REPUBLIC OF THE MARSHALL ISLANDS

Office of the Maritime Administrator

ROYAL DIAMOND 7 CASUALTY INVESTIGATION REPORT

Explosion with Fire and Explosion with Loss of Life

17 March 2012 and 24 March 2012

Official Number: 3255

IMO Number: 9367437

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AUTHORITY

An investigation under the authority of 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.

Office of the
Maritime Administrator

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INTRODUCTION

At approximately 1129[1] on 17 March 2012, there was an explosion that was followed by a series of additional explosions and a fire in the Bosun Stores on board ROYAL DIAMOND 7. At the time, the ship was discharging a cargo of Toluene at the New Pir Pau Terminal in Mumbai, India. With assistance from the terminal and local authorities, the ship's crew fought the fire, which remained contained in the forward spaces. The fire was brought under control at approximately 1900, at which time the ship got underway from the terminal and proceeded to the outer anchorage. The ship's crew continued to fight the fire, which was reported extinguished at 2100. The ship anchored in the Mumbai outer anchorage at 0030 on 18 March 2012. Three (3) members of the ship's crew were burned while engaged in firefighting efforts. They were taken ashore for medical treatment; two (2) returned to the ship on 20 March 2012 and the third was repatriated on 07 April 2012 after being discharged from the hospital. The fire and explosion caused structural damage to the forecastle deck and extensive damage in the Bosun Stores; however, there was no breach of the ship's hull or cargo tanks.

ROYAL DIAMOND 7 remained at the outer anchorage until 20 March 2012 and at 1545 shifted to the inner anchorage to facilitate attendance by Classification Society surveyors to conduct damage surveys and attendance by flag and port State representatives to conduct marine safety investigations. On 22 March 2012, shore laborers came on board to remove debris from the Bosun Stores. Technical personnel were also on board to review repairs that would be required before the ship would be allowed to sail; no repair work was started.

Shortly after 1100 on 24 March 2012, there was a single explosion in the bow thruster space. The explosion occurred while the crew was pumping out firefighting water that had accumulated in the space. The Chief Officer, Bosun, and an Ordinary Seaman (OS) received burns and were evacuated for medical treatment onshore. Four (4) shore laborers were also burned and taken ashore for treatment. The Bosun died later that day while being treated in the hospital.

The explosions and fire on 17 March 2012 were the result of Toluene accumulating undetected in the Bosun Stores during cargo discharge operations in the Port of Mumbai. Toluene entered the common line on the starboard cargo manifold through two (2) leaking cargo valves and then migrated to the Bosun Stores through the gas freeing line, which was not isolated from the starboard cargo manifold. The ignition source for the explosions and fire on 17 March 2012 was not identified, although it is likely that it was part of the electrical system.

The explosion that caused the death of the Bosun on 24 March 2012 was the result of Toluene vapors being ignited by the discharge of static electricity when a portable pneumatic pump that was being used to pump out the bow thruster space was moved.

1 All times are local time (UTC +5.5) unless otherwise stated.

FINDINGS OF FACT

The following findings of fact are based on the information available to the Administrator:

Vessel Details

1. Vessel Particulars: see chart to right.

2. ROYAL DIAMOND 7 is a double hull oil / chemical tanker with seven (7) sets of cargo tanks divided port and starboard. Each cargo tank is fitted with a separate submerged cargo and stripping pump. The cargo piping is above deck and there are segregated cargo lines running from each tank to the port and starboard manifolds, which are located amidships. The cargo lines can be connected either individually to the terminal when multiple cargoes are being handled or to a common line using an elbow fitting when a given cargo is carried in more than one (1) cargo tank. There is a spool piece with spectacle flanges in the common line; when necessary, it can be split so that two (2) cargoes loaded in multiple tanks can be handled simultaneously. There is also a stern manifold located starboard side aft, which is connected to the starboard cargo manifold.

3. A gas freeing line extends from the gas free fan, which is located forward in the gas free room that is under the forecastle deck, to the forward end of the starboard cargo manifold common line. The gas freeing line is isolated from the common line by two (2) butterfly valves and a spool piece fitted with a spectacle flange. *See Figure 1*.

Figure 1: Line diagram of gas freeing line connection to the common cargo line and photograph of the spool piece with the spectacle flanges in the "blanked" position. There is a butterfly valve between the spool piece and the gas freeing fan (CO-180) and another butterfly valve between the gas freeing fan and the common line at the starboard cargo manifold (CO-135).

VESSEL PARTICULARS

Vessel Name
ROYAL DIAMOND 7

Registered Owner
GSH2 Chem-Prod Carrier I AS

ISM Ship Management
Dongkuk Marine Co., Ltd.

Flag State
Republic of the Marshall Islands

IMO No. 9367437	**Official No.** 3255
Call Sign V7PL9	**Length** 120.86 meters
Date of Build 2008	**Gross Tonnage** 8,539 MT
Construction Steel	**Persons on Board** 23 *(including three (3) security guards)*

Vessel Type
Oil / Chemical Tanker

Cargo
Ethyl Acetate, Vinyl Acetate Monomer, Paraffin, Toluene, D-Sol, Phenol

Classification Society
Korean Register of Shipping (KRS)

Safety Management System Recognized Organization
American Bureau of Shipping (ABS)

Minimum Safe Manning
16

4. The fan room for the gas freeing system is located on the main deck on the starboard side, aft of the Bosun Stores. The fan is powered by an electric motor located inside the Bosun Stores. The shaft for the fan penetrates the bulkhead separating the fan room from the Bosun Stores. The shaft penetration is fitted with a gas tight gland. The suction, or supply, side of the gas free fan is connected to ducting that runs through the bulkhead in the Bosun Stores to a mushroom vent located on the forecastle deck. There is an air vent for the Bosun Stores in the supply duct for the gas freeing fan. Access to the fan room is through a watertight door in the aft bulkhead leading directly to the main deck. *See Figure 2*.

5. Access to the Bosun Stores is through a deckhouse located on the centerline of the raised forecastle deck. Immediately to starboard of the deckhouse is the mushroom vent that is connected to the suction duct for the gas free fan. A vertical ladder leads down from the Bosun Stores to the bow thruster space. The trunk used to access the bow thruster space opens directly into the Bosun Stores. Electrical equipment in the Bosun Stores includes electrical breaker boxes and electrical motor controllers for the gas free fan motor and the bow thruster. The Bosun Stores is not classified as a hazardous location and the electrical fixtures are not required to be intrinsically safe.[2]

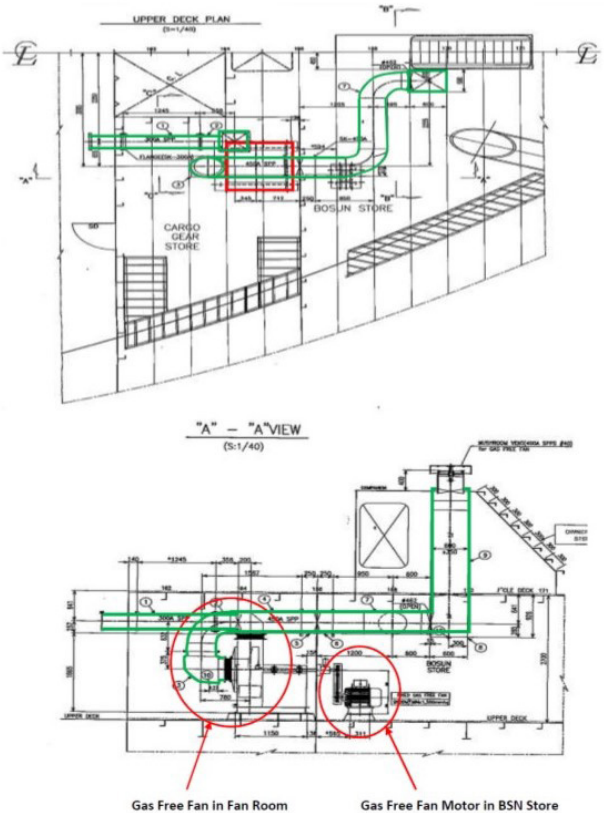

Figure 2: General arrangement of gas freeing fan room and Bosun Stores showing location of the piping for the supply air (green) along with the gas free fan and motor (red circles).

2 Section 10.1.4 of the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) requires that electrical equipment installed in hazardous locations conform to the requirements of the International Electrotechnical Commission (IEC) Standard 60092-502. The IEC Standard also includes guidance for determining whether a space on board a tank ship is a hazardous location.

Change of Management and Crew Details

6. On 21 February 2012, Dongkuk Marine Co., Ltd. ("Dongkuk Marine") assumed management of ROYAL DIAMOND 7 while the ship was loading Toluene and D-Sol in Ulsan, Republic of Korea. The No. 1P and 1S cargo tanks were loaded with ethyl acetate that had been previously loaded in Taizhou, China. Concurrent with the change of management, an American Bureau of Shipping (ABS) surveyor attended the ship to conduct an initial audit to issue the ship an interim International Safety Management (ISM) Certificate.[3] Based on the findings of the audit, in accordance with the International Maritime Organization's (IMO's) ISM Code, ABS issued an interim ISM Certificate that was valid for a period of six (6) months pending full implementation of Dongkuk Marine's Safety Management System (SMS) on board the ship.

7. As of 27 March 2012, Dongkuk Marine was the third party manager for 22 ships. Of these, 14 were chemical tankers, four (4) were chemical / oil tankers, three (3) were liquid petroleum gas carriers, and one (1) was a product tanker.[4]

8. With the exception of the Chief Officer, who had joined the ship on 08 February 2012, there was a total change of crew concurrent with a change of management from Executive Ship Management PTE to Dongkuk Marine on 21 February 2012. All of the officers held Standards of Training, Certification and Watchkeeping (STCW) endorsements for service on oil / chemical tankers; the Bosun and other ratings held STCW endorsements for service on tankers.

9. Prior to joining ROYAL DIAMOND 7, the Master, Chief Officer, Chief Engineer, and Bosun attended a pre-joining session conducted by Dongkuk Marine on 30-31 January 2012. The other officers and ratings attended a training seminar at the manning agency's office with Dongkuk Marine's technical manager on 07-09 February 2012.

10. The Chief Officer joined on 08 February 2012 and was on board for cargo operations conducted in the Chinese ports of Guangzhou and Taizhou while the ship was managed by Executive Ship Management PTE.

11. At the time of the marine casualty, the Master had been sailing for approximately nine (9) years, of which more than five (5) years were on oil / chemical tankers; he had been with Dongkuk Marine for 1.5 years. He received his national Certificate of Competence as Master in May 2009. The Chief Officer had been sailing for slightly less than six (6) years with approximately 4.5 years of experience on oil / chemical tankers; he had less than one (1) year experience with Dongkuk Marine. The Bosun had been sailing for 22 years, all of which was on oil / chemical tankers, and had been with Dongkuk Marine sailing as a Bosun for 13 years.

Voyage from Ulsan and Loading in Taiwan

12. After finishing loading cargo in Ulsan, ROYAL DIAMOND 7 got underway on 21 February 2012 for Taiwan, where the ship was scheduled to load cargo in Kaohsiung and Mailiao.

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3 The interim ISM Certificate was valid through 20 August 2012.

4 Lloyd's List Intelligence (http://www.lloydslistintelligence.com/llint/companies, accessed 27 March 2012).

13. During the voyage from Ulsan to Kaohsiung, the No. 2P cargo tank was dried in preparation for loading vinyl acetate monomer. This was done by connecting the No. 2P cargo line to the common line at the starboard cargo manifold with an elbow fitting, replacing the spectacle flange with the spool piece to connect the fixed gas freeing line to the common line, and opening the valves in the common line and gas freeing line. The tank drying operation required approximately three (3) days to complete. Upon completion, the elbow fitting connecting the No. 2P cargo line to the common line was removed. However, the spool piece was not removed and the isolation valve in the gas freeing line was not closed. It is not known if the butterfly valves on either side of the spectacle flanges (see Figure 1) were closed.

14. ROYAL DIAMOND 7 loaded normal paraffin and phenol in Kaohsiung and vinyl acetate monomer in Mailiao. No incidents were reported during the loading operations.

Arrival in Mumbai, India

15. ROYAL DIAMOND 7 was scheduled to discharge Toluene in Mumbai. The ship's cargo condition on arrival is shown in Table 1.

Port Cargo Tanks			Starboard Cargo Tanks		
Tank	**Cargo**	**Quantity (m^3)**	**Tank**	**Cargo**	**Quantity (m^3)**
1P	Ethyl Acetate	831.859	1S	Ethyl Acetate	826.649
2P	Vinyl Acetate Monomer	1075.042	2S	Normal Paraffin	1046.516
3P	Toluene	1188.235	3S	Toluene	1187.735
4P	Toluene	1166.440	4S	Toluene	1160.818
5P	D-Sol	1184.400	5S	Toluene	1159.353
6P	Toluene	1008.436	6S	Phenol	937.790
7P	Normal Paraffin	329.804	7S	Toluene	318.223

Table 1: Loading Condition on Arrival in Mumbai

16. Based on the Material Safety Data Sheet that was on board ROYAL DIAMOND 7, Toluene is a flammable liquid with a vapor density of 3.2, which is three (3) times heavier than air, and a specific gravity of 0.8718. In addition, it is not soluble in water. The implication is that Toluene vapors will accumulate in low spaces and will float on water without entering into solution. The lower explosive limit (LEL) is 1.27% and the upper explosive limit (UEL) is 7.0%. Toluene has a conductivity of one (1) picosiemens per meter (pS/m) and is classified as a static accumulator.[5]

5 International Chamber of Shipping, Oil Companies International Marine Forum, and International Association of Port and Harbors, International Safety Guide for Oil Tankers and Terminals (ISGOTT), 5th Ed. (Livingston, UK: Witherby Seamanship International, 2006), 55 – 56.

17. On 16 March 2012, a Safety Tool Box meeting was held with the members of the crew who would be involved in cargo operations to review cargo discharge procedures as well as the properties of Toluene.[6] In addition, the Pre-Arrival Checklist for Cargo Operations was completed. Based on a review of the completed Pre-Arrival Checklist, which was signed by the Chief Officer, the cargo related systems, including piping, venting, gas detection, and alarms were found in order.[7] Although it had been reported that the cargo lines and associated systems, i.e., cargo valves, drain lines, and common lines, were pressure tested, it was subsequently determined that they had not been pressure tested by the ship's crew since the change of management. The Ship / Shore Safety Checklist was also completed.[8] Based on a review of this completed checklist, all was in readiness, including that all unused cargo and bunker connections were properly secured with fully bolted blank flanges.[9]

18. ROYAL DIAMOND 7 tendered a Notice of Readiness to discharge cargo at 1020 and arrived at the anchorage off Mumbai at approximately 1115 on 16 March 2012, where the ship anchored while awaiting berthing instructions. While at anchor the crew prepared to discharge using either the port or starboard manifold by connecting the cargo lines for the No. 4P, 4S, 6P, and 7S cargo tanks to the common lines located at the manifolds using elbow fittings.

19. At 1845, ROYAL DIAMOND 7 commenced preparations to shift from the anchorage to the New Pir Pau Terminal pier, where the ship moored port side at 0020 on 17 March 2012.

Cargo Discharge in Mumbai and First Explosion Event

20. At approximately 0040 on 17 March 2012, a representative from the terminal signed the Ship / Shore Safety Checklist that had previously been signed by ROYAL DIAMOND 7's Chief Officer. The facility's cargo arm was connected to the port side common line at 0120 and cargo discharge operations were commenced at 0240. The connections and valve alignment at the port cargo manifold were reported checked by the Bosun before Toluene was discharged. However, neither the Duty Officer nor the Chief Officer personally verified that the connections and the cargo manifold valves were properly lined up. In addition, the Chief Officer did not determine if the elbow fittings connecting the cargo lines for the No. 4P, 4S, 6P, and 7S cargo tanks to the common line at the starboard manifold had been removed or ensured that the spectacle flanges were in place and that the valves in the gas freeing line were closed before cargo discharge was commenced.[10]

21. Starting at 0300, the crew began conducting hourly checks of the ship's mooring arrangements as well as of the cargo hose. Also at 0300, the crew started conducting checks every two (2) hours of the main

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6 The minutes of the Safety Tool Box meeting were documented on Dongkuk Marine Form, No. OS-0205-TB, issued 15 December 2010.

7 Dongkuk Marine Form, No. S-0510-PC.

8 Dongkuk Marine Form, No. S-510-CS, issued 30 March 2010.

9 See item 13 on the completed Ship / Shore Safety Checklist.

10 Section 6.11.8 of the Dongkuk Marine's Quality and Safety Management System (QSMS) (revision date 15 December 2010) manual requires the Chief Officer "to personally check that the correct line up of valves has been made and that all required isolations by spools or spectacles are made, and all draining ports of pump and line are closed, and also vapor lines, valves and vents are correctly set. Vessel's manifold valves should not be opened until the responsible shore staff informs vessel that shore is ready to receive cargo, and until vessel is also ready in every respect."

deck and adjacent spaces, including the deck stores, for the presence of flammable and toxic vapors.[11] No flammable or toxic gases were reported detected when done at 0300, 0500, 0700, 0900, and 1100. The Chief Officer stated that the deck stores included the Bosun Stores. He also reported that the atmosphere in the Bosun Stores was not checked. In addition, starting at 0400, the crew began checking every two (2) hours the readiness of the ship's firefighting equipment as well as the mooring arrangements. The crew also checked to ensure that all doors and ports leading to the accommodations, stores, and machinery spaces were closed.[12]

22. The discharge of the Toluene from cargo tanks No. 4P, 4S, and 6P was completed without incident by 1000 and it was expected that the discharge from cargo tank No. 7S would be completed by approximately 1100.

23. It was reported that the Pilot, who had been ordered for 1200, boarded ROYAL DIAMOND 7 at 1125. He was met at the gangway by the Third Officer, who then escorted him to the bridge. Upon arriving on the bridge, the Master and Pilot conducted a Master / Pilot exchange while the Third Officer conducted preparations for getting underway. The Third Officer stated one (1) steering motor was already running and that he put the radars in standby; he stated that no other equipment, including the bow thruster, was started or tests conducted.

24. Shore side cargo surveyors were reported on deck checking the cargo tanks. It was reported that the surveyors were using Ullage / Temperature Interface (UTI) gauging via the sighting ports located on the top of the cargo domes and that no cargo tank domes or other accesses to the tanks were opened.

25. It was stated that at 1129, there was an explosion in the vicinity of the fan room or Bosun Stores. There was a second explosion, also from the vicinity of the fan room or Bosun Stores, within approximately two (2) to three (3) minutes after the first explosion. The Third Officer reported seeing black smoke coming from the forward part of the ship and that the ship's fire alarm was sounded; it could not be confirmed if it was activated by the Master or automatically by the smoke detectors that were located in the Bosun Stores. The Pilot reported the explosion and fire to the local authorities.

26. The Chief Officer, who was in the cargo control room stripping cargo tank No. 7S, stated he stopped the discharge operation as soon as he heard the explosion. At the time, the Bosun was on the main deck near cargo tank No. 7S assisting with stripping cargo tank No. 7S, an Able Bodied Seaman (AB) was in the vicinity of the cargo manifold, and an OS was on the poop deck making a round of the deck. No other members of the crew or other personnel were on deck.

27. It was reported that at approximately 1134, firefighting operations were started with water spray trained in the vicinity of the Bosun Stores from monitors on shore as well as two (2) tug boats. The Chief Officer

11 Dongkuk Marine Form No. S-0701-C03, issued 1 September 2006.

12 Dongkuk Marine Form No. S-0510-CS, issued 31 March 2010.

stated that at approximately 1135, he ordered the Bosun to disconnect the cargo arm and directed other crew members to start fighting the fire using shipboard systems.

28. It was reported that the fire appeared to subside and three (3) members of the crew started to move forward along the ship's starboard side with a charged fire hose to apply cooling water. These crewmembers were not wearing firefighter's outfits. When they were approximately 7 to 8 m aft of the fan room, there was a third explosion inside the Bosun Stores and fire was reported observed breaking out inside the fan room. This was at approximately 1145. Two (2) ABs and an Oiler were reported injured when the explosion occurred; they were taken by ambulance to a hospital onshore for treatment.

29. The ship's crew, along with assistance from shore side firefighters, continued to fight the fire from on board as well as from on shore. As the fire was brought under control, a detailed damage assessment was conducted. The assessment included sounding all ballast tanks, as well as checking the ullage, temperature, and pressure in the cargo tanks. Gas checks were also conducted. It was reported that no apparent damage to the hull or integrity of the cargo and ballast tanks was detected.

30. At approximately 1900, the fire was reported under control and the local authorities ordered ROYAL DIAMOND 7 to proceed to the outer anchorage. The ship was proceeding to the outer anchorage under its own power at 1905. The crew continued to fight the fire; it was reported extinguished by 2100. When the ship reached the pilot station, the Pilot disembarked and ROYAL DIAMOND 7 continued to proceed to the outer anchorage, where the ship anchored at 0030 on 18 March 2012.

Consequences of the First Explosions and Fire Event

31. In addition to the seafarers who were injured during firefighting, the survey conducted after the first explosions and resulting fire identified the following damage:

    a. Hull: the paint on both the port and starboard sides of the forecastle bulkhead in way of the Bosun Stores was burnt.

    b. Forecastle deck: areas of the deck plating were deformed; the framing for the booby hatch was deformed and the hatch cover was lifted from the hatch coaming; the watertight door and frame leading to the Bosun Stores were deformed; and, the mushroom vents for the fan used to ventilate the bow thruster space and for the suction line supplying the gas freeing fan were deformed.

    c. Gas freeing room: sections of the deck and bulkheads were deformed; paint throughout the space was burnt; watertight door leading to the main deck was deformed; and, the light outside the entrance was burnt.

    d. Paint room[13]: paint coating throughout the space was damaged by heat; and, the joint on the hydraulic return line from the bow thruster space was broken.

13 The paint room is located on the ship's port side and is accessed via a watertight door leading to the main deck. The paint room's forward and inboard bulkheads are common with the Bosun Stores.

e. Bosun Stores: the deck, bulkheads, and stiffeners throughout the space were deformed; paint throughout the space was burnt; electrical control boxes, wiring, and light fixtures throughout the space were completely burnt; the motor for the gas freeing fan, the compressor that supplied compressed air to the deck, and the fan for the bow thruster space were completely burnt; and, the fire detection sensor and wiring were completely burnt. In addition, the contents of the Bosun Stores, e.g., fire extinguishers, mooring lines, etc., were destroyed or heavily burnt.

f. Bow thruster space: filled with firefighting water and foam and was not entered. The railing and grated cover for the entrance to the space from the Bosun Stores were destroyed.

Operations Onboard Post the First Explosions and Fire Event and the Second Explosion Event

32. Sometime after anchoring, the ship's crew, in coordination with Dongkuk Marine's Emergency Response Team, began work to identify and remove any post-fire hazards in preparation for conducting required repairs. Safety measures that were taken included: conducting a safety meeting for the entire crew where the need to follow safety procedures from the QSMS was emphasized; a risk assessment was conducted before each job; electrical connections to the deck and forward spaces were disconnected; and, firefighting equipment was kept ready for immediate use.

33. Initial work that was conducted included removing all elbow fittings connected to the common lines at the port and starboard cargo manifolds, as well as removing the spool piece from the gas freeing line and replacing it with the spectacle flange. As previously stated, the elbow fittings connecting the cargo lines for cargo tanks No. 4P, 4S, 6P, and 7S to the common line at the starboard cargo manifold were still in place. As this was done, the valves in the cargo lines for cargo tanks No. 4P, 4S, 6P, and 7S were found closed. However, there was evidence that the valves for both the 4P and 7S cargo lines were leaking. In addition, both the valve between the common line and the gas freeing line and the valve between the spool piece and the gas freeing fan were open. *See Figure 1*.

34. It was reported that when the spool piece in the gas free line was removed and replaced with the spectacle flange, approximately 200 liters (L) of Toluene was drained from the gas freeing line. Subsequently, 20 L of Toluene was drained from the drain cock located at the bottom of the housing for the gas freeing fan. The gas freeing line was then flushed with seawater and gas freed before the spectacle flange was installed.

35. The bow thruster space and trunking was flooded with a mixture of firefighting water and foam up to the deck of the Bosun Stores; the level of water and foam in the Bosun Stores was up to the sill on the watertight doors. The crew was reported to use a pneumatic pump to transfer the firefighting water and foam that was in the bow thruster space and Bosun Stores to the forepeak tank. In addition, the space was ventilated using a water driven fan. Throughout the operation, the concentration of toxic and flammable gas as well as oxygen in the space was monitored. On 20 March 2012, the reported

atmospheric concentration of Toluene in the Bosun Stores was in excess of 500 parts per million (ppm).[14] In addition, the water being pumped from the bow thruster space was reported to smell like Toluene.

36. On 20 March 2013, ROYAL DIAMOND 7 was shifted to the inner anchorage in preparation for conducting temporary repairs. The ship was reported to anchor at approximately 1545.

37. Workers boarded the ship on 22 March 2012 to assist the crew with cleaning the Bosun Stores. The workers were scheduled to remain on board while this work was being performed. No cleanup work was reported performed that day.

38. Cleaning of the Bosun Stores commenced on 23 March 2012 by members of ROYAL DIAMOND 7's crew and shore workers. Based on the ship's records, before work started, the atmosphere inside the Bosun Stores was tested at 0800 for oxygen and toxic gases by the Chief Officer; the oxygen level was 20.9% by volume and the toxic gas level was 1 ppm. It was not recorded whether the atmosphere was tested for flammable gases. In addition, the Checklist for Entry into Enclosed Spaces was completed[15] and a Permit for Cold Work was issued.[16] Both were reviewed and signed by the Master. In addition, a Safety Tool Box meeting was held; the minutes of the meeting were signed by members of the ship's crew but not the shore workers. It was reported that the shore workers were given a safety briefing. Lighting was provided by portable electric lights that, according to the Chief Engineer, appeared to be explosion proof. Work performed during the day consisted of removing debris from the Bosun Stores and beginning to clean soot and burnt paint off surfaces. It was reported that no tools were used to perform this work.

39. Although a risk assessment was prepared, it did not address potential hazards associated with the presence of Toluene in the bow thruster trunk. This would have included Toluene vapors, as well as Toluene on top of the firefighting water that had filled the space on 17 March 2012. The oxygen level inside the Bosun Stores was checked every two (2) hours throughout the day and was consistently determined to be 20.9% by volume. According to the Master, Toluene vapors were highest around mid-day and were almost not detectable early in the morning and evening; however, there is no record that the vapor concentration was measured or recorded.

40. The removal of debris and cleaning of burnt surfaces resumed on the morning of 24 March 2012. Before work started, the Checklist for Entry into Enclosed Spaces was completed, a Permit for Cold Work was issued, and a Safety Tool Box meeting was held. A risk assessment was also conducted but, again, it did not address potential hazards associated with Toluene in the firefighting water that had flooded the bow thruster trunk. The recorded oxygen level in the Bosun Stores was 20.9% by volume at 0800 and again at 1000. The concentration of flammable gases was not recorded. In addition to removing debris and cleaning, the crew began to transfer approximately 55 to 60 cubic meters (m^3) of firefighting

14 500 ppm is equivalent to 0.05%, which is below the LEL of Toluene.

15 Dongkuk Marine Form No. S-0508-CE, issued 31 July 2011.

16 Dongkuk Marine Form No. S-0508-CL, issued 1 Dec 2004.

water from the bow thruster trunk into the forepeak tank. This was accomplished by lowering a pneumatic powered Wilden pump with a rope from the deck of the Bosun Stores down into the bow thruster trunk and then running the discharge hose to an open manhole cover for the forepeak tank. It was reported that the pneumatic pump was not grounded[17] while suspended inside the bow thruster trunk. Samples of the water from the bow thruster trunk had been taken to a laboratory for analysis but the results had not been reported to the Master before the crew began to transfer the water to the forepeak tank.

41. Sometime after 1100 on 24 March 2012, the Bosun reported to the Chief Officer that the pneumatic pump was not taking suction. The Bosun then proceeded forward with an OS to check the pump; the Chief Officer also went forward. The Bosun entered the Bosun Stores and began to pull the pump up out of the bow thruster trunk. Several shore workers were inside the Bosun Stores. The Chief Officer and OS were on the forecastle deck next to the open deck hatch where they could see into the Bosun Stores. It was reported that the Bosun began to shake the pump by repeatedly moving the rope that was used to suspend it up and down. At approximately 1125 on 24 March 2012, there was an explosion and flash fire that reportedly originated in the bow thruster trunk.

42. Upon hearing the explosion, the Master immediately sounded the fire alarm and announced that there was an explosion in the forward area of the ship. The crew mustered and proceeded forward to fight any fire. When they went forward they reported that there was some smoke in the Bosun Stores but no fire. The atmosphere was tested and no flammable gas detected (0.0% LEL).

Consequences of Second Explosion Event

43. The Bosun, who was tending the rope that was made up to the pneumatic pump, suffered severe burns on the front of his body. Four (4) of the shore laborers, working in the Bosun Stores at the time, suffered burns. The Chief Officer, who had been standing next to the open deck hatch on the forecastle deck, received burns on his face and arms. The OS suffered extensive burns on his face and body.

44. Immediately after the explosion, the Bosun climbed out of the Bosun Stores using a portable ladder to reach the forecastle deck. Upon reaching the deck he stripped off his coveralls, which were observed to be on fire. He then walked aft on the catwalk and sat down outside the accommodation block, where he was attended by the ship's Third Officer. It was observed that the Bosun's skin had turned black. The crew members and shore workers who were burned also came aft and were provided first aid. Concurrently, the Master made arrangements for all of the injured persons to be transferred ashore for treatment and within an hour they had been disembarked onto the pilot boat. They were subsequently transferred to a police boat for transport to waiting ambulances and were taken to the hospital for treatment.

17 In accordance with Wilden's instructions, the pump is required to be grounded when handling flammable liquids or when the discharge of static electricity is a danger.

45. The Bosun died on 24 March 2012 while being treated in the hospital. Both the Chief Officer and OS were admitted to the hospital and subsequently repatriated. The details regarding whether any of the shore workers were hospitalized were not made known to the Administrator.

46. No additional damage to the ship or pollution was reported as a result of the second explosion event.

Post Explosion Cleaning Operations and Repairs

47. Following the explosion on 24 March 2012, the ship was ordered to shift to the outer anchorage. In addition, all cleaning operations were stopped until the ship was attended by a marine chemist to monitor the space and a detailed plan was developed for pumping out the bow thruster trunk, which had been determined to contain Toluene.

48. After receiving permission from the port authorities on 05 April 2012, the ship's staff, assisted by shore side technical experts, began to gas free the Bosun Stores and to transfer the water from the bow thruster space to the No. 4 wing tanks. This was completed on 06 April 2012, and on 07 April 2012 the Bosun Stores were gas freed. After the port authorities confirmed that the Bosun Stores were gas freed, the ship was permitted to shift to the inner anchorage on 09 April 2012 in order to complete temporary repairs. Following the completion of the temporary repairs and survey by the ship's Classification Society on 19 April 2012, the flag State approved the issuance for short-term certificates so that the ship could proceed to Dubai, United Arab Emirates, with intermediate port calls to discharge her cargo, for permanent repairs.

Crew Work Rest Hours

49. Based on the ship's record of rest hours in the 24 hour period prior to the first explosion on 17 March 2012, the Chief Officer had a total of 10 hours of rest. However, it was divided into three (3) periods, two (2) of which were four (4) hours long and one (1) that was two (2) hours long. He had more than 77 hours rest in the seven (7) days prior to the first explosion. The Chief Officer reported that he went to his cabin to sleep between approximately 0430 and 0900 on 17 March 2012 but he was not able to sleep. During the 24 hour period prior to the second explosion on 24 March 2012, the Chief Officer had 14 hours of rest, 13 of which were in a continuous period. He had also had more than 77 hours of rest in the seven (7) days prior to the second explosion.

50. The Bosun had 15 hours of rest in the 24 hour period prior to the first explosion on 17 March 2012. His rest was divided into three (3) periods, one (1) of which was seven (7) hours long, one (1) was six (6) hours long, and one (1) was one (2) hours long. He had more than 77 hours of rest in the seven (7) days before the first explosion. During the 24 hours before the second explosion on 24 March 2012, the Bosun had 16 hours of rest, 15 of which were in one (1) continuous period, and more than 77 hours of rest in the preceding seven (7) days.

ANALYSIS

The purpose of the analysis is to identify the causes of this very serious marine casualty.

Bosun Stores

In accordance with Section 10.1.4 of the IBC Code (IMO Resolution MSC.225(64)), spaces that may contain a hazardous atmosphere are to be designated as a hazardous location following the guidance in the IEC Standard 60092-502 – Electrical installations in ships – Tankers – Special features. When determining whether a space should be classified as a hazardous location, it is necessary to determine whether the space contains any potential sources of release. Some examples of potential sources of release that are listed in Table 1 of IEC Standard 60092-502 include: venting and other openings to cargo tanks and cargo piping, as well as "seals of valves and flanges and other connections and pipe fittings."

Section 3.2.2 of the IBC Code requires that "to guard against the danger of hazardous [vapors], due consideration shall be given to the location of air intakes and openings into accommodation, service and machinery spaces and control stations in relation to cargo piping and cargo vent systems."[18] As stated previously, there was an opening, i.e., an air vent, from the supply duct for the gas freeing fan into the Bosun Stores. This air vent was a potential source of release[19] of hazardous vapors into the Bosun Stores when the spool piece connecting the gas freeing line to the common cargo line *(see Figure 1)* was in place. Although not likely during normal operations, the presence of Toluene in the Bosun Stores demonstrated that cargo vapors could enter this space.[20]

It is possible that the initial fire and explosion could have been prevented if the Bosun Stores had been classified as a hazardous location and fitted with appropriate electrical equipment per Section 10.1.4 of the IBC Code. It is noted that the United Kingdom Marine Accident Investigation Branch (UKMAIB) made essentially this same point based on their marine safety investigation of a fire and explosion on board the BORDER HEATHER.[21] Similarly, it could likely have been prevented if the supply duct for the gas freeing line was constructed of continuous fully welded pipes and not fitted with an air vent in the Bosun Stores.[22]

First Explosion and Fire Event

The damage that was identified on the forecastle deck and forward spaces after the explosions and fire that occurred while Toluene was being discharged on 17 March 2012 indicates that the explosions and resulting fire originated in the Bosun Stores or bow thruster space. Although it is possible that the first explosion might have occurred in the gas freeing room, it is thought unlikely as there would have been more damage inside that space.

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18 This requirement is incorporated into the applicable Korean Register of Shipping (KRS) rules for tankers carrying dangerous chemicals in bulk. See KRS, Rules of the Classification of Steel Ships, Part 7, Chapter 6, Section 302.2.

19 See Section 4.1.4 of IEC Standard 60092-502 regarding sources of release.

20 See first explosion and fire event analysis.

21 UKMAIB, "Report on the investigation of explosion and fire on Border Heather in Grangemout, Firth of Forth, Scotland 31 October 2004." The UKMAIB report included a recommendation that the International Association of Classification Societies (IACS) develop a Unified Interpretation that any space associated with or containing piping that can be connected to a tanker's cargo system be considered as a dangerous space, i.e., hazardous location. It is noted that IACS did not adopt such a Unified Interpretation. See IACS, Interpretations of the IMO IBC Code and the IBC Code (2011).

22 See IEC Standard 60092-502, paragraph 4.1.4.2.

Fuel Source

ROYAL DIAMOND 7 commenced discharging Toluene via the port side cargo manifold at approximately 0240 on 17 March 2012. Based on the information available through crew interviews and examination of the ship's cargo piping, it was determined that the elbow fittings connecting the cargo lines for cargo tanks No. 4P, 4S, 6P, and 7S to the common line at the starboard cargo manifold were in place. All four (4) of these tanks had previously been loaded with Toluene and were discharged in Mumbai on 17 March 2012. It was also determined that the starboard cargo manifold valves for both the No. 4P and 7S cargo lines were leaking. It was also determined that the valve between the common line and the gas freeing line, and the valve between the spool piece and the gas freeing fan were both open. *See Figure 1*. It was, therefore, possible for Toluene to flow undetected from the No. 4P and 7S cargo lines via the common line to the gas freeing line. Once in the gas freeing line, the Toluene and Toluene vapors could flow, again undetected, forward to the gas freeing fan and its associated ducting. *See Figure 2*.

How much Toluene entered the gas freeing line was not determined. However, it is noted that approximately 200 L of Toluene was drained from the gas freeing line and 20 L was drained from the gas freeing fan after the first explosion and subsequent fire. Given that some Toluene would have been consumed in the fire and that the firefighting water that accumulated in the bow thruster space contained Toluene, this indicates the total volume that had entered the gas freeing line was significant. Toluene, either as a liquid or a vapor, could enter the Bosun Stores through the vent fitted in the air duct on the suction side of the gas freeing fan. The conclusion that a sufficient quantity of Toluene, either as a liquid or a vapor, entered the Bosun Stores to provide a fuel source for the explosions and subsequent fire is supported by the observed damage.

Based on the fact that Toluene is approximately three (3) times heavier than air, concentrations of Toluene vapors would have been heaviest near the deck of the Bosun Stores, where pockets of liquid Toluene could also have collected. Some Toluene would also have likely flowed down into the bow thruster space. It is not known how much Toluene, either as a liquid or vapor, entered the Bosun Stores. Also, not known is how high above the deck the concentration of Toluene vapors was between the UEL and LEL.

Ignition Source

Identifying the ignition source for the initial explosion and subsequent fire cannot be determined with certainty. It is known that there was a light fixture with a broken cover. As a result, vapors could potentially come in contact with the fluorescent tube and the associated electrical contacts. However, it is noted that this fixture was located on the overhead, where, given that the density of Toluene vapors is 3.2, the concentrations would most likely have been lowest.

Although it was noted that the Third Officer denied that the bow thruster had been energized as part of the preparations for getting underway, it is noted that the electrical motor control box for the bow thruster was more heavily damaged than any of the other electrical control boxes located in the Bosun Stores. This damage included evidence that the door had been blown open, indicating that it had been subjected to internal pressure; in contrast, the doors on the other electrical control boxes were found closed. However, it is also noted that one (1) side of the box was pushed inward, indicating it was exposed to external pressure. This may also have caused the door

to open. Lastly, it must be remembered that the Bosun Stores is not classified as a hazardous area and that none of the electrical equipment in this space is suitable for use in a potentially explosive atmosphere. Therefore, any electrical system in the Bosun Stores had the potential to be the ignition source.

Static electricity is another potential ignition source. Five (5) conditions must exist for static electricity to ignite a flammable gas or liquid:

1. there must be an effective means of static charge generation;
2. there must be a means of accumulating and maintaining a charge of sufficient electric potential;
3. there must be a static electricity discharge of sufficient energy;
4. there must be a fuel source at a concentration within its LEL and UEL with a minimum ignition energy less than the energy of the static discharge; and,
5. the static arc and fuel source must occur in the same place and at the same time.[23]

Toluene is a static accumulator and can accumulate static charge by flow or agitation. Therefore, Toluene spilling onto the deck from the air vent or coming in contact with contaminants, e.g., dust, rust scales, etc., would be expected to accumulate a static charge. The ignition energy of Toluene is 0.24 micro Jules (mJ),[24] which is typically considered to be low. Although it is likely that the Toluene in the Bosun Stores was accumulating some quantity of static charge, based on the information available it is not known how much charge was developed or whether any discharges that may have occurred[25] were in a concentration of Toluene vapors that was within the explosive limits.

Whilst static electricity cannot be eliminated, based on the information that is available, the most likely ignition source was an electrical system.[26]

Cleanup Operations Between Explosion Events

Prior to starting cleanup operations, all of the electrical circuits to the forward spaces were disconnected to remove electricity as a potential ignition source. In addition, the crew isolated the gas freeing line from the cargo lines by removing the spectacle flange and draining the remaining Toluene from the gas freeing line and the housing of the gas freeing fan. The gas freeing line was then flushed with water and gas freed. After determining that the Bosun Stores were safe to enter based on the oxygen level inside, a Permit for Cold Work was issued and third party contractors, along with members of the ship's crew, began to remove debris from the space and to pump out the water in the bow thruster space.

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23 National Fire Protection Association (NFPA) 921: Guide for Fire and Explosion Investigations, 1995 Ed., section 14-8.6.

24 Chen, Jyh-Yuan, McAllister, Sara, Fernandez-Pello, A. Carlos: Fundamentals of Combustion Processes, (New York: Springer, 2011), p. 289. For comparison the ignition energy of methane is 0.28 mJ and for gasoline 0.8 mJ.

25 See ISGOTT, pp. 54-55 for a discussion of the types of discharges that could have potentially occurred.

26 It is noted that identifying static electricity as the ignition source often requires eliminating other plausible sources of ignition. See NFPA 921, section 14-8.7.

It is noted that although the oxygen level in the Bosun Stores was monitored on a regular basis on 23-24 March 2012, the concentration of flammable vapors was not monitored. However, it is also noted that the atmosphere in the bow thruster space was not tested to determine if Toluene vapors were present. In addition, the firefighting water that had accumulated in the bow thruster space was not tested to determine if it contained Toluene, although the crew reported that the water pumped from the space on 20 March 2012 smelled like Toluene. Lastly, it is noted that the pneumatic pump that was being used to dewater the bow thruster space was not grounded. This indicates a lack of awareness regarding the potential for Toluene to have accumulated in the bow thruster space and the corresponding risks.

Second Explosion Event

Based on the eyewitness report of the Chief Officer and OS who were standing on the forecastle deck watching the Bosun when the second explosion event occurred, the explosion originated in the immediate vicinity of the pneumatic pump that was being used to dewater the bow thruster space.

Fuel Source

Although it was not confirmed by testing until after the second explosion event, the firefighting water that had accumulated in the bow thruster space was contaminated with Toluene. It is likely that some Toluene entered this space before the fire and explosion that occurred on 17 March 2012 and that additional Toluene was washed down into the bow thruster space as firefighting water was applied during the subsequent response. It is also noted that the ship's crew reported that the firefighting water that was pumped out of the bow thruster space before the second explosion event smelled like Toluene.

Based on the fact that Toluene has a vapor density of 3.2 and a specific gravity of 0.8718, it is likely that there was a layer of Toluene vapors in the bow thruster space immediately on top of the firefighting water. The concentration of vapors would have been near 100% Toluene at the interface of this layer and the firefighting water and would have decreased as the distance from the firefighting water increased. At some distance, there would have been a layer where the concentration of vapors would have been between the LEL and UEL, i.e., an explosive layer. Based on the information available, it cannot be determined how high above the firefighting water this was or how thick the explosive layer was. However, based on the fact that there was not a post-explosion fire, it is likely the explosion was ignited at a point where the concentration of Toluene vapors was at or near the LEL, where the ratio of air and fuel was less than optimum.[27]

Although the Bosun Stores was ventilated, the Bosun Stores and bow thruster space were not determined to be gas free before cleanup work started on 23 March 2012. The atmosphere in these spaces was tested to determine if there was sufficient oxygen for entry and to determine the level of toxic fumes that may have been present. However, there is no indication the levels of Toluene vapors were determined. Even though ship management and ship's staff were aware that firefighting water pumped from the space after the first explosion and fire smelled like Toluene, it appears it was not recognized that Toluene could still be present in

27 NFPA 921, section 13-8.2.1

the space. This is supported by the fact that the risk assessment conducted before the cleanup work started on 23 March 2012 did not address the presence of Toluene.

Ignition Source

Based on the information available, electricity or open flame can be ruled out as the ignition source for the second explosion event. As stated above, there are five (5) conditions that must exist for static electricity to ignite a gas or liquid. The flow of the water and Toluene through the pneumatic pump and the discharge hose would have generated a static charge. Because the pump was not grounded, i.e., bonded, the generated charge would have been accumulated by the Toluene. The movement of the pump would have disturbed the layer of Toluene vapors and discharged the accumulated static charge. Because Toluene vapors had accumulated in the bow thruster space, there would have been a layer where the vapor concentration was between the LEL and UEL. Although it is not known how high above the surface of the firefighting water the layer where the concentration of Toluene vapors was between the LEL and UEL, the discharge hose would have passed through this layer. Similarly, the Bosun may have pulled the pneumatic pump up into the explosive layer. Based on the description of the explosion, the discharge of static electricity most likely occurred within the layer of Toluene vapors where the concentration was at or near the LEL.[28]

Ship Management

Dongkuk Marine had experience managing chemical tankers and their QSMS included measures intended to ensure that cargoes, including Toluene, could be handled safely. Based on a review of the applicable QSMS procedures, if they were followed, Toluene would not have been able to accumulate undetected in the gas freeing line. However, based on how the cleanup operations on board were carried out following the first explosion, it is not clear that ship management's risk assessment procedures were sufficient to ensure response and cleanup operations could be conducted safely. Evidence of this is that the Bosun Stores and bow thruster space were not gas freed before cleanup operations started, even though it was reported that firefighting water pumped from the space smelled like Toluene.

It is noted that Dongkuk Marine's Emergency Response Team was activated and that the superintendent attended ROYAL DIAMOND 7 following the first explosion and fire. However, based on the information available, it appears that ship management did not assess the competence of the Master, Chief Officer, and Bosun to effectively and safely conduct cleanup operations, particularly after determining why Toluene was in the gas freeing line.

Crew

ROYAL DIAMOND 7 was manned in accordance with the Minimum Safe Manning Certificate and the involved crew members were experienced in the operation of oil and chemical tankers and had recently participated in a briefing conducted by Dongkuk Marine prior to signing on board ROYAL DIAMOND 7.

During the voyage from Ulsan to Kaohsiung, the No. 2P cargo tank had been dried in preparation for loading vinyl acetate monomer, which required connecting the gas freeing line to the cargo piping. As the senior ship's

28 NFPA 921, section 13-8.2.1

officer responsible for operations on the cargo deck, the Chief Officer should have been aware that the gas freeing line was not isolated from the cargo piping after the tank drying operations were completed. It is noted that this was not corrected when the ship loaded cargo in Kaohsiung. Although the Chief Officer had served on board ships managed by Dongkuk Marine for less than one (1) year, the principles of tanker safety, including isolating gas freeing lines from cargo lines when not in use, are the same throughout the shipping industry. Similarly, the Bosun, as the senior deck rating, as well as the other deck officers and rating who may have been involved in the loading operation in Kaohsiung, should also have been aware that the gas free line was connected to the cargo piping and brought this to the Chief Officer's attention. This is an indication that both the Chief Officer and the Bosun, who both were becoming familiar with ROYAL DIAMOND 7, were not making full use of the procedures in Dongkuk Marine's QSMS and were overly relying on their experience to ensure that critical tasks were performed. This is also an indication of a risk that exists following a change in management and the initial implementation of a SMS on board a ship – even when the SMS itself might be well established.

Based on their experience, both the Chief Officer and Bosun should have been familiar with the need to ground a portable Wilden pump being used to pump water that was known or suspected to contain flammable liquids or when the discharge of static electricity was a hazard. It is also noted that neither the ship's Master, the attending ship's superintendent, nor Dongkok Marine's QSMS, directed the Chief Officer to ensure that the pump was grounded. Similarly, it is noted that Dongkok Marine's QSMS did not address grounding portable pumps when discharging spaces contaminated with an explosive cargo such as Toluene.

The work/rest hour records for the Chief Officer and Bosun indicate that they had sufficient rest prior to starting cargo operations in Mumbai on 17 March 2014, although the rest periods for both during the previous 24 hours had been divided into three (3) periods rather than two (2) periods as required. None of the Chief Officer's three (3) rest periods were more than four (4) hours long. It is also noted that the Chief Officer reported he was not able to sleep between approximately 0430 and 0900 on 17 March 2012. It is noted that during the 15 hour period prior to when ROYAL DIAMOND 7 arrived at the outer anchorage and started to discharge cargo, the ship's crew prepared for cargo discharge operations, as well as weighed anchor, made the several hour transit from anchorage to berth, moored, and made final preparations for cargo operations. Both the Chief Officer and Bosun were involved in various aspects of all of these operations. Therefore, it is likely that both the Chief Officer and Bosun were experiencing some degree of fatigue prior to commencing cargo operations on 17 March 2012.

Both the Chief Officer and Bosun had sufficient rest during the days prior to the second explosion and the resulting death of the Bosun. Although both the Chief Officer and Bosun were technically rested, it is probable that they were experiencing some degree of fatigue due to stress associated with the first explosion and fire, as well as pressure to complete the cleanup of the Bosun Stores in preparation for temporary repairs and attendance by representatives of ship management, Classification Society surveyors, port and flag State investigators, etc.

CONCLUSIONS

The following conclusions regarding the causes of this very serious marine casualty are based on the above findings of fact and analysis:

1. The immediate cause of the first explosion and fire on 17 March 2012 was that Toluene vapors that had accumulated in the Bosun Stores were ignited when they came in contact with charged electrical equipment. Although the specific electrical system or component that was the ignition source cannot be identified, it is noted that the electrical equipment in this space is not suitable for use in an explosive atmosphere.

2. Toluene accumulated in the Bosun Stores without the knowledge of the ship's crew due to a number of factors:

    a. neither the Duty Officer nor the Chief Officer ensured that the spool piece had been removed, that the spectacle flanges fitted, and that the valves in the gas freeing line were closed after tank drying operations were completed during the voyage from Ulsan to Kaohsiung;

    b. the Chief Officer did not supervise setting up the cargo lines before cargo discharge was commenced as required by Dongkuk Marine's QSMS;

    c. the starboard cargo manifold valves for both the No. 4P and 7S cargo lines were leaking;

    d. neither the Duty Officer nor the Chief Officer determined if the elbow fittings connecting the cargo lines for the No. 4P, 4S, 6P, and 7S cargo tanks to the common line at the starboard manifold, which had been put in place before it was known whether the ship would moor port or starboard side alongside, were removed prior to discharging cargo as required by Dongkuk Marine's QSMS; and,

    e. the atmosphere in the Bosun Stores was not checked during cargo operations on 17 March 2012 as required by Dongkuk Marine's QSMS.

3. The immediate cause of the injuries to the crew members who were part of the fire team assigned to conduct boundary cooling was that they were not protected from the hot gases produced by the secondary explosion due to the fact that they were not wearing firefighter's suits. It is noted that their faces were the most heavily burned, which indicates that a flash hood or similar protective equipment would have been needed to provide suitable protection from the hot gases. An additional immediate cause was that they were improperly located, i.e., they were too close to the boundary being cooled.

4. The likely immediate cause of the explosion on 24 March 2012 was that the Wilden pump being used to discharge the bow thruster space was not grounded as required, causing the accumulation of static electricity. This static electricity was then discharged when the Bosun was moving the pump, causing the ignition of the Toluene vapors that had collected in the bow thruster space above the firefighting water.

5. Because Toluene vapors are three (3) times heavier than air, it is likely that some Toluene collected in the bow thruster space before the first explosion and fire on 17 March 2012. Additional Toluene likely entered the bow thruster space as it filled with firefighting water. Neither Dongkuk Marine nor the Master or Chief Officer apparently recognized the potential that Toluene may have collected in the bow thruster space and as a result did not ensure the associated risks were appropriately addressed. It was only after the explosion on 24 March 2012 that the firefighting water was tested for the presence of Toluene.

6. The likely cause of the Bosun's death was direct exposure to the hot gases produced by the second explosion.

ACTIONS TAKEN

Based on their review of this very serious marine casualty, Dongkuk Marine took a number of actions addressing the following:

1. measures intended to improve the safety culture on board the Company's managed ships;
2. a comprehensive review and revision of the Company's QSMS;
3. measures to improve verification of onboard implementation of the QSMS, including senior management visits to ships in the Company's managed fleet and increased external third party audits;
4. enhancing training for sea staff, including changes to pre-joining briefings; and,
5. enhancing training for shore staff.

The Administrator concurs with these actions.

RECOMMENDATIONS

The following Recommendations are based on the above conclusions, and in consideration of the Corrective Actions taken by Dongkuk Marine:

1. That the Administrator advise all ship owners and managers of RMI registered chemical tankers to inspect the supply line for their ship's gas freeing system to determine if there are any openings into accommodation, service and machinery spaces, and control stations. If any openings are found, they should, in consultation with the ship's Classification Society, refit the supply duct so that there is a gastight boundary between the supply duct and the space in which the duct is located.

2. That KRS submit a proposal to IACS to adopt a Unified Interpretation of Section 3.2.2 of the IBC Code to ensure that there is a gastight boundary between any piping that can be connected to the ship's cargo system and any space through which it passes.[29]

The Administrator's investigation into this incident is closed. It will be reopened if additional information is received that would warrant further review.

29 See IEC Standard 60092-502, section 4.1.4.