# REPUBLIC OF THE MARSHALL ISLANDS

Maritime Administrator

## VALARIS DS-17 MARINE SAFETY INVESTIGATION REPORT

Occupational Fatalities

Las Palmas, Canary Islands, Kingdom of Spain | 21 April 2023

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## AUTHORITY

An investigation, under the authority of the Republic of the Marshall Islands laws and regulations, including all international instruments to which the Republic of the Marshall Islands is a Party, was conducted to determine the cause of the casualty.

*Maritime Administrator*

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| °C | Degrees Celsius |
| 2/E | Second Engineer |
| 2/O | Second Officer |
| BWT | Bilge Water Tank |
| C/E | Chief Engineer |
| C/O | Chief Officer |
| CPR | Cardiopulmonary Resuscitation |
| EU | European Union |
| EU-OSHA | European Agency for Safety and Health at Work |
| FOT | Fuel Oil Tank |
| FPSO | Floating Production, Storage, and Offloading |
| FSU | Floating Storage Unit |
| HSE | Health, Safety and Environment |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IACS | International Association of Classification Societies |
| IDLH | Immediately Dangerous to Life or Health |
| JSA | Job Safety Analysis |
| m | Meter |
| $m^3$ | Cubic Meter |
| mm HG | Millimeters of Mercury |
| No. | Number |
| OIM | Offshore Installation Manager |
| P | Port |
| PPE | Personal Protective Equipment |
| ppm | Parts per Million |
| PTW | Permit to Work |
| REL | Recommended Exposure Limit |
| S | Starboard |
| SCBA | Self-contained Breathing Apparatus |

## LIST OF ABBREVIATIONS AND ACRONYMS (continued)

SDS . . . . . Safety Data Sheet

STEL . . . . . Short-term Exposure Limit

TWA . . . . . Time Weighted Average

UK HSE . . . . . United Kingdom Health and Safety Executive

US ATSDR . . . . . United States Agency for Toxic Substances and Disease Registry

US NIH . . . . . United States National Institute of Health

US NIOSH . . . . . United States National Institute of Occupational Safety and Health

US OSHA . . . . . United States Occupational Safety and Health Administration

UTC . . . . . Universal Coordinated Time



## DOCUMENTS CITED

ED2-2023 . . . . . High Concentration of Hydrogen Sulfide (HsS) in Cargo and Slop Tanks

Environ Sci Pollut Res Int. . . . . Environmental Science and Pollution Research International

MLC, 2006 . . . . . Maritime Labour Convention, 2006

MSA No. 3-24 . . . . . Marine Safety Advisory No. 03-24, Enclosed Space Entry Incidents

PR No. 37 . . . . . Procedural Requirement for Confined Space Safe Entry

STCW Code . . . . . Seafarers Training, Certification and Watchkeeping Code


# PART 1: EXECUTIVE SUMMARY

On 21 April 2023, the Republic of the Marshall Islands-registered drill ship VALARIS DS-17, managed by ENSCO International Inc. (the "Company"), was alongside in a shipyard at Las Palmas, Canary Islands, Kingdom of Spain. The ship was scheduled to depart Las Palmas on 1 May 2023. Work that needed to be completed prior to the ship's departure included cleaning the BWT.

The BWT had to be mechanically ventilated for at least 24 hours before it could be entered by a cleaning crew. In preparation for starting mechanical ventilation, the ship's 2/E No. 1 and a Motorman opened the BWT starboard access hatch. The hatch was located on the tank top beneath the deck plates in the No. 1 Aft Pump Room and was accessed by climbing down a 1.5 m vertical ladder.

After opening the access hatch, the Motorman climbed up the vertical ladder to the deck plates. The Motorman, who had stepped from the ladder onto the deck plates, saw that the 2/E No. 1 had stopped climbing up the ladder and laid his chest on the deck plates. The Motorman grabbed hold of the 2/E No. 1's coveralls and yelled for help. A third-party electrician who was working in the No. 1 Aft Pump Room responded. Within seconds of the third-party electrician reaching the scene, both the 2/E No. 1 and the Motorman, who was kneeling on the deck plates while holding onto the 2/E No. 1's coveralls, fell through the open access hatch into the BWT. The third-party Electrician immediately informed crewmembers who were in the Engine Control Room and the alarm was raised.

Members of the ship's rescue team reported smelling what was described as a "strong smell of rotten eggs" when they entered the No. 1 Aft Pump Room to initiate an enclosed space rescue. Neither the 2/E No. 1 nor the Motorman were breathing or had a pulse when they were removed from the BWT by members of the ship's rescue team. Efforts to resuscitate the 2/E No. 1 and the Motorman were unsuccessful, and they were determined to be deceased.

The marine safety investigation conducted by the Republic of the Marshall Islands Maritime Administrator (the "Administrator") determined that the PTW for opening the BWT access hatch was not issued in accordance with the Company's established procedures. Though portable gas detectors were available on board, one was not available on-site as required by the Company's relevant Work Instructions when the 2/E No. 1 and Motorman opened the BWT access hatch. The Administrator's investigation also determined that physical access to the BWT access hatch was restricted, which increased the risk of exposure to any gases that were within the BWT ullage space after the hatch was opened and while climbing the ladder up to the deck plates. The investigation further identified that the crewmembers were aware the atmosphere in the BWT ullage space contained hydrogen sulfide but that they may not have been aware that it could potentially contain high concentrations of hydrogen sulfide.

The below lessons learned were identified.

- Administrative controls, such as PTWs and Work Instructions, must be implemented consistently and in accordance with established procedures to be an effective means of reducing exposure to hazards.
- The importance of identifying connected spaces and their hazards.
- The importance of identifying and addressing hazards associated with the location where the work will be conducted when planning a job.
- The importance of being aware that, when opening access hatches, tanks may contain higher concentrations of hydrogen sulfide, or other toxic gases, than might be expected.

# PART 2: FACTUAL INFORMATION

The following Factual Information is based on the information obtained during the Administrator's marine safety investigation.

Ship particulars at the time of the incident: *see* chart to right.

## SHIP PARTICULARS

**Vessel Name**
VALARIS DS-17

**Registered Owner**
Rowan Rigs S.à.r.l.

**ISM Ship Management**
ENSCO International Inc.

**Flag State**
Republic of the Marshall Islands

| IMO No. | Official No. | Call Sign |
|---|---|---|
| 9646950 | 4645 | V7YE9 |

| Year of Build | Gross Tonnage |
|---|---|
| 2014 | 52,242 |

| Net Tonnage | Deadweight Tonnage |
|---|---|
| 15,672 | 33,428 |

**Length x Breadth x Depth**
213.1 x 36 x 18.2 m

**Ship Type**
Drill Ship

**Document of Compliance Recognized Organization**
Bureau Veritas

**Safety Management Certificate Recognized Organization**
N/A

**Classification Society**
American Bureau of Shipping

**Persons on Board**
Marine Crew: 88
Other: 90

***Narrative***

In June 2022, VALARIS DS-17 *(see Figure 1)* entered the shipyard at Las Palmas to undergo work required for the ship's reactivation. The ship was scheduled to depart from Las Palmas on 1 May 2023. The ship had been in lay-up at Las Palmas since 15 October 2019.

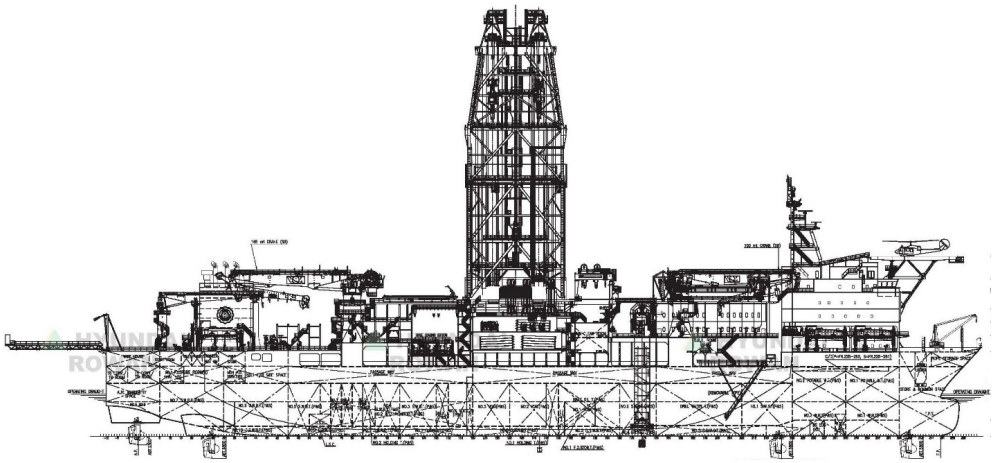

*Figure 1: VALARIS DS-17 General Arrangement.*

While VALARIS DS-17 was in lay-up, the BWT was used to store oily water that accumulated in the bilge wells located in the ship's machinery spaces. It was also used to store a mixture of the cleaning agent[1] and wash water that was generated when the Nos. 2 P and S FOTs were cleaned in February 2023.

The BWT had a capacity of 268.3 $m^3$ and was located on the centerline below Nos. 1 and 2 Aft Pump Rooms *(see Figure 2)*. Access hatches (i.e., manhole covers) for the BWT were located on the tank top in the Nos. 1 and 2 Aft Pump Rooms. The tank top was 2.6 m above the bottom shell. The BWT was naturally vented to the atmosphere. The vent head was located on the main deck and was 16 m above the tank top. The BWT was not fitted with sample points for testing the atmosphere in the tank's ullage space. Both the Nos. 1 and 2 Aft Pump Rooms had permanent mechanical ventilation.

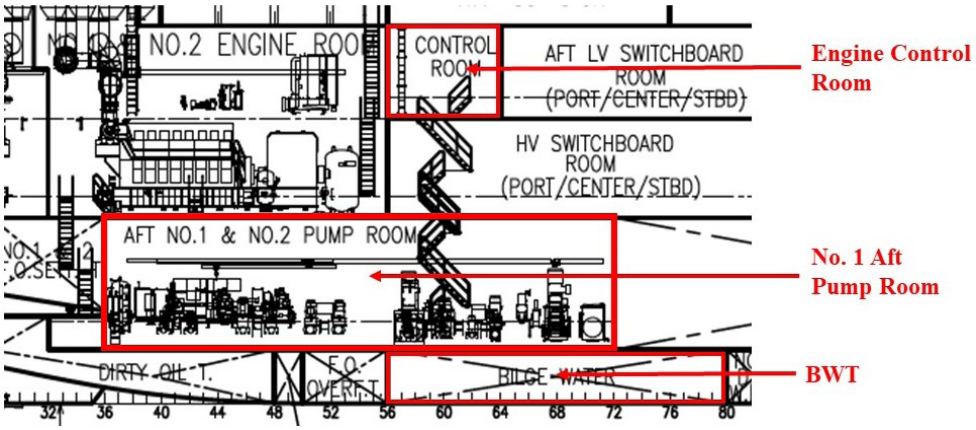


*Figure 2: Locations of the BWT, Nos. 1 and 2 Aft Pump Rooms, and the Engine Control Room on board VALARIS DS-17.*

1 The SDS for the cleaning agent that was used stated the product "was not classified as hazardous through inhalation."

In preparation for cleaning the BWT as part of the ship's reactivation, 35 $m^3$ of oily water was discharged ashore from the BWT on 27 March 2023. A layer of solids approximately 0.14 m deep across the bottom of the BWT remained following the discharge. Both access hatches were opened and the BWT was mechanically ventilated using portable blowers after the oily water was discharged.[2]

A third-party cleaning crew was scheduled to begin cleaning the BWT on 30 March 2023. Prior to their entry into the tank, a PTW, Gas Test, and Confined Space Entry Certificate were issued. Based on the Gas Test Certificate, the atmosphere inside the tank was safe for entry with 20.9% oxygen, no flammable gases, 0 ppm hydrogen sulfide, and 0 ppm carbon monoxide. In addition, the cleaning crew reviewed the Company's Work Instructions for confined space entry and rescue. The 2/E No. 1[3] was assigned as the Verifying Authority and was responsible for ensuring the conditions of the PTW, which included those identified on the Confined Space Entry Certificate and Work Instructions, were complied with while the work was being conducted.

At approximately 1010[4] on 30 March 2023, members of the third-party cleaning crew entered the BWT to begin cleaning the tank. In addition to chemically resistant coveralls, boots, and gloves, they were wearing half-face respirators and personal multi-gas detectors. After entering the BWT, the cleaning crew used a vacuum to remove the layer of solids that was on the bottom of the tank.

The cleaning crew's personal gas detectors started to activate less than an hour after they entered the BWT. They immediately stopped work and exited the tank. It was determined that the gas detectors had activated due to the presence of hydrogen sulfide.[5] The reason stated on the PTW for the work stoppage was: "Work stopped due to gas detected." The PTW was then closed. The 2/E No. 1 signed the PTW when it was closed. The BWT access hatches were closed after the work was stopped.

On 8 April 2023, VALARIS DS-17 got underway from Las Palmas for sea trials. Testing of the pumps in the Mud Room was conducted as part of the sea trials. Sea water leakage from these pumps was contained in the Mud Room drain tanks. This sea water, which was reported to have entrained sediment, was transferred to the BWT.

VALARIS DS-17's C/E sent an email to the shipyard's Project Manager on 17 April 2023 requesting to have a team ready to clean the BWT when the ship returned from sea trials either late the next day or early on 19 April 2023. He also stated there was approximately 40 $m^3$ in the tank that would need to be discharged before the cleaning crew could access the tank. The contents of the tank included the sea water entrained sediment that had been transferred from the Mud Room drain tanks. The shipyard's Project Manager responded by indicating that the BWT access hatches must be opened, the tank ventilated for at least 24 hours, and that hydrogen sulfide gas levels needed to be taken into account. The C/E responded by stating that the BWT would be ready on 24 April 2023. The shipyard's Project Manager replied a few minutes later, stressing the importance of the BWT being ventilated and indicated that there should be two blowers at each of the two access hatches. Both 2/Es were included in copy on these emails.

2 The trunks for the blowers passed through the access hatches.

3 VALARIS DS-17's crew included two 2/Es.

4 Unless stated otherwise, all times are ship's local time (UTC +/- 0).

5 The personal multi-gas detectors were set to activate upon detecting 10 ppm of hydrogen sulfide.

VALARIS DS-17 returned to Las Palmas from sea trials and was moored at the shipyard on the afternoon of 19 April 2023. The observed weather was generally good with winds of Beaufort Force 2-4 and seas of 1-2.5 m. The ship's recorded pitch, roll, and heave were generally less than 0.5°.

On 20 April 2023, 50 $m^3$ of a mixture of oily water that had been transferred from the bilge wells in the machinery spaces and sea water from the drain tanks in the Mud Pump Room was discharged ashore. The transfer was supervised by the 2/E No. 1.

On the morning of 21 April 2023, the C/E assigned the 2/E No. 1 and a Motorman to open the BWT access hatches. The PTW was issued at 0837 by VALARIS DS-17's Master. The PTW identified the 2/E No. 2 as the Permit Owner and 2/E No. 1 as the Verifying Authority.[6] Based on the PTW, the task did not require entering a confined space. The PTW did not reference the Company's Work Instruction for opening or closing tank hatch covers or indicate that a Job Safety Analysis had been completed as required by the Company's PTW procedures.[7] There is also no indication that the 2/E No. 1 and Motorman reviewed this Work Instruction before they started work.

At approximately 0900 on 21 April 2023, the shipyard's Project Manager sent an email to VALARIS DS-17's C/E asking him to confirm whether the BWT would be ready on 24 April 2023. He also restated the need for both access hatches to be open. The shipyard's Project Manager also asked the C/E to let him know when the access hatches were open and ventilation started. Both 2/E Nos. 1 and 2 were included in copy on these emails between the C/E and the shipyard's Project Manager. It is not known if the 2/E No. 1 saw these emails before he and the Motorman started opening the starboard side access hatch for the BWT.

After isolating the BWT by closing and sealing the tank's inlet and outlet valves, the 2/E No. 1 and Motorman went to the No. 1 Aft Pump Room to open the starboard side BWT access hatch, which is on the tank top approximately 1.5 m below the deck plates. The access hatch was reached by climbing down a vertical ladder *(see Figure 3)*.[8] It is not known when the 2/E No. 1 and Motorman started opening the access hatch.

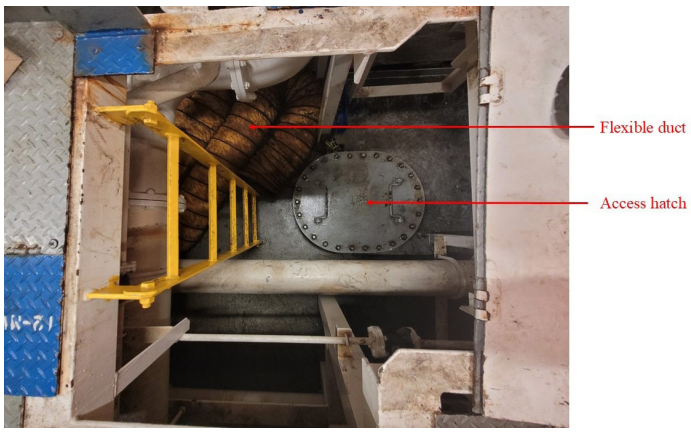


*Figure 3: The BWT access hatch and vertical ladder for accessing the tank top in the No. 1 Aft Pump Room. There is also a vertical ladder inside the BWT.*

6 2/E No. 2 stated he did not initiate the PTW. There is no indication that the 2/E No. 2 had any involvement with opening the BWT access hatches on 21 April 2023.

7 The Company's PTW procedures are addressed later in this report.

8 The port side BWT access hatch is located on the tank top in the No. 2 Aft Pump Room.

Sometime after they opened the access hatch, the Motorman climbed up the vertical ladder to the deck plates. He was followed by the 2/E No. 1. When he was on the deck plates, the Motorman saw that the 2/E No. 1 had stopped climbing and was leaning with his chest on the deck plates. The Motorman grabbed the 2/E No. 1's coveralls and yelled for help. A third-party Electrician working in the No. 1 Aft Pump Room immediately responded. Within seconds of the third-party Electrician reaching the scene, both the 2/E No. 1 and the Motorman, who was kneeling on the deck plates, fell through the open access hatch into the BWT.

The third-party Electrician immediately went to get assistance. He saw a shipyard worker and told him to call for help. The shipyard worker used a portable radio to call for assistance and the third-party Electrician went up to the Engine Control Room *(see Figure 2)*. He reached the Engine Control Room at 1318 and reported that two crewmembers had fallen into the BWT. A crewmember in the Engine Control Room immediately called the Bridge. At 1320, a watchstander on the Bridge made an announcement for the ship's rescue team to proceed to the No. 1 Aft Pump Room and then called the ship's Master. The Master immediately called the C/O and told him to go to the No. 1 Aft Pump Room. The Master then called for an ambulance.

The C/O and members of the rescue team arrived in the No. 1 Aft Pump Room by 1326. They reported smelling what the 2/O, who was a member of the rescue team, described as a "strong smell of rotten eggs." The C/O directed crewmembers to get SCBAs with extra bottles, a rescue tripod, and a gas detector.[9] Members of the rescue team could not recall if they found the flexible duct lowered into the BWT of the access hatch or if the blower was running when they arrived.

VALARIS DS-17's 2/O put on an SCBA and entered the BWT at 1337. He observed that the 2/E No. 1 and the Motorman were lying face up near the BWT access ladder.[10] He also observed that neither appeared to be breathing. While the 2/O was conducting his assessment inside the BWT, the Bosun and a Floor Hand both donned SCBAs and prepared to enter the BWT.

Just after the Floor Hand entered the BWT, the low-air alarm on the 2/O's SCBA activated. The 2/O immediately exited the BWT. The Bosun then entered the tank.

The rescue tripod was rigged by 1345 and by 1350 the 2/E No.1 and Motorman had been lifted out of the BWT and laid on the deck plates. Neither was breathing or had a pulse. VALARIS DS-17's medical team, which included two nurses, immediately started to administer CPR to both the 2/E No. 1 and Motorman.

The Bosun and Floor Hand had both exited the BWT by 1351. Other crewmembers then immediately began closing the BWT access hatch.

The ambulance crew and local firefighters entered the No. 1 Aft Pump Room at approximately 1355 and took over the efforts to resuscitate the 2/E No. 1 and Motorman. At 1415, the medical doctor, who was part of the ambulance crew, determined that both the 2/E No.1 and Motorman were deceased.

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9 The gas detector that was brought to the scene was a multi-gas detector capable of detecting hydrogen sulfide, carbon monoxide, oxygen, and combustible gases. It had four alarms for hydrogen sulfide: low (1.6 ppm), high (15 ppm), TWA (20 ppm), and STEL (15 ppm). The detection range for hydrogen sulfide was 0-200 ppm. It had most recently been calibrated on 7 March 2023.

10 The ladder extended from just below the tank top to the bottom shell.

A gas detector was not found on the tank top near the BWT access hatch when the area was examined after the hatch was closed. Neither the 2/E No. 1 nor the Motorman were wearing a safety harness when they were removed from the BWT.

A portable blower with an attached flexible duct was observed on the tank top in the vicinity of the BWT starboard side access hatch after the 2/E No. 1 and the Motorman were removed from the tank *(see Figure 3)*. Based on information provided by rescue team members, it could not be determined if the 2/E No. 1 and Motorman had lowered the duct into the BWT or if they had started the blower.

The report of the autopsies conducted at Las Palmas for both the 2/E No. 1 and Motorman stated that the cause of death was anoxic anoxia due to gas poisoning, most likely sulphur compounds and immediate acute respiratory failure.[11] Post-mortem blood testing ruled out carbon monoxide poisoning as a cause of death.

***Involved Crewmembers***

The Master, C/E, and 2/E No. 1 were all experienced seafarers who had each worked on board Company-managed ships for at least 10 years. The 2/E No. 1 had worked for 10 years as a C/E before joining VALARIS DS-17 as a 2/E. The Motorman had four years of experience at sea and had worked on board Company-managed ships for 10 months.

The 2/E No. 1 had completed training addressing the Company's PTW procedures and enclosed space entry procedures in late February and early March 2023. He also had previously completed the Company's six part Building Offshore Leadership and Development training, which included modules addressing hazard identification and risk reduction.

The Motorman completed the Company's HSE orientation training in July 2022.

The Administrator did not observe any indication that either the 2/E No. 1 nor the Motorman had failed to receive the amount of rest mandated by the STCW Code, Section A-VIII/1, paragraphs 2 and 3 and MLC, 2006, regulation 2.3.

***Company's PTW Procedures***

The Company's PTW procedures defined a multiple step process intended to ensure that hazardous work was "planned, controlled, communicated, and safely executed." The PTW procedures included the different roles and responsibilities of personnel involved with either conducting or managing hazardous work.

The first step in the PTW process was for the Permit Owner, who was either the person performing or supervising a task that required a PTW, to complete a draft permit that identified the work that was planned, any additional permits or certificates that might be required,[12] relevant Work Instructions, and worksite safety precautions that would be implemented. The Permit Owner was also responsible for conducting a JSA with those who would be conducting the work before the PTW was approved.



11 The autopsy report is in Spanish. The cause of death as stated in the report was "Que la causa fundamental del fallecimiento anoxia anoxica por intxicación por gases (muy probalemente compuestos sulfurados), siendo la inmediata insuficiencia respiratoria aguda." The English translation is: "That the fundamental cause of death was anoxia due to gas poisoning (most likely sulfur compounds), with immediate acute respiratory failure."

12 Additional permits or certificates that might be required included a confined space entry permit, gas test certificate, and energy isolation certificate.

Approval of a PTW was a two-part process. The first part was for the assigned Verifying Authority to review the permit and verify that the Permit Owner was appropriate for the area (e.g., location on board)[13] where the planned work was going to be conducted or for the type of system[14] for which work was planned. The Verifying Authority was also required to determine if there were any conflicts with other work being conducted, participate in the JSA, and inspect the worksite to ensure that any barriers and controls required by the relevant Work Instructions, or those identified during the JSA, were in place before the permit was forwarded to the Permit Issuer.

The Company's PTW procedures prohibited the Permit Owner from also being the Verifying Authority. They also prohibited the Verifying Authority from being directly involved in the task that was being performed.

The second part of the PTW approval process was for the Permit Issuer, which on a Company-managed drill ship is the Master, to approve the PTW after verifying that the identified Verifying Authority was appropriate for the area or system and that there were no conflicts with other work.

After the PTW was approved and work was started, the Verifying Authority was responsible for monitoring the work to ensure that it was being done in accordance with any stated conditions and the relevant Work Instructions.

When the planned task was completed, the Permit Owner and the Verifying Authority were required to inspect the worksite to ensure it had been returned to a safe condition before the permit was closed by the Permit Issuer.

***Company's Work Instructions***

The Company maintained a library of Work Instructions for tasks that might be performed on board Company-managed ships. These Work Instructions identified the minimum personnel required to perform the task, the required PPE, and the required equipment and tools. They also identified the criticality or importance of the task and if a PTW is required. The Work Instructions also included warnings and cautions regarding potential hazards associated with the task and noted identifying actions that should be taken to control each of the identified hazards.

The Company's library of Work Instructions included instructions for opening and closing hatches. The criticality of the task was identified as high. The Work Instruction indicated that a PTW was required and that the minimum required number of personnel needed to complete the task was two. One person was to be identified as the Verifying Authority and a second person to perform the work. The required PPE included full body harness with suspension trauma safety straps and a self-retracting lifeline. The required equipment and tools were barriers with warning signs, a gas detector, pry bar, and an adjustable spanner.

Warnings identified on the Work Instruction for opening and closing hatches included that the tank could contain a hazardous atmosphere. The identified action for determining if the tank contained a hazardous atmosphere was to place a gas detector next to the hatch cover to detect any gases escaping from the tank. The warnings also included possible exposure to an open deck or confined space, and that openings in the deck pose a serious fall hazard. The identified actions for addressing these hazards included installing barriers with warning signs and minimizing the length of time a hatch was left open. Use of required PPE (i.e., body harness with self-retracting lifeline) also addressed this hazard.

13 Examples of areas on board include the Accommodations, Engine Room, drilling related spaces, tanks and voids, etc.

14 Examples of systems on board include propulsion systems, drilling-related equipment, ship's structure, HVAC, etc.

***Hydrogen Sulfide***

Hydrogen sulfide is a colorless, highly toxic gas that, at low concentrations, smells like rotten eggs and is commonly referred to as a "knockdown" gas. It has a vapor density of 1.19 and is heavier than air.

Hydrogen sulfide is produced naturally from decaying organic matter by sulphate reducing bacteria.[15] It is also produced as a byproduct in many different industrial processes, including oil and gas production.

Inhalation is the typical cause of hydrogen sulfide poisoning. The STEL[16] established by EU-OSHA and the REL[17] established by US NIOSH is 10 ppm.[18] Concentrations of 100 ppm, which is the IDLH value established by US NIOSH,[19] will cause a loss of smell and trouble breathing and the potential for death within 48 hours. Concentrations of 500-700 ppm can cause a person to collapse within five minutes and death after 30–60 minutes of being exposed. A couple of breaths of concentrations of 700-1,000 ppm hydrogen sulfide will result in a loss of consciousness and death within minutes. Concentrations greater than 1,000 ppm will cause nearly instant death.[20]

The UK HSE safety bulletin ED2-2023 issued in April 2023 reported that concentrations of hydrogen sulfide exceeding the detection limits of the standard gas monitoring equipment used on board ships had been detected in ullage spaces of cargo and slop tanks on some FPSOs and FSUs.[21] The safety bulletin also noted that there was an increased potential for sulphate reducing bacteria in cargo and slop tanks that contained a high water cut (i.e., content) to produce hydrogen sulfide.

***Testing of BWT Contents and Atmosphere***

Samples were taken from the oily water that was in the BWT[22] on 17 May 2023 and tested to determine if they contained sulphate reducing bacteria which convert sulphate present in organic matter into hydrogen sulfide through microbial reduction.[23] Each of the samples indicated that there was a high to very high presence of sulphate reducing bacteria in the oily water.

The atmosphere in the ullage space of the BWT contained approximately 5 ppm of hydrogen cyanide when tested on 17 May 2023. The BWT had been ventilated and determined safe for entry before the atmosphere inside the tank was tested. Hydrogen cyanide is highly poisonous and at low concentrations has a distinctive bitter almond odor.[24] As



15 Sulphate reducing bacteria are anaerobic microorganisms and are common in anoxic environments. They can be found in sea water and fresh water with high concentrations of decaying organic material and sediments and can survive in a broad range of environmental conditions. *See* https://bio.libretexts.org/Bookshelves/Microbiology/Microbiology_(Boundless)/05%3A_Microbial_Metabolism/5.09%3A_Anaerobic_Respiration/5.9C%3A_Sulfate_and_Sulfur_Reduction; and https://www.nature.com/articles/nrmicro1892.

16 STEL is the limit value above which exposure should not occur over a 15-minute period. *See EU Commission Directive 2009/161/EU*.

17 The REL is the ceiling or maximum concentration that should not be exceeded at any time. *See US NIOSH Pocket Guide to Chemical Hazards*.

18 *See* EU *Commission Directive 2009/161/EU* and US NIOSH *Pocket Guide to Chemical Hazards*.

19 *See* US NIOSH, *IDLH Values* (https://www.cdc.gov/niosh/idlh/intridl4.html).

20 *See* US OSHA, *Hydrogen Sulfide* (https://www.osha.gov/hydrogen-sulfide/hazards).

21 As previously noted, the maximum concentration of hydrogen sulfide that could be detected by the portable multi-gas detector used during the rescue of the 2/E No. 1 and Motorman from the BWT was 200 ppm.

22 Bilge water from the ship's machinery spaces had continued to be transferred to the BWT after 21 April 2023.

23 *See* Hedlund, F. H. (2023). *Confined space hazards: Plain seawater, an insidious source of hydrogen sulfide*. Journal of Occupational and Environmental Hygiene, 20(8), 322–328.

24 *See* US NIH National Library of Medicine, *Hydrogen Cyanide: Acute Exposure Guideline Levels* (https://www.ncbi.nlm.nih.gov/books/NBK207601/).

a liquid, it is highly volatile with a vapor pressure of 680 mm HG at 25°C[25] and a boiling point of 25.5°C. As a gas, it has density of 0.94 and readily mixes with air.[26]

Hydrogen cyanide is commonly manufactured by oxidation of ammonia-methane mixtures under controlled conditions.[27] Concentrations of cyanides have been identified in petrochemical sludge.[28]

The STEL established by US OSHA is 10 ppm and the REL established by US NIOSH is 4.7 ppm. The IDLH value established by US NIOSH is 50 ppm.[29]

# PART 3: ANALYSIS

The following Analysis is based on the above Factual Information.

***Hazard Awareness***

The 2/E No. 1 was the Verifying Authority for cleaning the BWT on 30 March 2023 and had signed the PTW when it was closed after hydrogen sulfide was detected inside the tank. He was also included in copy on the emails sent on 17 and 21 April 2023 between the C/E and the shipyard's Project Manager that included multiple references to the presence of hydrogen sulfide inside of the BWT. Although the 2/E No. 1 might not have seen the emails that the shipyard's Project Manager sent on the morning of 21 April 2023, it is likely he was aware that the atmosphere inside the ullage space of the BWT contained hydrogen sulfide.

It is not known if the 2/E No. 1 conducted a pre-task brief with the Motorman to review the hazards associated with opening the BWT starboard access hatch before they started work. It is also not known if the Motorman was aware that hydrogen sulfide had been detected in the BWT while the cleaning crew was in the tank on 30 March 2023.

***Hazard Exposure and Fall into the BWT***

It could not be confirmed if the 2/E No. 1 and Motorman had started to mechanically ventilate the BWT after opening the access hatch before they climbed up the vertical ladder to the deck plates. What is known is that the Motorman had transferred from the vertical ladder to the deck plates and that the 2/E No. 1 then climbed up the ladder until he stopped and leaned over with his chest lying on the deck plates. It is also known that the Motorman had grabbed hold of the 2/E No. 1's coveralls and yelled for help before both he and the 2/E No. 1 fell into the BWT.

The BWT tank top formed a physical barrier between the Nos. 1 and 2 Aft Pump Rooms and the BWT *(see Figure 2)*.[30] This physical barrier was broken when the 2/E No. 1 and Motorman opened the BWT access hatch. Removing this

25 The vapor pressure of water is 3.31 mm HG at 25°C.

26 *See* US ATSDR, *Medical Management Guidelines for Hydrogen Cyanide* (https://wwwn.cdc.gov/tsp/mmg/mmgdetails.aspx?mmgid=1141&toxid=249) and US NIOSH *Pocket Guide to Chemical Hazard*s.

27 *See* US ATSDR, *Medical Management Guidelines for Hydrogen Cyanide* (https://wwwn.cdc.gov/tsp/mmg/mmgdetails.aspx?mmgid=1141&toxid=249).

28 *See* Jaszczak E, Polkowska Ż, Narkowicz S, Namieśnik J. *Cyanides in the environment-analysis-problems and challenges.* Environ Sci Pollut Res Int. 2017 Jul;24(19): 15929-15948.

29 *See* US NIOSH, *IDLH Values* (https://www.cdc.gov/niosh/idlh/intridl4.html).

30 IACS PR No. 37, defines a connected space as "a space that is connected, by either permanent or intermittent means to a source space that may contain a hazardous atmosphere." Based on this definition, the Nos. 1 and 2 Aft Pump Rooms were both connected spaces. PR No. 37 further states that the atmosphere in a connected space is presumed to be hazardous until testing proves otherwise.

physical barrier created the risk of the 2/E No. 1 and Motorman, and anyone else in the No. 1 Aft Pump Room, being exposed to hazardous gases contained within the ullage space of the BWT as the gases inside the ullage space were displaced by air entering the tank (i.e., natural ventilation). The risk of exposure after the access hatch was opened would have been highest for gases whose weight was lighter than or similar to the weight of air, and to any gases that were present in large quantities.

The risk of exposure would have increased if mechanical ventilation had been started. Mechanical ventilation would have increased circulation within the ullage space of the BWT by blowing air from within the No. 1 Aft Pump Room into the tank. This would have caused any gases that were in the ullage space to mix with the air and to be displaced from the BWT as mechanical ventilation was continued.

Physical access to the BWT access hatches in both the Nos. 1 and 2 Aft Pump Rooms was restricted both by their location beneath the deck plates, and the proximity of piping that was between the tank top and the deck plates and the structural supports for the deck plates *(see Figure 3)*. This would have increased the risk of continued exposure to gases that might have been displaced from the BTW due to either natural and/or mechanical ventilation as the 2/E No. 1 and Motorman climbed or waited to climb the 1.5 m vertical ladder to reach the deck plates and egress from the No. 1 Aft Pump Room.

The consequences of any exposure would have been dependent on a number of different factors including the characteristics and concentration of the gases that were present inside the BWT and the length of exposure. The initial consequences of the 2/E No. 1's exposure prior to falling into the BWT was more severe than the initial consequences of the Motorman's exposure. This was evident based on the fact that the 2/E No. 1 had stopped climbing and leaned over on the deck plates whereas the Motorman climbed up the 1.5 m vertical ladder, transferred to the deck plates, and then yelled for help before they both fell into the BWT.

The autopsy reports stated that both the 2/E No.1 and the Motorman died due to gas poisoning and immediate acute respiratory failure. This indicates they were both ultimately exposed to very high concentrations of what the autopsy reports stated was most likely sulphur compounds.[31] This is consistent with both having been directly exposed to the atmosphere inside the BWT.

The fact that the third-party Electrician left the No. 1 Aft Pump Room to get assistance rather than attempting to assist the 2/E No. 1 and Motorman after they fell into the BWT may have prevented an additional fatality.

***BWT Contents***

The contents of the BWT on the morning of 21 April 2023 when the 2/E No. 1 and Motorman opened the access hatch consisted of a combination of:

(a) sludge that had not been removed from the tank before the third-party cleaning crew stopped working and the access hatch was closed after they exited the BWT on 30 March 2023 when their portable gas detectors activated, indicating the presence of hydrogen sulfide;

31 As stated previously, post-mortem blood testing ruled out carbon monoxide poisoning.

(b) sediments that might have been entrained in the sea water that was transferred to the BWT from the Mud Room drain tanks during sea trials; and

(c) any unpumpable oily water that remained in the tank after 50 $m^3$ of oily water was discharged ashore on 20 April 2023.

The atmosphere in the ullage space of the BWT was not tested on 21 April 2023. It is likely that it included some concentration of hydrogen sulfide based on the fact that:

(a) the BWT access hatch was closed after the third-party cleaning crew exited the tank on 30 March 2023 and was not reopened until the morning of 21 April 2023;

(b) the continued transfer of machinery space bilge water to the BWT after 21 April 2023 would have increased the volume of oily water that was in the tank but would not have significantly changed the composition of the tank's contents;

(c) members of the rescue team reported an odor that the 2/O described as a "strong smell of rotten eggs" when they entered the No. 1 Aft Pump Room after the 2/E No.1 and the Motorman were reported to have fallen into the BWT; and

(d) the high to very high presence of sulfide reducing bacteria in the samples of oily water that were collected from the BWT on 17 May 2023.

How much hydrogen sulfide might have been present in the ullage space of the BWT when the 2/E No. 1 and Motorman opened the access hatch on 21 April 2023 could not be determined.

It is likely that the composition of the BWT's contents were significantly the same on 21 April 2023 when the 2/E No. 1 and Motorman opened the access hatch as it was on 17 May 2023 when the contents of the tank were tested. Therefore, it is considered likely that the atmosphere inside the tank's ullage space also contained an unknown quantity of hydrogen cyanide.

Because the BWT was not fitted with sample points, the atmosphere in the tank's ullage space could not be tested to determine if it was hazardous or what gases might be present until after the access hatch was opened.

***Company's PTW Procedures and Work Instructions***

Administrative controls are a low-level means of reducing risk by controlling exposure to a hazard in situations when it is not possible to either eliminate the hazard, substitute the hazard with one that is less hazardous, or isolate the hazard.[32] These types of controls lower risk by reducing exposure to a hazard while a particular task or activity is being conducted by providing written instructions for the task or activity. They also lower risk by providing warnings or relevant safety information. Administrative controls must be implemented consistently to be effective. Examples of administrative controls include the Company's PTW procedures and Work Instructions.

The Company's PTW procedures incorporated multiple safeguards for ensuring hazardous work was "planned, controlled, communicated, and safely executed." The potential benefits of these safeguards were nullified since the Company's

32 *See* US NIOSH, *Hierarchy of Controls* (https://www.cdc.gov/niosh/hierarchy-of-controls/about/index.html).

PTW procedures were not properly implemented when the PTW for opening the access hatch for the BWT was issued on 21 April 2023. Gaps in the implementation of the Company's PTW procedures included the:

(a) crewmember who was listed on the PTW as the Permit Owner was not involved in the task;

(b) Verifying Authority was directly involved in performing the task; and

(c) Permit Issuer approved the PTW without the relevant Work Instruction being identified and without a record that a JSA had been conducted.

Other PTWs that were reviewed as part of the Administrator's investigation, including the one issued on 30 March 2023, listed the relevant Work Instructions and recorded that a JSA had been completed. When relevant, they also identified other permits or certificates that might have been required. Each also complied with the requirement that the Permit Owner and the Verifying Authority were not to be the same person.

A factor that may have contributed to the identified gaps in the implementation of the Company's PTW procedures may have been a sense of urgency to ventilate the BWT so that it would be ready by 24 April 2023, when a cleaning crew was scheduled to clean the tank before VALARIS DS-17 was reactivated.

***Company's Work Instructions***

The Company's Work Instructions for opening and closing hatches included multiple barriers for reducing exposures to hazards associated with this task. These barriers included placing a gas detector next to the hatch cover that was being opened or closed.

A gas detector would not have prevented the 2/E No. 1 and Motorman, or potentially anyone else who was in the No. 1 Aft Pump Room, from being exposed to any gases that might have been displaced from the BWT when the access hatch was opened. However, it would have reduced the risk of exposure by alerting them that gases were being displaced so that they could close the access hatch, if it was safe to do so, and then evacuate the space.

A gas detector was not found on the tank top in the vicinity of the BWT access hatch and neither the 2/E No. 1 nor Motorman were wearing a personal gas detector after the 2/E No. 1 and Motorman were recovered from the BWT. It is not known why a gas detector had not been placed on the tank top next to the entrance to the BWT or why neither the 2/E No. 1 nor the Motorman were not wearing a personal gas detector when they opened the access hatch.

The Company's Work Instructions for opening and closing a hatch did not include barriers addressing the risks associated with opening or closing hatches where there was restricted access or where there was increased risk of continued exposure while leaving the area.

***Enclosed Space Rescue Operation***

Members of the rescue team reported smelling, what one crewmember described as, a "strong smell of rotten eggs," which is an indication of the presence of hydrogen sulfide, when they entered the No. 1 Aft Pump Room. Although the C/O directed members of the rescue team to get SCBAs and a portable gas detector, he and other members of the rescue team remained in the No. 1 Aft Pump Room rather than leaving the space. The atmosphere inside the Pump Room

was not tested and those members of the rescue team who remained within the Pump Room without SCBAs while the access hatch remained opened continued to be exposed to toxic gases.

The Company's enclosed space rescue procedures did not address actions that should be taken or barriers that should be implemented when conducting an enclosed space rescue from inside a connected space.

# PART 4: CONCLUSIONS

The following Conclusions are based on the above Factual Information and Analysis and shall in no way create a presumption of blame or apportion liability.

1. Causal factors that contributed to this very serious marine casualty include:
   (a) crewmembers' apparent lack of awareness of the potential for the atmosphere in the BWT ullage space to contain high concentrations of hydrogen sulfide or other toxic gases (e.g., hydrogen cyanide);
   (b) improper implementation of the Company's PTW procedure in that the:
      (i) crewmember who was listed on the PTW as the Permit Owner was not involved in the task;
      (ii) Verifying Authority was directly involved in performing the task; and
      (iii) Permit Issuer approved the PTW without the relevant Work Instruction being identified and there not being a record that a JSA had been conducted; and
   (c) the consequences of the 2/E No. 1 and Motorman being exposed to high concentrations of hydrogen sulfide and any other toxic gases that may have been within the BWT ullage space after opening the starboard access hatch and while climbing the ladder up to the deck plates in the No. 1 Aft Pump Room.
2. Additional causal factors that may have contributed to this very serious marine casualty include:
   (a) actual or perceived pressure to ventilate the BWT so that the tank could be cleaned before VALARIS DS-17's reactivation and scheduled departure from Las Palmas;
   (b) the lack of sample points for testing the atmosphere inside the BWT without opening an access hatch;
   (c) a portable gas detector was not available on-site as required by the Company's Work Instructions when the BWT starboard access hatch was opened; and
   (d) the Company's Work Instructions for opening and closing a hatch did not address the risks associated with opening or closing hatches where there was restricted access or risk of continued exposure while leaving the area.
3. Actions or events that reduced the adverse consequences of this very serious marine casualty include:
   (a) the third-party Electrician leaving the No. 1 Aft Pump Room to get assistance rather than attempting to assist the 2/E No. 1 and Motorman after they fell into the BWT.

# PART 5: PREVENTIVE ACTIONS



In response to this very serious marine casualty, the Company has taken the following Preventive Actions:

1. Developed Work Instructions for:
   (a) breaking containment of tanks that are identified as having the potential to contain hydrogen sulfide; and
   (b) the use of mechanical ventilation when preparing a confined space for entry to address the type of ventilation, arrangement of blowers and ducts, duration, etc.

2. Issued a safety alert summarizing industry alerts addressing deadly concentrations of hydrogen sulfide being found in bilges, storage tanks, ballast tanks, etc., and calling attention to the fact that seawater and biodegradable cleaners are strongly associated with the production of hydrogen sulfide by sulphate reducing bacteria. This safety alert required, among other things:
   (a) an assessment of tanks on board all Company-managed vessels to establish an inventory (e.g., register) of tanks that could potentially contain hydrogen sulfide;
   (b) that tanks containing a mixture of seawater and oily-water, sludge, or sewage, be labeled as potentially containing hydrogen sulfide;
   (c) that crewmembers wear an SCBA and personal gas detector when opening tanks that might contain hydrogen sulfide unless the contents of the atmosphere inside the tank can be determined before opening a manhole or access hatch; and
   (d) the list of cleaning agents accepted for use on board Company-managed vessels be reviewed and revised to eliminate biodegradable detergents and cleaning agents containing phosphate.

3. Issued a safety alert that was intended to remind and reinforce specific requirements of the Company's confined space entry procedures, including a reminder that when preparing to open a manhole or hatch cover to "always assume that a confined space contains hazardous gas(es) or trapped pressure." It also included a reminder that all responders to a confined space rescue were required, without exception, to wear an SCBA. This safety alert, among other things:
   (a) prohibited the use of forced ventilation of tanks in which hydrogen sulfide was detected unless the exhausts were routed to open air, away from people, and ignition points;
   (b) required all Designated Permit Issuers to review the Company's PTW procedure, the JSA procedures, Confined Space Entry Procedure, and relevant Work Instructions identified in the safety alert; and
   (c) required the vessel's OIM or Master to "personally and physically verify required controls and precautions have strictly been satisfied before authorizing any confined space entry or preparatory work (i.e., manhole removal, gas testing, and forced ventilation)" pending completion of the assessment of tanks to identify tanks that could potentially contain hydrogen sulfide.

4. Required manhole covers for tanks that are evaluated to potentially contain hydrogen sulfide be modified by installing external sample points so that the atmosphere inside the tank can be tested before the manhole is opened.

5. Issued guidance regarding the use of hydrogen sulfide scavenging chemicals to reduce the concentration of hydrogen sulfide in a tank when the concentration would pose a risk to the safety of personnel.

6. Developed and implemented e-learning training modules addressing:
   (a) what is hydrogen sulfide;
   (b) testing a confined space;
   (c) opening hatches;
   (d) ventilation; and
   (e) confined space rescue.
7. Revised the Emergency Drills and Exercises Management Procedure to include a requirement for conducting drills for unexpected hydrogen sulfide encounters.

The Administrator has taken the following Preventive Actions:

1. Issued MSA No. 03-24 reminding ship managers of the need for continued vigilance regarding enclosed space entry and rescue training. MSA No. 03-24 includes a number of recommendations based on a review of enclosed space entry incidents that had occurred on board Republic of the Marshall Islands-registered ships between 2020–2023.

# PART 6: RECOMMENDATIONS

The following Recommendations are based on the above Conclusions and in consideration of the Preventive Actions taken.

1. It is recommended that the Company:
   (a) conduct an assessment to identify toxic gases that might be contained in tanks on board all Company-managed vessels and include the findings of this assessment in the inventory of tanks on board Company-managed vessels;
   (b) review and, as necessary, revise:
      (i) PTW procedures to address the gaps that were identified in their implementation when the PTW was issued to open the BWT starboard access hatch on 21 April 2023;
      (ii) Work Instructions for opening and closing hatches to:
         1. address the risks associated with opening or closing hatches where there was restricted access or risk of continued exposure while leaving the area; and
         2. require testing for toxic gases listed on the vessel's inventory of tanks;
      (iii) onboard hazard awareness training to address:
         1. the potential for some tanks to contain unexpectedly high concentrations of hydrogen sulfide or other toxic gases (e.g., hydrogen cyanide); and
         2. the identification of hazards associated with connected spaces; and
      (iv) enclosed space rescue procedures to:

1. address testing of the atmosphere inside a connected space prior to entry by the rescue team; and
2. establish controls for minimizing the potential for members of the rescue team to be exposed to hazardous gases; and

(b) review the lessons learned from this very serious marine casualty with Masters and senior officers during on-signing briefings.

The Administrator's marine safety investigation is closed. It will be reopened if additional information is received that warrants further review.