The Bahamas Maritime Authority

Marine Safety Investigation Report

into a fatality on Grandeur of the Seas on 21 January 2025

The Bahamas conducts marine safety or other investigations on ships flying the flag of the Commonwealth of the Bahamas in accordance with the obligations set forth in International Conventions to which The Bahamas is a Party. In accordance with the IMO Casualty Investigation Code, mandated by the International Convention for the Safety of Life at Sea (SOLAS) Regulation XI-1/6, investigations have the objective of preventing marine casualties and marine incidents in the future and do not seek to apportion blame or determine liability.

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The Bahamas Maritime Authority

1. Summary

What happened

On 21 January 2025, an electrical cadet on board a Bahamas flagged passenger ship went into an access space to troubleshoot a level transmitter for a bilge water settling tank. He attempted to exit the space but lost his footing on a ladder he placed outside, and became stuck in a suffocating position.

His positioning gave the appearance he was still working as intended, but was later discovered to be unconscious by members of the engine room staff who removed him and placed him on the deck. After attempting resuscitation, he was declared deceased by the shipboard medical team.

Post-casualty tests of the atmosphere inside the access space confirmed the presence of Hydrogen Sulphide (H_2S) gas.

Why it happened

The space was not identified as enclosed, confined or dangerous. Neither the victim, nor anyone else in his department, considered that additional precautions needed to be taken before entry. The bilge settling tank's contents originated from untreated sources that favoured conditions for the formation of H_2S gas, which propagated in the space through a corroded ventilation pipe.

The level transmitter being housed inside the access space was an oversight by design as there was no technical reason for the transmitter to be located in the space. The electrical cadet had worked in the space two weeks prior to the casualty, troubleshooting the same level transmitter while under supervision. He believed the environment in the access space would be the exact same as his previous attendance.

What can we learn

Spaces containing equipment requiring maintenance should be designed to be easily accessible, safe and suitable for crew. The most effective risk control is elimination at the design stage.

The standard industry terms "enclosed" or "confined" space may not be sufficient to alert seafarers to potential hazards. Areas not normally occupied should be treated with the same caution as if entering a space that was previously "closed".

Shipboard oily water management should not put people at risk. Tanks used to hold untreated contents from various sources need regular sample analysis to detect conditions that promote hydrogen sulphide generation.

2. Factual Information

Grandeur of the Seas

Vessel Type	Passenger	**Flag**	Bahamas
Owner	Grandeur of the Seas Inc	**Manager**	Royal Caribbean Cruises Ltd
Classification Society	Det Norske Veritas	**Gross/Net Tonnage**	73,817 / 44,122
Built	1996 Helsinki	**Propulsion**	Four generators connected to two electric motors, driving two fixed pitch propellers.

IMO No.	Callsign	Length overall	Breadth	Depth
9102978	C6SE3	279m	32.20m	15.85m

Last BMA Inspection	Last PSC Inspection
Tampa, 17 August 2024. No deficiencies	Miami, 11 August 2024. No deficiencies

Crew Details

Rank/Role on board	Chief Electrician	Second Engineer environmental	Second Electrical Engineer (Duty)	Electrical Cadet
Qualification	III/6	III/2	III/6	N/A
Certification Authority	Romania	Romania	Bulgaria	N/A
Nationality	Romanian	Romanian	Bulgarian	Ghanian
Age	45	41	54	26
Time in rank	13y, 8m	10y 9m	2y 4m	1y
Time on board	2 months	1 month	11 days	4 months

Environmental Conditions

Wind Direction	Wind Force	Wave Height	Precipitation / Sky	Visibility Range	Light Conditions
ESE	4	<0.5m	Partly cloudy	Very good	Daylight

Voyage Details

Departure Port	Labadee, Haiti	Arrival Port	Puerto Plata, Dominican Republic
Time of departure	17:16	Estimated time of arrival	06:00
Voyage duration	13 hours	Voyage distance	Approximately 52 nm
Cargo	N/A	POB	787 Crew/ 2152 Passengers
Stage of passage	On passage	Traffic density	Light

Narrative

All times in this report are local time (UTC-5)

On 21 January 2025, the Bahamas registered passenger vessel, Grandeur of the Seas, was berthed in Labadee, Haiti. The electrical team gathered for a meeting at 07:00 in the electrical workshop on Deck 0, where team members were divided into groups for tasks assigned throughout the day. The chief electrician and two second electrical engineers were tasked with changing batteries on the main switchboard.

Another second electrical engineer, who was the duty electrician for the day, along with the electrical cadet, were tasked with working on a main engine propulsion fan motor in the morning. Later in the afternoon they were troubleshooting a washing machine in the laundry room.

At 14:45, the second engineer environmental (2/E) was on watch in the engine room and started the oily water transfer pump to begin a transfer from the bilge water tank (M6P) into the bilge water settling tank (M4). This was in preparation for bilge water processing through the oily water separator after departure.

After some time elapsed, the 2/E checked the trend analysis on the vessel monitoring system (VMS) and observed the tank level for M6P was decreasing but the tank level for M4 was showing a straight line, indicating the level transmitter was malfunctioning.

The 2/E called the duty electrician's phone, which was answered by the electrical cadet. The 2/E explained his observations and requested for the level transmitter to be checked.

At the time the electrical cadet was still with the duty electrician in the fore store on Deck 2, searching for a part related to their ongoing work in the laundry room. The electrical cadet explained to the duty electrician the request from the phone call he received, and that he recently checked "the sensor"[1] believing the issue was "probably the line again".[2]

The electrical cadet apologised to the duty electrician that he had to leave him alone. The duty electrician asked if help was required but it was declined as the electrical cadet stated he "was just working on the same sensor in past weeks"[3]. The electrical cadet told the duty electrician if he needed anything, he will call.

At 15:36, the electrical cadet left the fore store on Deck 2, and walked towards the laundry room, arriving there at 15:38 to collect his tool bag. He then proceeded to the engine room, resting his tool bag down in the port separator room and proceeded to the engine control room (ECR).

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[1] The level transmitter is also called a sensor due to the informal reference of a "bubbler sensor" – since it uses air and produces bubbles.
[2] The line he was alluding to was the control air supply line for the level transmitter (sensor).
[3] This was under the supervision of another second electrical engineer

The electrical cadet entered the ECR at 15:44 and discussed the sensor issue with the 2/E. He also observed the trend analysis for both tanks involved in the transfer (M6P and M4) on the VMS.

He departed the ECR, and at 15:54 he is seen carrying a ladder in the direction of tank M4, which was subsequently rigged for entry into the access space above tank M4, which contained the sensor.

After rigging the ladder, the electrical cadet returned to the separator room to collect his tool bag. He then proceeded in the direction of tank M4.

At 16:00, the ECR was given 1 hour notice to departure. The 2/E stopped the transfer from M6P to M4 and handed over the watch to his reliever.

Shortly after 16:00, the incoming second engineer environmental received a call that a provision door was stuck open, prompting the attendance of some members of the electrical team and the outgoing 2/E.

At 17:02, the first engineer (1/E) and 2/E were back in the engine room preparing final checks for departure. The 1/E was heading to the evaporator room in order to close a watertight door, when he passed and quickly glanced at the ladder stationed outside tank M4, appearing to support a person working in the access space above tank M4.

The 2/E was immediately behind the 1/E and also noticed the ladder and person. However, he saw the person's feet were not supporting their bodyweight.

The 2/E went around the ladder, and realised it was the electrical cadet, who was not showing signs of consciousness and appeared stuck. He immediately shouted for help and the 1/E ran towards him, now aware of the unsupported body.

The 1/E and 2/E tried to pull the electrical cadet out, but his right underarm was coming into contact with a ventilation duct immediately outside the access space. They pushed him inside slightly and turned his body, enabling them to remove him from the space and place him on the deck.

Recreation of victim's body position on ladder with back and front view (with use of dummy)

Other members of the engine room team immediately gathered around from hearing the shouting. The 1/E used his radio to announce a code Alpha in the engine room. He then splashed water on the victim's face to see if he would get a response. The 1/E and a nearby crew member then began conducting CPR (cardiopulmonary resuscitation).

Ship's security and medical teams arrived on scene at 17:06, finding the victim in cardiopulmonary arrest. He had no pulse, was not breathing and his pupils were fixed and dilated. The victim was given high quality CPR but could not be resuscitated.

The victim was transported via stretcher from the engine room at 17:50 and placed in the shipboard morgue at 19:30.

Post-casualty tests conducted by the crew lead to the discovery of a corroded section of the ventilation pipe to atmosphere for tank M4's second stage. This was later confirmed to be the source of Hydrogen Sulphide (H_2S) ingress into the space.

Legislation and Guidance

Royal Caribbean Group in their Safety Quality and Management (SQM) System have a designated chapter for work permits, shipboard Job Safety Analyses and Safety Equipment Requirements. In this chapter the company's confined space entry policy, along with the required permit, is made available.

The policy references: IMO Annex to Resolution A.1050 (27) – Revised recommendations for entering confined spaces aboard ships[4]; IACS Re. 2000/Rev2 – Confined Space safe practices; SOLAS Ch. III/ Reg.19 – Emergency Training and Drills, and SOLAS Ch. XI-I/Reg.7 – Atmosphere testing instrument for enclosed spaces.

IMO Resolution A.1050 (27) – Revised recommendations for entering enclosed spaces aboard ships was created to encourage the adoption of safety procedures aimed at preventing casualties to ships' personnel entering enclosed spaces where there may be an oxygen-deficient, oxygen-enriched, flammable and/or toxic atmosphere. Resolution A.1050 (27) defines an enclosed space as:

> A space which has any of the following characteristics: limited openings for entry and exit; inadequate ventilation; and is not designed for continuous worker occupancy.

The Bahamas Maritime Authority's Marine Notice 36: Management of Occupational Health & Safety describes the general duties of employers and employees in relation to health and safety, in line with Merchant Shipping (Health and Safety – General Duties) Regulations 1984. Marine Notice 36 does not provide specific guidance on working safely onboard ships but states that the shipowner shall comply fully with the International Labour Organization's Code of Practice "Accident prevention on board ship at sea and in port" or other recognised Codes of Practice including the United Kingdom's Maritime & Coastguard Agency "Code of Safe Working Practices for Merchant Seafarers".

Previous Similar Cases

Valaris DS-17 (2023) Republic of the Marshall Islands

The Marshall Islands registered drill ship VALARIS DS-17 was alongside in a shipyard and needed to clean a bilge water tank (BWT). In preparation to mechanically ventilate the tank, a second engineer (2/E) and motorman, went into the aft pump room and climbed down a vertical ladder to open the access hatch for the tank. When leaving the space, the motorman noticed the 2/E stopped climbing and laid his chest on the deck plates. The motorman attempted to grab the 2/E's coveralls and called for help. A first responder observed both crew members kneeling on the deck plates before falling into the BWT hatch. Both died as a result of exposure to hydrogen sulphide, released from the tank when they opened the access hatch.
See: www.register-iri.com/wp-content/uploads/Republic-of-the-Marshall-Islands-Office-of-the-Maritime-Administrator-VALARIS-DS-17-Casualty-Investigation-Report.pdf

Strategic Harmony (2023) Singapore

On board a Singapore registered bulk carrier, the chief mate and deck cadet entered the Dirty Water Tank Port (DWTP) to open a surface drop valve to discharge the waste water that had accumulated inside. Both crew members collapsed in the tank and were subsequently evacuated from the DWTP. Soon after administering medical oxygen, the chief mate recovered but the deck cadet passed away.
See: www.mot.gov.sg/docs/default-source/about-mot/fatality-of-deck-cadet-onboard-strategic-harmony-at-sea-on-1-may-2023---final-report.pdf?sfvrsn=465f3e32_1

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[4] Resolution MSC.581(110) was not adopted at time of casualty.

Monarch of the Seas (2005) Bahamas
When performing maintenance on pulper system pipe work, noxious fumes were released when pipe flanges were broken by two engine room crew. The pulper system had a holed pipe which passed through an adjacent fresh water ballast tank depositing food waste, resulting in a significant generation of Hydrogen Sulphide gas. The release of the gas resulted in three fatalities and 18 other crew members being treated in the hospital.
See: www.bahamasmaritime.com/wp-content/uploads/2020/10/BMA-Investigation-Report-Hydrogen-sulphide-release-onboard-Monarch-of-the-Seas.pdf?swcfpc=1

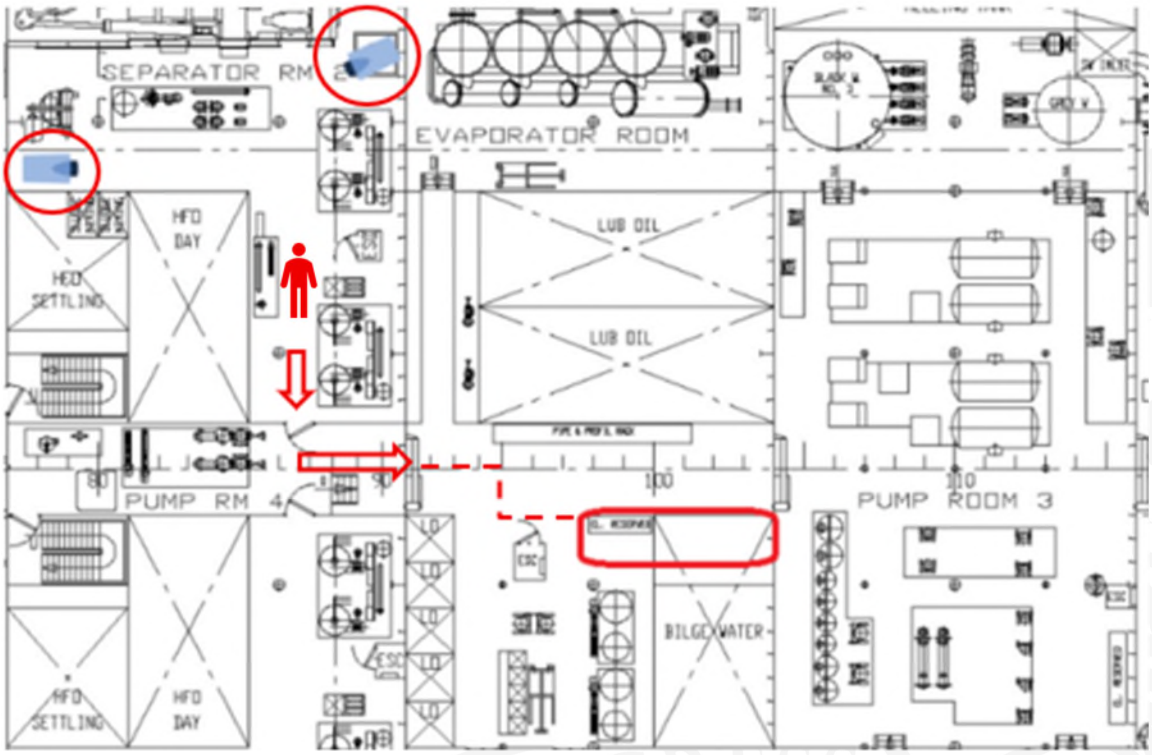
3. Analysis

The purpose of the analysis is to determine the contributory causes and circumstances of the casualty as a basis for making recommendations to prevent similar casualties occurring in the future.

The postmortem indicated the cause of death as probable mechanical (positional) asphyxia. Postmortem toxicological examination showed no evidence of detectable toxic exposure. It is likely the victim became aware of a hazard in the access space and attempted to exit, but lost his footing and became stuck in a suffocating position.

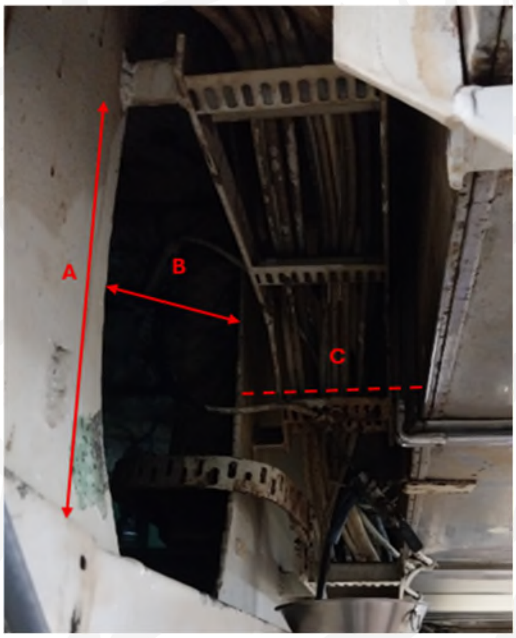
Scene and Space

The casualty occurred on the tank top deck, in the access space on top of the bilge water settling tank M4. The electrical cadet was last seen on the port side separator room CCTV cameras collecting his tool bag, exiting the room, and walking in the forward direction. Afterwards, he climbed into the access space above tank M4 using the ladder he previously rigged.



Tank top deck arrangement showing CCTV cameras and personnel movements

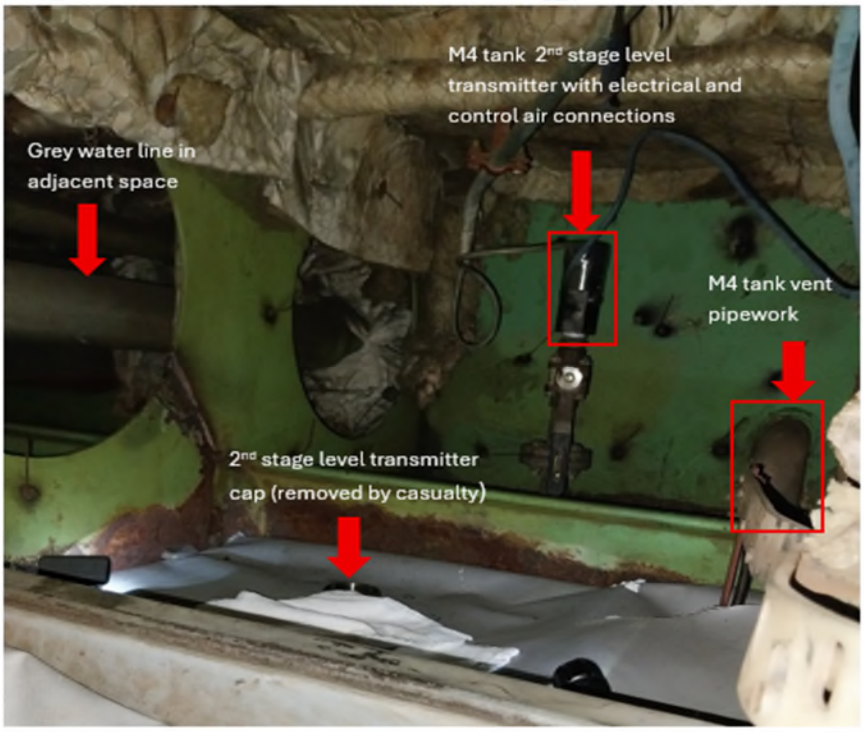
The height of the entrance to the access space was approximately 180cm from the floor plates, hence the rigging of a 183cm (6ft) ladder. Immediately beneath the space is a water fountain, so the ladder was rigged slightly to the port side of its entrance. There is also a ventilation duct running outside of the space.



Ladder outside of access space and dimensions of entrance

- **A-** Available overhead clearance for access space entry (cable duct to base of entrance): 35cm
- **B-** Width of entrance: 41cm
- **C-** Distance from bulkhead to ventilation duct running outside of the space: 23cm

The interior of the access space consists of bulkhead insulation and for tank M4: the tank top covers for both stages, the level transmitter for the second stage, and the ventilation pipework exiting the space leading to atmosphere. The space is not entirely enclosed, as there is accessibility to an adjacent area containing a grey water line.



Interior of access space (top of tank M4)

The dimension of the space on the tank top is approximately 188cm long (port to starboard) and 90cm wide (fore to aft). The M4 tank vent pipework is located 20cm aft of the second stage level transmitter.

In the wider maritime industry, the terms enclosed and confined are used interchangeably to describe a space meeting the criteria as defined in IMO Resolution A.1050 (27).

While the onboard policy addressing confined space entry contains a checklist that addresses potential hazards associated with work in a confined space, it is only applicable if spaces which meet the criteria stipulated in IMO Annex to Resolution A.1050 (27) are identified as confined spaces by staff.

The access space above bilge settling tank M4 satisfies the criteria to be designated as an enclosed/confined space.

Crew perception and internal process

The ventilation at the exterior of the access space falsely eliminated concern for airborne hazards being present when entering the space. Electrical officers believed the only potential hazard, with very low likelihood, would be a minor shock when working on the level transmitter. Therefore, it was never considered necessary to undergo the procedures required for entry into an enclosed/confined space.

The electrical cadet was nearing the end of his cadetship training, with the expectation he would be employed as an Electro-Technical Officer (III/6) on his next contract. He had requested additional responsibilities, and was entrusted with the electrical department's duty phone to respond to calls or requests as required to facilitate his development.

The 2/E called the duty electrician's phone to report the level transmitter issue and request the electrical department to troubleshoot. He was not aware whom he was speaking with. The electrical cadet was with the designated duty electrician when he answered the phone and explained the request to him before leaving, and was allowed to proceed unaccompanied.

After he left the fore store on Deck 2 at 15:36, the electrical cadet did not have any further communication with members of the electrical team. He believed the level transmitter issue and environment around tank M4, would be the exact same encountered two weeks prior when he was in the space troubleshooting under the supervision of another second electrical engineer.

When the electrical cadet left the ECR, after discussion with the 2/E, the engine room team assumed he went to liaise with members of the electrical department, not begin troubleshooting the sensor by himself.

Royal Caribbean Group could not provide any policies relating to the designation of a duty officer and answering of duty phones. The standard practice within their fleet is the duty electrician and accompanying phone is designated to a second electrical engineer.

The first officer (1/O) who lead the code Alpha response was equipped with a MSA Altair 4XR multigas detector. On approach to the access space and around its perimeter, no abnormal readings in oxygen deficiency or hazardous gases were detected.

He donned an SCBA (self contained breathing apparatus) to gain a better perspective of the access space above tank M4 and connected a sampling tube to the multigas detector. The 1/O could not fit in the space with an SCBA donned. Another crew member held the SCBA's air cylinder outside the access space, while the 1/O with his facemask on probed inside the space with the sampling tube. He was able to confirm fluctuating readings of hydrogen sulphide (H_2S) of up to 91 ppm.

The 1/O is also the responsible officer for the enclosed space training on board the vessel. He did not consider the space where the casualty occurred to be enclosed/confined.

As perceived by the crew, the access space was not considered to have the ability to produce or contain hazards that would be detrimental for any shipboard personnel entering the space.

Hydrogen Sulphide

Bilge water tank M6P, is located on the tank top deck between frames 77-91 with a total capacity of 125.3 m^3. Bilge water settling tank M4 is a two-staged holding tank located on the tank top deck between frames 100-104 with a total capacity of 54.90 m^3. Sludge tank M11 is located between frames 51-56 with a total capacity of 13.70 m^3.

Tank M4 is segregated into first and second stage tanks with a partition and an elbowed pipe that connects the stages. All transfers into tank M4 are directly into the first stage, which then allows flow into the second stage of the tank. The standard practice on board is to transfer into the first stage and allow it to 'settle', relying on gravity to naturally separate water and any other mixtures within the tank due to differences in density. The connecting pipe is designed so that the contents near the bottom of the first stage can flow into the second stage. The second stage has an outlet connected directly to the Oily Water Separator where the contents are processed and discharged appropriately.

Entries in the Oil Record Book indicate it was routine to manually drain any settled water from the sludge tank M11 into bilge water tank M6P. Miscellaneous engine room related leaks are also transferred into tank M6P, which are referred to as either "oily water" or "bilge water" in oil record book entries.

Members of the engineering staff confirmed there had previously been grey water system[5] leaks into the engine room bilge, which were transferred into tank M6P, and subsequently transferred into tank M4. There were also transfers to tank M11 from exhaust gas boiler maintenance. Therefore, there were a variety of untreated sources that eventually made its way into bilge water settling tank M4.

Post-casualty, oily water samples were taken from: the first and second stage of tank M4, tank M6P, and tank M11 on board Grandeur of the Seas. In order to establish a baseline for readings, samples were also taken from the same tanks on a sister ship, Enchantment of the Seas. The samples were sent to Kappa Laboratories Inc. for analysis[6], with the following results:

[5] Grey water means drainage from dishwater, shower, laundry, bath and washbasin drains and is not classified as sewage as defined in Regulation 1.3 of MARPOL Annex IV.
[6] Methodology can be found at https://www.fda.gov/media/187365/download

Anaerobic Plate Count (cts/ml)		
Tank	**Grandeur of the Seas**	**Enchantment of the Seas**
M4 Stage 1	600	10
M4 Stage 2	110	50
M6P	5,200	2,400
M11	*TNTC[7]	8,000

Lab analysis results for tanks: M4, M6P and M11 for Grandeur and Enchantment of the Seas

Anaerobic plate count readings can indicate that favourable conditions exist to produce Sulphate Reducing Bacteria (SRB), which under certain conditions contributes to the production of hydrogen sulphide (H_2S).

Sulphate Reducing Bacteria (SRB) are anaerobes that are sustained by organic nutrients. They are present in holding tanks containing sludge, black and grey waters. Generally, they require a complete absence of oxygen and a highly reduced environment to function efficiently (anaerobic conditions with negative oxidation-reduction potential). Nonetheless, some can survive in aerobic conditions, but become dormant and stop producing the enzymes necessary to reduce sulphate.

The majority of SRB's die off under aerobic conditions. The remaining dormant SRB's are ready to "wake up" when anaerobic conditions occur and will rapidly repopulate.

Chemically, sulphate consists of one sulphur atom surrounded by four oxygen atoms (SO_4^{-2}). Sulphate reducing bacteria strip away the four oxygen atoms leaving the sulphur atom in a form known chemically as sulphide (S^{-2}). The four oxygen atoms are used by the SRB to change carbon containing "foods" or "fuels" into carbon dioxide. If the waters in which the sulphate reducers lacks suitable metals, or if it is at all acidic, the sulphide will associate itself with hydrogen, yielding H_2S.

SRB's have also been implicated in the corrosion of cast iron and steel, ferritic stainless steels, 300 series stainless steels (also very highly alloyed stainless steels), copper nickel alloys, and high nickel molybdenum alloys. They are almost always present at corrosion sites. Their mere presence, however, does not mean they are causing corrosion. The key symptom that usually indicates their involvement in the corrosion process of ferrous alloys is localized corrosion filled with black sulphide corrosion products.[8]

H_2S once combined with water can form sulfuric acid (H_2SO_4) which can lead to excessive corrosion in tanks and associated piping systems.

Post-casualty, the transfer that was being conducted from M6P to M4 was replicated with gas sampling monitors in place. Less than one minute into the transfer, the odour of noxious gas filled the immediate

[7] TNTC - Too Numerous To Count indicates high microbial load and prevents accurate calculation without further dilution

[8] Memo from Nova Tech Consultants Inc. on Monarch of the Seas: www.bahamasmaritime.com/wp-content/uploads/2020/10/BMA-Investigation-Report-Hydrogen-sulphide-release-onboard-Monarch-of-the-Seas.pdf

area and the access space had readings of H_2S exceeding 100ppm, which later lead to the discovery of the corroded ventilation pipe.

The corroded vent pipe for tank M4 was 20 cm away from the sensor the electrical cadet was checking, and served as the ingress point for H_2S. The same is shown below:

Flanged connection for level transmitter near corroded M4 ventilation pipe (to atmosphere)

In air, hydrogen sulphide has an odour similar to rotten eggs (<1ppm), between 3-5ppm the odour is strong. Exposure to concentrations of 20-150 ppm cause dryness and irritation in a person's nose and throat with irritation in the eyes. Prolonged exposure at this concentration can cause coughing, hoarseness, shortness of breath and runny nose. Concentrations exceeding 150ppm cause olfactory fatigue and a person's ability to smell the gas is blocked. Prolonged exposures above this concentration significantly increases the likelihood of fatality.[9]

The victim was last seen on CCTV at 15:55. It is not known whether or not he entered the access space while the transfer was still ongoing, or after the transfer had been stopped at 16:00, but noting the above, it's likely he entered after the transfer was stopped.

The exact H_2S reading at the time the electrical cadet entered the access space could not be determined. While the autopsy states the victim did not die as a direct result of toxic exposure, it is likely he detected traces of the gas while checking the sensor, as any remnants would have settled on the top of the tank (H_2S is heavier than air). In an attempt to exit, he may have slipped and lost his footing, missing the ladder, and ended up in a suffocating position.

Bilge holding tank M4 was last cleaned during the vessel's drydock period in May 2024. As per the vessel's PMS, it is scheduled for cleaning on an annual basis and the next scheduled cleaning was for 10 April 2025 (less than 3 months post-casualty). The tank cleaning schedule was advanced and completed.

[9] https://www.worksafe.govt.nz/topic-and-industry/hazardous-substances/guidance/substances/preventing-harm-from-hydrogen-sulphide/

Sensor function and importance

The sensor was a Timon level transmitter operating between a 0-400mbar pressure range with a 4-20mA (milliampere) signal output. Also known as a 'bubbler' sensor, the level transmitter has an external connection fitted to supply control air (originating from the ship's control air system) into a flanged connection fitted on the tank (producing bubbles once liquid is present). The pressure required to pass air into the tank is directly proportional to the tank's hydrostatic pressure, thus enabling conversion into a mA signal which provides a corresponding level of height via the equipped programmable logic controller in the head of the sensor. This level transmitter model is not unique to this specific access space, and is fitted in numerous tank level monitoring applications throughout the vessel.

Additionally, the sensor triggered a Hi-level and Hi-Hi level alarm. Both tiers of alarms activate in the engine control room, but only the Hi-Hi level alarm activates the automatic cut off function for the oily water transfer pump. If the sensor is in error, neither alarms will activate and the transfer pump will continue to operate until it is manually stopped, or the tank being discharged is emptied. There have been previous instances of tank M4 overflowing due to the malfunction of this sensor.

Tank M4 is not fitted with any method of manually sounding, so if the second stage sensor is not functioning, the engineering team cannot immediately determine the level in the tank.

The second stage sensor for tank M4 was replaced on 07 November 2024 by a second electrician due to an incorrect indication of tank level on the VMS. A work order was created in the vessel's PMS to document this replacement.

Work on the sensor was not considered a "standard job" by the electrical department, as the sensor was only worked on as requested or required. The victim had previously worked in the space, under supervision, addressing a similar issue with the sensor two weeks prior to the casualty. The second electrical engineer who supervised the electrical cadet during that period stated he was present at the entrance to the access space, with his head inside directing as required. The supervisor was unable to enter the space due to its confinement.

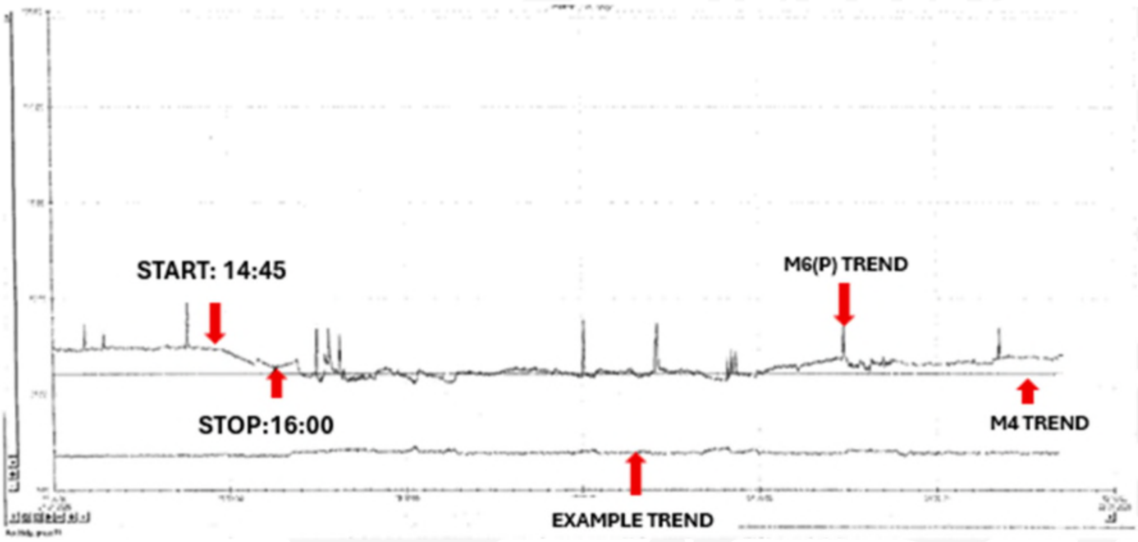
During this previous attendance, the electrical cadet and second electrician met with the engine room team on watch who confirmed at that time, tank M4 was empty.

There were no official work instructions, job safety analyses, or standard operating procedures for checking the level transmitter. The chief electrician outlined what a routine check would consist of:

- Check the sensor for any abnormal condition
- Using a mA tester to verify signal, simulate low and high level in the tank by closing the ball valve from the tank
- If readings are abnormal, sensor is removed and taken to electrical workshop with variable air pressure to simulate tank levels

Members of the electrical team stated these ad hoc procedures were adopted previously and passed down between relievers, but not formally documented in any of the vessel's established procedures.

The trend analysis below is for M6P and M4 tank, labelling the points for when the transfer started and stopped. The victim and 2/E observed the same trend for tank M4 (a flat line) in the ECR. A flat line on the trend indicates either a sensor error or disrupted airflow. An example of an unrelated tank trend is also shown as an example of a tank which is static and has a functioning level transmitter.



Printout of trend analysis for tanks M6(P) and M4 around the time of casualty (21 Jan 2025)

Review of the trend analysis history indicates the level transmitter for M4 began failing around 13:00 on 19 January 2025, two days prior to the casualty.

At some point in the vessel's history, the first stage level transmitter for tank M4 had been relocated outside of the access space. No record was available of when this alteration occurred. It is likely this was completed by a member of the electrical team as a matter of convenience: to avoid having to enter the access space to troubleshoot. Post-casualty, the second stage level transmitter was also relocated outside of the access space, thus ensuring ease of access for any future maintenance required.

First stage (left) and second stage (right) level transmitter for tank M4, relocated outside of access space

4. Conclusions

- An electrical cadet died as a result of probable mechanical (positional) asphyxia after entering an access space to troubleshoot a level transmitter for a bilge water settling tank. He was unaware that any hazards were present, having previously worked in the space under supervision, he believed the conditions would be the same.
- The access space was not designed to accommodate continuous work by shipboard staff and the sensor had no technical reason to be located inside the space. The space was also not designated as enclosed, confined, or dangerous, thus there were no safety precautions in effect involving work inside the access space.
- The transfer history in the Oil Record Book indicated that various sources of untreated water had been transferred into bilge water settling tank (M4) and contributed to favourable conditions for hydrogen sulphide gas formation. This was verified by lab analysis results showing high anaerobic plate counts throughout tanks within the system used for transferring.
- The first stage sensor for the bilge water settling tank had been relocated outside at an unknown point in the vessels history, indicating a need to avoid potential hazards in entering the access space for troubleshooting the sensor. The second stage level transmitter was also relocated outside of the access space post-casualty, ensuring ease of access for any future maintenance required.

5. Lessons to be learned

- Spaces containing equipment requiring maintenance should be designed to be easily accessible, safe and suitable for crew. The most effective risk control is elimination at the design stage.
- The standard industry terms “enclosed” or “confined” space may not be sufficient to alert seafarers to potential hazards. Language and images may prime seafarers to expect dangers only when entering areas that have to be opened or unsealed. Any area not normally occupied should be treated with the same caution as if entering a space that was previously “closed”.
- Shipboard oily water management should not put people at risk. Operators should be aware that untreated sources of oily water may not produce hazards in isolation, but their handling and mixing with other sources may develop hazardous conditions. Tanks used to hold untreated contents from various sources need regular sample analysis to detect conditions that promote hydrogen sulphide generation.

6. Actions Taken

Royal Caribbean Group has:

- Addressed the immediate cause of hydrogen sulphide generation.
- Removed and replaced the corroded ventilation pipe for tank M4, conducted pressure tests and painted the tank ceiling with corrosion-resistant paint.
- Replaced and relocated both 1st and 2nd stage sensors for tank M4 external to the access space.
- Created a fleet wide plan to address gaps in knowledge for confined space operations.

7. Recommendations

The investigation found that the access space containing the sensor had limited openings for entry and exit, inadequate ventilation and was not designed for continuous worker occupancy - making it an enclosed space. The control measures expected to protect crew from exposure to hazards within an enclosed space were not in place as it had not been recognised as one during the vessel's design or nearly 30 years of operation. Post casualty, the sensor was relocated to be accessed from a safe space. Relocation did not impede its function. Therefore, it is recommended that:

Royal Caribbean Group (RCG):

- During the design and build phase of their vessels, thoroughly assess options to eliminate, substitute or engineer out exposures to hazards within enclosed/confined spaces.
- Identifies all enclosed spaces onboard existing vessels, taking into account updated guidance in IMO Resolution MSC.581(110).

Det Norske Veritas (DNV):

- During the design and build phase of their vessels, thoroughly assess options to eliminate, substitute or engineer out exposures to hazards within enclosed/confined spaces.

Bahamas Maritime Authority:

- During attendance in the design, build, or operation phase of vessels, take into account the lessons to be learned from this casualty to help identify spaces that can be made safer.

The investigation also found that contents from the grey water system was mixed with contents of the oily water system when transfers were made from the bilges into tanks M6P and M4. Contents of both systems are managed in isolation, but can create hazardous conditions once mixed or stored together over extended periods. Therefore it is recommended that:

Royal Caribbean Group (RCG):

- Create and enforce procedures and an inspection regime for systems which may be subjected to cross contamination as a result of specific shipboard operations (grey water in bilge being transferred to oily water system).