for vertical movement over the moonpool or TUP and Traverse mode for horizontal movement between the moonpool and TUP. These modes place the winches into one of the two modes, speed control mode and constant tension mode which in turn place the winch drives into one of the two modes, speed control mode and direct torque mode. The relationship of these modes is explained in Table 0-1.

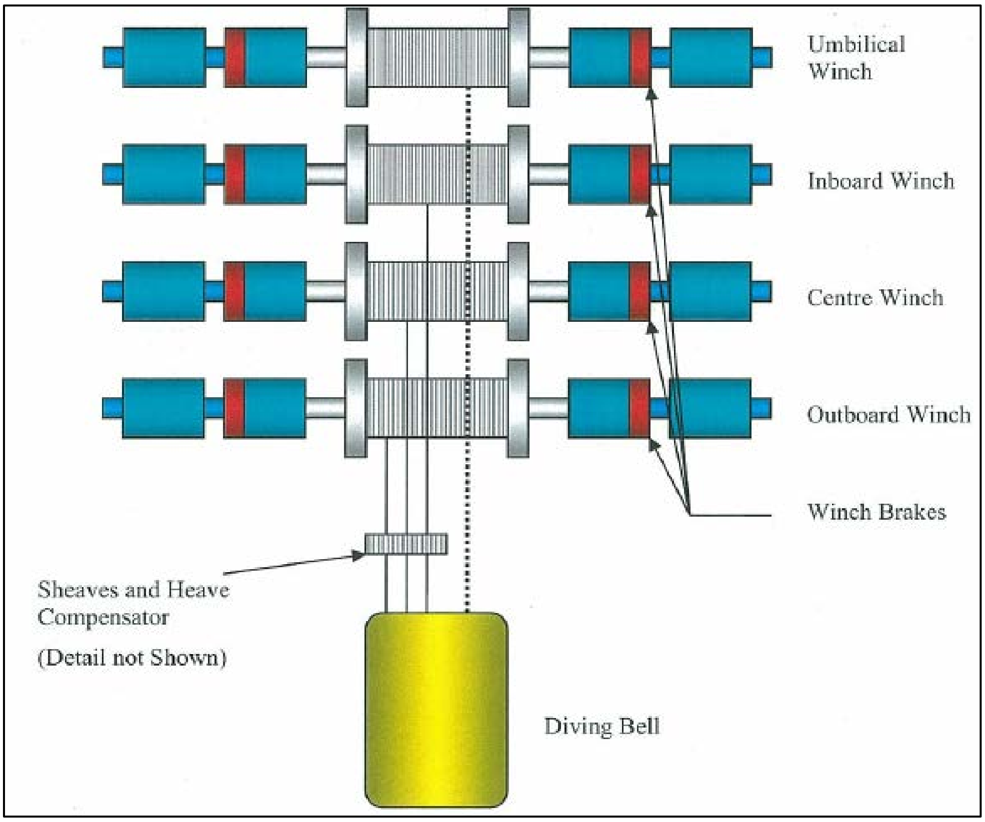


Figure 0-3: Winch arrangement

System Mode	Winch	Winch Modes	Design Tension (Te)	Drive	Drive Modus
Winch	Inboard	Speed Control	9.0 – 11.0	Master	Speed Control
				Follower	Direct Torque Control (reference from master)
	Centre	Constant Tension	2.5 – 5.0	Master	Direct Torque Control
				Follower	Direct Torque Control (reference from master)
	Outboard	Speed Control	9.0 – 11.0	Master	Speed Control
				Follower	Direct Torque Control (reference from master)
	Umbilical	Constant Tension	0.5 – 1.5	Master	Direct Torque Control
				Follower	Direct Torque Control (reference from master)
Traverse	Inboard	Minimum Constant Tension	1.5	Master	Direct Torque Control
				Follower	Direct Torque Control (reference from master)
	Centre	Minimum Constant Tension	1.5.	Master	Direct Torque Control
				Follower	Direct Torque Control (reference from master)
	Outboard	Minimum Constant Tension	1.5	Master	Direct Torque Control
				Follower	Direct Torque Control (reference from master)
	Umbilical	Minimum Constant Tension	0.5	Master	
				Follower	Direct Torque Control (reference from master)

Table 0-1: Winch System Modes

Winch Mode

With all three Main Winches active, when in Winch Mode, the inboard and outboard winches will be in Speed Control Mode with the Centre Winch in Constant Tension Mode. In the event of loss of a Main Winch, the remaining two Main Winches are able to raise and lower the Diving Bell. In this case the drives on both winches will operate in Speed Control Mode. This is not an automatic function, should a Main Winch fail then the system will stop and the operator can manually select to disable the failed winch and run on the remaining two. In Winch Mode, the Umbilical Winch shall operate in Constant Tension Mode.

Traverse Mode

In Traverse Mode, all winches will operate in Minimum Constant Tension Mode. This is a mode identical to Constant tension but with a reduced Maximum Tension limit for horizontal movement between the moonpool and the TUP.

Brakes

The Motors, on each winch of which there are two, have a 8 Te hydraulic disc brake that is electrically controlled by the drive controlling the motor. A Hydraulic Power Unit (HPU) provides hydraulic power to the brakes via hydraulic accumulators that allow the brakes to be released even when hydraulic power is not available. Loss of hydraulic power (pressure) activates the brakes in a 'fail safe' manner.

Under normal operation (i.e. when releasing the dead mans lever) before the brake is engaged the drive decelerates the load using braking resistors as required to dissipate the energy.

For an Emergency Stop the LARS HPU is immediately shut down as 440V power supply is removed from the pump. The hydraulic pressure required by the Winch Drive Brakes for the controlled stop of the winches is removed and the brakes stop the winches.

At the same time as the brakes being activated the Winch drives utilize timed delay contacts to allow the drives to stop in a controlled manner. The timed delay contacts on the winch drive safety relays only remove the power to the drives after the time delay has elapsed thus allowing the drives to perform a controlled stop. During this time delay period the winches decelerate rapidly using brake resistors if required to dissipate the excess energy.

Figure 0-4: PICTURE 1 - 3 x wire winches and 1 x umbilical winch (port side)

11.2.3 Vertical Locking Pin Sensor

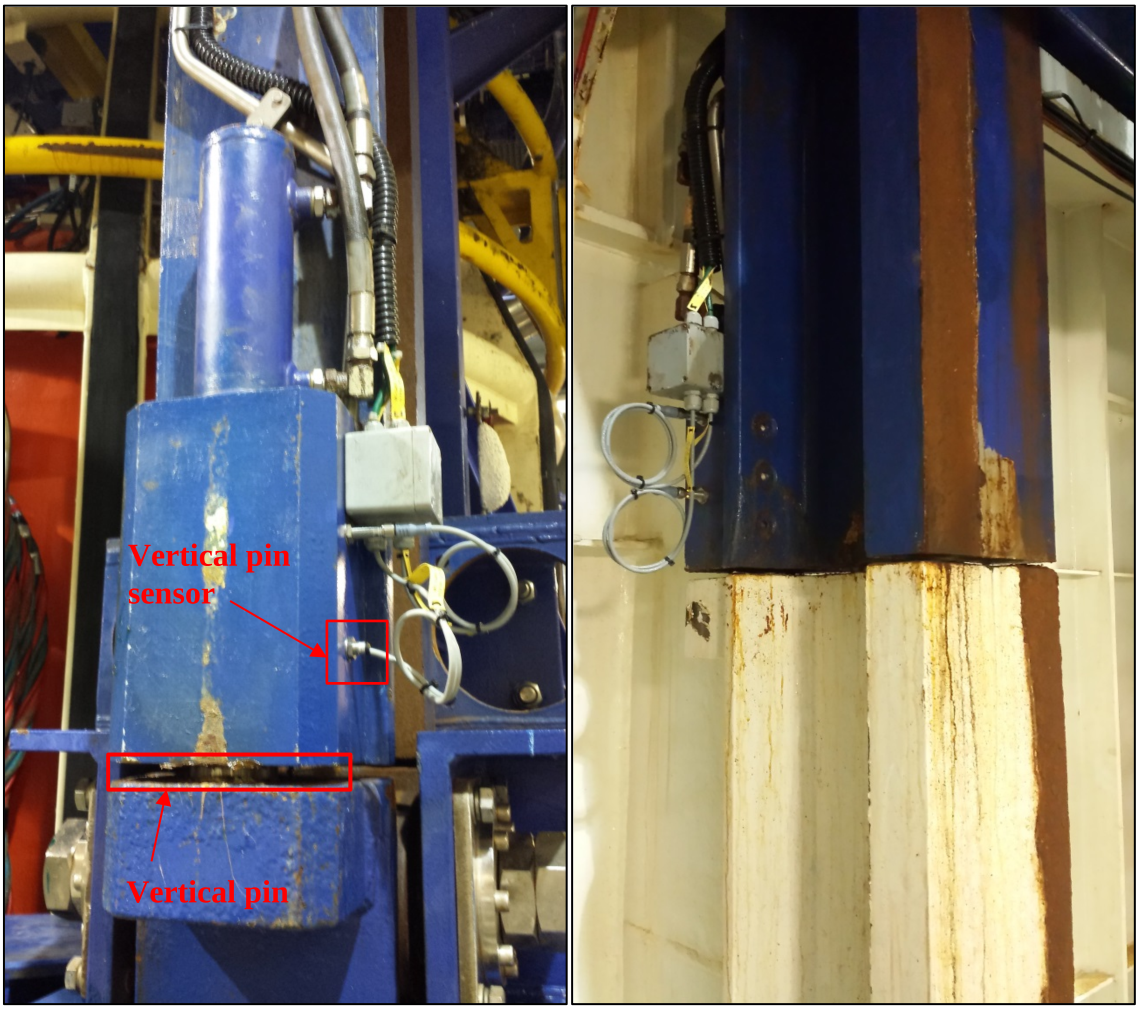


Figure 0-5: PICTURE 2 - Vertical locking pin sensor (left) and guiding rails (right)

Figure 0-5 shows the vertical locking pin 1 lock sensor which reported inconsistent (faulty) and led to the automatic soft stop of the system during initial lowering of the bell through the moonpool. From build, these sensors have a history of faulty operation and have almost all been swapped out for more reliable and robust ones with a greater activation range. In the case if this sensor it was an excessive build-up of grease that led to the faulty operation.

Figure 0-6: PICTURE 3 - Umbilical termination plate (left) and standard umbilical entry / termination (right)

Figure 0-6 shows the chinese finger used to secure the main umbilical to the bell frame via wire strops and shackles. This system has been manufactured for a maximum design load of 1.5 Te and normal working load of 0.5 Te.

During launch and recovery the bell is contained within a cursor system. This is made up of an inner frame (drophead) and an outer frame (main cursor) and ensures bell stability during launch and recovery and transfer from the hyperbaric complex to the moonpool. It further ensures a smooth transition through the moonpool in the air/water interface to the bottom of the moonpool guide rail stops, Figure 0-7.

The entire cursor system is passive and all lifting and lowering of the bell and cursor system is carried out by 3 independent winches attached to the top of the bell, Figure 0-4.

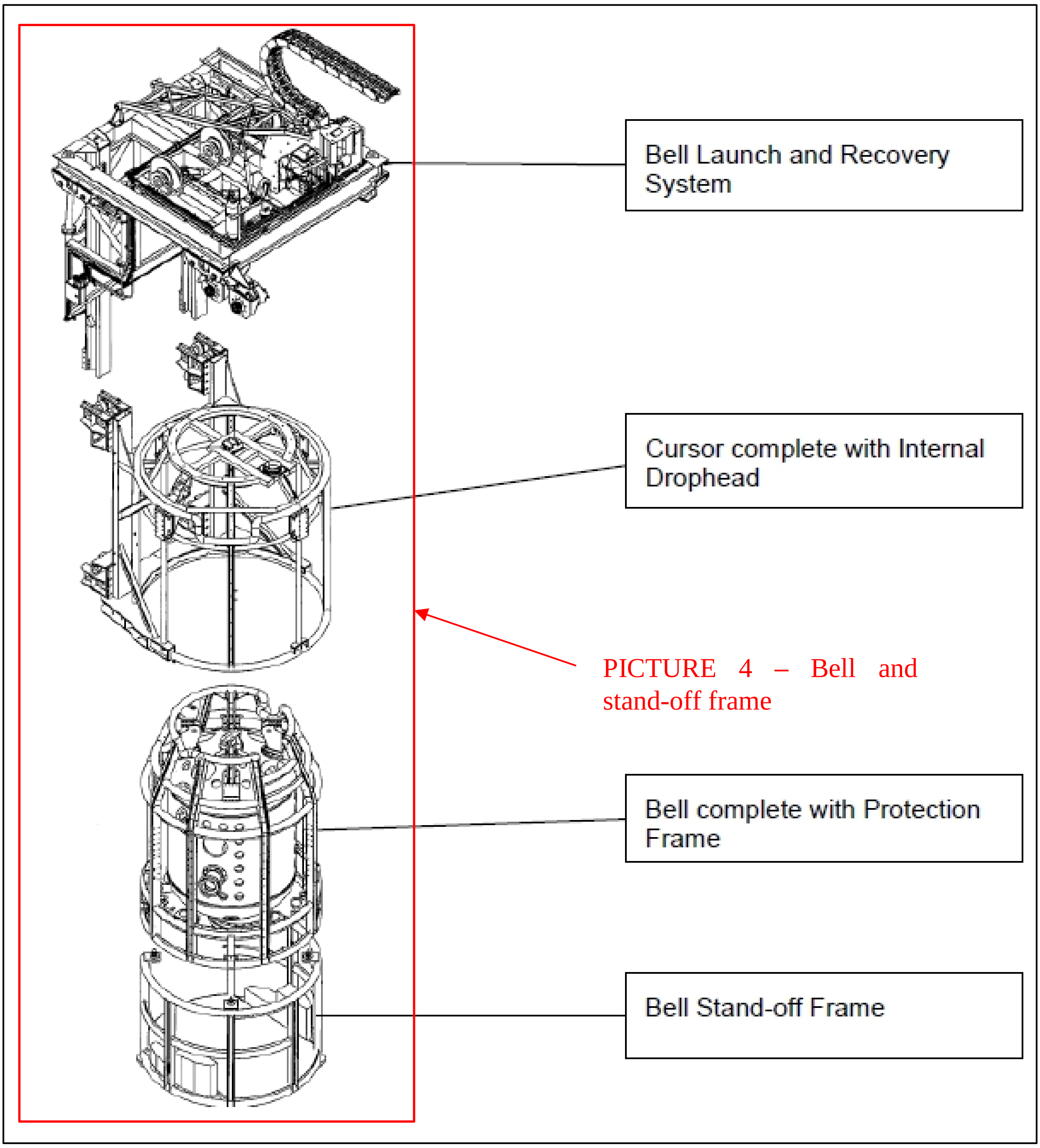


Figure 0-7: Diving Bell Deployment Set-Up

Figure 0-8: PICTURE 4 - Diving bell attached to stand off frame above deployment moonpool (stbd bell)

11.2.4 Dive Control

Dive Control on-board the Skandi Arctic is a shared control room with ROV Control.

Both starboard and port bell LARS' are controlled from this room as the 3 man dive team is transferred from the saturation system in to the bell. There is one Dive Supervisor for each diving bell and a 3rd Supervisor assisting in launch and recovery of the bells. For night operations the AOCM acts as the 3r supervisor for LARS operations.

The Dive Supervisor is communicating with the divers through a clear coms system that is monitored by various functions on the DSV, typically the Bridge, Sat. control, Deck, Crane, ROV, Client office, Project office etc.

A Bell Dive Report Sheet is completed with all the particulars from each bell run.

Relevant and site specific documentation pertaining to normal operation and emergency operations shall be available in Dive Control. These procedures shall include minimum requirements in order to commence an operation, criteria for suspension and emergency procedures.

There is a common shift handover logbook for Dive Control where a summary of project events and status including procedural changes and equipment breakdown is noted.

A separate Bell Defects book is used for noting defects to be rectified.

Figure 0-9: Overview of dive control stations (port and stbd)

11.2.5 Port Lars Control Panel

The port bell LARS station consists of a touch screen HMI, joystick and emergency stop button which can be seen just forward of the joystick (Figure 0-10). Additionally monitors display necessary video feeds.

The system is controlled by the operator manually via the HMI screens and the proportional joystick with dead man's trigger. The PLC system limits the maximum available winch speed automatically based on the bell position and the proportional joystick allows the operator to control the required speed within these limits. Movement of the bell is only possible when the dead man's handle is depressed; this eliminates any accidental motion caused by accidental movements of the joystick. The traversing of the trolleys is also controlled by the joystick. Vertical motion of the joystick controls bell launch and recovery and horizontal movements. The operator controls discrete functions such as bell Hooks and Trolley Locking Pins manually via buttons on the HMI screen. There are also multiple HMI screens for use by technicians for system maintenance and calibration. Theses HMI screens are password protected.

The system is normally operated in either winch mode for launch and recovery of the bell or traverse mode for traversing the bell between the moonpool and the TUP.

Either a 3rd Dive Supervisor or the AOCM normally act as LARS operator with the ability to call the on duty mechanical, electrical, PLC technician or Dive Chief Engineer for advice or action as required. Any nonstandard operation such as overriding a sensor requires at a minimum the electrical technician to carry it out.

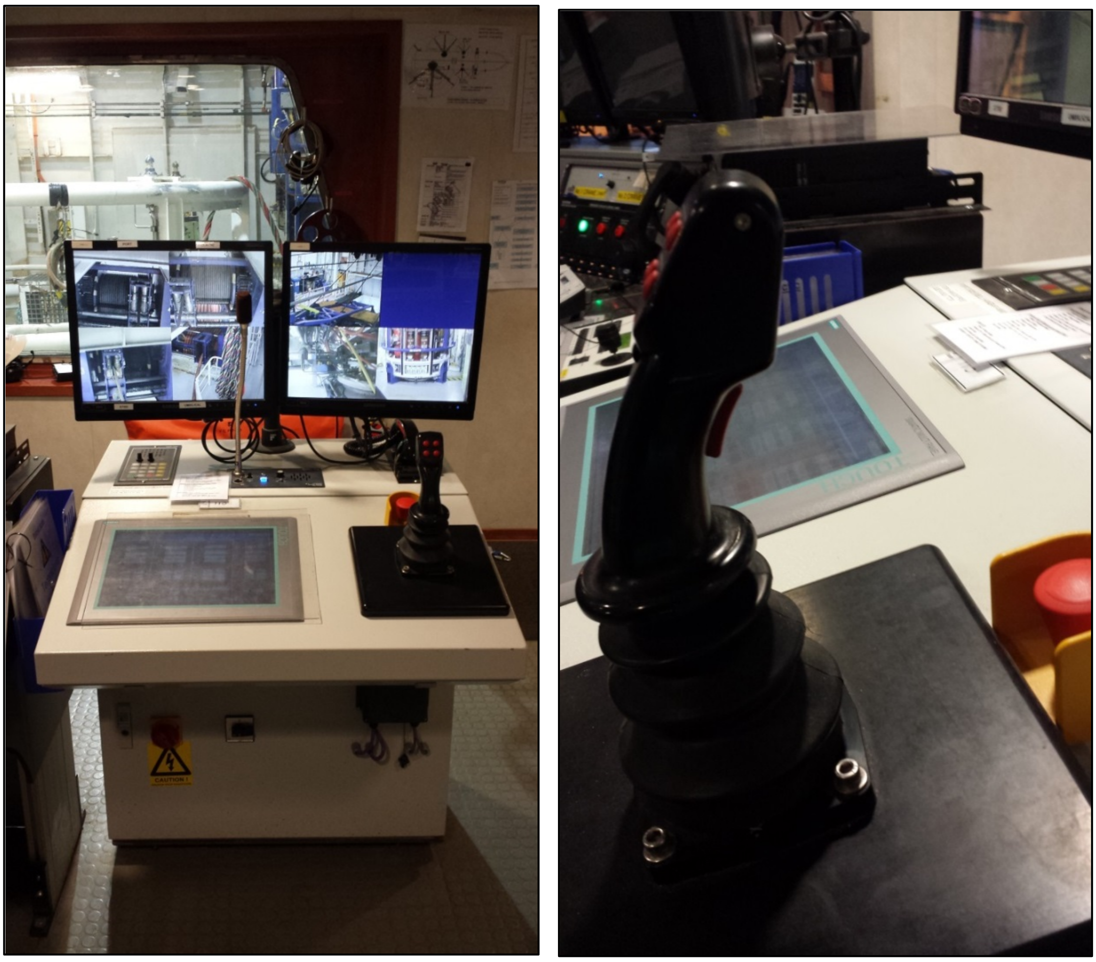


Figure 0-10: Port bell LARS station with cctv & HMI (left) and joystick with dead man trigger (right)

11.2.6HMCS Trends Database

A significant volume of data parameters from the LARS PLC know as system tags are passed to and logged in the HMCS archieve database. This information can be reviewed off line using the ADHO Trends function. This facility was used extensively by the investigation team to understand the system behaviour and operator actions carried out during the incident. This trends data can be displayed and interrogated in a flexible manner as shown in the following Figures 0-11 to 14. It is also possible to display the alarms record for the LARS system as in Figure 0-15.

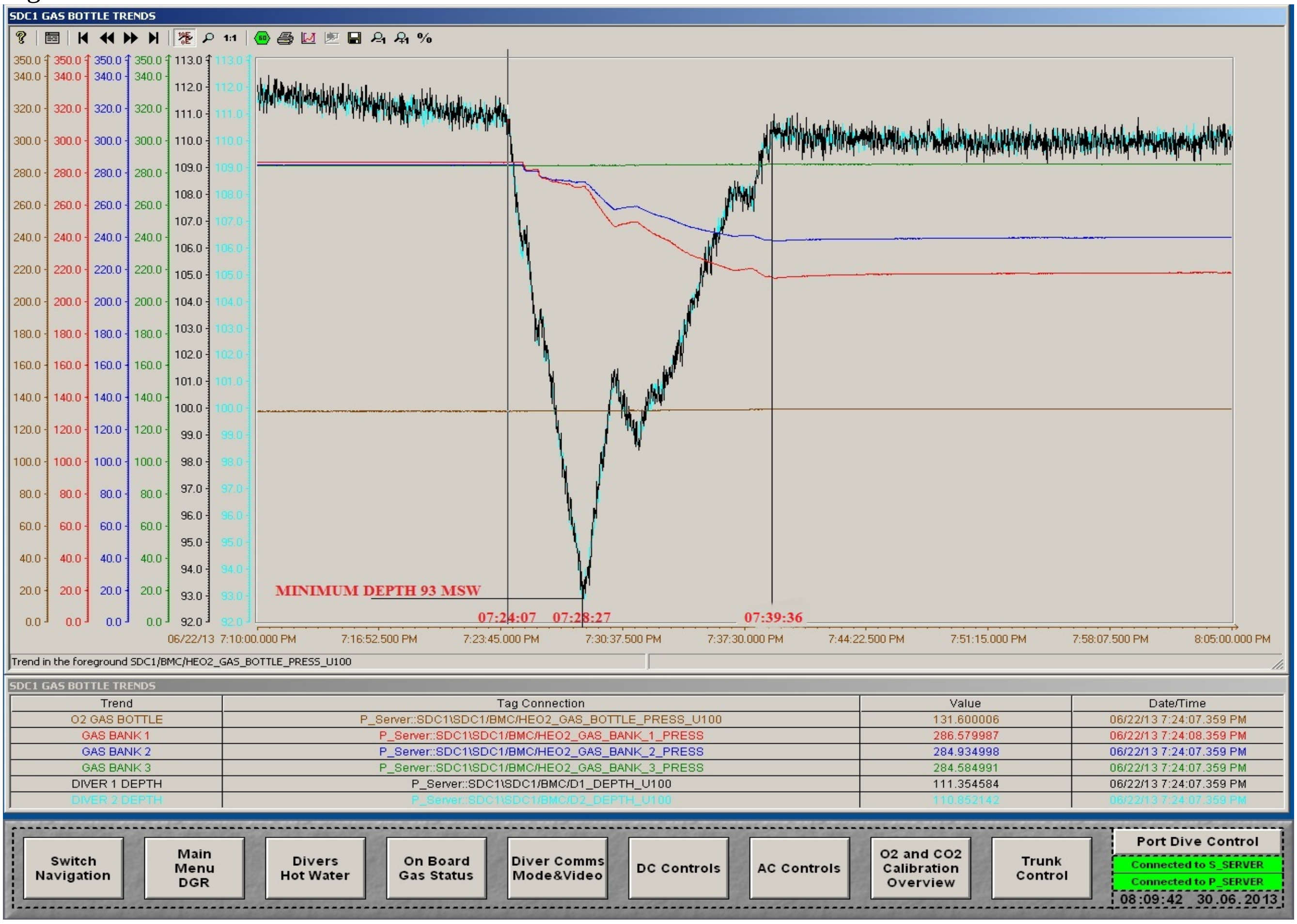


Figure 0-11 Port LARS bell internal depth and on-board gas bank pressures with key times

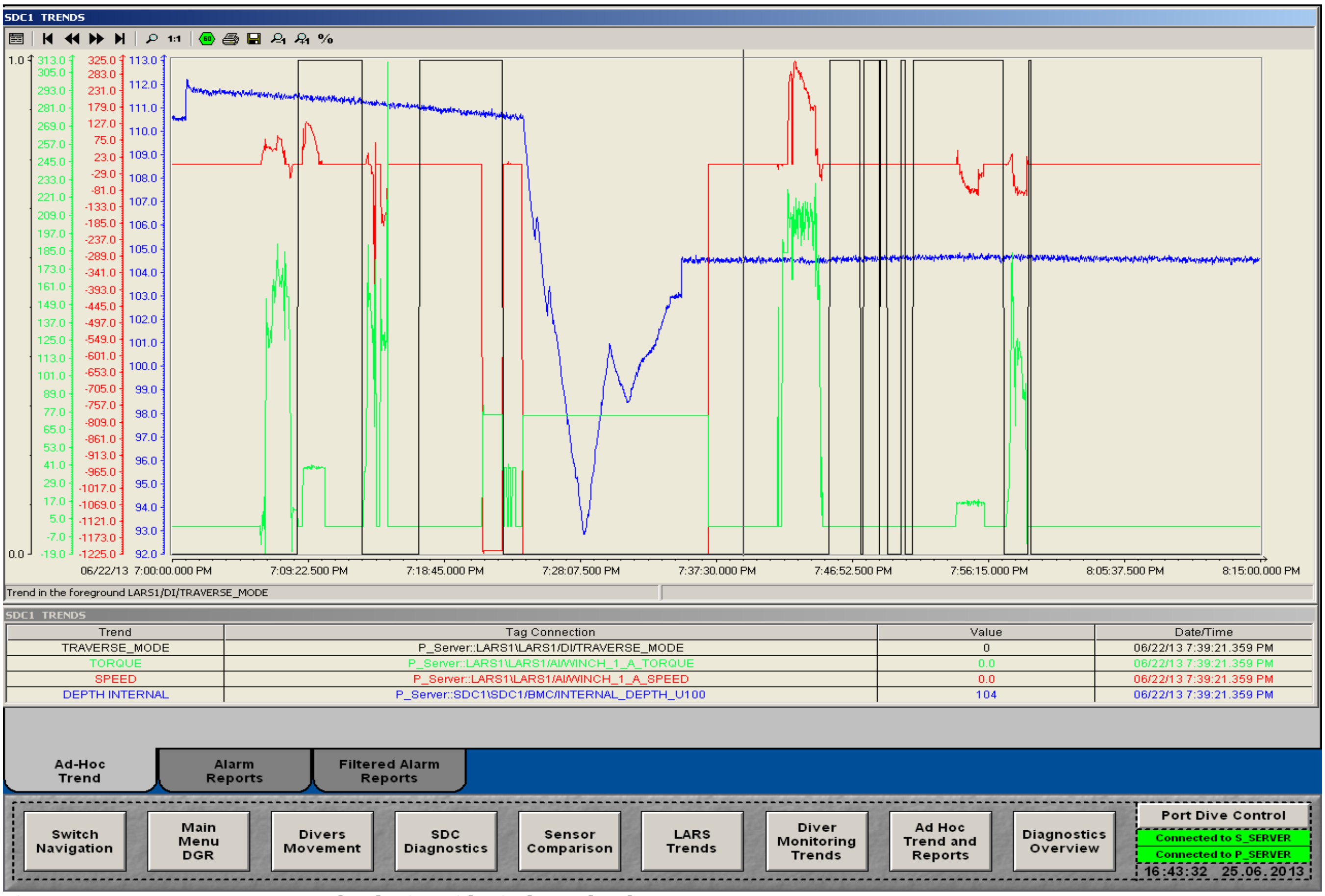


Figure 0-12 Port LARS Traverse Mode selection with winch speed and torque

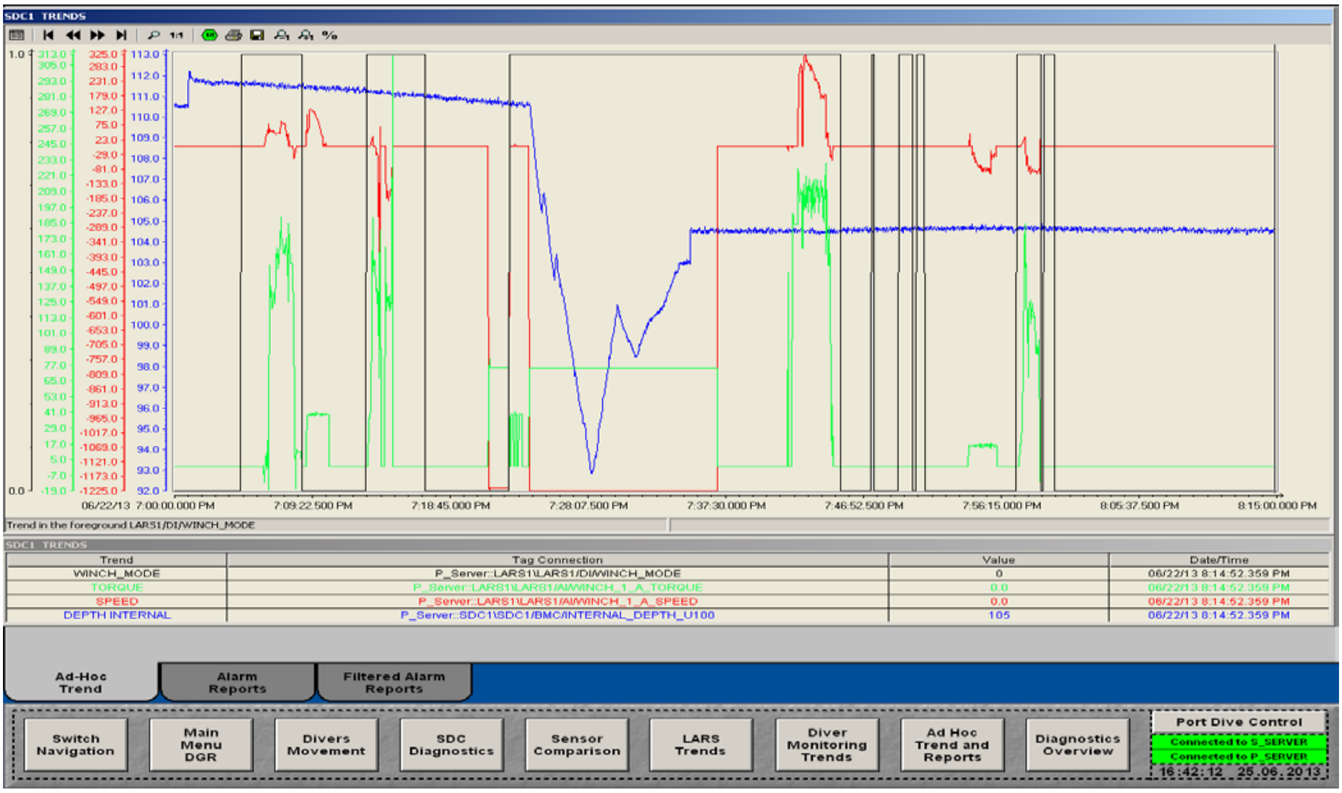
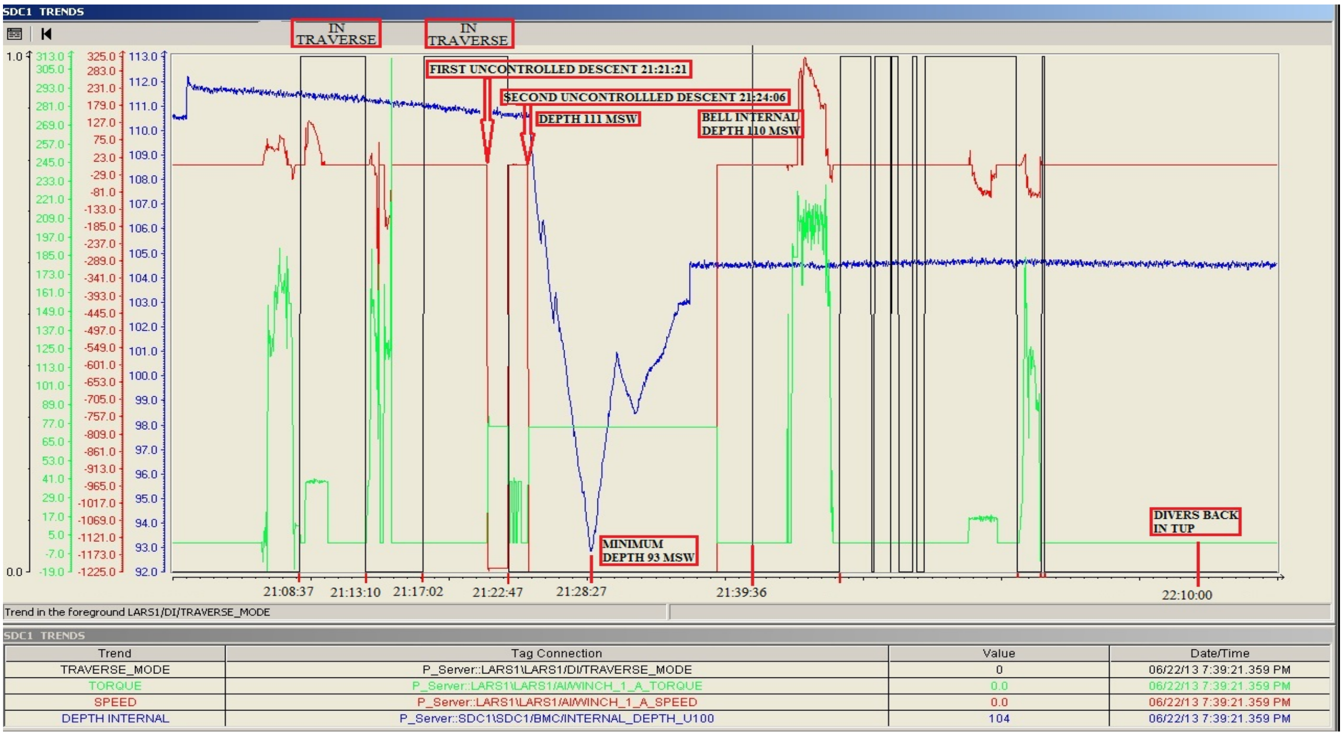
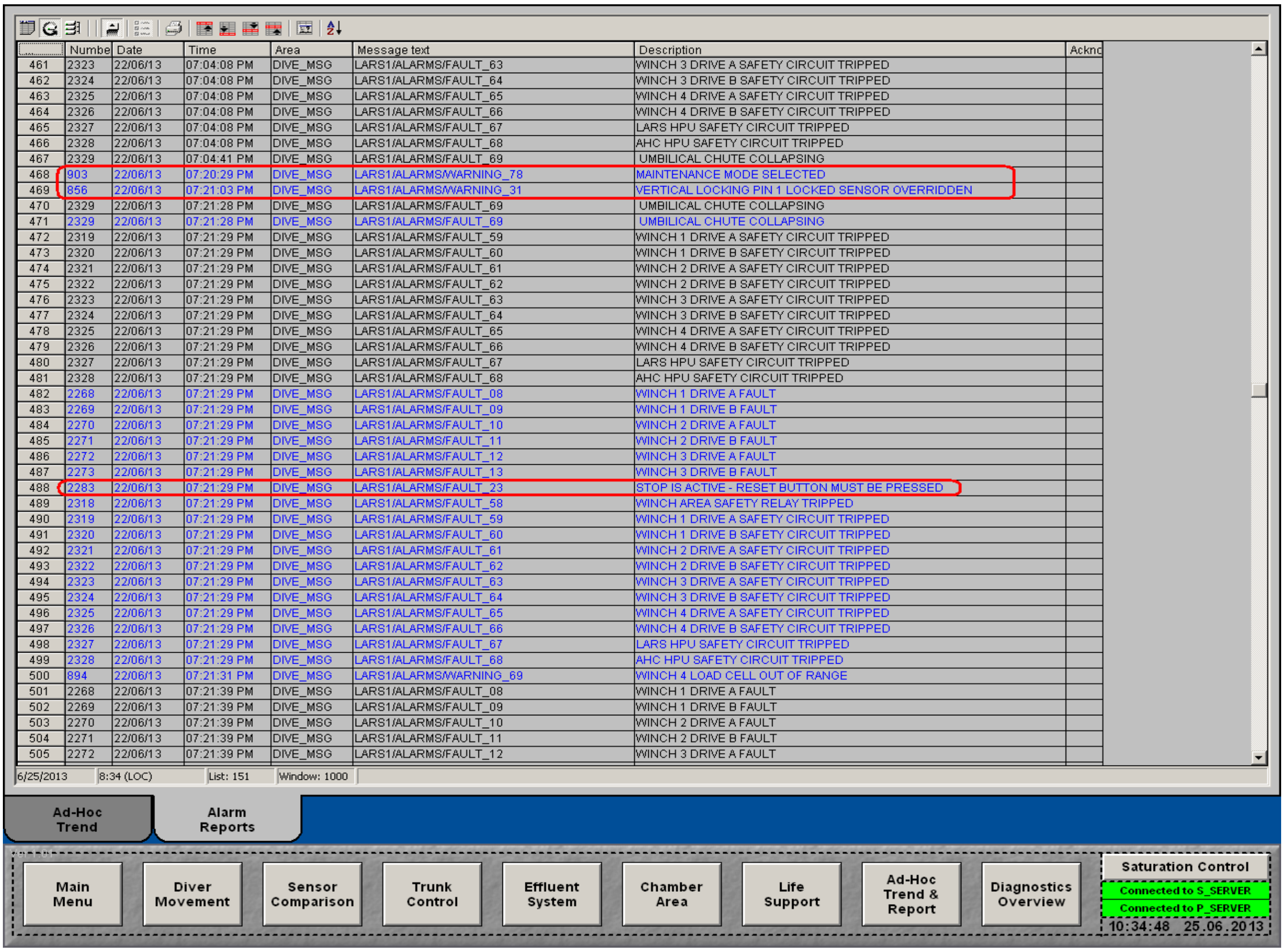


Figure 0-13 Port LARS Winch Mode selection with winch speed and torque



Trend	Tag Connection	Value	Date/Time
TRAVERSE_MODE	P_Server::LARS1\LARS1/DI/TRAVERSE_MODE	0	06/22/13 7:39:21.359 PM
TORQUE	P_Server::LARS1\LARS1/AI/WINCH_1_A_TORQUE	0.0	06/22/13 7:39:21.359 PM
SPEED	P_Server::LARS1\LARS1/AI/WINCH_1_A_SPEED	0.0	06/22/13 7:39:21.359 PM
DEPTH INTERNAL	P_Server::SDC1\SDC1/BMC/INTERNAL_DEPTH_U100	104	06/22/13 7:39:21.359 PM

Figure 0-14 Port LARS Key Times



	Numbe	Date	Time	Area	Message text	Description	Ackno
461	2323	22/06/13	07:04:08 PM	DIVE_MSG	LARS1/ALARMS/FAULT_63	WINCH 3 DRIVE A SAFETY CIRCUIT TRIPPED	
462	2324	22/06/13	07:04:08 PM	DIVE_MSG	LARS1/ALARMS/FAULT_64	WINCH 3 DRIVE B SAFETY CIRCUIT TRIPPED	
463	2325	22/06/13	07:04:08 PM	DIVE_MSG	LARS1/ALARMS/FAULT_65	WINCH 4 DRIVE A SAFETY CIRCUIT TRIPPED	
464	2326	22/06/13	07:04:08 PM	DIVE_MSG	LARS1/ALARMS/FAULT_66	WINCH 4 DRIVE B SAFETY CIRCUIT TRIPPED	
465	2327	22/06/13	07:04:08 PM	DIVE_MSG	LARS1/ALARMS/FAULT_67	LARS HPU SAFETY CIRCUIT TRIPPED	
466	2328	22/06/13	07:04:08 PM	DIVE_MSG	LARS1/ALARMS/FAULT_68	AHC HPU SAFETY CIRCUIT TRIPPED	
467	2329	22/06/13	07:04:41 PM	DIVE_MSG	LARS1/ALARMS/FAULT_69	UMBILICAL CHUTE COLLAPSING	
468	903	22/06/13	07:20:29 PM	DIVE_MSG	LARS1/ALARMS/WARNING_78	MAINTENANCE MODE SELECTED	
469	856	22/06/13	07:21:03 PM	DIVE_MSG	LARS1/ALARMS/WARNING_31	VERTICAL LOCKING PIN 1 LOCKED SENSOR OVERRIDDEN	
470	2329	22/06/13	07:21:28 PM	DIVE_MSG	LARS1/ALARMS/FAULT_69	UMBILICAL CHUTE COLLAPSING	
471	2329	22/06/13	07:21:28 PM	DIVE_MSG	LARS1/ALARMS/FAULT_69	UMBILICAL CHUTE COLLAPSING	
472	2319	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_59	WINCH 1 DRIVE A SAFETY CIRCUIT TRIPPED	
473	2320	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_60	WINCH 1 DRIVE B SAFETY CIRCUIT TRIPPED	
474	2321	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_61	WINCH 2 DRIVE A SAFETY CIRCUIT TRIPPED	
475	2322	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_62	WINCH 2 DRIVE B SAFETY CIRCUIT TRIPPED	
476	2323	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_63	WINCH 3 DRIVE A SAFETY CIRCUIT TRIPPED	
477	2324	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_64	WINCH 3 DRIVE B SAFETY CIRCUIT TRIPPED	
478	2325	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_65	WINCH 4 DRIVE A SAFETY CIRCUIT TRIPPED	
479	2326	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_66	WINCH 4 DRIVE B SAFETY CIRCUIT TRIPPED	
480	2327	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_67	LARS HPU SAFETY CIRCUIT TRIPPED	
481	2328	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_68	AHC HPU SAFETY CIRCUIT TRIPPED	
482	2268	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_08	WINCH 1 DRIVE A FAULT	
483	2269	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_09	WINCH 1 DRIVE B FAULT	
484	2270	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_10	WINCH 2 DRIVE A FAULT	
485	2271	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_11	WINCH 2 DRIVE B FAULT	
486	2272	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_12	WINCH 3 DRIVE A FAULT	
487	2273	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_13	WINCH 3 DRIVE B FAULT	
488	2283	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_23	STOP IS ACTIVE - RESET BUTTON MUST BE PRESSED	
489	2318	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_58	WINCH AREA SAFETY RELAY TRIPPED	
490	2319	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_59	WINCH 1 DRIVE A SAFETY CIRCUIT TRIPPED	
491	2320	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_60	WINCH 1 DRIVE B SAFETY CIRCUIT TRIPPED	
492	2321	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_61	WINCH 2 DRIVE A SAFETY CIRCUIT TRIPPED	
493	2322	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_62	WINCH 2 DRIVE B SAFETY CIRCUIT TRIPPED	
494	2323	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_63	WINCH 3 DRIVE A SAFETY CIRCUIT TRIPPED	
495	2324	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_64	WINCH 3 DRIVE B SAFETY CIRCUIT TRIPPED	
496	2325	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_65	WINCH 4 DRIVE A SAFETY CIRCUIT TRIPPED	
497	2326	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_66	WINCH 4 DRIVE B SAFETY CIRCUIT TRIPPED	
498	2327	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_67	LARS HPU SAFETY CIRCUIT TRIPPED	
499	2328	22/06/13	07:21:29 PM	DIVE_MSG	LARS1/ALARMS/FAULT_68	AHC HPU SAFETY CIRCUIT TRIPPED	
500	894	22/06/13	07:21:31 PM	DIVE_MSG	LARS1/ALARMS/WARNING_69	WINCH 4 LOAD CELL OUT OF RANGE	
501	2268	22/06/13	07:21:39 PM	DIVE_MSG	LARS1/ALARMS/FAULT_08	WINCH 1 DRIVE A FAULT	
502	2269	22/06/13	07:21:39 PM	DIVE_MSG	LARS1/ALARMS/FAULT_09	WINCH 1 DRIVE B FAULT	
503	2270	22/06/13	07:21:39 PM	DIVE_MSG	LARS1/ALARMS/FAULT_10	WINCH 2 DRIVE A FAULT	
504	2271	22/06/13	07:21:39 PM	DIVE_MSG	LARS1/ALARMS/FAULT_11	WINCH 2 DRIVE B FAULT	
505	2272	22/06/13	07:21:39 PM	DIVE_MSG	LARS1/ALARMS/FAULT_12	WINCH 3 DRIVE A FAULT	

Figure 0-14 Port LARS Alarms List showing maintenance mode and sensor override activation

APPENDIX B – LARS CONTROL SYSTEM

12. LARS CONTROL SYSTEM

12.1 Summary

The main item to note from the design process is that despite it being identified in the initial LARS HAZOP Report (EVID-074) there is no evidence that any consideration was given in the detailed design documentation and actual HMI implementation to the interaction between maintenance actions (interpreted here as when the system was placed in maintenance mode) and launch and recovery operations (involving selection of other modes).

The full HMCS PLC code including the LARS has been through multiple revisions. This is now tracked using the TMOS MAF Modification Authorisation Process which appears fit for purpose. Other less rigorous processes were used prior to the implementation of MAF in 2011. It is not possible to state exactly when the code was implemented that allowed this incident to take place but it is believed that this has been present since commissioning.

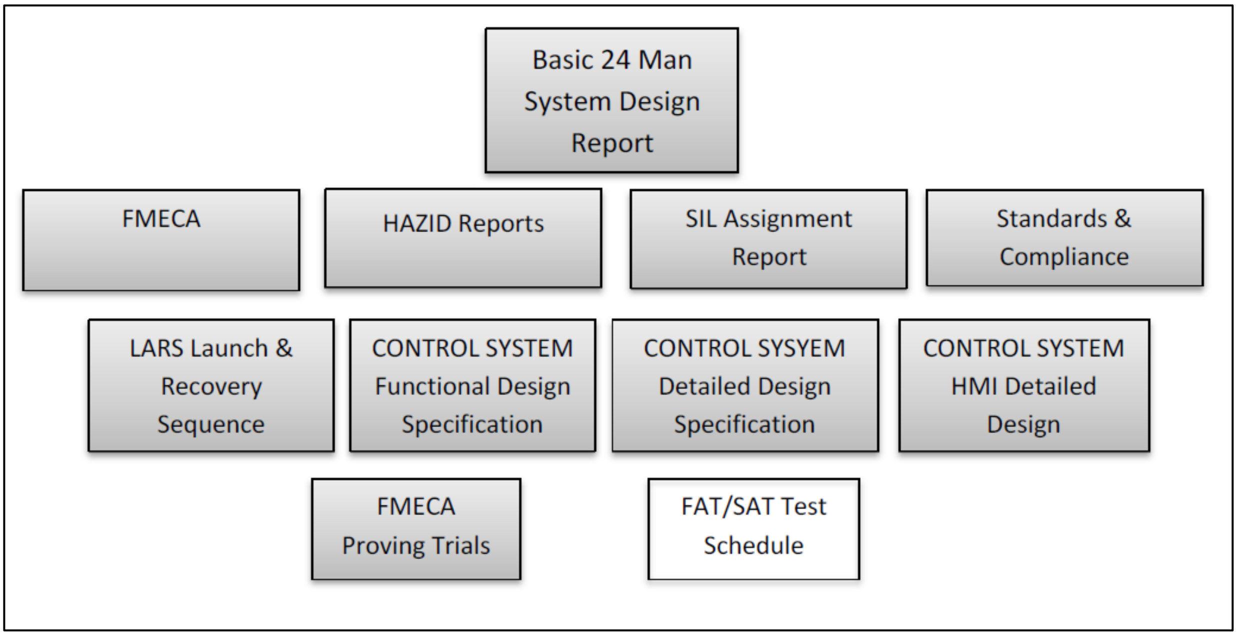
The braking sequences appear to have performed as intended with all actions being soft stop with the exception of the emergency stop which applies the brakes immediately on loss of hydraulic pressure. The perception on-board that releasing the deadman's trigger does not apply the brakes is probably because it is a soft stop using electronic braking. In the case of this incident the high system inertia due to the abnormal descent speed placed extra demands on the brakes leading to a perceived 'slow' stop. Indications from the HMCS Trends database (Black Box) are that for the second uncontrolled descent the time between the brakes off and brakes on was less than 3 seconds and the total descent time was 6 seconds.

12.2 PURPOSE

The purpose of this appendix is to explain the actions, procecesses and documentation steps involved in the development of the LARS control system. It also gives details of the control and operations philosophy that are relevant to this incident.

12.3 LARS DEVELOPMENT PROCESS

The development process for the LARS control system evolved through several documented stages
The key documents identifying this process are identified below:



12.3.1 FMECA

Divex FMECA 24 Man System (EVID-076) Annex B considers many possible failure modes some of which would lead to man umbilical failure but does not consider errors in the PLC coding and incorrect mode selection by operators/technicians leading to critical failures. This FMECA specifically excludes the SDC (Bell) which is covered in a separate report below.

For the SDC (Bell) Divex FMECA SDC (EVID-078) Annex B Ref 3 refers to complete loss of main umbilical but does not highlight loss of bell pressure as an effect. It only considers outputs from the bell such as gas reclaim but does not consider the pneumo gas hoses which were, because one way valves can't be fitted were responsible for the 18 msw upwards depth excursion (pressure drop) experienced by the divers during this incident.

Noble Denton FMECA (EVID-77) details failure modes and effects for the LARS at Section 15 but does not consider errors in the PLC coding allowing incorrect operator/technician inputs which led to this incident happening. Further it does not specifically consider loss of bell internal pressure as a failure mode.

Noble Denton FMECA Proving Trials (EVID-086) identify various trials that were carried out of LARS failures (Tests 203 through 216) including sensor overrides but there is nothing identified that would have revealed the particular failure mode that led to this incident.

12.3.2 LARS Hazard Identification Reports

Early LARS Hazard Identification Report Jan 2007 (EVID-074) and LARS Hazard Identification Report Response April 2009 (Evid-075) & SDC Hazard Identification Report (EVID-079) identified hazards associated with the LARS system and sought to incorporate into the design or mitigate issues in a traceable manner. The Summary of EVID-075 stated that the aim of the report was '*To provide transparency, traceability and confidence that suitable activities have been carried out and incorporated where appropriate Items* 34, 39, 43, 40, 44, 47 identify hazards relating to the incident.

In particular Item ref 34 ' *Failure to assess safety implications of maintenance actions allowable during diving operations*' was very closely related to this incident.

12.3.3 LARS SIL Assignment Report

Divex commissioned Atkins to carry out a SIL assignment for the LARS dated April 2009 (EVID-085). This is critical to the design process as it concludes that:

'The study has concluded that no SIL requirements exist for the control system.
This is the case without the need to consider a number of external risk reduction measures, some of which are described in section 3.1 of this document.'

Atkins' reasoning is extracted here:

2.6 Failure Requirements

When using BS EN 61508, Ref 1, to derive SILs, it is important to understand whether the mode of operation falls into the Low or High demand category to ensure the correct SIL is assigned. The following definitions are paraphrased from the standard (Part 4 Section 3.5.12):

- **Low Demand** – where the frequency of demands on the safety related system is no greater than one per year and no greater than twice the proof test frequency.
- **High Demand –** where the frequency of demands on the safety related system is greater than once per year or greater than twice the proof test frequency.

The elements of the LARS control system that form the safety related system are only required to be operational during LARS operations (not operating continuously) and the failure rates are calculated to be less than once per year (refer to LOPA worksheets), hence the demands on the safety related system will be less that once per year. Divex have not indicated that there is a proof test frequency for the LARS control system and hence this has not influenced the selection process. **It is therefore considered appropriate to define the LARS control system as a Low Demand system in the context of BS EN 61508, Ref 1.**

2.7 Safety Integrity Requirements

The following table presents the requirements for SILs required by Ref 1 for a **Low Demand** system. Where additional risk reduction is indicated to be required by the LOPA, the resulting number is compared with this table to establish the SIL.

The report also makes a series of recommendations most of which could be interpreted as relevant to this incident.

In particular hazard number H151 *'Drive switch from speed control to constant tension when not in the hooks'* which was newly introduced at the request of Divex (recommendation 8) during the writing of the report has a direct relevance to the incident particularly when coupled to H014 ' *Excessive bell speed during launch and recovery'* which it is believed is relevant with respect to the failure of the main umbilical gas connections.

12.3.4 Launch and Recovery Sequence for LARS System

(EVID-073) This matrix identifies the operating sequence for launch and recovery operations and the states of sub-systems at each stage. This document was very important for the developers to identify the required coding relating to parameters such as winch tensions and sensor states.

12.3.5 Functional Design Specification For The LARS Control System

(EVID-070) This document specifies the physical arrangement of the LARS and control hardware and how the PLC based control system manipulates the hardware to perform the launch and recovery processes.

It specifies the ability of a 'qualified person' to use the PLC HMI to override individual sensor signal failures and that this function shall be password protected. There is a comprehensive interlock matrix which cover winch and traverse mode but gives no consideration for maintenance mode which is not covered in this document.

It states that the system shall be certified by Lloyds Register and that it must adhere to BS EN61508 Functional safety of electrical / electronic/ programmable electronic safety related systems.

12.3.6 LARS Control System Detailed Design Specification

(EVID-071) The purpose of this document is to explain further the details behind the launch and recovery system hardware and PLC coding. There is limited reference to overrides and no reference to maintenance mode in this document.

12.3.7 LARS HMI Detailed Design Specification

(EVID-072) This document describes the functional requirements of the LARD human Machine interface (HMI).

At section 2.7 it details the dashboard (home screen) but there is no reference to the indication of winch drive state of CT or SP depending on the mode that the system is operating in.

At sections 2.11, 2.12 and 2.13 it details the three overrides screens.

At section 2.19 it details the Maintenance screen where it states that ‘ This screen is used by a supervisor or authorised person to place the system into Maintenance Mode. Maintenance Mode bypasses some of the PLC interlocks to allow completion of various maintenance tasks that the PLC would otherwise inhibit.’ There is reference to the LARS Operation and Maintenance manual but this document was not found by the Investigation team and not actual document reference could be found. Maintenance mode as detailed in this manual has extremely limited functionality compared to the one actually implemented in the operational system.

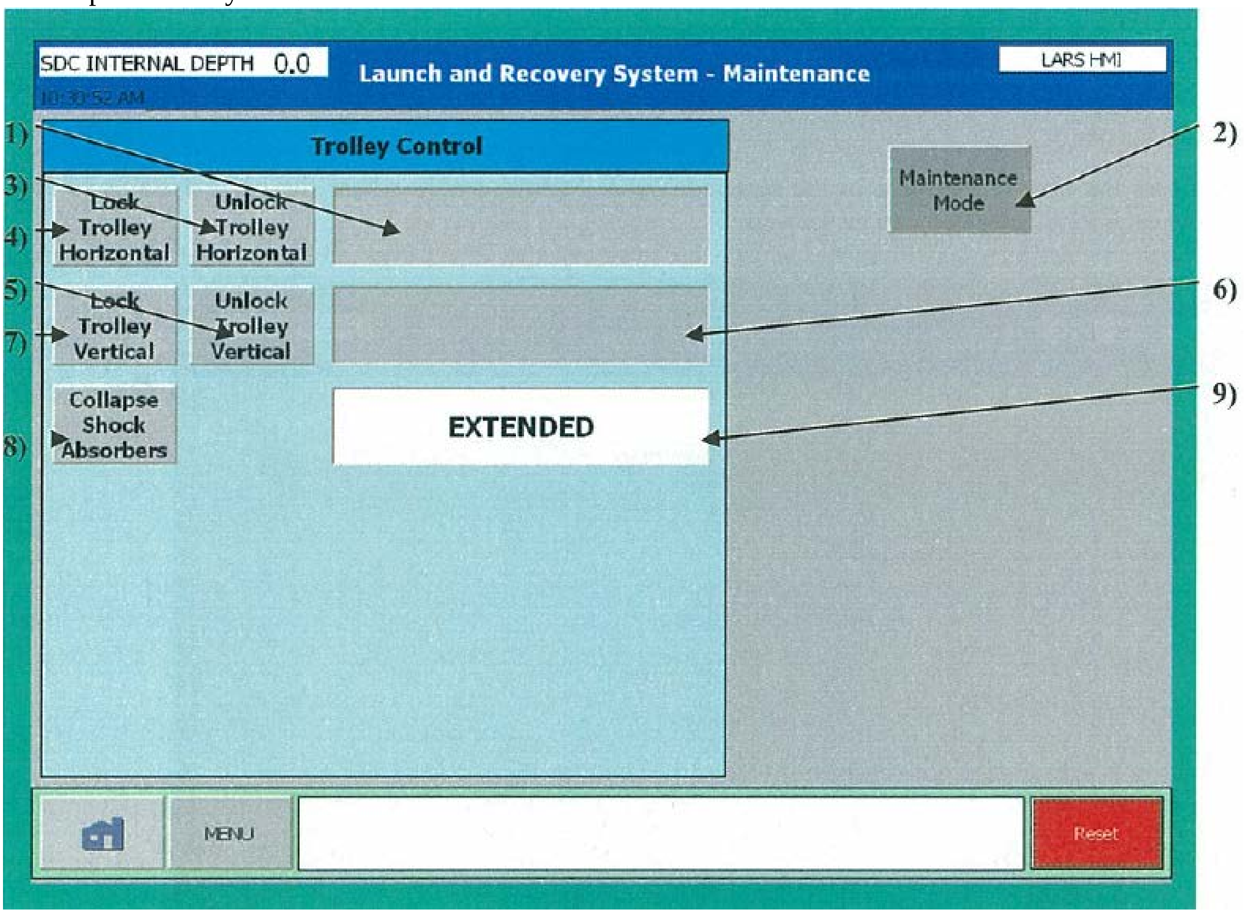


Fig F-1 Maintenance Screen from design document

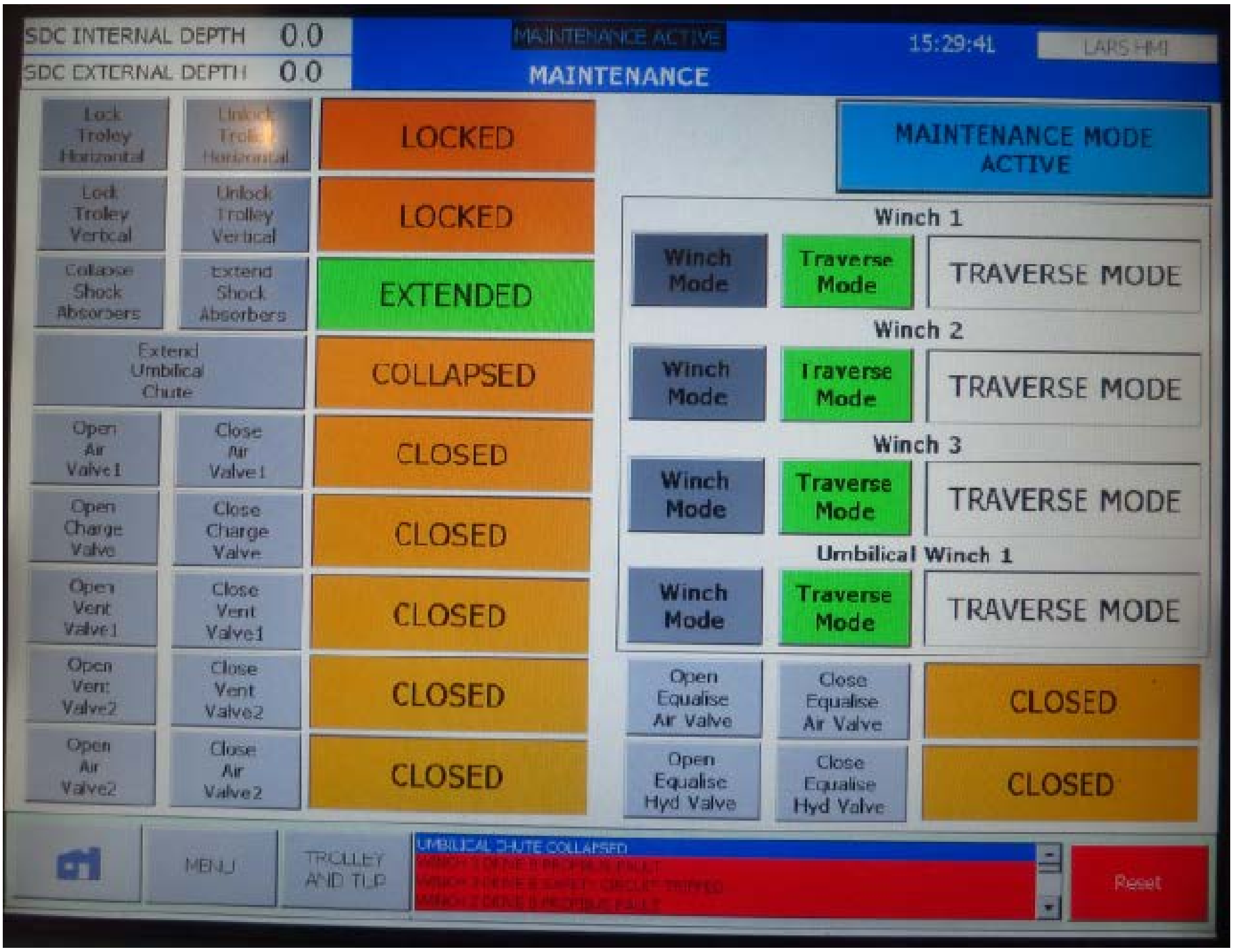


Fig F-2 Maintenance screen on operational system

At section 2.24 the password philosophy details two user levels where the upper level only is password protected. However verbal statements from the Control Systems Superintendent and PLC Technician suggest that historically separate passwords existed for access to maintenance mode and override functions. There currently exists only one password that is common to all protected modes or functions.

12.3.8LARS FAT/SAT Test Schedules

These documents were not found or reviewed by the Investigation Team despite there being clear document numbers available. The Noble Denton FMECA Proving Trials Report (EVID-86) was the only as built test report inspected relating the LARS control system. These proving trials include a range of LARS specific trials some of which involve override selection and non standard system configurations. There is nothing including in the trials that would have identified the specific failure mode involved in this incident.

It is possible that the equipment manufacture has further documentation relating to commissioning of the LARS control systems but this line of enquiry was not investigated further.

12.4 PLC Code Modification Authorisation Process

TMOS document MOS-QMT-026 Rev3 is the standard procedure for managing modifications and is the process used to modify the PLC Code. This process uses an electronic database Modification Authorisation Form (MAF) with supporting attachments and signatures. An example of a relatively complex change 58.MAF065 to allow all local PLC HMI (including the LARS PLC) to display local time rather than system time was examined (EVID-059). There is also example data on 58MAF080 which relates to changes to the Gasmizer control which is in the same position as the LARS control sytem of not having a SIL rating and hence no considered a safety related system. The use of the MAF system is relatively new the earliest entry seen being August 2011.

Prior to this an alternative system was used that did not have the same level of control. For the core HMCS of safety related systems the change process went through ICS Triplex Silvertech who were the original manufacturers of the system though this did not apply to the LARS control system for the reasons stated above i.e. it was not classed as a safety related system (within the scope of IEC 61508).

The PLC code, revisions and management system leading to the 'as built' configuration have not been examined but it is believed that the coding that allowed traverse mode winch setting to be active when the bell is out of the hooks over the moonpool was in place from commissioning.

Note that it is likely that more rigorous factory and vessel testing of this control system may have identified the impact on functional safety of the use of maintenance mode during manned underwater operations.

12.5 LARS control Philosophy

The system is controlled by the operator manually via the HMI screens and the proportional joystick with dead man's handle. The PLC system limits the maximum available winch speed automatically based upon the SDC position, and the proportional joystick allows the operator to control the required speed within these limits. Movement of the SDC is only possible when the dead man's handle is depressed; this eliminates any accidental motion caused by spurious movement of the joystick.

The traversing of the Overhead Trolley is also controlled by the operator using the joystick and dead man's handle. The joystick provides proportional control in both directions.
The operator controls the discrete functions such as SDC Hooks and Trolley Locking Pins manually via buttons on the HMI screens. The status of each of these functions is displayed graphically on the same screens. If a function is requested by the operator but is not available, the specific cause of this interlock is enunciated on the HMI displays.

12.5.1 Braking Philosophy

The system is brought to a stop in one of two ways. Either a soft stop which is designed to protect the system from mechanical damage or emergency stop where which is as the name suggests is designed to stop the SDC as quickly as possible.

There is a strong perception on-board the vessel that releasing the deadman's trigger does not stop the bell descent or recovery. This is because it initiates a soft stop sequence as detailed below and hence acts in a slower manner that is less stressful to the system than the emergency stop. The other difference in this incident is that unlike in normal braking operations the critical winches were in CT mode and hence the brakes were required to act against a load of approximately 20Te moving at about three times its normal speed.

12.5.1.1 Soft Stop

If the dead man's handle is released during launching or recove1y of the SDC then the winches will perform a controlled stop. This stop utilizes the ramp down function within the drive control logic and decelerates the SDC to a standstill over a defined time period utilizing brake resistors if required to dissipate any excess energy. Once the drives have decelerated the winches to a standstill, the drives will engage the winch holding brakes and after confirming that the brakes have engaged via the pressure switch feedback signals then the drives will be disabled. The power will remain on to the drive units.

Any hydraulic motion such as Overhead Trolley traverse stops when the dead man's handle is released. To recommence movement the dead man's handle must be depressed and the Joystick operated in the required direction or the appropriate selection made on the HMI. All HPU's and ancillary equipment will remain enabled.

12.5.1.2Emergency Stop

The LARS HPU is immediately shut down as 440V power supply is removed for the pump. The hydraulic pressure required by the Winch Drive Brakes for the controlled stop of the winches is removed and the brakes stop the winches.

At the same time as the brakes being activated the Winch drives utilize timed delay contacts to allow the drives to stop in a controlled manner. The timed delay contacts on the winch drive safety relays only remove the power to the drives after the time delay has elapsed thus allowing the drives to perform a controlled stop. During this time delay period the winches decelerate rapidly using brake resistors if required to dissipate the excess energy.

The Active Heave Compensator HPU pump is immediately shut down as 440V power supply is removed and the system is simultaneously switched into passive mode.

APPENDIX C – EVIDENCE LOG

Evidence LOG

NR0233560 - Kneler A Work Over - Port Bell Investigation

Evidence Code						
Unique Number	**Originator**	**Item Number (Action Log)**	**Document Type**	**Date Entered into Log:**	**Subject**	**Hyperlink**
NR033560-EVID-001	JKO		Hard Copy	30.06.13	Dive system Defect log book port bell	EVID-001
NR033560-EVID-002	JKO		DOC	30.06.13	Introduction / opening meeting with Police attendence list	EVID-002
NR033560-EVID-003	JKO		Hard Copy	30.06.13	Shift handover log from 05-06-2013 to 25-06-2013	**Transfered to EVID-34**
NR033560-EVID-004	CSA		Electronically	07.08.13	Skandi Arctic LARS investigation - Audit Information Request 1	EVID-004
NR033560-EVID-005	JKO		Electronically	30.06.13	Bell Launch Procedure Aide Memoire	EVID-005
NR033560-EVID-006	HPA		Electronically	02.07.13	Technip Elec Tech	EVID-006
NR033560-EVID-007	HPA		Electronically	02.07.13	Technip Medic/Hyperbaric Nurse	EVID-007
NR033560-EVID-008	HPA		Electronically	02.07.13	Technip Diver	EVID-008
NR033560-EVID-009	HPA		Electronically	02.07.13	Technip Trainee Dive Supervisor	EVID-009
NR033560-EVID-010	HPA		Electronically	02.07.13	Marathon Snr Dive Rep	EVID-010
NR033560-EVID-011	HPA		Electronically	02.07.13	Technip PLC Tech	EVID-011
NR033560-EVID-012	HPA		Electronically	02.07.13	Technip Senior Dive Supervisor	EVID-012
NR033560-EVID-013	HPA		Electronically	02.07.13	LSS	EVID-013
NR033560-EVID-014	HPA		Electronically	02.07.13	Technip Mech Tech	EVID-014
NR033560-EVID-015	HPA		Electronically	02.07.13	Technip AOCM	EVID-015
NR033560-EVID-016	HPA		Electronically	02.07.13	Technip Launch Crew	EVID-016
NR033560-EVID-017	HPA		Electronically	02.07.13	Technip Dive Tech Sup	EVID-017
NR033560-EVID-018	HPA		Electronically	02.07.13	Technip Mech Tech	EVID-018
NR033560-EVID-019	JKO	12	Electronically	04.07.13	Umb chineese finger application	EVID-019
NR033560-EVID-020	JKO		Electronically	04.07.13	Available onboard gas volume (post incident) and calculation	EVID-020
NR033560-EVID-021	JNO	45	Electronically	04.07.13	Starboard LARS common failure mode	EVID-021
NR033560-EVID-022	OLO		Electronically	14.07.13	Marathon Dive Rep & Return to Diving	EVID-022
NR033560-EVID-023	OLO		Electronically	14.07.13	Technip Standby Diver	EVID-023
NR033560-EVID-024	OLO		Electronically	14.07.13	Technip OCM	EVID-024
NR033560-EVID-025	J Cramb	1	Hard Copy	03.07.13	Certification records for Dive System & LARS - Paper	EVID-025
NR033560-EVID-026	J Cramb	2	Hard Copy	03.07.13	Maintenance Records & Fleet Stats comparison	EVID-026
NR033560-EVID-027	J Cramb	4	Electronically	03.07.13	Breakdown corrective records	EVID-027
NR033560-EVID-028	J Cramb	4	Hard Copy	03.07.13	Breakdown corrective records - related cases	
NR033560-EVID-029	J Cramb	3	Electronically	03.07.13	Synergi case searches - related long case reports	EVID-029

Evidence LOG

NR0233560 - Kneler A Work Over - Port Bell Investigation

Evidence Code						
Unique Number	**Originator**	**Item Number (Action Log)**	**Document Type**	**Date Entered into Log:**	**Subject**	**Hyperlink**
NR033560-EVID-030	J Cramb	4 10	Hard Copy	03.07.13	LARS historical issues since build	
NR033560-EVID-031	JKO	5 10	Electronically	03.07.13	El. Tech Shift & Daily handover notes.	EVID-031
NR033560-EVID-032	JKO	6 10	Electronically	03.07.13	Mech. Tech Shift & Daily handover notes.	EVID-032
NR033560-EVID-033	JKO	7 10	Electronically	03.07.13	PLC Tech Shift & Daily handover notes (includes End of Trip handover).	EVID-033
NR033560-EVID-034	OLO	8	Hard Copy	03.07.13	Dive control shift handover logbook. Copies of related issues/cases.	EVID-034
NR033560-EVID-035	JNO	9 11 13 40 42	Digital	03.07.13	HMCI archive data supporting winch status, brake status and modes selected throughout incident. **All files archived and may be interrogated in Westhill, ABZ.**	EVID-035
NR033560-EVID-036		13			Photos of analog Bell Onboard Gas Bank Pressure Gauges. Stby Diver Bell checklist photographed HMCI Tags Ref EVI-035... Calculation E-mail from Sat. Control - e-mail LSS to OLO.	EVID-036
NR033560-EVID-037	JKO		Hard Copy	03.07.13	GDM; MOS-DIV-11101 Dive Organisation and Reporting Manual, page 9 MOS-HSE-040 SMS interface & Responsibility matrix (this includes Org charts).	EVID-037
NR033560-EVID-038	JKO	48	Hard Copy	03.07.13	Dive system daily and weekly reports (typ. Examples)	EVID-038
NR033560-EVID-039	JKO		Hard Copy	03.07.13	Internal Bell valve isolation check list in case of rupture.	EVID-039
NR033560-EVID-040	JKO		Hard Copy	03.07.13	Starboard + portside SDC internal checklist (interim) Originals	EVID-040
NR033560-EVID-041	JKO	34	Hard Copy	03.07.13	Local Time Synchronisation HMCS and PLC	EVID-041

Evidence LOG

NR0233560 - Kneler A Work Over - Port Bell Investigation

Evidence Code						
Unique Number	**Originator**	**Item Number (Action Log)**	**Document Type**	**Date Entered into Log:**	**Subject**	**Hyperlink**
NR033560-EVID-042	JNO	40	PDF	04.08.13	LARS100-SP-1364SCADA-PLC Interface Specification - Tags, Alarms, Warnings	EVID-042
NR033560-EVID-043	JKO		Electronically	03.07.13	Winch motor drive screen photos	EVID-043
NR033560-EVID-044	JNO		JPG	04.08.13	Port LARS HMI Pictures of Incident Sequence	EVID-044
NR033560-EVID-045	JKO	45	Electronically	03.07.13	LARS test for common failure mode - EVID-021	This is EVID-021
NR033560-EVID-046	JKO		Electronically	03.07.13	Skandi Arctic DP Log of 22-06-2013	EVID-046
NR033560-EVID-047	JKO		Hard Copy/ email	03.07.13	Email: ToR Investigation Skandi Arctic Port LARS Failure - Draft	EVID-047
NR033560-EVID-048	JKO		Hard Copy	03.07.13	Timeline during incident according to OCM	EVID-048
NR033560-EVID-049	JKO		Hard Copy/ email	03.07.13	Email: Visitors list police and PSA Visit Arctic	
NR033560-EVID-050	JKO		Hard Copy	03.07.13	Neurological Symptoms Checklist (example)	EVID-050
NR033560-EVID-051	JKO		Hard Copy	03.07.13	Attendance list: Investigation team Communication to Divers	
NR033560-EVID-052	jko		Electronically	04.07.13	First hand event description AOCM on Whiteboard	EVID-052
NR033560-EVID-053	OLO		Electronically	14.07.13	Captain	EVID-053
NR033560-EVID-054	JKO	18	Electronically	04.07.13	Diver supervisor training (AOCM)	EVID-054
NR033560-EVID-055	JKO			04.07.13	Tech support (EL tech / mech tech) training	EVID-055
NR033560-EVID-056	JKO		PDF	04.07.13	PLC tech training	EVID-056
NR033560-EVID-057	EWS		PDF	06.08.13	Correspondanse, safety delegates	EVID-057
NR033560-EVID-058	JNO		Electronically	04.07.13	HMCI/LARS Alarms and Faults Log	EVID-058
NR033560-EVID-059	JNO		Electronically	08.08.13	Example of MAF Management of Change No 58 For PLC	EVID-059
NR033560-EVID-060	JCR	22	Electronically	06.07.13	Ship Org Chart Skandi Arctic	EVID-060
NR033560-EVID-061	JCR	27	Electronically	06.07.13	Incident reporting lines	EVID-061
NR033560-EVID-062	HPA		Electronically	07.07.13	Persons involved in the incident	EVID-062
NR033560-EVID-063	HPA		Electronically	07.07.13	DPR007 to DPR010	EVID-063
NR033560-EVID-064	OLO		Electronically	07.07.13	Technip Engineer	EVID-064
NR033560-EVID-065	OLO		Electronically	07.07.13	2nd Officer	EVID-065
NR033560-EVID-066	OLO		Electronically	07.07.13	Safety Delegate	EVID-066
NR033560-EVID-067	OLO		Electronically	07.07.13	Meeting in Aberdeen 11 July	EVID-067
NR033560-EVID-068	JNO		PDF	12.08.13	Shift List	EVID-068

Evidence LOG

NR0233560 - Kneler A Work Over - Port Bell Investigation

Evidence Code				Date Entered into Log:	Subject	Hyperlink
Unique Number	Originator	Item Number (Action Log)	Document Type			
NR033560-EVID-069	OLO		Electronically	07.07.13	HMC100-SP-804 - SDC LARS Control Functional Requirements Specification Rev 0	EVID-069
NR033560-EVID-070	JNO		PDF	23.07.13	SY113-SP-1451 LARS Functional Design Specification	EVID-070
NR033560-EVID-071	JNO		PDF	23.07.13	SY113-SP-1239 LARD Detailed Design Specification	EVID-071
NR033560-EVID-072	JNO		PDF	23.07.13	SY113-SP-1713 LARS HMI Detailed Design Specification	EVID-072
NR033560-EVID-073	JNO		PDF	23.07.13	SY-113-TD-714 LARS Launch & Recovery Sequence	EVID-073
NR033560-EVID-074	JNO		PDF	23.07.13	SY113-RP-280 LARS Hazard Report	EVID-074
NR033560-EVID-075	JNO		PDF	23.07.13	SY-113-TD-753 LARS Hazard Report Response	EVID-075
NR033560-EVID-076	JNO		PDF	23.07.13	SY113-RP-709 FMECA 24 Man System (Divex)	EVID-076
NR033560-EVID-077	JNO		PDF	23.07.13	A6339-1 FMECA 24 Man System (Noble Denton)	EVID-077
NR033560-EVID-078	JNO		PDF	23.07.13	SDC100-RP-673 FMECA SDC (Divex)	EVID-078
NR033560-EVID-079	JNO		PDF	23.07.13	SY113-RP-281 SDC & Dive Control Hazard Report	EVID-079
NR033560-EVID-080	JNO		PDF	23.07.13	MOS-DIV-116 SDC Launch -LARS Normal Procedure	EVID-080
NR033560-EVID-081	JNO		JPEG	24.07.13	Interlocks Overriddes Screens on LARS HMI	EVID-081
NR033560-EVID-082	JNO		PDF	19.08.13	Report 10B REview Ed Gardyne Safewell Solutions	EVID-082
NR033560-EVID-083	JNO		WMV	25.07.13	Port LARS Cursor Camera Descents 1 & 2 (WMV)	EVID-083
NR033560-EVID-084	JNO		MP4	25.07.13	Port Bell Internal Camera Descents text overlay (MP4)	EVID-084
NR033560-EVID-085	JNO		PDF	26.07.13	LAR100-SDR-1804 LARS SIL Assignment Report	EVID-085
NR033560-EVID-086	JNO		PDF	31.07.13	A6510-Skandi Arctic FMECA Proving Trials	EVID-086
NR033560-EVID-087	JNO		PDF	04.08.13	DOF Incident Observation Report	EVID-087
NR033560-EVID-088	SIM		Electronically	07.07.13	Resonsible Compitent Diving Doctor Statement	EVID-088
NR033560-EVID-089	OLO		PDF	20.08.13	Response to Report Rev 01(Draft)	EVID-089
NR033560-EVID-090	-		-		Spare	
NR033560-EVID-091	-		-		Spare	
NR033560-EVID-092	-		-		Spare	
NR033560-EVID-093	OLO		Electronically	12:07.13	Job Description Senior Supervisor Technician	EVID-093
NR033560-EVID-094	-		-		Spare	
NR033560-EVID-095	OLO		Electronically	12:07.13	Similar Case Investigation	EVID-095
NR033560-EVID-096	OLO		Electronically	12:07.13	DOF/Technip Skandi Arctic SMS Interface & Responsibility Matrix	EVID-096
NR033560-EVID-097	OLO		Electronically	13.07.14	Competence Assessment-Verifiers Reports	EVID-097

APPENDIX D – DETAILED TIMELINE

INCIDENT TIME LINE – NOTES AND KEY

NOTES

1. Local time is based on a 2 hour offset from UTC set in the HMCS. Other times such as winch drive controls and video are reconciled to local time where appropriate.

2. There are multiple screens available at the LARS control panel. The ones used during normal operations are: TROLLEY & TUP and DASHBOARD. Additionally the Technicians accessed MENU, MAINTENANCE, OVERRIDES2 and possible others.

3. The winch drives can be set into one of three modes:
- **OFF** – As stated, the winch drives are off, brakes are on and no movement of the bell and LARS is possible.
- **TRAVERSE MODE** – Selected when traversing the trolley and bell between the TUP and the Moonpool. In this mode all winches are configured to control/monitor a constant torque (CT) on their wires/umbilical and do not expect to take the full weight of the bell and cursor.
- **WINCH MODE** – Used for vertical movement of the bell either over the TUP or the Moonpool In this mode Winches 1 and 3 are configured to take the majority of the load of the bell and cursor and control/monitor on speed (SP).

4. There are four winches in the LARS system and some confusion in terminology exists. A simplified view is as follows:
- **Winch 1** (W1) is the outboard winch on the port bell. This is configured to take 40-45% of the total load in WINCH MODE and maintain CT in TRAVERSE MODE.
- **Winch 2** (W2) is the middle bell wire winch which is normally set to CT in both WINCH and TRAVERSE MODE. This is configured to take 10-20% of the load and is only switched to SP if there is a failure of either W1 or W3 and is the 'secondary means of recovery'
- **Winch 3** (W3) is the inboard winch on the port bell. This is configured to take 40-45% of the total load in WINCH MODE and maintain CT in TRAVERSE MODE.
- **Winch 4** (W4) is the bell umbilical winch and is configured to maintain CT in either WINCH of TRAVERSE MODE.

KEY TO SYSTEM INDICATION AND STATE

Green circle	CORRECT INDICATION SAFE SYSTEM STATE
Green circle with red hatching	INCORRECT INDICATION SAFE SYSTEM STATE
Red circle with green hatching	CORRECT INDICATION UNSAFE SYSTEM STATE
Red circle	INCORRECT INDICATION UNSAFE SYSTEM STATE

KEY TO WINCH MOTOR DRIVE INDICATION AND STATE

W1–SP W2–CT W3–SP W4-CT (green)	NORMAL SAFE STATE FOR OPERATION IN WINCH MODE
W1–CT W2–CT W3–CT W4-CT (green)	NORMAL SAFE STATE FOR OPERATION IN TRAVERSE MODE
W1–CT W2–CT W3–CT W4-CT (red)	UNSAFE STATE FOR OPERATION IF BELL OUT OF THE HOOKS

CT – CONSTANT TENSION When winches manage themselves and do not expect the load of the bell

SP – SPEED CONTROL When winches manage the full load of the bell (& standoff frame & cursor). For normal operations this applies to W1 & W3 only

TIME LINE FOR BELL RUN PRIOR TO INCIDENT

CORRECT Indication SAFE System State (applies throughout, arrow down)

LOCAL TIME[1]	OPERATOR/DIVER/ SYSTEM ACTION	LARS HIMI DISPLAY SCREEN[2]	OPERATING MODE ON T&TUP SCREEN[3]	WINCH MOTOR DRIVE STATE (SP OR CT)[4]	NOTES/EVIDENCE
21:00:00	DIVERS IN BELL TUP TOP DOOR CLOSED	TROLLEY & TUP	OFF	W1–SP W2–CT W3–SP W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal operation *(EVID-035)(EVID-058)* HPU off. All brakes on. No abnormal alarms or warnings.
21:01:00	BELL TRUNK SEALED	TROLLEY & TUP	OFF	W1–SP W2–CT W3–SP W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal operation *(EVID-035)(EVID-058)* HPU off. All brakes on. No abnormal alarms or warnings.
21:04:00	BELL TRUNK ON SURFACE (VENTED) LOCKED OFF SYSTEM	TROLLEY & TUP	WINCH	W1–SP W2–CT W3–SP W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal operation *(EVID-035)(EVID-058)* HPU on. No abnormal alarms or warnings.
21:06:30 TO 21:08:37	WINCH MODE SELECTED - BELL RAISED FROM TUP	TROLLEY & TUP	WINCH	W1–SP W2–CT W3–SP W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal operation *(EVID-035)(EVID-058)* No abnormal alarms or warnings.
21:08:37	TRAVERSE MODE SELECTED	TROLLEY & TUP	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal operation *(EVID-035)(EVID-058)* No abnormal alarms or warnings.
21:08:50 TO 21:10:35	BELL TRAVERSED TO MOON POOL	TROLLEY & TUP	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal operation *(EVID-035)(EVID-058)*No abnormal alarms or warnings.
21:10:35 TO 21:13:10	STAND OFF FRAME FITTED & LOCKED	TROLLEY & TUP	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Launch crew fit stand off frame. Normal operation *(EVID-035)(EVID-058)* No abnormal alarms or warnings.

TIME LINE FROM START OF BELL LOWERING OVER MOONPOOL TO END OF FIRST UNCONTROLLED DESCENT

LOCAL TIME[1]	OPERATOR/DIVER/ SYSTEM ACTION	LARS HMI DISPLAY SCREEN[2]	OPERATING MODE ON T&TUP SCREEN[3]	WINCH MOTOR DRIVE STATE (SP OR CT)[4]	NOTES/EVIDENCE
			CORRECT Indication SAFE System State		
21:13:10	WINCH MODE SELECTED (TRAINEE DIVE SUPERVISOR)	TROLLEY & TUP	WINCH	W1–SP W2–CT W3–SP W4-CT	Prior to this action the Trainee Dive Supervisor is operating the LARS with the AOCM supervising in close attendance. Normal procedure to this point is described in *EVID-080 Serials 1 through 34* - however it is believed that a locally produced Aide Memoire is used *(EVID-005)*. Bell over moonpool. Trolley locked in position and no alarms. Winch mode selected *(EVID-035 Slide 7*) to commence lowering through the moonpool to target depth.
21:13:55	BELL OUT OF HOOKS AND STARTS LOWERING (TRAINEE DIVE SUP)	TROLLEY & TUP	WINCH	W1–SP W2–CT W3–SP W4-CT	Up to this point the operation has been normal. Trainee Dive Sup commences lowering of bell *(EVID-080 Serials 35 through 42*) Witness statements *(EVID-015/009)*
21:14:58	BELL STOPPED ON VERTICAL LOCKING PIN 1 SENSOR ALARM	TROLLEY & TUP	WINCH	W1–SP W2–CT W3–SP W4-CT	Vertical Pin1 Locked sensor fault triggers an alarm and subsequent soft stop of the bell and displays on the LARS Alarm list as 'VERTICAL LOCKING PIN 1 SENSORS INCONSISTENT' (No 289) Not recorded in HMCS Trends Archive. (*EVID-035)(EVID-058 Slide 17:30:27 No 289*). **This was the initial trigger but has no further significance to the incident.** Proximity sensor problems such as this have happened before. See witness statements *(EVID-017, EVID-006)* The action of overriding a proximity sensor is something that though not 'common' has been carried out previously.
			INCORRECT Indication SAFE System State		
21:17:02	TRAVERSE MODE SELECTED	TROLLEY & TUP	TRAVERSE	W1–SP W2–CT W3–SP W4-CT	**Switch from WINCH to TRAVERSE MODE** recorded in LARS HMCS archive (*EVID-035 Slide 6 & 7*) This is the first of two actions that put the system into the unsafe state that led to the incident. Software Safety Interlocks *(EVID -081 Slide 1)* prevent unsafe operation in that the winch motor drives are not switched to CT. *(EVID-082 Slide 1)* Despite enquiry the investigation team is not able to establish more facts and the reason for this selection of TRAVERSE MODE and the person who carried it out is not known. No further investigation will be carried out on this. Technicians EL and Mech called to dive control to investigate the reason for the system stop.
			CORRECT Indication UNSAFE System State		
21:20:29	MAINTENANCE MODE SELECTED – EL TECH	MENU-PASSWORD-MAINTENANCE	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	**This is the second action required to put the system into an unsafe state. The safety interlocks are now disabled and the winch motor drives are all switched to CT as this is the setting 'read' from the LARS PLC as it is in TRAVERSE MODE on the Trolley & TUP screen.** *(EVID—082 Slide 2)* **This then allows the brakes to be disengaged with winches 1 and 3 in the unsafe CT state and thus not configured to take the full load of the bell and cursor.** This mode is not normally used during operations with the occasional exception of 'balancing or levelling the winches' to enable recovery to the hooks. (Not to be confused with synchronising the winches) *(EVID-017, EVID-006).* This mode is password protected and only used by technical rather than operational personnel There is almost no documentation on the use of Maintenance mode and no procedures in place for when it should be used and by whom. El Tech does not know why he selected MAINTENANCE MODE as it is not needed to select overrides. *(EVID-006)* Warning message at top of all screens 'MAINTENANCE ACTIVE' *(EVID-082 Slide 016)*
21:21:03	PROXIMITY SENSOR OVERRIDE SELECTED - EL TECH	MENU-OVERRIDDES 2	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Vertical Locking Pin 1 Locked Sensor overridden by EL Tech in normal manner except for no password required because he had entered the password when entering MAINTENANCE MODE. There was no further security input required when he chose the override. The action of selecting an override had no safety implications as the locking pin had been physically verified as in place. The problem was that it was done via MAINTENANCE MODE where by default all safety interlocks were disabled. Warning message at top of all screens 'OVERRIDES ACTIVE' and 'MAINTENANCE ACTIVE' *(EVID-082 Slide 016 & 022)*
21:21:12	LOWERING - AOCM ACTIVATES DEADMANS	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Activating the Deadmans trigger initiates hangar alarms, energises the drive motors and then releases the hydraulic brakes. *(EVID-035) (EVID-070/071)* Because the winch (1 & 3) motors are in CT rather than SP (Speed) mode they are not configured to take the full weight (24 T) of the bell and cursor. Nominal CT Settings in TRAVERSE MODE are 1.5 Te on winches 1 through 3 and 0.5 Te on winch 4. Total of 5 Te maximum expected and then the winches will start paying out to maintain tension.
21:21:21	BELL FIRST UNCONTROLLED DESCENT (1st)	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Once the collective CT value of the winches (5Te) is exceeded the uncontrolled descent begins.*(EVID-035)* Cursor camera shows time from first movement to stop as approximately 10 seconds. Relatively slow acceleration and deceleration to stop observed. Bell internal camera also shows very minor shock to bell and divers during descent. *(Videos EVID-082/1 EVID-083)*
21:21:21 TO 21:21:31	AOCM RELEASES DEADMANS INITIATING SOFT STOP	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	This is part of the 'SOFT STOP' or 'NORMAL STOP' logic with progressive deceleration/resistive braking of the winch motors. Once stopped by the motors the drives will engage the brakes by depressurising the hydraulics keeping the brakes off. The power remains on the drive units. *(EVID-070/071)*
21:21:21 TO 21:21:31	EL TECH ACTIVATES E-STOP INITIATING EMERGENCY STOP	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	The activation of the E-Stop trips the Main Safety Relay which removes 440v power supplies leading to loss of hydraulic pressure and thus engages all 6 winch drive motor brakes (and main umbilical brakes). The motors initiate resistive breaking for 3 seconds (built into this braking 'logic') before losing power. Each wire winch brake is rated to 8T thus allowing 100% over capacity if all 6 brakes are considered. *(EVID-058-Alarms_2)*
21:21:21 TO 21:21:31	WINCH MOTOR DRIVE STOP FUNCTION INITIATING SOFT STOP	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Once the speed on the winch motors exceeds the maximum level a 'SOFT STOP' or 'NORMAL STOP' is initiated with progressive deceleration/resistive braking of the winch motors. Once stopped by the motors the drives will engage the brakes by depressurising the hydraulics that normally keeps the brakes off (fail safe system). The power remains on the drive units. A single over speed trip activated ALL drive motor trips via the PLC that monitors these drives. *(EVID-070/ 071)*
21:21:28	UMBILICAL CHUTE COLLAPSING ALARM INITIATING SOFT STOP	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Indicates that the hydraulic rams on the Umbilical chute are compressing (total movement allowable 400 mm) *(EVID-058-Alarms_2)*. This initiates a stop sequence according *to (EVID-070 Sect 3.2.5.9.1.1)*
21:21:29	E-STOP ACTIVE ALARM SAFETY RELAY TRIPPED	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Multiple alarms on both LARS PLC and winch motor drives all initiating stop actions *(EVID-058-Alarms_2)*. Note both 'Soft Stop' and 'Emergency Stop' are carried out. It hasn't been possible for the investigation team to ascertain which action brought the bell to a stop first and it is largely immaterial.
21:21:31	UMBILICAL WINCH (4) LOAD CELL 1 OUT OF RANGE ALARM INITIATING SOFT STOP	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Indicates that the Umbilical load cells register excessive tension in the main umbilical *(EVID-058-Alarms_2).* This initiates a soft stop sequence according *(EVID-070 Sect 3.5.9.1.1)* Note that this is the 5th stop signal received by the system, 4 automatic and one manual (Deadman's trigger, Emergency Stop (Manual), winch overspeed, umbilical chute collapse, umbilical load cell out of range)
21:21:31	END OF FIRST UNCONTROLLED DESCENT (1st)	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Due to a combination of the preceding actions the bell is brought to a stop after 10 seconds within 2-3 mtrs with the cursor approximately 1 mtr above the moonpool deck. *(Videos EVID-082/1 EVID-083).(EVID-035)*
21:21:31	BELL STATIONARY IN MOONPOOL	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	All 6 winch drive motors stopped. Hydraulic power unit (HPU) to the brakes tripped. All brakes engaged.*(EVID-035)*

TIME LINE FROM END OF FIRST UNCONTROLLED DESCENT TO END OF SECOND UNCONTROLLED DESCENT

LOCAL TIME[1]	OPERATOR/DIVER/ SYSTEM ACTION	LARS HMI DISPLAY SCREEN[2]	OPERATING MODE ON T&TUP SCREEN[3]	WINCH DRIVE MODE (SP OR CT)[4]	NOTES/EVIDENCE
21:21:31	BELL STATIONARY IN MOONPOOL AT END FIRST DESCENT	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	All 6 winch drive motors stopped. Hydraulic power unit (HPU) to the brakes tripped. All brakes engaged.*(EVID-035)* The bell is an a stable and safe state though the system is still configured incorrectly for lowering and recovery operations.
21:21:31 TO 21:22:47	RESETS OF: E-STOP , HPU MAIN SAFETY RELAY RESET	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	All 6 winch drive motors stopped. All brakes engaged.*(EVID-035)* Reset sequence required before the bell can be moved involves re-setting: The E-STOP on the LARS HMI, The Main Safety Relay (Not in dive control), The Hydraulic Power Unit(HPU), Trolley & TUP screen Reset. (EVID-058/Alarms_2)(EVID-080). This sequence was carried out by the EL and Mech Techs.
			INCORRECT Indication UNSAFE System State		
21:22:47	WINCH MODE SELECTED (PROBABLY BY EL TECH)	TROLLEY & TUP	WINCH	W1–CT W2–CT W3–CT W4-CT	The EL Tech probably switched from TRAVERSE to WINCH MODE on the TROLLEY & TUP screen. However there is conflicting evidence as in his interview he states that he 'checked' that the system was in WINCH MODE both before the first and the second uncontrolled descent. (EVID-006). The Trends analysis suggests that the data recording the switch between modes is accurate though it can't be confirmed that the actual indication on the TROLLEY & TUP screens was correct. A run through with both the Starboard LARS (EVID-021) and Port LARS (EVID-044). suggests that the indications on this screen match the indications from the Trends (Data archive) analysis Because MAINTENANCE MODE is active the action of selecting WINCH MODE on the Trolley & TUP screen has no effect on the actual state of the winch motor drives which remain in CT. However the Trolley & TUP screen incorrectly displays the system as being in WINCH MODE.
21:24:06	LOWERING - AOCM ACTIVATES DEADMANS	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Exactly as for the first uncontrolled descent. Activating the Deadmans trigger initiates hangar alarms, energises the drive motors and then releases the hydraulic brakes. *(EVID-035) (EVID-070/071)* Because the winch (1 & 3) motors are in CT rather than SP (Speed) mode they are not configured to take the full weight (24 T) of the bell and cursor. Nominal CT Settings in TRAVERSE MODE are 1.5 Te on winches 1 through 3 and 0.5 Te on winch 4. Total of 5 Te maximum expected and then the winches will start paying out to maintain tension.
21:24:06 TO 21:24:21	SECOND BELL UNCONTROLLED DESCENT (2nd)	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Once the collective CT value of the winches (5Te) is exceeded the uncontrolled descent begins.*(EVID-035)* Cursor camera shows time from first movement to stop as approximately 10 seconds. Once again relatively slow acceleration and a quicker deceleration to stop observed on cursor camera. Bell internal camera shows a more pronounced reaction to the stop from the divers but still appears to be minor. *(Videos EVID-082/1 EVID-083)*
21:24:06 TO 21:24:21	AOCM RELEASES DEADMANS	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	This is part of the 'SOFT STOP' or 'NORMAL STOP' logic with progressive deceleration/resistive braking of the winch motors. Once stopped by the motors the drives will engage the brakes by depressurising the hydraulics that normally keeps the brakes off (fail safe system). The power remains on the drive units. *(EVID-070/071)*
21:24:08	EL TECH ACTIVATES E-STOP. MECH TECH ACTIVATED E-STOP	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	The activation of the E-Stop trips the Main Safety Relay which removes 440v power supplies leading to loss of hydraulic pressure and thus engages all 6 winch drive motor brakes (and main umbilical brakes). The motors initiate resistivreb for 3 seconds (built into this braking 'logic') before losing power. Each wire winch brake is rated to 8T thus allowing 100% over capacity if all 6 brakes are considered. *(EVID-058-Alarms_2)*
21:24:06 TO 21:24:21	WINCH MOTOR DRIVE STOP FUNCTION INITIATING SOFT STOP	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Once the speed on the winch motors exceeds the maximum level a 'SOFT STOP' or 'NORMAL STOP' is initiated with progressive deceleration/resistive braking of the winch motors. Once stopped by the motors the drives will engage the brakes by depressurising the hydraulics keeping the brakes off. The power remains on the drive units. A single over speed trip activated ALL drive motor trips via the PLC that monitors these drives. *(EVID-070/071)*
21:24:08	SAFETY RELAY TRIPPED	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Multiple alarms on both LARS PLC and winch motor drives initiate stop actions *(EVID-058-Alarms_2)*. Note both 'Soft Stop' and 'Emergency Stop' are carried out. It hasn't been possible for the investigation team to ascertain which action brought the bell to a stop first and it is largely immaterial.
21:24:10	UMBILICAL WINCH (4) LOAD CELL 1 OUT OF RANGE ALARM INITIATING SOFT STOP	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Indicates that the Umbilical load cells register excessive tension in the main umbilical *(EVID-058-Alarms_2)*. This initiates a soft stop sequence according *(EVID-070 Sect 3.5.9.1.1)* Note that this is the 5th stop signal received by the system, 4 automatic and one manual (Deadman's trigger, Emergency Stop (Manual), winch overspeed, umbilical chute collapse, umbilical load cell out of range)
21:24:06 TO 21:24:12	UMBILICAL MULTIPLE CONNECTIONS FAILED	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	All connections to the Port Bell Umbilical termination plate are severed. Port Bell D1 hot water external isolation and check valves sheared off at the penetrator. Port Bell D2 hot water external isolation valve rotated through 90 degrees at the penetrator. Video *(EVID-084)*
21:24:12	BELL STARTS LOSING INTERNAL PRESSURE	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Multiple gas connections begin leaking. Initial bell internal depth is 111 m (11 Bar over ambient).
21:24:21	DIVERS INSTRUCTED AND BEGIN TO SHUT ALL VALVES	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Dive Supervisor instruct the divers to 'close the valves in the bell' - repeatedly. Video *(EVID-084)* Divers begin shutdown drill to stop the uncontrolled loss of gas/upwards depth excursion.
21:24:21	SECOND BELL STOP	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Due to a combination of the preceding actions the bell is brought to a stop within the moonpool zone. Timing of the cursor camera video indicated a total bell movement time of approximately 6.5 seconds. *(Videos EVID-082/1 EVID-083).(EVID-035)*
21:24:21	BELL STATIONARY IN MOONPOOL	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Bell stationary. Brakes engaged. All 6 winch drive motors stopped. Hydraulic power unit (HPU) to the brakes tripped. Gas and 1 hot water connections severed. Main umbilical power and communications intact, all interfaces normal. Continuing loss of bell pressure (upwards depth excursion). Divers closing valves

TIME LINE FROM END OF SECOND UNCONTROLLED DESCENT TO DIVERS IN TUP

LOCAL TIME[1]	OPERATOR/DIVER/ SYSTEM ACTION	LARS HMI DISPLAY SCREEN[2]	OPERATING MODE ON T&TUP SCREEN[3]	WINCH DRIVE MODE (SP OR CT)[4]	NOTES/EVIDENCE
21:24:21	BELL STATIONARY IN MOONPOOL	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Bell stationary main umbilical intact, all interfaces (except LARS configuration) normal. Brakes engaged. All 6 winch drive motors stopped. Hydraulic power unit (HPU) to the brakes tripped. Continuing loss of bell pressure (upwards depth excursion). Divers closing valves
21:24:21 TO 21:28:27	BELL CONTINUES LOSING INTERNAL PRESSURE	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Video *(EVID-084)*. HMCS LARS Trends *(EVID-035)*
21:24:21 TO 21:28:27	BELL DIVERS CLOSING VALVES & BLOWING DOWN BELL	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Video *(EVID-084)*. HMCS LARS Trends *(EVID-035)*
21:28:27	BELL AT MINIMUM DEPTH OF 93 M	TROLLEY & TUP	WINCH	W1–CT W2–CT W3–CT W4-CT	Divers increase blow down rate and start returning bell to living depth of 110 m. HMCS LARS Trends *(EVID-035)* From initial de-pressurisation it takes 4 min 15 sec to de-pressurise to the minimum depth. A further 11 minutes sees the bell back to it initial living depth of 110 mtrs
21:28:30	BELL CONTINUE BLOWDOWN STILL LOSING PRESSURE	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Video *(EVID-084)*. HMCS LARS Trends *(EVID-035)*
21:30:10	BELL BLOWDOWN RE-COMMENCES	TROLLEY & TUP OR DASHBOARD	WINCH	W1–CT W2–CT W3–CT W4-CT	Divers re-checking valve configuration. Second to last leak is isolated (valve closed). Video *(EVID-084)*. HMCS LARS Trends *(EVID-035)*
21:32:57 TO 21:34:50	CYCLES MAINTENANCE MODE (x3) (PLC TECH)	VARIOUS	WINCH	W1–CT/SP W2–CT W3–CT/SP W4-CT	PLC Tech identifies that the winces are in the incorrect state for WINCH MODE and also that the sytem shoud not be in MAINTENANCE MODE. He cycles 'MAINTENANCE MODE active/not active three times and confirms from the DASHBOARD screen MAINTENENCE screen that the winches are switching between the expected states. Once satisfied that the system is responding correctly he leaves it in WINCH MODE with MAINTENANCE MODE not active. *(EVID-035,EVID-011)*
			CORRECT Indication SAFE System State		
21:34:50	MAINTENANCE MODE DE-ACTIVATED - WINCH DRIVES IN SAFE STATE	MAINTENANCE, DASHBOARD TROLLEY & TUP	WINCH	W1–SP W2–CT W3–SP W4-CT	**Because MAINTENANCE MODE is now de-selected (not active) and WINCH MODE has been previously selected on the Trolley & TUP screen the system reverts to a safe state with correct indications.** *(EVID-058 / page Alarm_4) (EVID-035)*
21:35:19	BELL LAST LEAK STOPPED - BLOW DOWN CONTINUES	TROLLEY & TUP OR DASHBOARD	WINCH	W1–SP W2–CT W3–SP W4-CT	From this point the Bell internal depth signal 'flat lines' as it has been isolated. The Dive Supervisor continues monitoring depth via Diver 1 and Diver 2 depth transducers. *(EVID-035)* Video *(EVID-084)*
21:39:36	BELL BLOWN DOWN TO LIVING DEPTH OF 110 M	TROLLEY & TUP OR DASHBOARD	WINCH	W1–SP W2–CT W3–SP W4-CT	Divers have isolated all leaks and blown down the bell back to 110 m living depth. *(EVID-035)* Onboard gas banks gas usage was approximately 15% of the total available capacity. (EVID-020) All power and communications elements of the umbilical still working. *(EVID-058)*
21:41:43	COMMENCE RECOVERING BELL FROM MOONPOOL - PLC TECH	TROLLEY & TUP OR DASHBOARD	WINCH	W1–SP W2–CT W3–SP W4-CT	From this point on the recovery is 'normal'. However the PLC tech and El Tech carry out extra confirmation steps at critical stages to ensure that this is the case. *(EVID-035)*
21:44:49	BELL IN HOOKS NO LOAD ON WINCHES	TROLLEY & TUP OR DASHBOARD	WINCH	W1–SP W2–CT W3–SP W4-CT	Normal operation *(EVID-035)*
21:45:16 TO	TRAVERSE MODE SELECTED & BELL TRAVERSED TO TUP – EL TECH	TROLLEY & TUP OR DASHBOARD	TRAVERSE	W1–CT W2–CT W3–CT W4-CT	Normal operation *(EVID-035)* Vertical locking pin 1 override de-activated (21:47:00)(*EVID-058)*
21:57:17	WINCH MODE SELECTED – BELL OVER TUP START LOWERING	TROLLEY & TUP OR DASHBOARD	WINCH	W1–SP W2–CT W3–SP W4-CT	Normal operation *(EVID-035)(EVID-058)*
21:58:56	BELL MATED WITH TUP CLAMP CLOSING NO LOAD ON WINCHES	TROLLEY & TUP OR DASHBOARD	WINCH	W1–SP W2–CT W3–SP W4-CT	Normal operation *(EVID-035)(EVID-058)*
22:01:07	SAFETY RELAY TRIPPED	TROLLEY & TUP OR DASHBOARD	OFF	W1–SP W2–CT W3–SP W4-CT	Bell trunk sealed onto TUP. Pressure in Trunk initiates trip which ensures no further movement of the LARS. *(EVID-035)*
22:10:00	DIVERS BACK IN TUP	TROLLEY & TUP OR DASHBOARD	OFF	W1–SP W2–CT W3–SP W4-CT	Divers subsequently talked through neurological tests by hyperbaric nurse who was in contact with the Duty diving doctor onshore and were given a clean bill of health. Witness statement of Hyperbaric nurse *(EVID-007)*

APPENDIX E – ROOT CAUSE ANALYSIS

Fundamental Root Causes Referenced to Root Cause Analysis Diagrams

Fundamental Root Cause	Cause Box No.
During the construction of Skandi Arctic the bell launch control systems were given a low hazard rating and therefore lacked the level of technical safety scrutiny given to other, more highly rated systems.	1, 2, 3, 4, 8, 9, 15, 16, 26, 32, 33
Although there are organisations and systems for conducting audit and correction of non-compliances, these has not detected or corrected the deviations identified by the investigation team in diving technical risk management, diving procedures, and related systems.	1, 2, 3, 4, 6, 8, 9, 11, 12, 14, 15, 16, 18, 19, 20, 21, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33
The implications of introducing PLC technology to the diving industry might not have been fully understood, and the related roles, responsibilities & competencies of both technical and operational personnel are not sufficiently well clarified.	5, 6, 11, 10, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 31
The diving organization has not sufficiently defined the emergency response to reasonably foreseeable hazard conditions, and not optimized equipment, checklists, training or drills for effective use. Furthermore emergency related processes are not audited for effectiveness or for feedback to improve related technical, procedural or competency systems.	10, 16, 22, 23, 24, 25, 28, 29, 30, 31, 33
There was insufficient supervisory understanding of both the bell launch and recovery control system and the situational awareness needed to understand and control the human and equipment response to a complex hazardous situation.	7, 10, 16, 22, 28

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ROOT CAUSE ANALYSIS - WHAT HAPPENDED

The Skandi Arctic DSV had an uncontrolled descent of the port diving bell

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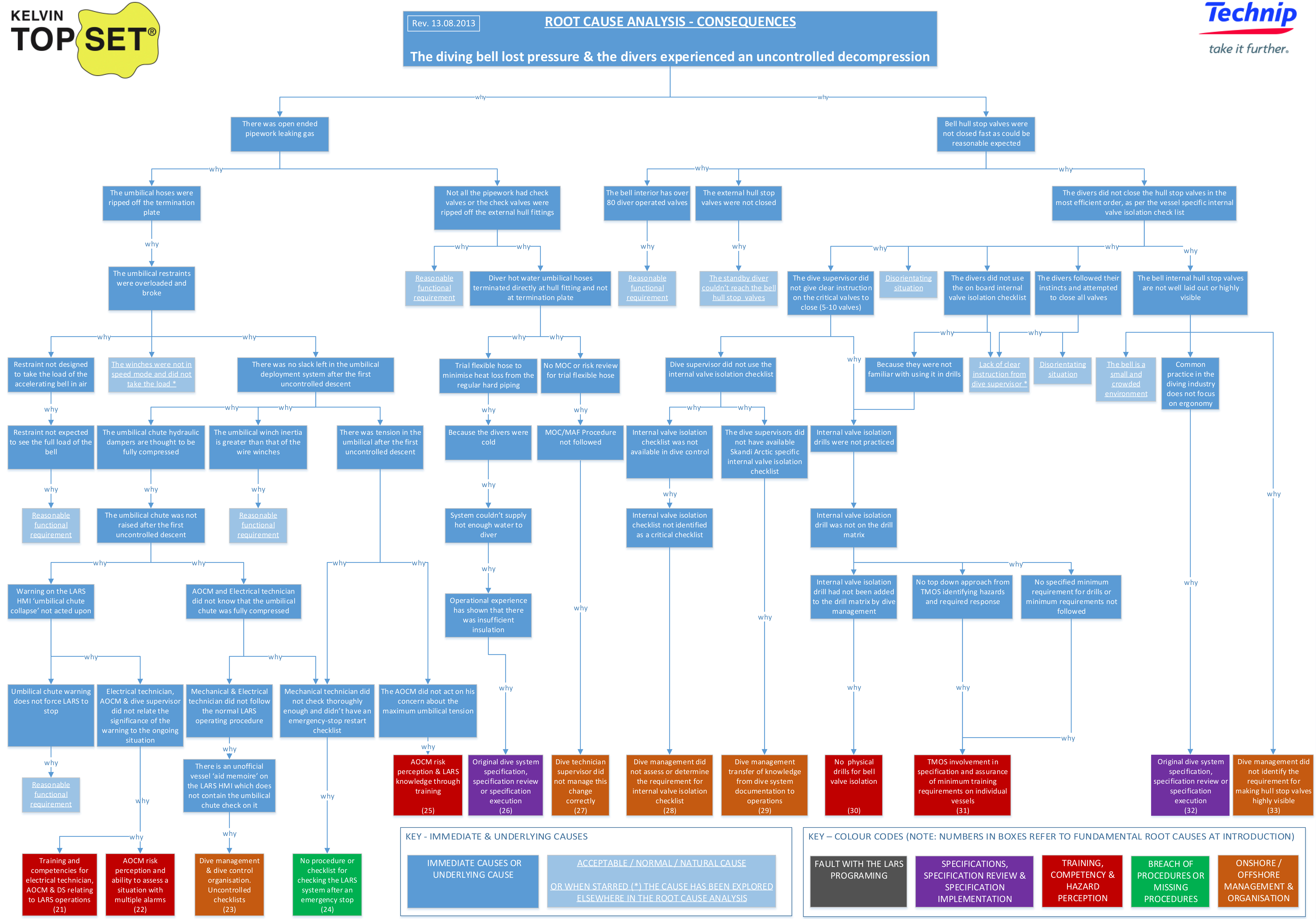

APPENDIX F – POTENTIAL CONSEQUENCES ANALYSIS

POTENTIAL CONSEQUENCES ANALYSIS FOR THIS INCIDENT

Description	Perceived Consequence	Current Mitigating Measures	Incident Potential
Bell in moonpool. Bell internal door closed. Further loss of pressure in bell – divers not able to close valves in time. Bell not immediately available for launch crew to close bell external hull valves.	Diver decompression illness due to gas formation in all diver body tissue (Gas Embolism).	Umbilical terminated on termination panel – provides weak link to preserve main supply checkvalves. Checkvalves on main gas supply and hot water supply lines – only 4 x 3/8" lines leaking – average leak rate 4,2 mtrs/minute. Sufficient onboard gas for maintaining pressure inside bell for 95 minutes. Launch crew rig up with safety harnessess etc. Access bell and close external hull stops. Bell onboard gas charging lines available in bell hangar for maintaining bell internal pressure. Pressure loss rate can be reduced by taking bell to working depth, i.e. reducing pressure difference between inside / outside bell. Deploy bell to depth to reduce gas loss. Starboard bell diver intervention on port bell external valves. Bell emergency umbilical deployed for connection by ROV at depth. Through water transfer to Starboard bell alternatively another DSV.	**5B** **5 Catastrophic / B Unlikely**
Damage to bell hull penetrations: - loss of external hull valves for containing the gas in bell. - loss of check valves on main gas supply lines. - rapid pressure loss inside bell. Worst case 2 x 3/4" in addition to 4 x 3/8" lines. Would have tripled leak rate to nearly 13 mtrs/min. - bell atmosphere would fog up and take away visibility. - commumications distrurbance. - onboard gas emergency blowdown capacity not able to match gas leak rate. Bell not immediately available for launch crew to close bell external hull valves	Diver decompression illness as a result of rapid decompression. Hypoxia setting in Not sufficient gas flow into bell to compensate.	Bell hull penetration valves inside bell for closing by the divers. Onboard gas for compensating/reducing pressure loss inside bell for some time. Bell onboard gas charging lines available in bell hangar for maintaining bell internal pressure. Emergency blowdown valve can be supplemented by 2 x diver helmet free flow. Launch crew rig up with safety harnessess etc. Access bell and close external hull stops. Deploy bell to depth to reduce gas loss. Starboard bell diver intervention on port bell external valves. Bell emergency umbilical deployed for connection by ROV at depth. Through water transfer to Starboard bell alternatively another DSV.	**5C** **5 Catastrophic / C Possible**
In case of further uncontrolled descents with the LARS over moonpool. Loss of communication, light and video to the bell, hence divers without communication and guidance from surface Bell in water – not immediately accessible for standby diver.	Diver injury - as bell hits water surface resulting in a sudden stop. - snatch loads in bell LARS winch wires (slack wires). - diver decompression illness	Onboard emergency power source for light and scrubber. Through water comms when bell is below 15 msw. Bell hull penetration valves inside bell for closing by the divers. Sufficient onboard gas for maintaining pressure inside bell for 95 minutes. Bell emergency umbilical deployed for connection by ROV at depth. Bell weight in water 7Te (less than in air 24Te) slower descent rate in water. Any single (3 off) winch able to maintain bell weight in water. Deploy bell to depth to reduce gas loss. Starboard bell diver intervention on port bell external valves. Bell emergency umbilical deployed for connection by ROV at depth. Through water transfer to Starboard bell alternatively another DSV.	**3B** **3 Significant / B Unlikely**
Uncontrolled descent over TUP (approx.. 1,7m height between bell and TUP flanges)	Damage to TUP and bell sealing surface – unable to mate bell to TUP. Injury to divers due to impact with trunk potential unconsciousness. Further material damages and prolonged repair process.	Bell secured by traverse frame rollers - only short distance vertical movement. Bell hull penetration valves outside bell for closing by standby diver & launch crew. Bell onboard gas charging lines available in bell hanger for maintaining onboard gas supply to bell interior. Possibility for decompressing divers in bell – medical lock on bell. Through water transfer to Starboard bell alternatively another DSV providing LARS functional and divers unharmed.	**3C** **3 Significant / C Possible**
Divers loss of consciousness, unable to control bell internal pressure.	Impact injuries rendering divers unconscious Diver decompression illness	System brakes set up with soft stops. Bell in moonpool / in water below vessel hull – bell lowering speed reduced in water. Standby diver ready for external intervention on bell. Starboard bell diver intervention on port bell external valves. BIBS with 10/90 Helliox from onboard gas banks.	**5A** **5 Catastrophic / A Very Unlikely**
High ppO2	Hyperoxia by over pressurising the bell internal atmosphere.	Onboard gas selected according to depth 10/90 Heliox. Depth gauges monitoring bell internal pressure. Diver depth transducer for topside readout. Starboard bell diver intervention on port bell external valves and onboard gas panel.	**5A** **5 Catastrophic / A Very Unlikely**
Low ppO2	Hypoxia by reduction of bell internal pressure.	Onboard gas selected according to depth 10/90 Heliox. Bell atmosphere at 3.3% Heliox after TUP. Pure oxygen onboard gas available for makeup of bell atmosphere. Shallowest depth for 3.3% Heliox and ppO2 = 210mbar on BIBS equals 54msw. BIBS with 10/90 Heliox from onboard gas banks. Shallowest depth for 10/90 Heliox and ppO2 = 210mbar on BIBS equals 11msw.	**2A** **2 Moderate / A Very Unlikely**
Insufficient onboard gas supply. Damage to onboard gas supply valves and stainless steel piping loosing onboard gas capacity. Not able to sustain bell internal pressure if unable to close internal / external valves.	Decompression illness.	Bell hull penetration valves inside bell for closing by the divers. Bell hull penetration valves outside bell for closing by launch crew & standby diver or divers at depth.. Bell emergency umbilical deployed for connection by ROV at depth. Launch bell to seabed and perform through water transfer to starboard bell breathing on 2 x SLS.	**5B** **5 Catastrophic / B Unlikely**
Umbilical whip lines uncontrolled in bell hanger area until gas flow closed. area	Injury to personnel in bell hanger from uncontrolled umbilical whips Personnel injuries from loose equipment.	Remote control of umbilical gas supply at Dive Supervisor desk. Personnel standing clear when moving bell in bell hanger area.	**2B** **2 Moderate / B Unlikely**

APPENDIX G – HUMAN FACTOR EVALUATION

Human Factors Investigation
Incident at DSV Skandi Arctic 22-JUN-2013

Date of issue: 11-AUG-2013
Produced by:
Terje Lövöy,
Senior Partner
Gimmestad AS
+47 41 37 4000
terje.lovoy@gimmestad-as.no
www.gimmestad-as.no

1. Introduction

Technip has engaged Gimmestad AS as an independent third party to evaluate human factor interfaces with LARS and diving control with a special focus on procedures and checklists after the incident on DSV Skandi Arctic 22-JUN-2013. A complete internal report is made by Technip. This report is a supplement to the complete report.

2. Executive Summary

In our conclusion this is about procedures not working or used as intended because they are too complex and not as user-friendly as they could be. The problem is not isolated to LARS or a single vessel; it is a system challenge. It could also be called a system potential because better solutions exist. We recommend that procedures should be designed by local subject matter experts but in accordance with a new cross company standard based on a management strategy for user-friendly documentation.

3. Factual Information

3.1 Safety barriers

The incident is the result of a chain of events that passed through several safety barriers. First the chain of events passed system warnings and the SDC Launch – LARS Normal Procedures. Once the incident occurred it also bypassed the Internal Valve Isolation Checklist (Rupture or Loss of Umbilical). Finally the experience and calmness of the divers in the SDC stopped the leak and contained the problem. As the main report describes, the divers used approximately 4 minutes to identify and close the correct valves and to start the return of pressure.

3.2 Procedure and checklist contents

The risk of mode confusion was probably not identified before this incident. Consequently the hazards associated with mode confusion are not sufficiently emphasized in the SDC Launch – LARS Normal Procedures. The Internal Valve Isolation Checklist (Rupture or Loss of Umbilical) does not differentiate items that must be done immediately from clean-up items. There are no cues in the checklist to help quickly identify the most critical valves. The most critical valves are not colored, marked or located together.

3.3 Use of procedures

It is unclear if and how the LARS operators referred to normal procedures. The divers and surface crew did not follow a set standardized solution immediately after the umbilical ruptured. The Diving Supervisor was calm and repeatedly asked the divers to close all valves and it took several minutes after the umbilical ruptured before the appropriate checklist was located.

An informal abbreviated "aid memoire" list was used because the LARS procedure in the manual was perceived as too complex. Various crewmembers on the vessel explain that the way this crew used the procedure is not uncommon. It can therefore be argued that this is more a system problem than a problem with a few individuals. The problem is not isolated to one procedure since at least some of the root causes are related to the general procedure design.

3.4 Procedure and checklist design

Other high reliability organizations, like the nuclear, air and space industry have come up with new and more user-friendly design principles. Even though the current Technip procedures have a traditional design that is acceptable in many industries, the fact remains that they do not use the latest philosophies available.

4 Considerations

4.1 Safety Barriers

System safety should be built on proactive, reactive, redundant and flexible barriers.
In this case we have several proactive barriers. One of these is the SDC Launch – LARS Normal Procedures designed to proactively prevent errors. The Internal Valve Isolation Checklist is a reactive barrier to manage errors that might slip through.

It can be argued that enhanced normal procedures could have prevented the error and that an improved emergency checklist could have managed the error quicker.
The logic behind this claim is that:

- They would be used more/quicker
- It would be easier to find the needed page and use it correctly

It is impossible to design procedures and checklist for every possible scenario. The human is the only intelligent and also the only flexible barrier and in this incident it was this that stopped the chain of events before it became an accident. The ideal situation would be to have skilled individuals using their experience as a team in combination with good procedures and checklists. We need both, and one does not exclude the other. This is only true if the procedures are so user-friendly that they can be done without taking too much attention away from the tasks to be accomplished.

In this incident we have a very modern vessel, state of the art diving systems, skilled personnel and good procedures. There is however a potential to further improve the procedure. This conclusion is supported by benchmarking with other industries as well as interviews with crew and managers from the vessel.

4.2 Procedure and checklist contents

Improved normal LARS procedures could highlight the risks of operation outside the normal mode. Notes and warnings can be used to focus on critical steps. The enclosed example visualizes how notes and warnings can be used to focus on the risks and hazards associated with mode confusion.

If an umbilical should rupture there are a few critical items that must be done first and quickly. The checklist should refer to some easy to find markings and locations.

The airline industry has two types of emergency checklists:

- A few problems are so urgent that they require a few immediately action items that are done from memory. A checklist is read afterwards to verify that nothing is forgotten.
- Read and do checklist are used for all other emergency items that does not require an immediate action.

4.3 Use of procedures

There is a link between how user-friendly procedures and checklists are to how much they will be used in real life. Based on our discussion above, we can conclude that the procedures and checklist are not perceived as user-friendly. The traditional and complex design is probably a contributing factor to why they are not used more. The enclosed example also illustrates improved visual ergonomics to make it quicker and easier to extract information.

4.4 Procedure and checklist design

The final question would be to ask why the procedures are not designed more user-friendly. One contributing factor to this is probably that there are few Technip instructions for how the procedures and checklist should be designed and used. It takes more time to make something simple and user-friendly than to make something complex. Simplify does not just happen, it must be designed. An organization must place high value on simplicity and decide who the simplicity should be designed for.

5 Recommendations

5.1 Improve SDC Launch Procedure

Make a new normal SDC launch procedure as soon as possible, with notes and warnings to prevent mode confusion and dangerous states. Have these validated.

5.2 Improve Rupture of Umbilical Procedure

Make a new Internal Valve Isolation Checklist as soon as possible that starts with the most critical items. Locate the most critical valves together in an accessible place and mark them; refer to the marking and location in the checklist. Clearly split the procedure into immediate memory items and read and do clean-up items. Have these validated.

5.3 Management vision

Arrange a workshop for the appropriate management level to:

- Place a high value on simplicity and user-friendly procedures
- Look at strategies used by other organizations who transitioned to a system with more user-friendly procedures and checklists

The output should be a resolution to establish a new strategy for cross company standardization of how to make user-friendly procedures.

5.4 Long term plan

Make a plan for how to improve relevant operational documentation and training. This should include a new philosophy customized to Technip inspired by the latest principles for high performance procedure design. This plan should include who-what-when for design, implementation, effect confirmation and follow-up.

A4 procedure used today

Technip — SDC Launch – LARS Normal Procedure – Skandi Arctic

Normal SDC Launch Procedure	
1	Reset safety circuit via E-Stop Reset Button on Winch Area Panel
2	Press Reset on HMI select trolley & TUP Screen
3	Press the "SDC Target Depth" field to bring up the numerical keypad. Insert the target Depth for the dive & press enter (The bell winches will stop at this depth with an audible alarm.)
4	Vent the Trunk using Trunk control page on Dive Control SCADA, valve PY-005B
5	Confirm trunk vent successful by observing the extinguished " Pressure in Mating Trunk" lamp and confirming SDC Trunk Depth reads 0.0msw
6	Select Lars HPU Screen on HMI. Supv command remove the mating clamp mechanical interlock pin
7	Observe Mechanical Interlock pin inserted" lamp extinguished and the "Mech. I/Lock Pin removed" lamp illuminated green & start HPU
8	Confirm HPU pressure is approx 207Bar
9	Confirm Umbilical Collapsing Chute is fully extended
10	Confirm Shock Absorbers are extended
11	Press the open clamp button and observe the "open" indicator illuminate.(Clamp operation viewed in monitor)
12	Check the Tension set points for the centre winch & umbilical winch on the HMI (Dashboard page)
13	On HMI go to "trolley and TUP Page", select winch mode
14	On HMI go to Dashboard Page
15	Confirm all drives are enabled & in the correct modes (inboard & outboard in speed control, Centre & Umbilical in Constant Tension)
16	Press dead man's Handle on the Joystick, confirm brakes are OFF and raise
17	Confirm open is displayed in the "hooks Status field"(hooks will open automatically)
18	SDC will stop automatically on reaching high sensor.
19	Press Close Hooks keeping finger on HMI close command, confirm closed by indication on HMI & visually
20	Lower SDC onto Hooks & ensure winch wires are slack. Remove finger and release dead man's handle, confirm brakes are ON
21	Select traverse mode on the HMI
22	On HMI go to Dashboard page and confirm all winch's are in constant tension
23	On HMI go to the Trolley & TUP page, press the unlock trolley button. Confirm unlocked both on the HMI & locally
24	On HMI go to Dashboard page to monitor winch & wire status during traverse mode
25	Press dead man's handle on the joystick and traverse the SDC, confirm during traverse that winch's are in CT
26	Continue Traversing until trolley is in moonpool position
27	On HMI go to "Trolley & TUP" page & confirm "MP" light is on. Release dead man's handle on the joystick
28	Press "lock Trolley Button", once locked the status field will read locked.
29	Confirm SDC standoff frame locking pins are UNLOCKED ,(visually confirmed)
30	Press "Raise SDC Arms" & confirm raised position visually (rigger to confirm)
31	Manually lock stage to SDC Bump frame (separate Procedure)
32	Press "Lower SDC Arms" & confirm lowered both locally & on HMI
33	Press "Clear SDC Arms" to rotate them to the stowage position visually confirm this locally and on HMI
34	Select "Winch Mode" on HMI
35	On HMI go to Dashboard Page
36	Confirm all Drives are in the correct modes (inboard and Outboard in speed Control, centre and umbilical in CT
37	Press dead man's Handle on Joystick and select Raise
38	SDC will stop automatically upon reaching the High Sensors Hooks will open automatically
39	Release the dead man's handle
40	On HMI go to trolley and TUP page
41	Hooks, open automatically. confirm on HMI & locally that hooks are open & clear to lower SDC
42	Press dead man's handle on joystick & lower until clear of Hooks, hooks will close automatically

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Sample A5 procedure with enhanced design

Technip

NORMAL PROCEDURES

SDC Launch – LARS

34. Select WINCH MODE on HMI

Note: *Mode select buttons are not a valid verification of active mode. Use dashboard page to verify which mode the LARS is in.*

35. Verify selected winch drive modes on dashboard page:

- Inboard and outboard in SPEED CONTROL (SP)
- Centre and umbilical in CONSTANT TENSION (CT)

Warning!

Do not raise or lower SDC in TRAVERSE or MAINTENANCE modes as this may cause uncontrolled SDC lowering.

36. Press joystick dead man's trigger and select RAISE

Note: *SDC will stop automatically upon reaching the high sensor and hooks will open automatically.*

37. Release dead man's trigger

38. Make sure hooks are open and clear to lower SDC:

- Verify HMI indications
- Make local visual inspection

39. Press dead man's trigger and lower SDC until clear of hooks

▼ Continues next page ▼

Conceptual sample to illustrate layout. Contents is not correct and not approved for operational use. 2013-08-03