“MONARCH of the SEAS”

IMO Number 8819500
Official Number 9000119

Report of the investigation into hazardous material release during pipe work renewal.

at
Los Angeles, USA
on
2nd September 2005

The Bahamas Maritime Authority investigates incidents at sea for the sole purpose of discovering any lessons which may be learned with a view to preventing any repetition. It is not the purpose of the investigation to establish liability or to apportion blame, except in so far as emerges as part of the process of investigating that incident.

It should be noted that the Bahamas Merchant Shipping Act, Para 170 (2) requires officers of a ship involved in an accident to answer an Inspector's questions fully and truly. If the contents of a report were subsequently submitted as evidence in court proceedings relating to an accident this could offend the principle that a person cannot be required to give evidence against himself. The Bahamas Maritime Authority makes this report available to any interested parties on the strict understanding that it will not be used as evidence in any court proceedings anywhere in the world.

Date of Issue : 1st June 2009

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Abbreviations Used In This Report

ºC	Degrees Celsius
CO	Carbon Monoxide
DnV	Det Norske Veritas
ECR	Engine Control Room
GT	Gross Tonnage
H_2S	Hydrogen Sulphide
IMO	International Maritime Organisation
ISM	International Safety Management
JSA	Job Safety Analysis
kW	Kilo Watts
LEL	Lower Explosive Limit
LT	Local Time
m, m^3, cm	Metres, cubic metres, centimetres
NMD	Norwegian Maritime Directorate
NTM	Notice to Mariners
OOW	Officer of the Watch
PBT	Permanent Ballast Tank
ppm	parts per million
ST	Ship's Time
t	Tonnes (where 1t=1000kg)
USCG	United States Coastguards
UTC	Coordinated Universal Time
VDR	Voyage Data Recorder

1 SUMMARY

1.1 On 2nd September 2005, two engine room crew were overcome by fumes when performing maintenance on pulper system pipe work, noxious fumes were released when pipe flanges were broken.

1.2 Pulper systems process food waste from the ship's galleys before it is discharged overboard. The ship had berthed that morning.

1.3 The two engine room crew were seen collapsed on the deck of the starboard shaft tunnel, just before 09:00, by the Engine Foreman who raised the alarm by phoning 911 (ship internal emergency system) reporting what he had seen and requesting assistance. The Engine Foreman returned to the scene with the First Engineer and the Inventory Technical Specialist, these three people began a rescue attempt before Emergency Teams arrived.

1.4 The initial emergency announcement was made at 09:00 as an Alpha Emergency (medical). At the start of the incident the cause of the engine room crew collapsing was not known nor was it realised that the area was still contaminated with extremely toxic fumes.
NB The Medical Emergency Team does not respond with Self Contained Breathing Apparatus (SCBA).

1.5 When the Medical Emergency Team arrived at the scene, 09:02, a Bravo Emergency (fire/smoke) announcement was immediately requested and made. As the emergency progressed members of the emergency teams and rescuers became affected by the fumes. A staging area for equipment and personnel was set up away from the scene.

1.6 Assistance was requested, by the ships Operation Control Team, to the port authority. Local emergency services, paramedics and fire department responded swiftly.

1.7 The incident resulted in 3 fatalities, one person was detained in hospital and eighteen others were treated in hospital and released the same day, some required follow up treatment.
The 3 fatalities were the two crew members who removed the pipe and the Engine Foremen who first found them.
The First Engineer suffered a collapsed lung.

1.8 The pulper pipe passed through an adjacent fresh water ballast tank (T7017 Dry Tank 11), sections of this pipe line were later discovered to be holed and this had allowed large quantities of food waste to accumulate in the tank. The resulting chemical reaction had caused Hydrogen Sulphide, (H_2S) gas to be generated which released during the incident.

1.9 The fresh water ballast tank had previously been a void space and had been re-designated as part of a change in load line. No structural or system changes were made as part of this change of use.

2 PARTICULARS OF VESSEL

2.1 "Monarch of the Seas" was a two compartment passenger liner on 11 decks with 2,744 passengers and 831 crew, registered at Nassau, Bahamas.

She had the following principal particulars:

- Official Number - 9000119
- IMO Number - 8819500
- Call Sign - C6FZ9
- Length overall - 268.33 metres
- Length BP - 230.58 metres
- Breadth - 32.2 metres (waterline)
- Depth - 9.7 metres
- Draft - 7.55 metres
- Gross Tonnage - 73,937 tons
- Displacement - 47,505 tons

2.2 She was powered by 6 main engines that developed 20,490 kW (27,477b hp) and which drove 2 controllable pitch propellers. There are also two tunnel thrusters forward delivering 1362 kW via 2 electric power units.

2.3 The vessel was built in 1991 at Chantiers de l'Atlantique. At the time of the incident she was owned by Monarch of the Seas Inc., Liberia and managed by Royal Caribbean Cruises Limited.

2.4 The vessel was first registered under the Bahamas Flag in December 1995 and was entered with DnV Classification Society. At the time of the incident she complied with all statutory and international requirements and certification.

2.5 "Monarch of the Seas" was last subjected to a Bahamas Maritime Authority Annual Inspection at the Port of San Diego on 18 January 2005. The Passenger Ship Safety Certificate PSSC was renewed at the port of Los Angeles on 11 October 2004

2.6 "Monarch of the Seas" had received Port State Control Inspections following the casualty at the Port of San Diego on 16 September 2005; there were no relevant observations and no outstanding deficiencies from this inspection.

3 NARRATIVE OF EVENTS

3.1 All times noted in this narrative are given in the style of the standard 24 hour clock without additional annotation and as local time in the port of San Pedro, Los Angeles, California, which was UTC-7 (daylight saving). Timings are variously taken from the vessels Voyage Data Recorder, vessels Emergency Checklist (handwritten), witness statements or official reports.

3.2 The vessel was all fast alongside at the time of the incident, having entered port that morning Friday 2nd September 2005 at 07:00 and was due to sail at 17:30.

3.3 Two engine room crew were assigned, by the First Engineer, the task to replace a section of pulper pipe (with a previously fabricated pipe) located in starboard shaft tunnel. While the two engine room crew started work on removing the bolts from the pipe flanges, the First Engineer prepared a hot work permit. A hot work permit was being requested in case the flange bolts were stuck and needed cutting free. Both a company permit and a US Coast Guard permit would be required.

3.4 Just before 09:00 the Engine Foreman was passing the starboard shaft tunnel when he noticed the two engine room crew members lying on the deck, he made a 911 call to request help.
The 911 phone rang at 08:59 and an Alpha Emergency (medical) announcement was made at 09:00.
The Engine Foreman then went to First Engineers office and reported what he had seen. The Engine Foreman, the First Engineer and the Inventory Technical Specialist, who share an office with the First Engineer returned to the starboard shaft tunnel. On arriving at the scene, despite the First Engineer thinking there may be some gas in the area, they entered the shaft tunnel to attempt to assist the two crewmen. They entered in the following order, Engine Foreman, First Engineer and Inventory Technical Specialist.

3.5 On hearing the Alpha Emergency (medical) announcement the Electrical Cadet and Electrician left the electrical workshop and went to the incident scene and saw people lying on the deck. The Electrician went to get a Self Contained Breathing Apparatus (SCBA) from the Engine Control Room two decks above. The Electrical Cadet had smelt something but could not identifying it, on seeing the First Engineer lying shaking the Electrical Cadet took a deep breath and pulled the First Engineer to just outside the shaft tunnel door. The Electrical Cadet went to rescue another person and collapsed halfway out. The Electrician arrived and wearing the SCBA pulled the remaining 3 people out of the shaft tunnel. This rescue action was undertaken as the Medical Emergency Team arrived.

3.6 09:02 - When the Safety Officer arrived at the scene of the emergency, with the Medical Emergency Team, he made an immediate request to the bridge for a Bravo Emergency (fire/smoke) announcement to be made. At this time several crew members had already responded to the area (see 3.5 above). The Medical Emergency Team members gave treatment to the engine room crew who had been brought out of the shaft tunnel, other responders and ultimately also to members of the Medical and Fire/Smoke emergency teams who became affected by the fumes.

3.7 09:06 - It was quickly realised that the area outside the shaft tunnel was contaminated. A staging area for equipment, personnel and initial treatment of casualties, was set up at the Engine Control Room, two decks above the starboard shaft tunnel. This was early in the emergency, before the extremely noxious nature of the vapour and the extent of the contaminated area was fully realised. This swift action will have resulted in reduced casualty numbers.

3.8 09:12 - Assistance was requested from port authority emergency services, who arrived by 09.24. The Los Angeles Fire Department and Hazardous Materials Teams responded.

3.9 09:28 - The vessel emergency teams and crew, assisted latterly by the port authority emergency services, had worked quickly and efficiently to move casualties clear of the shaft tunnel area, initially to the staging area at the engine control room, and then from the space. The engine room and shaft tunnel space was checked to be clear of all crew and personnel before the area was isolated by shutting fire & watertight doors and shutting down the ventilation system.

3.10 With the scene of the emergency secure, the port authority Hazardous Materials Team, wearing full safety equipment, entered the starboard shaft tunnel and took measurements of the atmosphere near the open pulper pipe. These readings indicated a level of Hydrogen Sulphide (H_2S) gas in excess of 300 ppm (300 ppm being the maximum reading of the meter used).

3.11 10:36 - It was confirmed there had been 3 fatalities.

3.12 Concurrent with the emergency the following activities were being coordinated and controlled by Master, Command Control Team and ship's staff.
- passengers were being disembarked, extra port authority and immigration staff were requested to speed this operation.
- a roll call of engine staff was made.
- ships agents, port authority, flag state and company office were all contacted and kept appraised of developments.
- passengers due to embark for the scheduled evening sailing time were arriving at the passenger terminal but remained ashore.

3.13 13:30 - A Bahamas Maritime Authority investigator attended the vessel. US Coast Guard (USCG), DnV Classification Society and P&I Club representatives were already on board.
At this time the pulper pipe that had leaked liquid and gas during the incident, in the starboard shaft tunnel, was still open and H2S levels of 14 ppm were being obtained by a Los Angeles Police Department meter.

3.14 14.20 USCG Captain of Port Order 2005-223 was given to Master, Monarch of the Seas. - This stated:
"As a result of the marine casualty on your vessel, you are directed to remain in port and not load passengers or stores until such time as we are assured your vessel no longer poses a threat to passengers or crew. Termination of order – This order will remain in effect until the Flag state representative has certified to the Coast Guard that the vessel is safe for crew and passengers……"

3.15 15:00 - the original pulper pipe was re-secured by this time.
The Los Angeles Fire Department and ship's staff had fully discussed the hazards, risks and options for securing the area and a plan agreed. Ship's crew entered the area using chemical protective clothing and SCBA to re-secure the pipe in its original position. On reconnection of the pipe and ventilation of the area the atmosphere was fully tested by a National Fire Protection Association (NFPA) Certified Marine Chemist and the following readings obtained LEL - 0%, 0_2 - 20.9%, H_2S - 0ppm CO - 0ppm.

3.16 Those crew who had been treated at the local hospital were back on board by 17:00, with the exception of the First Engineer who had suffered a collapsed lung. It is believed that all have since made a full recovery although some did receive follow up treatment due to the effect of the gas.

3.17 5th September 2005 -DnV Classification Surveyor attended vessel at Los Angeles to verifying the agreed temporary modification to water ballast tank (T7017 Dry Tank 11) of extending the port/starboard air vents from inside the engine room casing to atmosphere through the bunker stations (P/S) on deck 1.
Permission was given by the DnV Classification Surveyor for the vessel to sail to next port with temporary hoses on the tank vents. The hoses had to pass through fire doors and DnV required extra fire patrols in the area to mitigate this additional risk. The hoses were later changed for fixed pipes.
NB: The permission from DnV Classification Society to sail with temporary hoses on the tank vents was later recorded on the vessels Survey Schedule as Condition of Class # 107. There is evidence to show that this CoC was repeatedly extended. Ultimately, the BMA sanctioned an extension beyond 31st December 2005, provided the work was completed during the forthcoming repair period in January 2006.

3.18 The pulper pipes which passed through the water ballast tank (T7017 Dry Tank 11) were suspected of leaking due to dirty smelly water having leaked from the tank vents at no 1 deck. This had happened on several occasions and in an effort to keep the area clean these vents had been connected by hoses to drains which led to the starboard shaft tunnel bilge. During the managers investigation these vents/hoses were found to have been blocked at the time of the incident.

3.19 Nearly 6 months prior to this tragic incident, a Near Miss incident occurred in the starboard shaft tunnel. On 7th March 2005, all 4 smoke detectors in the starboard shaft tunnel were activated. The initial responders noted smoke/fumes and strong smells in the area but no flames. Two crew members became dizzy and were taken to the ship's hospital for observation.
The source of smoke/fumes was never identified and the root cause(s) of the Near Miss incident were not investigated.

3.20 As a result of a load line change between 1999 and 2000, several hull spaces were re-designated, space T7017 Dry Tank 11 was re-designated as a Permanent Fresh Water Ballast Tank (PBT 11). At the time of this change no structural alterations were carried out to hull space T7017.

Post Incident Actions

3.21 With the original pulper pipe back in place and the tank vents permanently extended to atmosphere outside the machinery spaces, the noxious liquid and gas within Fresh Water Ballast Tank (PBT #11) were contained. The exact contents of the tank, at this stage, were not known and a strategy to achieve the emptying and cleaning of the tank had to be developed.
This situation was hampered by the following initial conditions:-

a) the nature of the fumes (H_2S in excess of 300 ppm) and liquid that had leaked from the pulper pipe during the incident indicated severe contamination of the tank contents
b) filling of the tank was only possible via the tank vents
c) emptying of the tank was only possible using the small bore bilge pumping system
d) the tank was required to be full for stability purposes, its shape causing a large free surface effect if the tank was slack.

3.22 The restrictions on filling and emptying the Fresh Water Ballast Tank (PBT #11) meant that activities to change the condition of the contents to allow entry and cleaning were severely compromised.
With the water removed from the tank, chemicals were added to neutralise the contents and the water level returned to full.
Gas readings were regularly taken at the tank vents along with liquid samples in order to gauge changes to the condition of the contents.
The condition of class (CoC 107) was continuously extended to allow the ship to trade with the tank still contaminated and the vents extended outside the engine room space.
The tank was finally emptied, cleaned, inspected and the internal pipe work repaired/bypassed at the January 2006 Dry dock.

4 ANALYSIS

4.1 **EVIDENCE:** The principle evidence was taken from the BMA Prelimainary Investigation and the Royal Caribbean Cruises Ltd Marine Accident Report, "Hazardous Material Accident September 2nd 2005", published in November 2006. Additional reports from RCCL into their resolution of issues with regard to stabilising the contents of Fresh Water Ballast Tank (PBT #11) and its subsequent cleaning were reviewed.

4.2 **TANK:** The tank was designated on ship's drawings as hull space T7017 a dry void with a volume of 433.7 m^3.
(See Appendix 1 Hull Space T7017 Cross Section & Location)
Hull space T7017 was a shallow double bottom tank with a 'U' shape, the upper port and starboard sections of which each had an individual vent which terminated in the engine casing on deck 1 just aft of the Engine Control Room.
The port and starboard shaft tunnels were situated inboard of the upper sections of the tank.
The tank had one sounding pipe located on the tank top, which was below the highest level of the tank and near the centreline of the ship.
The tank was also connected to the bilge system through a small pipe from the bottom of the tank.

4.3 **CHANGE OF USE OF TANK:** In accordance with the requirements of the stability manual approved by Norwegian Maritime Directorate, 12th May 1999 the vessel underwent a load line change which increased the maximum draft to 7.7m. As part of the required changes hull space T7017 Dry Tank #11 was converted to a fresh water permanent ballast tank (PBT #11). A further 6 dry void spaces were also re-designated as Fresh Water Permanent Ballast tanks and are required to be kept pressed up. Records related to the conversion of hull space T7017 (PBT #11) do not confirm when this was completed. No structural changes were made but it was recorded in maintenance records that the liquid sensor was disconnected and electrical parts were removed during a tank inspection in October 2000. The liquid sensor and alarm was a dry void space requirement to alert crew of liquid ingress. No system was installed to determine the level of the liquid in the tank above the height of the sounding pipe.

4.4 **NOTE:** The Monarch of the Seas suffered a casualty on 15th December 1998 when it struck the Proselyte Reef south of Philipsburg, St. Maarten, the Netherlands Antilles, the vessel was then deliberately grounded on a sandbank in Great Bay St. Maarten. This casualty resulted in damage to 11 double bottom spaces and water ingress to 2 pump rooms and a laundry area. The report of this incident, by the coastal state and USCG, does not question the vessels ability to stay afloat, in fact it praises the "stepped bulkheads" of the forward pump room as a primary reason the vessel would have remained afloat. However the stability manual was re-issued on 12th May 1999 following completion of repairs from this incident which took some 3 months.

4.5 **TANK OPERATION**: The tank was filled with fresh water through the vents and could only be emptied by a small bore bilge connection. Completion of the weekly sounding report entry for PBT #11 was achieved by removing the sounding cap and recording a full reading if water was present.

4.6 **TANK VENTING:** Following the conversion of hull space T7017 to a Permanent Ballast Space it was required to be kept pressed up and no means of monitoring the tank level was fitted. With the tank full the vents, situated in engine casing at deck 1, would periodically spill and flood this area. The water was dark and odorous and required extensive clean up, after several such incidents hoses were fitted to the vents and led to a funnel drain which terminated in the starboard shaft tunnel bilge. The significance of the dirty smelly water was not realised at the time the hoses were fitted to the vents. Following the gassing incident these hoses were noted to be blocked, indicating that their purpose had been forgotten over time.

4.7 **TANK MAINTENANCE:** Maintenance records indicate that hull space T7017 was inspected at dry docks in 2000 and 2003. During the inspection in October 2000, the liquid level gauge was disconnected and electrical parts were removed in preparation for filling with permanent water ballast. The maintenance report from May 2003 states that the tank was inspected by DNV and the Staff Captain. Subsequent inspection reports in October 2003 and October 2004 refer to the inspection conducted in May 2003 and state that the tank was not inspected because it is a permanent ballast tank. The tank was due for its next inspection in October 2005.

4.8 **CHANGE OF USE OF DRY VOID TANKS:** In May/June of 2003 the vessel underwent extensive refurbishment prior to commencing cruises with Los Angeles as its home port. As a result of these changes DnV reviewed the stability manual and dry void tanks DB 2 Port and Starboard, Dry Tanks 4, 7 and 12 were re-designated as fresh water permanent ballast tanks and required to be kept pressed up.

4.8.1 **Change of Ship Registry and Tank Designation -**

- **1998:** At the time of grounding incident the vessel was entered with Norwegian Ship Register.
- **1999:** Tank use changes took place including T7017, these were significant changes that required the new Permanent Ballast tanks to be kept FULL
- **2003 May:** DnV Report indicates that further dry void tanks were changed to Permanent Ballast
- **2005** Vessel changed registry to The Commonwealth of the Bahamas 15th February 2005.

*The above changes to the vessels tank designations and change of registry could be indicative of inadequate **Management of Change Control** between the Managers, the Classification Society and the Flag.*

4.9 **EVENT:** Crew members were assigned the duty of replacing a section of pulper pipe which was located in the starboard shaft tunnel. The replacement of this section of pulper piping was part of an overall project to re-route the pipe outside of T7017 Permanent Ballast Tank 11. The replacement pipe had been fabricated on board the vessel the previous day. The work was considered routine.

4.10 The pipe was located approximately 10.5 meters (35 feet) from the forward entrance to the shaft tunnel. Based on the condition of the pipe after the accident, the crew had completely unbolted the flange furthest from the tank and had loosened some of the bolts on the flange closest to T7017 Permanent Ballast Tank 11. A small amount of liquid escaped from the tank (approximately 5 gallons) along with the gas. The crew members had blanks nearby to close off the pipe at both ends after removal.

4.11 While two of the engine room crew began the job of unbolting the pipe, the First Engineer was busy completing a hot work permit related to the job. The hot work permit was requested in case some of the bolts were found to be seized and would need to be broken free using a cutting torch.
Just before 0900 the Engine Foreman walked by the starboard shaft tunnel and noticed two crew members lying on the deck.

4.12 At approximately 0900 the Engine Foreman called 911 to request help and went to the First Engineer's office. He told the First Engineer that two crew members were down in the shaft tunnel and he needed assistance. The First Engineer, Engine Foreman and the Inventory Technical Specialist (who shares an office with the First Engineer) all went down to the starboard shaft tunnel where they saw the two Mechanics lying on the deck. All three entered the shaft tunnel in the following order:
- Engine Foreman,
- First Engineer,
- Inventory Technical Specialist (ITSA)

4.13 The First Engineer thought that there may be gas in the area because two crew members were down; however, he did not smell anything as he proceeded towards the Mechanics. The First Engineer and the ITSA grasped the legs of Mechanic 1 and began dragging him out of the shaft tunnel. The ITSA felt dizzy and left the space, later passing out near the main engine outside of the shaft tunnel. The First Engineer and Engine Foreman collapsed inside the shaft tunnel while still attempting to rescue the two Mechanics.

4.14 The bridge officer called Alpha Emergency (medical) on the Public Address system at approximately 0901. The Electrical Cadet was in the electrical workshop with the Electrician when the Alpha Emergency was broadcast. The Electrical Cadet and the Electrician went to the starboard shaft tunnel where they saw two people lying on the deck (they were not part of the Alpha team). The Electrical Cadet stated that he smelled something strange, but could not identify the smell. The Electrician told the Electrical Cadet that he would get a breathing apparatus (which was in the Engine Control Room two decks above). The Electrical Cadet saw the First Engineer lying inside the shaft tunnel shaking, he then took a deep breath and entered the space pulling the First Engineer just outside the forward door of the shaft tunnel. The Electrician returned with a breathing apparatus and saw the Electrical Cadet pulling the First Engineer out of the shaft tunnel.

4.15 The Safety Officer also arrived at this time with Nurse 1 and saw the Electrical Cadet pulling the First Engineer out of the shaft tunnel. The Safety Officer Requested that the Bridge make a Bravo Emergency (fire and smoke) announcement and told the nurse not to go into the space, then left to get a breathing apparatus. The Electrical Cadet then took another deep breath and went in to rescue another crewmember. He was able to pull the second crewmember halfway to the exit of the shaft tunnel when he felt dizzy. He woke up lying next to the First Engineer just outside the shaft tunnel. The Electrician (wearing a breathing apparatus) then pulled the remaining three crew members (the two Mechanics and the Engine Foreman) out of the shaft tunnel.

4.16 Nurse 1 did not remember hearing the Safety Officer tell her not to go into the space. She saw the First Engineer lying on the deck just outside the shaft tunnel and went to assist. Nurse 1 began administering care to the First Engineer as more medical staff began arriving at the scene. Two Doctors and one more nurse also arrived and began working on the First Engineer and other three crew members pulled from the shaft tunnel. While administering care, several members of the medical staff were temporarily overcome by gas and collapsed but were revived. Victims and responders were gradually moved further forward (away from the shaft tunnel).

4.17 **PULPER PIPING:** The pipeline the crew members were working on was part of the ship's pulper system (food waste disposal). It originates in the Windjammer galley on deck 10 then passes through a booster pump on deck 9 then continues through the ship to the engine room where it passes through T7017 Permanent Ballast Tank 11. When it exits T7017 Permanent Ballast Tank 11 it then goes to a hydro-extractor in the incinerator room and then back through the tank before going overboard. *(See Appendix II Sketch representing pipe and tank layout)*

4.18 Both sections of pipe inside the tank were inspected (at dry dock in January 2006) and found to be holed, one hole in overboard line and two holes in the line from the Windjammer to the hydro extractor. A pipe patch was found on the pipe coming from the Windjammer booster pump indicating that this piping had been previously repaired. *(See Appendix III - Pictures of holed pipe work in tank)*

4.19 The engine casing where the tank vents terminate had been periodically flooding with water from the tank. This water was dark and odorous which lead the ship's personnel to believe that at least one of the pulper lines passing through the tank was holed. After several events requiring clean up of the engine casing, it was decided to re-route the vents using hoses. These hoses were lead to a funnel with a gooseneck which went down into the starboard shaft tunnel bilge.
During the investigation and follow-up work after the accident, it was discovered that these hoses were blocked.

4.20 **STABILITY:** T7017 Permanent Ballast Tank 11 is a full breadth tank with no full length bulkheads and thus has a very large free surface effect when slack (app. 26,000 M4). T7017 PBT 11 is required to be filled to provide extra bottom weight to counter additional weights in the upper levels of the vessel and maintain the required GM. Thus to achieve the required GM and prevent any instability arising from the large free surface effect, the tank must be pressed up.

4.21 The crewmember responsible for sounding the tank on a weekly basis said that he normally unscrews the sounding cap and if water comes out, he marks the tank full. He also mentioned that the water normally 'smells bad'.

4.22 **STARBOARD SHAFT TUNNEL:** This space was not classified as a confined space. Crew members enter this space at least every four hours as part of their normal watch routine to take a reading of the oil level on the controllable pitch propeller. This space is well ventilated and is accessible through a fire door at the forward end. There are no other entry or exit points for the shaft tunnel.

4.23 **CASUALTIES:** The three people who died were two Mechanics and the Engine Foreman. The two mechanics were the workers found collapsed inside the shaft tunnel and the Engine Foreman who was the first rescuer to enter the space. All three crew members' autopsies showed the cause of death to be Hydrogen Sulphide Poisoning.
Eighteen crew members were treated at local hospitals after complaining of symptoms such as sore throat and nausea. All were treated and released except the First Engineer who suffered a partially collapsed lung as a result of his exposure to the gas.
Over time more crew members returned to the hospital for further follow-up and several more crew members were also treated and released for possible gas exposure. Physician reports indicate that none of the crew members will suffer long term effects from their limited exposure.

4.24 **PREVIOUS EVENT:** On March 7th 2005 four smoke detectors were activated in the starboard shaft tunnel. When personnel went to inspect the area some smoke/fumes were noted as well as black sooty "liquid" on the pulper pipe work. A Bravo Emergency (Fire and Smoke) was sounded. Some of those attending the scene used gas masks but in spite of this felt giddy and in one case passed out and awoke in the medical treatment room.

4.25 The cause of the smoke and gas was never determined. It is not known whether this incident was related to the situation within T7017 Permanent Ballast Tank 11, however, the location, and nature of the event would seem to indicate that it may have been related. It is possible that the re-routed vents from the tank were periodically sending gas and/or pulp filled liquid into the starboard bilge within the shaft tunnel.

4.26 **WORK PLANNING:** There was no verbal or written Job Safety Analysis (JSA) conducted prior to beginning the work of removing the pipe. The Engine Policy and Procedures Manual of the Safety & Quality Management System is not specific as to which jobs actually require a JSA and leaves the decision to the judgment of the officer in charge of issuing the work.

4.27 Engine room crew had often changed out pulper piping which tended to deteriorate rapidly due to the nature of its contents. The feeling that this was another 'routine' job may have contributed to a lack of concern regarding the contents of the tank or of the pipe.

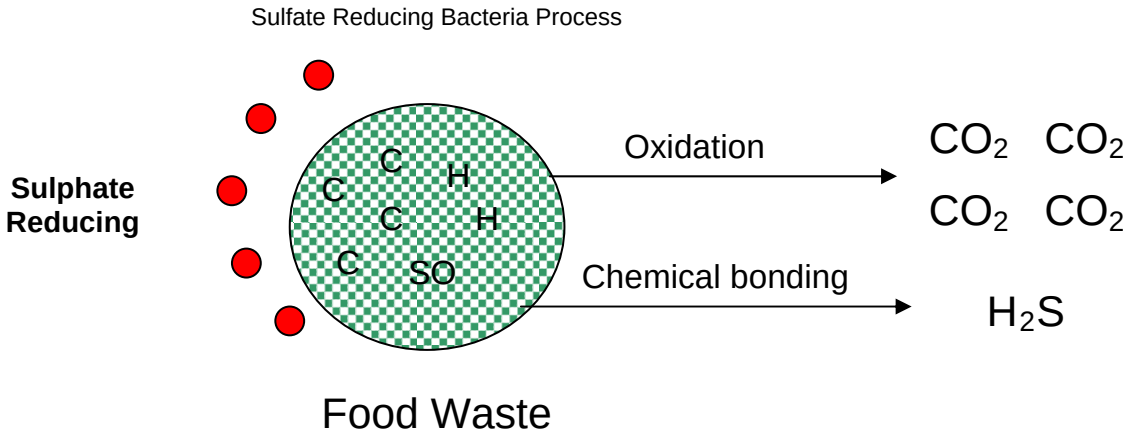
4.28 At the time of the incident the First Engineer was completing paperwork for a Hot Work Permit "in case" it was needed. The fact that the pipe was nearly fully removed during the time it took him to complete the paperwork would seem to indicate that a HW permit was never going to be needed.

4.29 When the tank was converted, the ship was registered under the Norwegian International Ship flag and was regulated by the Norwegian Maritime Directorate. Although no documents could be found specifically related to the conversion of this tank, the NMD Stability Booklet Approval letter to increase draft to 7.7 meters is dated 12 May 1999 and maintenance records indicate that the tank was prepared for conversion sometime in 2000.

4.30 Tank Ventilation - There was no evidence found to determine how long hoses had been attached to the vent pipes of T7017 Permanent Ballast Tank 11 and also no evidence to suggest that they were checked regularly by the crew. This lack of attention to the issue allowed the hoses to become blocked.

4.31 **HAZARDOUS GASES:** The pulper system is designed to transport food waste through the ship and eventually overboard. Under normal circumstances, food waste is not allowed to settle in tanks or pipelines because the system operates often; however, because the pulper pipe was breached inside the tank, contents of the pipeline were able to gather inside the tank and sit for long periods of time.

4.32 The production of hydrogen sulphide gas in this environment is both biological and chemical. In an anaerobic environment, sulphate reducing bacteria will consume food waste that contains carbon and sulphates (SO_4). The carbon provides food for the bacteria and the sulphate has four Oxygen atoms that are oxidized as the bacteria digest the carbon. Once the Oxygen atoms are split from the sulphate, the remaining sulphide ion is very unstable and looks to bond with available hydrogen atoms. The bonding of sulphide atoms with hydrogen atoms creates hydrogen sulphide (H_2S) see Figure below)



4.33 Most Sulfur Reducing Bacteria (SRB) requires an anaerobic environment to survive. This oxygen deficient atmosphere was provided within T7017 Permanent Ballast Tank 11 because the vents to this tank were blocked and oxygen content was reduced therefore allowing the SRB to actively produce the enzymes necessary to reduce sulfate. (*See Appendix IV SRB Memo from Nova Tech Consultants*) When the pipeline was opened by the crew, the liquid level of the tank was at or below the level of the pipeline penetration. By opening the pipe, the crew created a path for the gas to escape from the tank. Readings taken after the accident by the Los Angeles Fire Department indicated H_2S levels over 300ppm (the maximum reading of the gauge).

Opinion: It is difficult to determine exactly what caused the liquid in the tank to be slack at the time of the accident; however, the evidence suggests that when the pulper pipeline was pressurized and contents were passing through, the holes in the pulper lines may have caused a Venturi effect pulling the liquid out of the tank while also allowing contents of the pulper lines to enter the tank.

5 CONCLUSIONS

5.1 **INCIDENT.** The three men who lost their lives did so because of an uncontrolled release of an extremely toxic substance (Hydrogen Sulphide) during what was considered to be routine maintenance.

5.2 **COMPANY EMERGENCY PROCEDURES.** The speed of emergency team response, quick assessment of the situation at the scene and requesting specialist assistance all worked to ensure that the incident was brought under control swiftly. This will undoubtedly have reduced the number and severity of casualties.
The very comprehensive hand written emergency log and the transcript of bridge communication taken from the Voyage Data Recorder have greatly assisted the investigation process.

5.3 **JOB SAFETY ANALYSIS** should be used on all maintenance whether it is non-routine or routine this will ensure that all staff are fully aware of the reasons for, the scope of and the hazards associated with the work and/or operation. Such a comprehensive approach will thus ensure the provision of a process whereby forums are set up formally and informally at which questions and concerns can be aired and responded to prior to work commencing.

5.4 **PRE-PLANNING OF WORK**. A Hot Work permit related to the pipe removal work was being prepared "in case" bolts had to be cut off, when the incident occurred. The pipe removal was very nearly complete at the time of the incident. This would seem to indicate a lack of pre-planning and assessment of the requirements of the task and effort required to complete. Most pipe renewal on board ship is done with the requirement to have the system available for use as soon as possible. It is therefore not uncommon to remove, clean and replace or change out all bolts singly prior to starting the task, thus ensuring the speediest change out of the pipe. In this instance the completing of paperwork for a hot work permit "in case" it was needed would not seem to indicate poor pre-assessment of the task and lack of a robust Control of Work System.

5.5 **PREVIOUS NEAR MISS IN STARBOARD SHAFT TUNNEL.** This incident was not investigated to Root Cause. The Near Miss incident report contains a short paragraph of speculation, under the heading Root Cause Description, that a chemical may have entered the pulper system. One person was overcome by fumes in the Near Miss Incident but made a full recovery.
The investigation into this tragic incident identifies that there was much more to the near miss than was discovered at the time.

5.6 **LEADING TANKS VENTS TO BILGE.** The consequences of attaching hoses to the vents of hull space T7017 Permanent Ballast Tank 11 and leading these to bilge, were not assessed. The driver for this action would appear to be, removing a slip hazard and maintaining the cleanliness of the space with little thought as to how or why the dirty liquid was spilling on to the deck.

5.7 **CHANGE OF USE OF HULL SPACES.** Hull Space T7017 became a Fresh Water Ballast Space in 1999/2000, no structural changes took place and no additional equipment was fitted to the tank as a result. The dry space monitor was disconnected and electrical parts removed at this time. The change of use of the space was as the result of new stability conditions, several other tanks were also subject to a similar change of use. In 2003 stability information was again reviewed, after a major refit, resulting in further spaces being designated ballast spaces that must remain full.

5.8 **CORROSION OF PULPER PIPES.** Maintenance and replacement of pulper pipe was being done on a regular basis and thus became a "routine job". This mind set coupled with the Engine Policy and Procedures Manual not being specific about when Job Safety Analysis should be applied, resulted in work planning being less than adequate.
Information within the passenger ship industry points to their being an inherent problem with pipelines for pulper system, grey water and sewage water passing through void, cofferdam or ballast spaces. This is illustrated by the UK Marine Accident Investigation Branch (MAIB), Safety Digest 03/2004, Case 1 this incident involves an unexpected release of H2S and is further referred to in paragraph 6.2 in Recommendations.

5.9 **RCCL CONCLUDED THE FOLLOWING IN THEIR REPORT:** -
- Officers and Managers should periodically take the time to ensure that crew members are fully familiar with their duties (such as tank sounding) and are carrying them out correctly.
- All vessels should have multi-gas detectors which are capable of reading LEL, O_2, H_2S, & CO as well as personal gas detectors for confined space entry.
- Medical personnel should not enter a technical space until accompanied by an Officer who has knowledge of that space and declares it safe for entry.
- When an incident occurs, crew members who are not part of the designated response teams should not respond unless specifically requested by one of the responding Officers.
- Tank conversions should be reviewed and necessary structural changes made to ensure tank level can be monitored and routine maintenance can be conducted.

5.9.1 **RCCL RECOMMENDED (AMONG OTHERS) THE FOLLOWING CORRECTIVE ACTIONS**:-
- Change the Situation Management Plan, Alpha procedures to include the announcement of a staging area when the emergency is in a technical space. Add a senior technical person to the Alpha response team during emergencies in technical spaces.
- Review all procedures related to pipeline and tank entry/confined spaces.
- Develop safety training related to confined space and pipeline safety.
- Coordinate review of tank conversion process with classification society surveyors.

These actions have all been completed by RCCL.

6 RECOMMENDATIONS

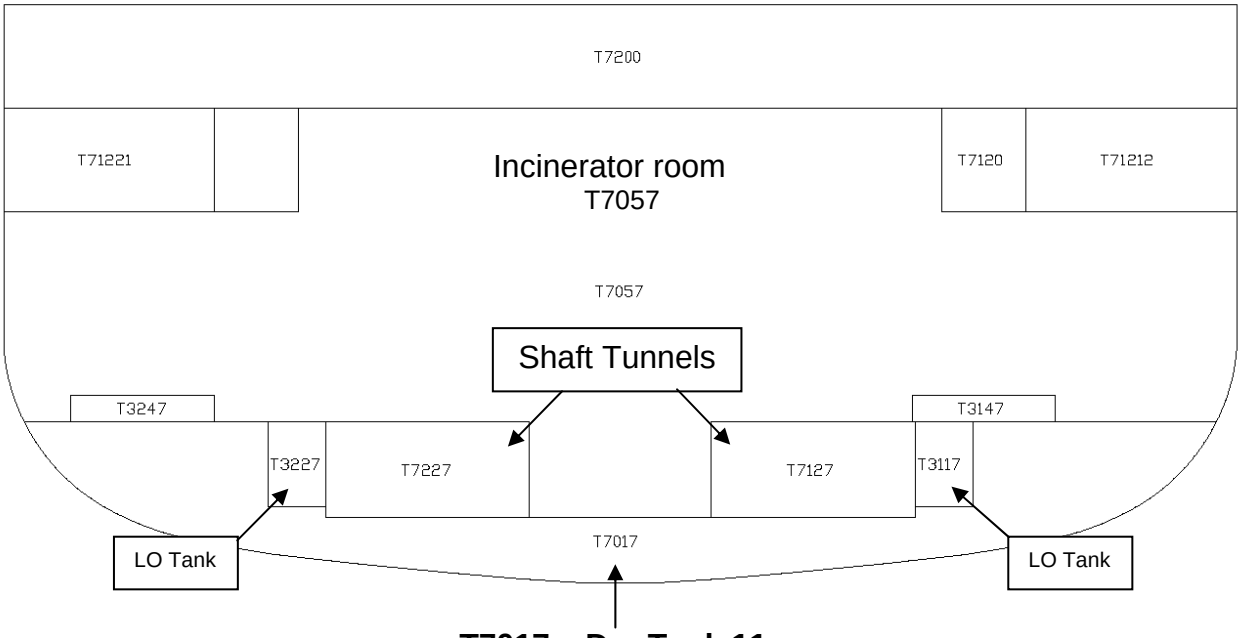
6.1 The process of **Change of Use of Hull Spaces** for passenger liners should be fully reviewed by Owner, Operator, Classification Society and Flag State members' representative groups. Throughout the life of a passenger liner, with periodic refurbishments, the passenger areas (topsides) are only going to get heavier, requiring that additional weight (ballast) is carried low in the ship to bring the stability criteria (GM) back to the original design condition. Current practice is to convert spaces to Permanent Water Ballast; however no industry process exists to ensure that all the aspects of this Change are fully reviewed in line with modern Safety Management System practices around Change Control as required by Occupation Health and Safety Management System (OHSAS) 18001. The review should set a standard approach for conversion of a void or dry space to a wet space and consider other options for providing the additional weight.

6.2 **Incident Sharing** - The UK, Marine Accident Investigation Branch, MAIB Safety Digest 3/2004 Case 1, ***(See Appendix V)*** refers to a passenger ship H_2S incident. In this MAIB incident grey water and sewage pipes which passed through a cofferdam had corroded resulting in sewage build up in the tank. In preparing for a routine inspection of the cofferdam, the senior officer was returning to the open access manhole when the Multi Gas detector, being carried, alarmed and showed an H_2S reading of 98 parts per million. The subsequent swift action in vacating the area and securing the space prevented any injuries. occurring. Companies should be encouraged to look beyond their own experience when looking for example incidents to use in incident investigation and awareness training. Similarly, Shipping Companies, Industry Sector Groups (e.g. Oil Companies International Forum), Flag State and Classification Societies should ensure that their procedures for incident dissemination are proactive in sharing the knowledge gained across all sectors of the marine industry.

6.3 **The Corrosion Protection, material specification and routing of Pulper System,** Grey Water and Sewage System pipe work should be reviewed by the Owner, Operator, Classification Society and Flag State members' representative groups. This incident and the MAIB Near Miss referred to in 6.2 graphically illustrate the potential consequences when the contents of these systems are deposited in spaces where it is not possible to monitor conditions resulting in hidden and unforeseen dangers.

APPENDIX I

Hull Space T7017, Cross Section & Location

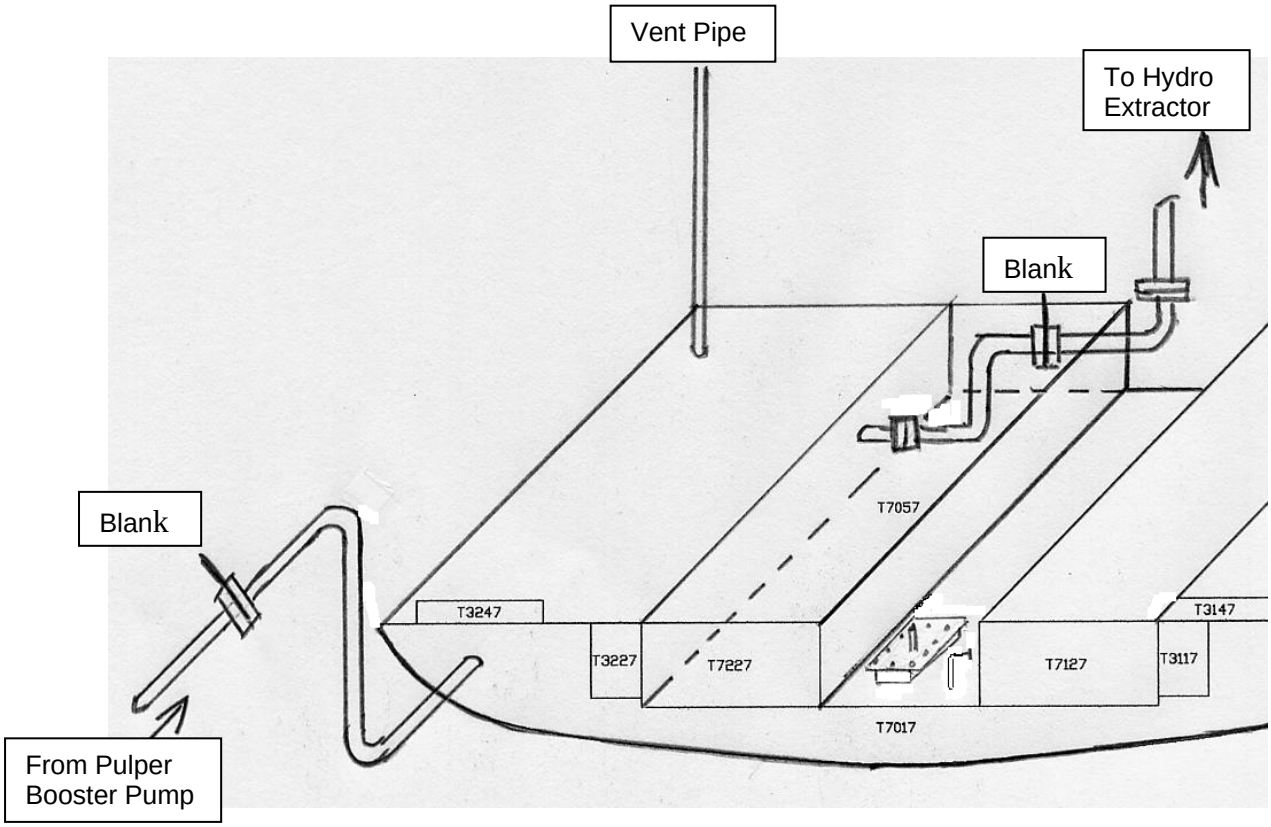


T7017 – Dry Tank 11

(Permanent Ballast Tank 11)

APPENDIX II

Sketch representing pipe and tank layout



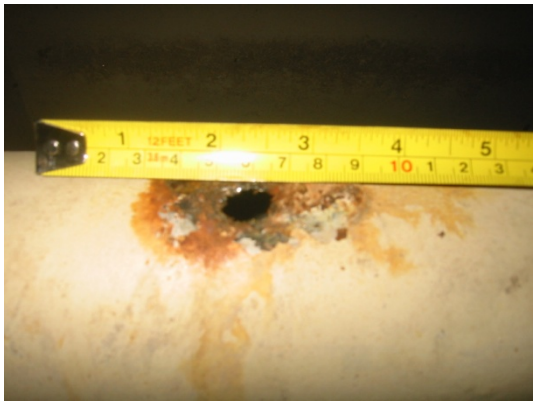
APPENDIX III

Pictures of holed pipe work in tank

Hole in overboard pulper pipe.
Width approximately 4 1/2 inches.

Hole in overboard pulper pipe.
Length approximately 3 inches.

First hole found in pipe leading from Windjammer booster pump going to incinerator room.



Second hole found in pipe leading from Windjammer booster pump going to incinerator room

APPENDIX IV

SRB Memo from Nova Tech Consultants Inc.

Sulphate Reducing Bacteria (SRB)

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 ORP). Nonetheless, some can survive in aerobic conditions, but become dormant and stop producing the enzymes necessary to reduce sulfate. 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 hydrogen sulphide (H_2S).

1 What happens to hydrogen sulphide when it enters the environment?

- *Hydrogen sulphide is released primarily as a gas and spreads in the air.*
- *Hydrogen sulphide remains in the atmosphere for about 18 hours.*
- *When released as a gas, it will change into sulphur dioxide and sulphuric acid.*
- *Hydrogen sulphide is readily soluble in water where it combines with water molecules to form sulphuric acid.*

SRB 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.

NovaTec Consultants Inc.

APPENDIX V

MAIB Safety Digest 3/2004 Case 1

Narrative

On board a passenger ship, a crossover line between the port and starboard ballast/treated black water/grey water tanks passed through an adjacent cofferdam. The pipework in the cofferdam had suffered corrosion, and this allowed sewage to build up in the tank. Ship's staff were aware of the problem, and permanent repairs were planned for the next refit which was due within a few months.

Because of the amount of liquid that had leaked into the cofferdam, it was decided to empty the contents using a portable salvage pump. The cofferdam had been opened on a number of occasions without cause for concern.

The appropriate tank rescue equipment was assembled in the vicinity of the tank lid, in accordance with the company's 'Permit to Work – Entry into Confined Spaces' procedures. Two ratings removed the port aft lid to ventilate the tank, so that the senior first officer could test the atmosphere and complete the Permit to Work. Immediately on lifting the lid, the ratings noticed a strong smell of sewage. They inserted the fan extension hose into the tank and vacated the area.

A short while later, the senior first officer arrived to conduct the routine atmosphere test. While approaching the tank, his multi-gas detector registered an alarm and recorded a hydrogen sulphide (HS) reading of 98 parts per million. The compartment was immediately evacuated and the watertight access doors closed.

The cofferdam lid was re-secured 15 minutes later by a rating wearing full compressed air breathing apparatus.

The ship's senior doctor examined the two ratings who had removed the cofferdam lid, and treated them for exposure to hydrogen sulphide.
They remained fit for duty.

The Lessons

1. Over-exposure to the potentially lethal toxic gases was prevented because the ratings vacated the area immediately after opening the cofferdam lid. The senior first officer fully recognised the dangers, and understood the meaning of the multi-gas detector alarm and reading levels. His direction to fully isolate the compartment stabilised the situation and prevented the possible contamination of other areas.

2. The need to quickly replace the cofferdam lid was recognised, and this was achieved in a controlled, safe manner, making use of the compressed air breathing apparatus to provide safety to personnel.

3. Strict adherence to the company's Permit to Work procedures ensured that all appropriate safety equipment was immediately available, and procedures were followed which reduced the risks associated with this potentially dangerous activity.

4. It is advisable to test the atmosphere on opening tank lids, because potentially lethal levels of H_2S can be released if tank levels are high and the surface is disturbed by the ship's movement. In addition, it is prudent to don breathing apparatus when opening tank lids if the atmosphere in the compartment is unknown.

5. Whenever corrosion or component failure compromises the integrity of sewage systems, every effort should be made to repair the defect as soon as possible to prevent exposure to toxic HS gases. If sewage systems, or compartments suspected of containing sewage, are opened, there will be a danger from the release of H_2S gas. Concentrations as low as 10 parts per million are toxic, as indicated in Marine Guidance Note 33 (M+F). It should also be noted that HS might be released from stagnant bilge areas that contain animal, vegetable or mineral oils which have been mixed with salt water, especially when the surface has been disturbed.

http://www.maib.gov.uk/cms_resources/Safety%20Digest_3_2004.pdf