Report on the investigation of

the starboard boiler explosion resulting in

one fatal and one serious injury on board the

Liquid Natural Gas tanker

Hilli

Grand Bahama Shipyard

Freeport, Grand Bahama

10 October 2003

Marine Accident Investigation Branch
Carlton House
Carlton Place
Southampton
United Kingdom
SO15 2DZ

Report No 4/2007
March 2007

Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2005 – Regulation 5:

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2005 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 13(9) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2005, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

BACS	-	British Association for Chemical Specialities
CIA	-	Chemical Industries Association
cm	-	centimetre
COSWP	-	Code of Safe Working Practices
DNV	-	Det Norske Veritas (Classification Society)
ECR	-	Engine Control Room
GBSL	-	Grand Bahama Shipyard Limited
HEL	-	Higher Explosive Limit
HPML	-	Harris Pye Marine Limited
HSE	-	Health and Safety Executive
IMO	-	International Maritime Organization
ISM Code	-	International Safety Management Code
ISO	-	International Standards Organisation
LEL	-	Lower Explosive Limit
LNG	-	Liquefied Natural Gas
m	-	metre
MSDS	-	Material Safety Data Sheets
P&I Club	-	Protection and Indemnity Club (insurance)
PDS	-	Product Data Sheets
shp	-	shaft horsepower
UEL	-	Upper Explosives Limit

Downcomers	-	Large bore pipes, external to the boiler furnace.
Emergent work	-	Work that is required to be undertaken which is only identified as a result of planned work, i.e. pipes that need replacing which have been found to be corroded following removal to provide access to other equipment/systems.
Flame Out	-	The unintentional extinguishing of a boiler burner flame. This can be caused by mal-operation, water in the fuel or incorrect air/fuel ratios.
Hot work	-	An activity involving riveting, welding, burning, the use of power actuated tools or similar fire-producing operations. Grinding, drilling, abrasive blasting or similar spark-producing operations are also considered as hot work.
Lower Explosive Limit	-	Also known as the Lower Flammable Limit, it is the minimum concentration of a flammable vapour in air, below which propagation of flame does not occur in the presence of an ignition source.
pH	-	The symbol represents the *potential for hydrogen.* It is the measure of the acidity or alkalinity of a solution: 7 represents neutrality, higher numbers indicate increasing alkalinity, lower numbers indicate increasing acidity.
Quarl	-	An area of formed brickwork or refractory that is concentric to a boiler combustion burner. Its purpose is to help form an airflow to constrain the burner flame profile.
Upper Explosive Limit	-	Also known as the Upper Flammable Limit, it is the maximum concentration of a flammable vapour in air, above which propagation of flame does not occur in the presence of an ignition source.
Windbox	-	The space between the outer and inner air casings of a boiler that allows air, under pressure, to be delivered to the combustion burners.

SYNOPSIS

(All times are UTC + 4)

During the late evening of 10 October 2003, two boiler, chemical cleaning specialists, one UK national and one Danish national, were preparing to examine the starboard boiler on board the LNG carrier *Hilli.* At 2200 a halogen lamp was placed inside the boiler steam drum. An explosion immediately followed, injuring both men. The UK specialist's injuries were fatal. The Danish specialist, although seriously injured, recovered 3 months later.

Hilli entered the Grand Bahama Shipyard Ltd at Freeport, Grand Bahama, on 4 September 2003, to undergo repairs to her starboard main boiler. The boiler had previously been damaged, twice before, following fuel-related explosions which were due to mal-operation.

Harris Pye Marine Ltd (HPML) of Barry, South Wales was contracted as the boiler repair specialists. They had good knowledge of the ship, having carried out previous work on board. As part of an extensive boiler tube replacement programme, HPML sub-contracted the post-repair chemical clean of the boiler to Mr Derek Walton, a chemical cleaning specialist well known to HPML. Mr Walton had earlier, chemically cleaned the boilers in June 2003, while *Hilli* was in Bazan Shipyard in Spain.

Mr Walton arrived in Freeport on 26 September. He undertook safety training with the shipyard's Health and Safety Department. Training included the use of Permits to Work, entry into confined spaces and accident reporting procedures. He also set up his chemical cleaning equipment to clean the starboard boiler in the same configuration as he had previously used in Spain. However, it is unclear what arrangements were made to ventilate the boiler, to release the evolved gases to atmosphere.

The chemical used to remove the boiler scale and corrosion was Unitor's Descalex. This inhibited sulphamic acid cleaner also contained a colouring agent to indicate the acid strength. The inhibitor provided a protective coating on the internal steel surfaces of the boiler, so that it was protected from acid attack which produces hydrogen gas.

On 9 October, the starboard boiler passed its pressure test. Mr Walton then started to internally clean the boiler of oils and greases using a proprietary alkaline cleaner. This work was completed early on 10 October. In the meantime, Golar Management (UK) Ltd arranged for an overseer, a Danish chemical cleaning expert, to fly to the Bahamas and oversee the chemical cleaning operation on their behalf, and produce a report on completion. Neither HPMC nor Mr Walton was informed of this arrangement. The overseer arrived at Freeport at about midnight on 9 October.

Mr Walton started to heat up the water in the water/acid mixing tank at about 0800 on 10 October. He then circulated the water to check the system integrity. Mr Walton was introduced to the overseer later that morning. The overseer mentioned that he had not previously used sulphamic acid and was sceptical that it would clean the boiler. Mr Walton discussed the cleaning procedure and gave the overseer a copy of the procedure he was using. The instructions were not for the Descalex product but for the Drew Marine (UK) Ltd cleaner – SAF-Acid. At 1300, the temperature of the water/acid mixing tank was 57ºC, and the overseer recommended that heating be stopped. By mid afternoon, 800kg of the cleaning chemical had been added and was being circulated around the boiler. At 1700 the overseer tested the water/acid mixture; the result confirmed that the inhibitors were still protecting the steel surfaces. At 2100 a further test was carried out, and this time the indications were that protection had ceased and the acid was dissolving the boiler steel. Although Mr Walton was sceptical of the result, he agreed to stop circulating the water/acid, as recommended by the overseer.

At 2145 Mr Walton arranged for the steam drum door to be removed, having already reduced the water/acid mixture level in the boiler. At 2200 both Mr Walton and the overseer approached the steam drum door. No tests were conducted to check the steam drum atmosphere for either toxic or flammable gases. Mr Walton picked up a nearby, non-intrinsically safe, halogen lamp and placed it just inside the steam drum. The overseer saw a small flame, and an explosion immediately followed. Mr Walton was thrown backwards by about 4.5 metres; he was unconscious and had severe burns. The overseer was also burnt, but less severely. There was no fire or severe damage to either paintwork or structure.

Both men were evacuated, first to a local hospital and then on to Florida, USA. The overseer eventually recovered, but Mr Walton died of his injuries on 19 October.

All the evidence points to an accumulation of hydrogen gas in the steam drum which evolved during the cleaning procedure. As the steam drum door was opened, the air combined with the hydrogen to create a mixture that was within the hydrogen explosive limits. As Mr Walton introduced the halogen lamp, either the hot lens or bulb, or an electrical spark from the lamp, ignited the mixture, causing the explosion.

Had the boiler been properly ventilated, the hydrogen build-up would not have occurred. The introduction of the hot halogen lamp into the untested, confined space of the steam drum, which was known to have possibly contained flammable gases, was a serious error of judgment.

Recommendations have been made to help prevent this type of accident re-occurring. They focus on:

- Revising acid suppliers' Product and Material Safety Data Sheets, to highlight the risk of hydrogen evolving and the importance of effective ventilation of closed systems and equipment.

- A review of cleaning procedures to include filling boilers with fresh water after any chemical clean to purge the boiler of flammable gases.

- The need to re-iterate the importance of closely adhering to confined space routines and the need to test these atmospheres for toxic and flammable gases including, specifically, hydrogen.

- The importance of comprehensive risk assessments and method statements for dangerous operations.

- Promulgating safety issues from this investigation in professional publications.

Figure 1

LNG Carrier *Hilli*

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *HILLI* AND ACCIDENT

Vessel details

Registered owner	:	Golar Hilli (UK) Ltd
Manager	:	Golar Management (UK) Ltd
Port of registry	:	London
Flag	:	UK
Type	:	LNG tanker
Built	:	1975 by Moss – Rosenberg, Norway
Classification society	:	Det Norske Veritas
Cargo	:	6 aluminium gas tanks with 124873 m^3 capacity
Length overall	:	293.75m
Beam	:	41.66m
Depth	:	25.00m
Gross tonnage	:	96235 tonnes
Main propulsion type and power	:	Boilers – 2 x Foster Wheeler ESD III monowall, producing 64000kg steam/hour at 62 bar Main engine – 1 x General Electric steam turbine developing 40000 shp
Service speed	:	19.7 knots

Accident details

Time and date	:	2200 on 10 October 2003
Location of incident	:	Grand Bahama Shipyard, Freeport, Grand Bahama, Bahamas
Injuries/fatalities	:	Fatally injured person – suffered 60% burns Seriously injured person – suffered 20% burns, mainly to his face and left arm
Damage	:	Fracture of a guardrail and damage to a packing crate.

(All times are UTC + 4)

1.2 ACCIDENT REPORTING

The accident was brought to the MAIB's attention in July 2006 by the widow of Mr Derek Walton, the sub-contractor who was fatally injured in the accident.

The Merchant Shipping (Accident Reporting and Investigation) Regulations 1999 were in force at the time of the accident. Under the regulations, the master should have reported the accident to the Chief Inspector of Marine Accidents by the quickest means available and within 24 hours. Paragraph 5(4) (a) and (b) of the regulations exempted the need to report accidents that occurred in a United Kingdom shipyard. However, the exemption was not extended to accidents occurring in a foreign shipyard.

Following the accident, the ship managers discussed the matter of reporting and investigation with the Maritime and Coastguard Agency, the consequence of which was that no report was made to the Chief Inspector of Marine Accidents.

The above regulations have since been replaced by *The Merchant Shipping (Accident Reporting and Investigation) Regulations 2005*. The new regulations have imposed increased accident reporting requirements. They now require ship owners to also report accidents by the quickest means available, unless they can ascertain that the master has done so.

1.3 VESSEL - GENERAL

Built in 1975, *Hilli* is a steel hulled, steam turbine, single shaft, liquefied natural gas carrier. The cargo is contained in six, spherical aluminium, cargo tanks to a Moss Rosenburg design, providing a total cargo capacity of 124,873m^3. The vessel had a total crew of 46.

Hilli was owned by Golar Hilli (UK) Ltd and spent the first 20 years trading between Das Island, Abu Dhabi and Japan. In May 2001 Golar Management (UK) Ltd took over the operation of the vessel from Osprey Maritime (Europe) Ltd. At this time, a decision was made to continue trading *Hilli* for a projected further 14 years. Part of this decision involved replacing life expired boiler components, and large scale instrumentation replacement.

Soon after the accident, the ship's technical management was transferred from Golar Management (UK) Ltd to Barber Ship Management which is based in Norway.

Hilli transferred from the Liberian to the UK registry on 29 January 2003.

1.4 BACKGROUND

Before the starboard boiler explosion on 10 October 2003, *Hilli* experienced two other, fuel-related explosions in the starboard boiler.

The first occurred on 9 April 2003 as the vessel completed discharging cargo at the Trunkline Terminal, Lake Charles, USA. Unburnt LNG fuel passed into the boiler windbox through a porous weld on a burner. A poor burner flame profile, caused by a deformed burner quarl, allowed the flame to be drawn into the windbox, igniting the flammable vapour and badly deforming the windbox plating and boiler air supply equipment.

Permanent repairs were carried out by South Wales based, Harris Pye Marine Ltd (HPML) during May and June 2003 at the Bazan Shipyard at El Ferrol in Spain. The repairs were coincident with the ship's scheduled dry docking.

The second explosion happened on 23 June 2003, while *Hilli* was at the Lake Charles outer anchorage. The starboard boiler had been shut down to change the feed water which had suffered an unacceptable high level of dissolved solids and chlorines since the earlier dry docking. On firing up the boiler, a number of "flame outs" occurred. These resulted in unburnt fuel accumulating in the furnace which was not cleared by proper air purging. During an attempt to light the burners, the unburnt fuel in the furnace ignited, causing an explosion. There was significant internal and external damage, including the distortion of a number of boiler tubes. Temporary repairs were made to the satisfaction of DNV and the Coastal State. As a result of the damage, *Hilli* was scheduled by Golar Management (UK) Ltd, to be taken out of service at the end of August 2003 for permanent repairs to the starboard boiler. The repairs were to include chemical cleaning of the internal parts of the boiler. Repairs were planned to be carried out at the Grand Bahama Shipyard Limited (GBSL) in Freeport, Bahamas. Once again, HPML was selected as the boiler repair prime contractor. In the event, *Hilli* did not arrive at the shipyard until 4 September 2003.

On both occasions, HPML sub-contracted Mr Derek Walton of Derek Walton Consultancy, an expert in chemically cleaning boilers and well known to HPML, to carry out the post repair, boiler chemical cleans. A copy of Mr Walton's report following the repair at El Ferrol is at **Annex A**.

1.5 FOSTER WHEELER ESD III BOILER

Hilli was fitted with two, Foster Wheeler ESD III, superheat boilers located in the engine room. These boilers could be fired by using either oil or LNG. Each boiler had a capacity of 25 tons when completely filled, and 15 tons in the steaming condition. Each produced 64000kg of steam/hour at 62 bar and at 513ºC.

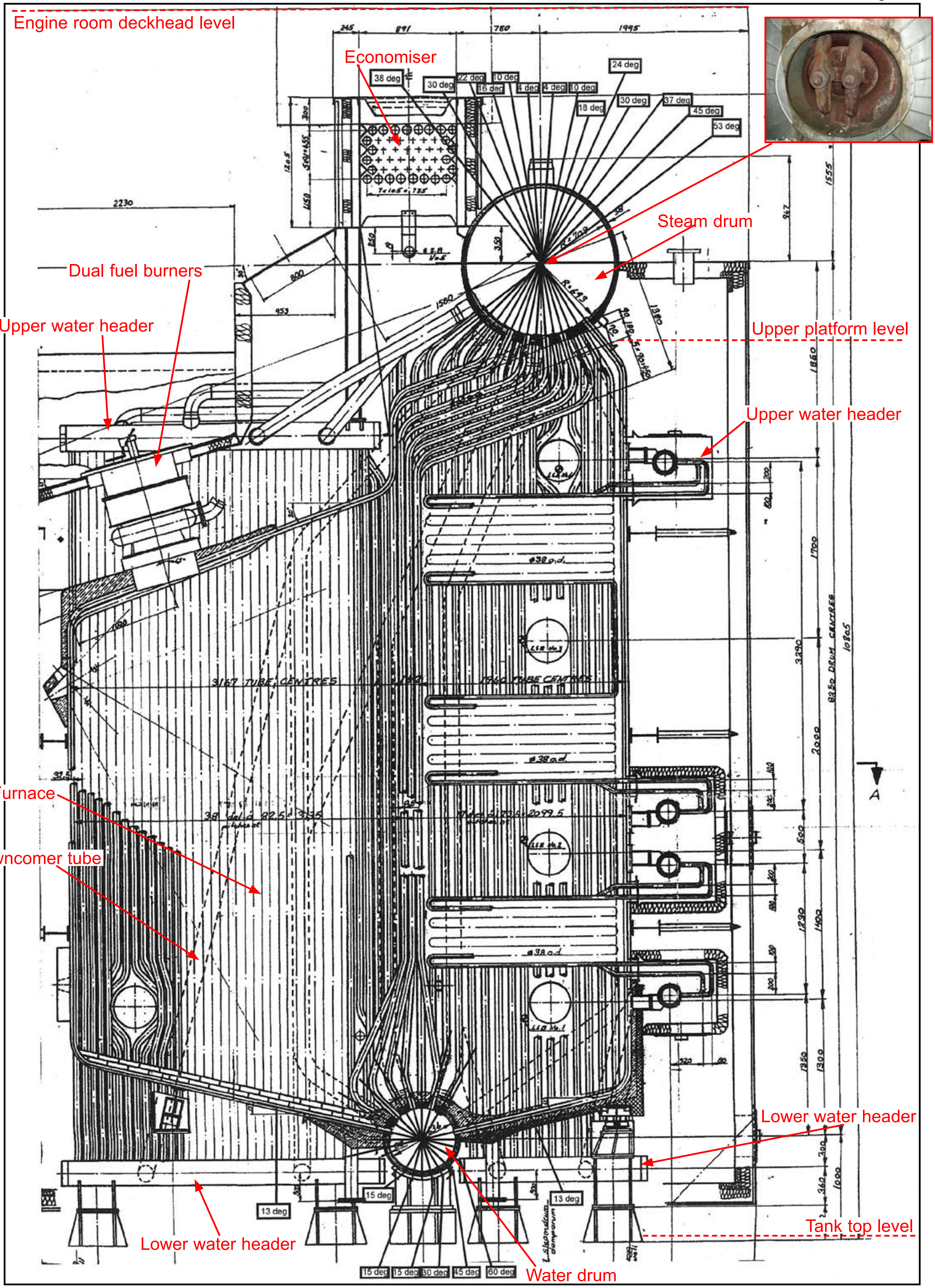
The boiler was of monowall construction, whereby the tubes were welded together by means of "fins" to form a gastight envelope. Three burners were located in the furnace roof, and could be supplied with either fuel oil or "boil off" gas from the cargo tanks.

An economiser was fitted in the uptakes which utilised the waste heat from the furnace to pre-heat the boiler feed water supply, which was then fed to the steam drum under controlled conditions. External downcomers transferred water from the steam drum to the water drum and lower water headers, to allow sufficient circulation back to the steam drum under all steaming conditions.

Hilli's boilers, in common with all other types, required periodic, internal chemical cleaning to maintain their efficiency. When certain types of acid are used, flammable gases will evolve when acid comes in contact with the unprotected, internal steel surface of the boiler.

The general arrangement of the boiler is shown at **Figure 2**, and views of the area around the after end of the starboard boiler steam drum are at **Figures 3 and 4**.

Figure 2



General arrangement of the Foster Wheeler ESD III boiler

Figure 3

Forward view of the starboard boiler steam drum top plate level

Figure 4

After view of the starboard boiler steam drum top plate level

1.6 NARRATIVE

1.6.1 Events leading to *Hilli's* arrival at Freeport, Bahamas

Hilli loaded cargo at Point Fortin, Trinidad and sailed for Savannah, USA on 22 August 2003. While on passage, the starboard boiler developed three leaking tubes, which required it to be shut down and taken out of action.

As this was *Hilli's* last cargo before the planned repair period in the Bahamas, the US authorities gave approval for the vessel to enter Savannah, on one boiler, and discharge her cargo on 27 August. The approval was extended for her to sail to the Bahamas on one boiler on 28 August. In the meantime, a five strong HPML workforce joined *Hilli* on 26 August for the passage, to carry out preparations for the starboard boiler repair.

On 31 August, HPML's Assistant Technical Director, who was responsible for all HPML related work, arrived at GBSL to meet with the shipyard personnel and Golar's Technical Superintendent. *Hilli* arrived off Grand Bahama at 2000 on 3 September, and the next day she berthed at GBSL's South Finger Pier at 1220 to begin her planned, 25-day afloat maintenance and repair period.

1.6.2 Activities prior to the starboard boiler chemical clean

All the LNG cargo tanks were certified gas free, and the boiler fuel systems fully isolated to allow for hot work to be carried out. Steady progress was made on the starboard boiler repairs, cargo tank calibration and upper deck pipe renewals until 14 September. Work was then delayed as Hurricane "Mindy", which was building in the area, approached the Bahamas. It was decided that *Hilli* should sail from her exposed berth, using only her port boiler, to escape the path of the hurricane. While at sea, it was found that some tubes in the port boiler had shown signs of leakage that also required repair. By 19 September the hurricane had passed and *Hilli* returned to her berth to continue the repair work.

Mr Walton arrived at Grand Bahama shipyard on 26 September. He spent the next 2 weeks checking and preparing the equipment for the chemical clean of the starboard boiler, undertaking GBSL safety training and familiarising himself with the GBSL facilities.

After completing a large amount of emergent work and replacement of 190 tubes, the starboard boiler was successfully pressure tested on 3 October. With the assistance of HPML staff, Mr Walton spent the next few days rigging the chemical cleaning equipment to the starboard boiler and conducting system integrity trials.

On about 4 October, a delivery of Unitor Descalex arrived, which was to be used as the chemical cleaning agent. The active part of the product was sulphamic acid, and the product contained an inhibitor to protect the boiler steel from acid attack. Mr Walton was surprised by this as he was expecting to use an Ashland Drew product called "SAF Acid". He was informed by Golar's Technical Superintendent that the Ashland Drew product was not available in time for the clean and that Unitor's Descalex product was a recognised alternative as stated on the GBSL's purchase order, copy at **Annex B**. The Product Data Sheets and Material Data Sheets for the Unitor Descalex and Ashland Drew's SAF Acid products are at **Annexes C and D** respectively.

On 9 October 2003 Mr Walton began degreasing the starboard boiler to remove oils and greases from the inside of the tubes and drums. He used Eazychem Alkaline Cleaner, which had been supplied by HPML, to do this.

Degreasing of the starboard boiler was completed early on 10 October and the boiler flushed through with fresh water. Mr Walton then returned to his hotel to rest.

In the meantime, Golar Management (UK) Ltd contacted the Norwegian company, Moss Varmetiknikk, to identify a suitable person to oversee the chemical clean on their behalf. A Danish boiler chemical cleaning expert was contracted to do this work. He was not advised on the extent of repair work, but his instructions were to assess the cleaning process and produce a short report of his findings **(Annex E)**. While Golar's Technical Superintendent was aware of this arrangement, the HPML staff were not, and neither was Mr Walton.

The overseer, who co-owned the Danish chemical cleaning company, SBC-Inter ApS, left Copenhagen on 8 October and flew to the Bahamas, via London and Miami, arriving at his hotel at about midnight on 9 October. He brought with him a packet of pH papers to test the boiler water acid/alkaline content, Fe strips **(Figure 5)** to test the water iron content, and steel wool which was used to test the chemical inhibitor's effectiveness.

Figure 5

Fe and pH test equipment

1.6.3 Starboard boiler clean - 10 October 2003

The starboard boiler chemical clean planned for 10 October was discussed during the daily project progress meeting chaired by Golar's Technical Superintendent. It was agreed that no "hot work" would be permitted in the engine room, but the question of issuing a Naked Light Certificate approving the use of portable lights and entry into the steam drum was not considered. The Technical Superintendent advised those at the meeting that the chemical clean was not to start until the overseer had the opportunity to review the arrangements. This was the first advice that the HPML team were given about the overseer's impending arrival.

Mr Walton had returned to *Hilli* at about 0800, and was advised soon afterwards of the overseer's intended role. While waiting to meet him, he started to heat up the water in the water/acid mixing tank. He injected steam at 120ºC from a shore side boiler directly into the tank located at the starboard side of the main deck **(Figure 6)**. He then started circulating the water around the starboard boiler. He also instructed the four HPML workers allocated to assist him, to assemble the 25kg containers of Unitor Descalex, in preparation for adding the contents to the water/acid mixing tank.

Figure 6

Position of the water/acid mixing tank on the starboard side of the main deck

The overseer met with Golar's Technical Superintendent at about 0830 to discuss the boiler cleaning arrangements. He requested that the economiser be included in the acid clean, but was advised that it had already been blanked from the circuit. The overseer also advised the Technical Superintendent that he had not used inhibited sulphamic acid before and was sceptical whether it was capable of removing the scale from the boiler. The Technical Superintendent acknowledged his concerns but advised that it was too late to change the chemicals, and stated that sulphamic acid had been used effectively to clean the starboard boiler following the repair at El Ferrol earlier in the year.

Between 1000 and 1100, the overseer met with Mr Walton. They discussed the intended cleaning procedure and the overseer's concerns regarding the suitability of the de-scaling product. Mr Walton indicated that he had mostly used sulphamic acid to clean boilers in the past. Although he had not specifically used Unitor Descalex before, he was confident that it would clean the boiler effectively, even though it was not his preferred product. Mr Walton then gave the overseer a drawing showing the positions of the acid circuit connections, copies of the Unitor Descalex Product and Material Safety Data Sheets and an acid cleaning procedure. The procedure provided was for the Ashland Drew SAF Acid product, and not for the Unitor Descalex which was being used; however, the overseer did not realise this at the time. Following the discussions, both men walked around the acid cleaning system, which was found to be leak free.

At 1300 the temperature of the water was steady at 57ºC, as measured at the water/acid mixing tank. The documentation provided by Mr Walton recommended a circulating temperature of between 60ºC and 70ºC; although the water was slightly less than the desired temperature, the overseer asked Mr Walton to turn off the steam. This was because he was concerned that the continued steam injection would adversely affect the ability of the chemical inhibitors to protect the internal steel surfaces of the boiler from acid attack.

Mr Walton was surprised by this as he normally continued to inject steam to maintain the temperature throughout the cleaning procedure. After some discussion it was agreed to isolate the steam and add the first of 32 x 25kg drums of Unitor Descalex to the water/acid mixing tank. The overseer then returned to Golar's shore side offices for discussions with Golar's Technical Superintendent and to explain his own procedure for assessing when the inhibitors ceased to protect the steel drum from the acid.

Still a little concerned about using sulphamic acid, the overseer decided to telephone his brother, in Denmark, who also worked for SBC-Inter ApS. He explained the procedure being used and asked whether he had any experience of the Unitor Descalex product; his brother had not.

At 1425, the last of the 800kg of Unitor Descalex was added to the water/acid mixing tank. The 5.3% acid mixture at about pH3, which was in accordance with the Unitor's guidance, was then circulated around the boiler. About 45 minutes later the colour of the returned acid/water at the mixing tank had changed from clear to red, indicating that the acid was fully dissolved and circulating correctly.

At about 1530, Mr Walton positioned his four assistants around the acid circuit to monitor it for leaks. He then made final adjustments to the return flow of the mixture, to the water/acid mixing tank, to balance off the system and so maintain a steady level, in both the boiler steam drum and the water/ acid mixing tank. Content that there were no leaks and that the acid levels were stable, he went to a cabin on board the ship for a short rest.

Meanwhile, the overseer continued to familiarise himself with the boiler and spent the latter part of the afternoon talking to the Technical Superintendent in his shore-side office. The overseer returned to *Hilli* at about 1645 and on the way he picked up a rusty pipe flange which he was to use to test the inhibitor's effectiveness.

Once back on board, the overseer met up with Mr Walton. He placed the rusty flange in the water/acid mixing tank, and explained to Mr Walton that when the flange appeared bright and shiny, it was an indication that the inhibitors were no longer working and that the acid was attacking the steel and not the scale. He also explained that to confirm his findings, his usual practice was to place a small ball of wire wool into a returned acid sample. When the wire wool rose to the surface, it indicated that the inhibitors had ceased to protect the surface and the steel was being dissolved by the acid, causing the wire wool to rise to the surface under the influence of the liberated gases. Mr Walton did not have any equipment or indicators to measure the effectiveness of the inhibitors.

At 1700, the overseer noted that the acid/water mix colour had changed from red to grey. The overseer, with Mr Walton present, took a sample from the water/acid mixing tank and used his total dissolved iron comparator strips to determine the amount of dissolved iron in the sample. It registered just over 5mg/litre. He further checked the sample by placing a ball of steel wool in the sample, and it stayed at the bottom. This indicated that the inhibitors were still active and protecting the internal steel surfaces of the boiler. Although this was not a procedure that Mr Walton normally used, he accepted the overseer's interpretation of the test. The overseer did not see Mr Walton conduct any tests during the cleaning process other than monitoring the acid/water mix colour change. The overseer then continued to regularly conduct the "steel wool" test.

At about 2100, the acid/water mix had turned a "greenish" colour, and the steel wool appeared at the surface of the sample, indicating that the boiler material was being dissolved by the acid at an increased rate.

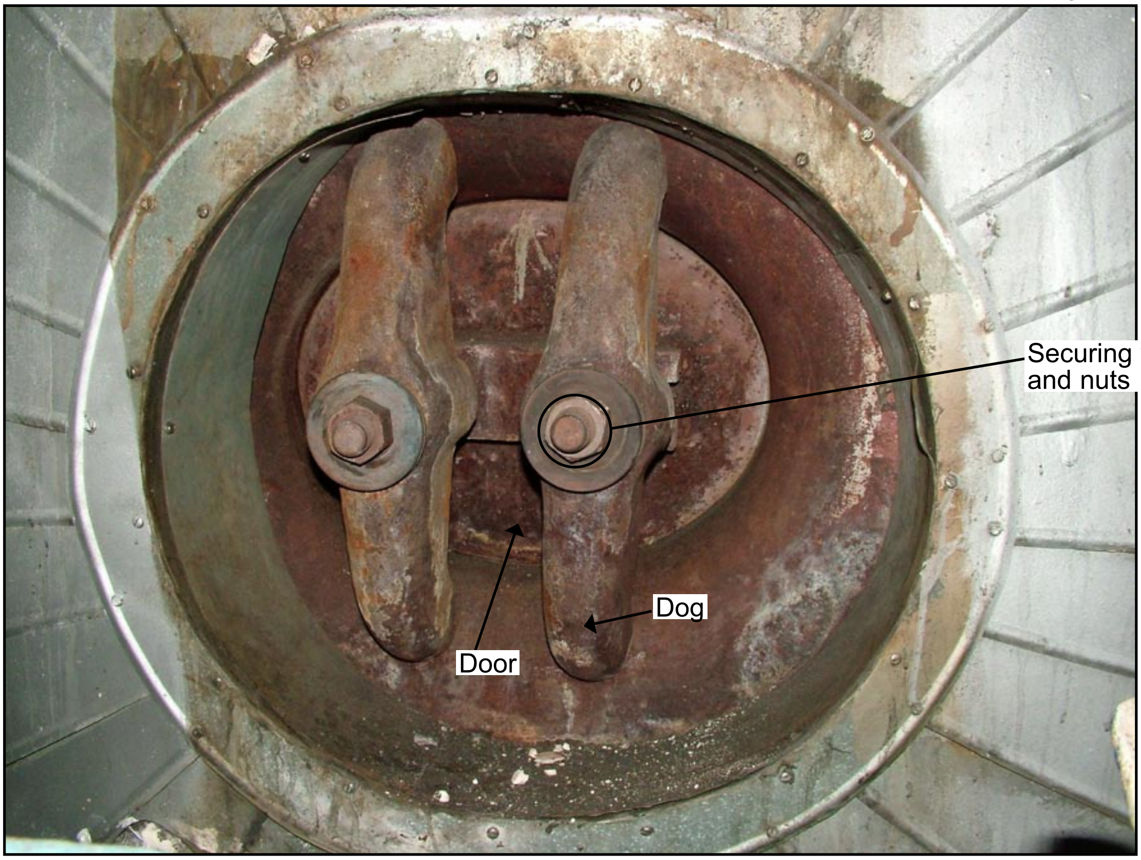
There followed a discussion between the overseer and Mr Walton regarding the interpretation of the results, with Mr Walton agreeing to stop the circulation of the acid. The overseer recommended that the boiler be drained immediately to prevent the boiler steel being dissolved by the acid. It was then agreed to open the steam drum for inspection before flushing it out with fresh water.

At about 2120, Mr Walton reconfigured the acid cleaning system and, on completion, restarted the air-driven centrifugal circulating pump to empty the boiler into a bowser located on the jetty. It was estimated that it would take about 1 hour to completely empty the boiler.

At about 2145 Mr Walton asked the HPML night shift foreman, who was in the engine room, to arrange for the steam drum after access door to be opened. Opening the steam drum at this point was in accordance with the cleaning instructions Mr Walton was using, a copy of which he had also passed to the overseer. A copy of the procedures obtained from the overseer, with his annotations, is at **Annex F**.

As Mr Walton and the overseer went to the Engine Control Room (ECR) for refreshments, two HPML workers went to the steam drum and removed the nuts and washers on the dogs, before removing the dogs themselves **(Figure 7)**. At about 2152 they pushed the hinged door into the steam drum **(Figure 8)**. As they forced the door inwards, they noticed a distinct suction, as the door opened and air was drawn into the steam drum. Neither of the workers noticed anything else untoward, and there were no unusual smells or vapours which aroused their suspicions. They then positioned a yellow, HPML halogen lamp on a guardrail, near to the steam drum, before going to the ECR to inform Mr Walton that the door had been opened. After that, both men went up to the main deck to take further refreshments.

Figure 7



Starboard boiler steam drum, door arrangement

Photograph courtesy of Harris Pye Marine Ltd

Figure 8

Starboard boiler – open steam drum

Horizontal view inside the starboard boiler open steam drum, see open drum door on left hand side

At 2200 Mr Walton and the overseer approached the opened steam drum. The overseer was surprised that the boiler room ventilation fans were not running and there appeared to be no method of forced ventilation to purge the steam drum of gases. However, he did not say anything to Mr Walton about his concerns. Both men looked into the steam drum and noticed that the internal surface was clear of scale and corrosion products. Neither Mr Walton nor the overseer had any equipment with them to test for the presence of toxic or flammable gases in the steam drum.

1.6.4 Explosion

Mr Walton positioned himself directly in front of the open steam drum door, with his head about 10cm from the entrance and with the overseer slightly to his right **(Figure 9)**. Mr Walton picked up the halogen lamp, which was already switched on, and placed it just inside the steam drum. The overseer then saw a very slight bluish spark or flame, which was immediately followed by an explosion, but no further flame. The explosion threw Mr Walton against a ladder guardrail, which broke under his impact, and up against a wooden crate situated 4.5 metres from the steam drum, where he came to rest.

The explosion was heard by the chief officer who was in his cabin and by workers in the engine room. *Hilli*'s second engineer, the HPML night foreman, Golar's Technical Superintendent and another HPML worker, all of whom were in the ECR, also heard the noise. With the exception of the second engineer, they went immediately to the area of the steam drum.

Figure 9

Re-enactment of Mr Walton's and the overseer's positions in front of the starboard boiler steam drum immediately prior to the explosion

1.6.5 Post accident actions

The overseer was by now shouting for help. His sweatshirt and "T" shirt had been partially blown off. He had suffered burns to the left side of his face, to his hands and to the left side of his body. As he ran from the engine room, he noticed that some unidentified workers had arrived to tend to Mr Walton. The overseer made his own way towards the starboard ECR door, where he was met by the second engineer. The second engineer took the overseer into the nearby boiler water analysis room, and helped bathe his eyes, face and hands with cold water. He was then taken to the crew's bathroom on the main deck, where he was stripped of his clothes and placed under a cold shower. The second engineer then arranged for clean sheets to cover the overseer.

At the same time, ship's staff, HPML workers and Golar's Technical Superintendent rushed to the aid of Mr Walton. They found him lying against the crate at the after engine room bulkhead. Most of his overalls had been burnt off, his trunk and face were badly burned and he appeared to be unconscious. The HPML night foreman immediately instructed one of his workforce to shut down the acid/water circulating pump.

The Technical Superintendent noticed the now badly damaged halogen lamp and saw that its lens was missing **(Figure 10)**. He also observed that the area was hot, and there was a slight haze, but there were no obvious, unusual smells. With the exception of a very small paper fire, and barely noticeable scorching of a small area of paintwork, there was no other evidence of explosion or fire.

Photograph courtesy of Harris Pye Marine Ltd

Figure 10

Damaged halogen lamp

At 2205, HPML's night shift foreman telephoned HPML's Assistant Technical Director, who was with the day shift foreman. They were advised of the explosion, and they immediately returned to the ship. It was also about this time that the GBSL personnel alerted the emergency services.

At 2207 Mr Walton was taken from the engine room onto the poop deck in a plastic stretcher. His wounds were washed down and sterile dressings applied under the direction of *Hilli*'s chief officer. He was then covered with a fire protection blanket.

Golar's Technical Superintendent checked on the condition of the overseer, who was found to be able to walk. At 2217 Mr Walton was transferred to the jetty using a shore crane and basket. The overseer followed at 2222. By about 2225, the HPML Assistant Technical Director and day foreman arrived at the jetty. Mr Walton reportedly said, "*I can't believe I have been caught like this",* to the Assistant Technical Director. He was unable to clarify what was meant by that before Mr Walton slipped into unconsciousness.

At 2235 two ambulances arrived at the jetty. Both men were immediately transferred to the Rand Memorial Hospital in Freetown, Bahamas. Mr Walton was accompanied by the HPML's Assistant Technical Director and the overseer by Golar's Technical Superintendent.

Due to the severe nature of their injuries, both men were airlifted to separate hospitals in Florida on 11 October, for further treatment. Mr Walton went to Jackson Memorial Hospital in Miami and was accompanied by an HPML employee. The overseer was transferred to Tampa General Hospital. On 16 October, Mrs Walton arrived at Miami, and was met by HPML's Group General Manager.

1.6.6 Injuries

Mr Walton suffered second degree burns to 60% of his body, and a fractured left arm. His condition deteriorated over the next few days, and he died from complications due to thermal injuries at 0142 on 19 October. His body was repatriated to the United Kingdom on 24 October 2003.

The overseer suffered second degree burns to 20-30% of his body and his condition was described as serious but stable. His condition rapidly improved. After spending a day in intensive care and a further 3 days on a general ward he was well enough to travel to Denmark, accompanied by his wife, on 15 October, for further treatment. The overseer completed his treatment on 10 December.

1.7 DAMAGE

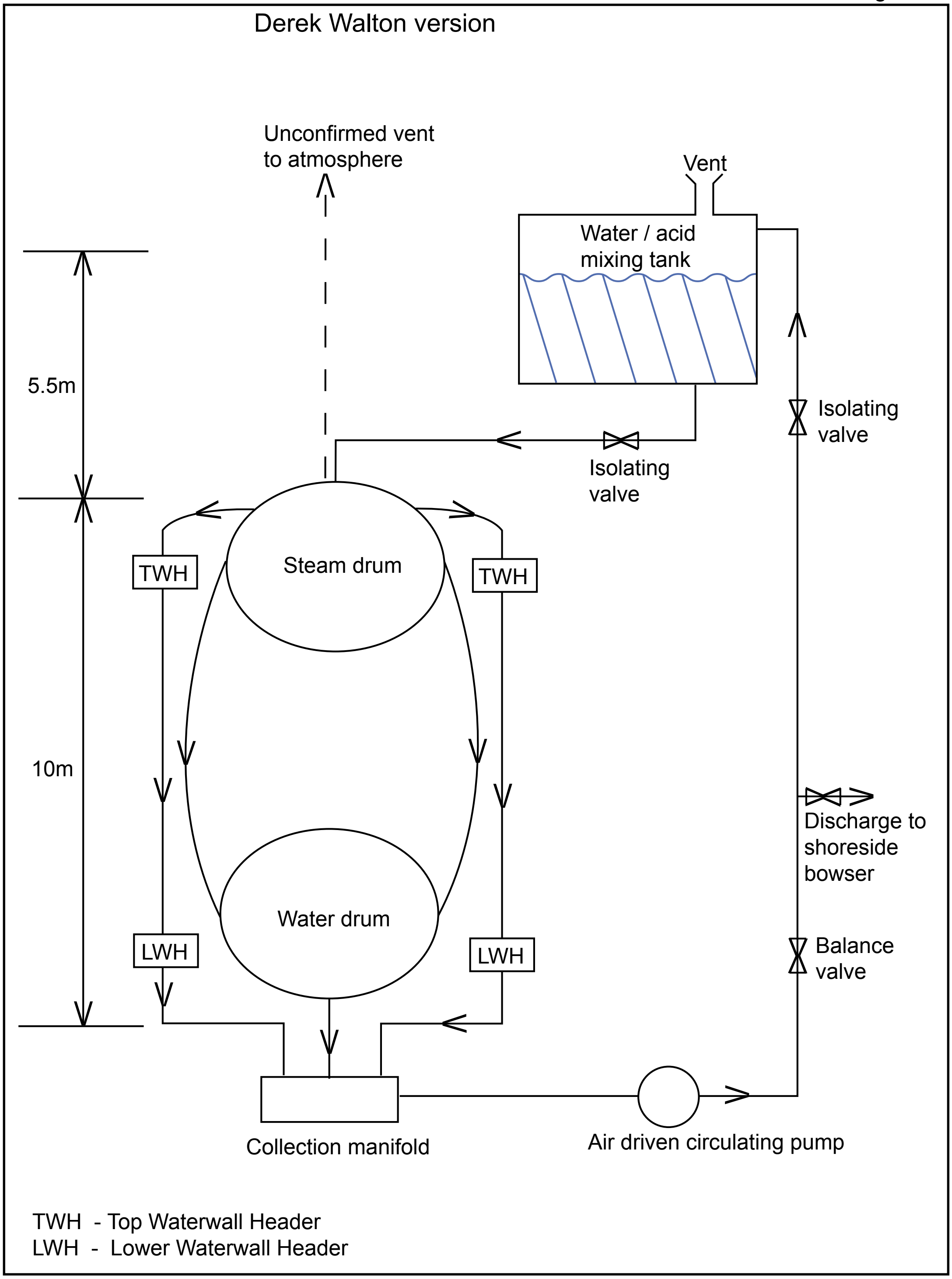
The damage resulting from the explosion was negligible. As Mr Walton was thrown away from the steam drum door he made contact with a ladder, top guardrail, which broke under the impact. The wooden crate against which Mr Walton came to rest had also shown some minor impact damage. The HPML halogen lamp was badly damaged in the explosion **(Figure 10)**, and it was reported that there was also some very slight scorching to a small area of paintwork.

1.8 DESCRIPTION OF THE BOILER CLEANING CONFIGURATION

1.8.1 Acid/water circuit arrangement

The starboard boiler cleaning equipment was provided by HPML, with the exception of the steam generator which was sourced by GBSL. The cleaning equipment was connected to the starboard boiler as illustrated in the schematic at **Figure 11**, and as confirmed by HPML's on site Assistant Technical Director and day foreman. The configuration was identical to that used by Mr Walton in El Ferrol, and was as described at **Annex A**.

Figure 11



Schematic of the boiler cleaning water/acid circulation

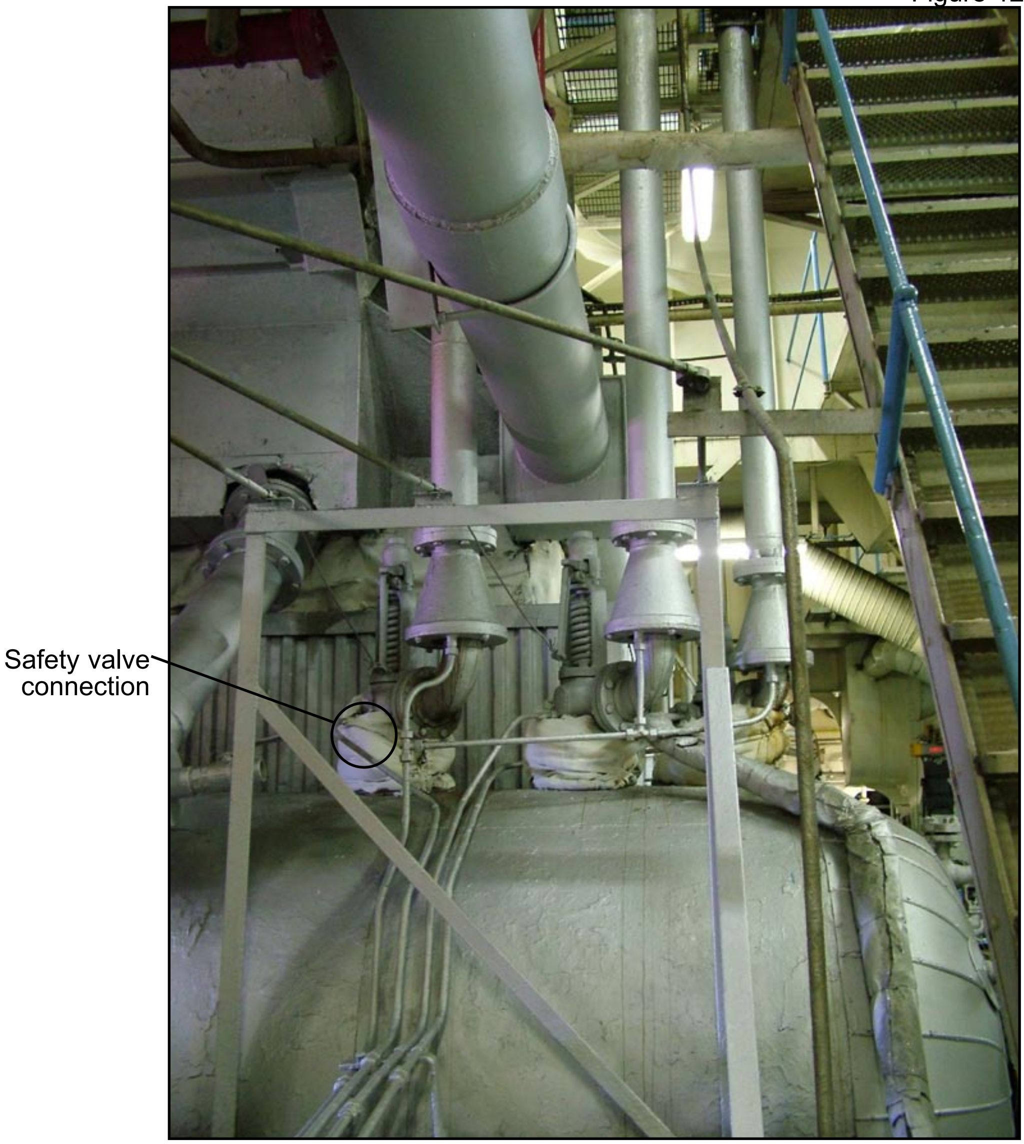
A water/acid mixing tank, with a non-gastight top, was situated at the after, starboard side of the main deck approximately 5.5m above the top of the steam drum**.** A plastic hose connected the mixing tank to the steam drum via one of the removed safety valve flanges **(Figures 6, 11 and 12)**.

Reinforced 75mm flexible hoses were connected to the run down valves of the bottom water wall headers and water drum. These hoses were led to a common manifold **(Figure 13)** from where a centrifugal, air-driven pump **(Figure 14)** took a suction and returned the acid/water mix back to the mixing tank via a flow control valve. A number of ball valves were fitted to the connections to allow the system to be isolated in the event of leakage and to enable the mixture to be discharged to a shore side bowser.

A plastic hose was connected to a gauge glass connection and was led vertically to a position above the water/acid mixing tank. This provided an indication of the level of mixture in the system.

This was the same arrangement Mr Walton had used at El Ferrol, earlier in the year, and is described at **Annex A**. It is possible to reverse the water/acid flow simply by changing over the pump suction and discharge hoses, and reconfiguring any non-return valves fitted to the system.

Figure 12



Starboard boiler steam drum safety valve – position of water/acid connection

Figure 13

Manifold and connecting hoses

Figure 14

Air driven centrifugal circulating pump

Photographs courtesy of Harris Pye Marine Ltd

1.8.2 Ventilation arrangements

It is unclear what arrangements Mr Walton made to ventilate the boiler during the cleaning operation, so that gases generated during the chemical reaction could be safely released to atmosphere.

Ventilation could have been achieved via the steam safety valves or the steam drum air release valve. This crucial aspect is discussed in greater detail at Section 2 of this report.

1.8.3 Operation

The water/acid mixture was allowed to enter the steam drum under gravity conditions. The mixture flowed to the top water wall headers, down through the water wall tubes and downcomers to the water drum and bottom water wall headers.

The mixture was collected at the manifolds from where the circulating pump took its suction. The level in the steam drum was maintained at just above the normal steaming level, i.e. half full, by adjustments of the flow control valve on the return to the water/acid mixing tank.

1.9 BOILER CLEANING

1.9.1 Reasons for an internal boiler clean

Internal boiler cleaning is necessary to remove the build-up of scale that can accumulate, principally through poor boiler water treatment regimes and contamination. The contaminants can be in the form of oils, oxygen or dissolved solids. Often scale will build up through contamination of the boiler feed water by chlorides, typically as a result of cross-contamination from sea water systems. If the scale is not removed it will affect the heat transfer properties to the feed water, causing loss in efficiency. In more severe cases, this can lead to tube pitting and local overheating, leading to eventual tube failure. In this case, Mr Walton did not produce a pre-clean inspection report and therefore it was not possible to determine the amount of scale or other contaminants present in the boiler prior to degreasing and chemical cleaning.

Internal chemical cleaning is also necessary after re-tubing, to remove oils and greases that are used during repairs. There are four distinct stages in the chemical cleaning process following re-tubing: pre-clean, chemical clean, neutralisation and passivation.

1.9.2 Pre-clean

Commonly known as “boiling out”, the pre-clean phase is intended to remove oils and greases used during re-tubing procedures. The boiler is typically filled with a 5% alkaline solution. This is heated to between 70 - 80ºC and circulated for up to 24 hours, depending upon the degree of contamination. On completion, the boiler is emptied and rinsed with cold water.

In *Hilli*’s case, Eazychem’s product, “Alkaline Cleaner” was used for pre-cleaning.

1.9.3 Chemical clean

On completion of the pre-clean it is necessary to carry out a chemical clean.

The purpose of the chemical clean is to remove internal scale deposits and corrosion products. Typical acids used include: citric, hydrochloric and sulphamic acid. In this case, Unitor's product, Descalex, contained 95% sulphamic acid and 5% inhibitor, and a pH colour change agent was used. The sulphamic acid, International Chemical Safety Card, obtained from the International Labour Organization's website at www.ilo.org is at **Annex G**.

Unitor recommends that a maximum strength of up to 10% Descalex acid solution be used. The concentration will be dependent upon the severity and type of contamination. The strength of the acid mixture can be checked by a variety of methods, but in this case pH papers were used and the colour change of the mixture monitored. Additional acid can be added to maintain the strength in the region of pH3 for the recommended duration of the clean. This is usually between 8 -12 hours during which the dissolved solids remain in suspension.

The overseer used dissolved iron comparator strips **(Figure 5)** to give a check on the progress of the chemical clean. A constant level, rather than an increase, of dissolved iron in the cleaning fluid provided an indication that no more corrosion products were being removed from the boiler. However, this interpretation relied on the cleaning fluid being of sufficient acidity and the inhibitor being fully effective throughout the cleaning process.

1.9.4 Neutralisation

Once the chemical clean has been completed, it is necessary to neutralise the acid/ water mixture. A 1% concentration of sodium hydroxide/water is typically used. The mixture is maintained at about pH7 and is circulated around the boiler for about 2 hours. The water is then drained off, the boiler opened and flushed through with fresh water.

It is possible to neutralise the acid by adding sodium hydroxide, or a similar neutraliser directly into the sulphamic acid/water mixture at the end of the chemical cleaning process. The benefit of doing this is to speed up the process because the boiler does not have to be drained, and it is commercially attractive because it avoids the costly disposal of the acid mixture. However, adding the neutraliser at this stage results in sludge being formed in the tubes, especially at the lower extremities of the boiler, and these have to be manually removed. Nevertheless, this was the procedure used by Mr Walton at El Ferrol, as instructed by HPML's Technical Superintendent.

Had the boiler clean proceeded as planned, it was intended to use Unitor's product, "Alkalinity Control", to neutralise the starboard boiler.

1.9.5 Passivation

To protect the internal surfaces of the boiler from dissolved oxygen pitting and flash rusting, it is necessary to re-instate an unbroken coating of ferric oxide, commonly known as magnetite, as soon as possible after neutralisation. Liquid hydrazine is typically used at concentrations of between 1.5 and 2 litres/tonne of boiler water. To ensure a satisfactory coating, the boiler is flashed at a low firing rate for about 12 hours, after which full protection can be expected.

1.9.6 Mr Walton's cleaning instructions

On 24 March 2003, Mr Walton compiled a set of generic boiler cleaning instructions. These included a piping flow diagram based on the use of Eazychem's descaling product However, these were not specific to the *Hilli* boiler configuration. He had also produced a set of generic Safety Precautions, a Boiler Cleaning Worksheet and Boiler Cleaning Time Check list. There was no evidence these documents were in use at the time of the accident. A copy of these documents is at **Annex H**.

1.10 INHIBITORS

Some acid cleaning products such as "Descalex" include an inhibiting chemical. Other products require a separate inhibitor to be added. Inhibitors in sufficiently high concentration will greatly reduce the dissolving rate of the steel surface while allowing a high rate of scale removal. The inhibitor efficiency varies considerably with conditions, including: temperature, surface finish, acid concentration, inhibitor type. Inhibitor efficiency can be as high as 95 to 98+%.

In this case, the inhibitor effectiveness was tested by dropping a small ball of wire wool into the acid sample. Initially the large surface area of the wool will be protected by the inhibitor. As the inhibitor effectiveness deteriorates, the surface of the wool will be gradually dissolved by the acid. When the wool rises to the surface of the sample, it indicates that the inhibitor is losing its protective properties, and that boiler steel is being dissolved by the acid.

1.11 CHEMICAL SUPPLIERS AND BOILER CLEAN SPECIALISTS' INSTRUCTIONS

1.11.1 Main chemical suppliers

In the United Kingdom there are four main marine boiler cleaning, chemical suppliers and on site cleaning specialists. These are:

Unitor, Drew Marine (UK) Ltd (a subsidiary of Ashland Drew), Eazychem and Nalco (a subsidiary of Nalfleet).

1.11.2 Chemical cleaning instructions

Unitor and Drew Marine (UK) Ltd provide generic instructions for chemical cleaning procedures that are commonly used by cleaning contractors. Copies of these are at **Annexes I and J** respectively. Eazychem's instructions for use are included in the Descaler Plus, Product Data and Material Safety Data Sheets **(Annex K)**. These companies also provide service engineers' support to contractors, when requested. All instructions clearly identify the need for effective ventilation during the cleaning procedures.

Nalco's preference is for their service engineers to provide general advice on the use of their product. Broad guidelines for using Nalco's sulphamic acid product, "Sea Shield" Safe Acid 79125, are contained in the Product and Material Safety Data Sheets at **Annex L**. Because of the potentially dangerous nature of chemically cleaning procedures, Nalco's preference is to conduct the cleaning operation themselves, using their trained and certified staff. An on-site visit is made to determine the most appropriate procedure, and from this a Method Statement is compiled, supported by appropriate risk assessments for each specific task. The Statement will indicate a comprehensive timeline, it identifies those responsible for various actions, emergency procedures, incident and accident investigation procedures and a safety policy appropriate to the chemical being used. The Method Statement is very comprehensive and is an example of "best practice".

1.11.3 Chemical Product and Material Safety Data Sheets

Unitor Descalex was the chemical in use during the chemical clean.

None of the Reactivity Sections in the Material Safety Data Sheets (MSDS) for Unitor's Descalex, Drew Marine's SAF Acid, Nalco's "Sea Shield" Safe Acid or Eazychem's Descaler Plus, all of which contain sulphamic acid, identifies the risk of generating hydrogen gas. Additionally, all of the MSDSs identify the product's "Fire and Explosion Hazard" as non-flammable, non-combustible or non-explosive during storage or transit.

Only the Product Data Sheets for Nalco's "Sea Shield" Safe Acid, and Drew Marine's SAF- Acid crystals, respectively highlight the risks of hydrogen and flammable/ hazardous gases evolving during cleaning and describe the function of the inhibitor.

1.12 SHIP'S PROGRAMME

Hilli arrived at the Grand Bahama Shipyard on 4 September for the refit that was originally planned for between 20 -25 days. The refit end date was unconfirmed because it was known that there would be a good deal of emergent work as the strip down of the starboard boiler progressed. The starboard boiler work remained the critical path throughout the refit period.

GBSL undertook some pump overhauls, painting and support for the HPML contract, while the ship's staff conducted low level maintenance tasks. Remedial work on the port boiler that was necessary following the discovery of leaking tubes after *Hilli* was required to leave the shipyard to avoid hurricane "Mindy", extended the refit to 48 days. The vessel finally left the shipyard on 22 October 2003. There followed 2 days of trials before *Hilli* was declared operational by Golar on 24 October 2003. The first post repair LNG cargo was loaded at Point Fortin, in Trinidad, on 10 November.

1.13 CONTRACTORS

1.13.1 Harris Pye Group

The Harris Pye Group was founded in 1978 and now employs over 500 staff worldwide. It is considered to be a leader in all aspects of boiler repairs, including tube fabrication and pressure component replacement, as well as combustion control equipment installation and repair.

Harris Pye Marine (UK) Ltd, an ISO 9001 company, is located at Barry in South Wales. The company had conducted a number of boiler inspections and repairs on board *Hilli* before the accident that occurred on 10 October 2003, so it was very familiar with the ship's equipment.

As part of the company's total boiler repair strategy, HPML decided to offer customers the option of post repair chemical cleaning. Mr Walton was well known to the company as an expert in this area, and was its preferred chemical cleaning sub-contractor. Up to the point of the accident, HPML had contracted Mr Walton to complete four other boiler chemical cleans, all of which passed without incident.

As HPML competed for offshore business, it identified the need to place the chemical cleaning procedures on a more formal footing. Mr Walton was contracted to produce a set of generic chemical cleaning instructions with supporting risk assessments that could easily be tailored to each individual contract. This work had been ongoing for some time and had not been completed by the time of the accident.

1.13.2 Mr Derek Walton

Mr Walton was married and was 61 years of age at the time of the accident. Although he was on medication for both hypertension and diabetes, he appeared to be fit to those who knew him, and well able to carry out his tasks.

After completing an engineering apprenticeship in 1963, Mr Walton decided on a career at sea. The next 17 years saw him rise to the rank of chief engineer having served with a wide range of companies, including Blue Funnel Line and Cunard. In 1980 he was employed by Drew Marine (UK) Ltd (a part of Ashland Drew), as a service engineer. He specialised in selling cleaning chemicals, predominantly to the marine industry. He also provided technical advice on the chemical cleaning of pressure vessels, including boilers and heat exchangers.

Having been made redundant in 2000, he established DW Marine Consultancy, which later became Derek Walton Consultancy. During this period Mr Walton was selective in his work, and was for the most part employed by HPML as a sub-contractor.

1.13.3 SBC-Inter ApS and the overseer

SBC-Inter ApS is a small family run Danish company specialising in chemically cleaning boilers and heat exchangers. The company is located at Taastrup, a few miles outside Copenhagen.

The overseer was 33 years of age at the time of the accident and joined the company in 2000. He and his brother were the only full time employees and were joint owners. He had no formal training in chemistry, marine engineering or boiler cleaning. His knowledge had been passed on from his father in the form of “on the job training”.

Most of the overseer’s chemical cleaning experience had been in the offshore industry. This included cleans on boilers, pipe systems and heat exchangers. He also had some experience in cleaning boilers on board steam-driven frigates of the Royal Norwegian Navy.

1.13.4 Grand Bahama Shipyard Ltd

Grand Bahama Shipyard Ltd (GBSL) is a privately owned shipyard facility located in the Freeport Maritime area of Grand Bahama. The shipyard was conceived in the 1980s and is an ISO certified company. The facilities include two floating docks and a wide range of fabrication, preservation and electrical and mechanical engineering support.

On 11 August 2003, GBSL was certified by DNV as having completed a Liquid Natural Gas Carrier Training and Familiarisation programme.

1.14 CONFINED SPACES ROUTINES

1.14.1 Confined Space Regulations 1997

The Confined Spaces Regulations 1997 came into force in the United Kingdom on 28 January 1998 as Statutory Instrument 1997 No 1713.

The Regulation 3 (2) requires that every self-employed person shall –

"(a) comply with the provisions of these Regulations in respect of his own work; and"

"(b) ensure compliance, so far as is reasonably practicable, with the provisions of these Regulations in respect of any work carried out by other persons insofar as the provisions relate to matters which are within his control".

Although Mr Walton was not subject to the regulations while in the Bahamas, they should nevertheless have been known to him. The principles set out in the regulations are very similar to those promulgated in GBSL's Health and Safety Manual.

1.14.2 MCA publication – Code of Safe Working Practices for Merchant Seamen (COSWP)

The COSWP is concerned with improving health and safety on board ships. Much of the publication relates to matters which are subject to regulations and, as such, it gives guidance on how such statutory regulations are fulfilled.

Chapter 17 of the COSWP provides comprehensive guidance on the training, procedures, precautions and hazards related to confined spaces. As a seafarer, it is possible that Mr Walton would have been aware of the publication. However, as *Hilli* is a UK registered vessel, her crew would have been fully aware of the content of the publication and the routines associated with confined spaces.

1.14.3 International Safety Management Code

The purpose of the Code is to provide an international standard for the safe management and operation of ships and for pollution prevention.

At the time of the accident, company safety management system documentation, in support of the Code, was provided by Golar Management (UK) Ltd. This included instructions to the crew covering Permits to Work and confined space routines. However, it was not possible to review the instructions in force at the time, because they had been replaced and destroyed following the change in technical management from Golar to Barber Ship Management (paragraph 1.3).

Chapters 6.1 and 10.2.4.1 of the current ISM covering Resources and Personnel and Repairs by Contractors respectively state the crew are:

- To provide all necessary support to contractors.
- Responsible for inspecting and accepting work.
- To ensure that contractors comply with the onboard safety requirements, which includes the issue of Permits to Work.

1.15 GRAND BAHAMA SHIPYARD SAFETY MANAGEMENT

A copy of GBSL's Health and Safety Policy Statement is at **Annex M**. Although this statement is dated 28 March 2005, GBSL management confirms that this version has not substantially changed from that which was in force at the time of the accident.

Paragraph 3 of the policy states that:

> *"All employees and sub-contractors are expected to co-operate with the company in carrying out this policy, and will ensure that their own work, so far as is reasonably practical, is carried out with the minimum risk to themselves and others".*

It was GBSL's requirement that all sub-contractors should undergo a 1-day period of training to cover health, safety, environmental and quality awareness aspects. The training specifically covered procedures for issuing Permits to Work, Hot Work Permits and entry into confined and enclosed spaces.

Mr Walton signed a GBSL record sheet stating that he had received this training. There is no such record for the overseer, and GBSL confirmed that he did not receive safety training.

Of particular note are the instructions laid out in Section 10 of the GBSL Health and Safety Manual, which were in force at the time of the accident. Paragraphs 10.2.1 and 10.3.1 lay out the definition of a confined space. Specifically, 10.2.1 states that:

> *"Confined space means any place, including any chamber, tank, vat, silo, pit, trench, pipe sewer, flue, well or similar place in which, by virtue of its enclosed nature, there arises a reasonably foreseeable 'specified risk':*
>
> *i) serious injury to persons at work from fire or explosion"*

and 10.3.1 states that:

> *"… spaces normally kept closed with limited or no ventilation*"

are regarded as confined spaces.

A copy of Section 10 of the Grand Bahama Shipyard Ltd's Health and Safety Manual - Safe Work in Confined Spaces, which was in force at the time of the accident, is at **Annex N**.

In May 2004 GBSL introduced its Safety Management System. Section SW010 covers confined and enclosed spaces. Paragraph 2.4 defines the meaning of entry as:

> *Entry means the action by which a person passes through an opening into a space. Entry includes ensuing work activities in that space and is considered to have occurred as soon as any part of the body breaks the plane of an opening into the space."*

1.15.1 Project progress meetings

Each morning at approximately 0830, a daily project progress meeting was convened which was chaired by Golar's Technical Superintendent. Attendees included HPML's Technical Director (whom Mr Walton reported to), GBSL production manager and safety officer, *Hilli*'s captain, chief officer, chief engineer and safety officer. Mr Walton did not attend the meetings.

It was during this meeting that Permits for Hot Work, Naked Light and Entry into Confined Space Certificates were issued. These remained valid for 24 hours, after which any extension had to be agreed. Copies of the permits and certificates were posted at the gangway and in other areas where the work was being conducted.

1.16 INDEPENDENT REPORT BY THE UNIVERSITY OF SOUTHAMPTON

The preliminary findings of the MAIB investigation indicated that the explosion was most likely to have occurred as a result of the build up of hydrogen gas. (This opinion is discussed fully at Section 2.)

Professor FC Walsh, BSc, MSc, PhD, CSci, CEng, FIMMM, CChem, MInstP, FRSC, FICorr, FIMF of the University of Southampton's Research Institute for Industry, was commissioned to determine the possibility of hydrogen evolution during chemical cleaning of the internal boiler surfaces using sulphamic acid.

Because the degree of other contaminants in the boiler was unknown, the University was instructed to only consider the reaction between the sulphamic acid and internal steel surfaces of the boiler.

The report concluded that:

- The most likely source of the explosive gas mixture in the boiler was hydrogen gas generated by corrosion of the internal surfaces of the steel boiler in the acid cleaner.
- A modest corrosion rate of approximately 24 microns, over the entire boiler area, within the period of the clean, would result in sufficient hydrogen to cause an explosive hydrogen-air mixture in the boiler gas space above the cleaner.
- The halogen lamp is likely to have been the source of ignition, followed by rapid flame propagation.
- Inspection of the steam drum via the access cover, without first removing the acid cleaner from the boiler, followed by adequate water rinsing and careful ventilation, did not represent best practice.

A copy of Professor Walsh's report is at **Annex O**.

1.17 HYDROGEN

Extracts from the United States Schatz Energy Research Center's website (http://www.humboldt.edu/~serc/h2safety.html) covering the hazards and physical properties of hydrogen are at **Annex P**.

The reference describes hydrogen as a colourless, odourless, and tasteless gas that cannot be detected by human senses. The hydrogen flame radiates little heat and virtually no visible light, as the energy from the flame is radiated in the ultraviolet region. As a result, hydrogen burns with a pale blue, almost invisible flame that is almost visually imperceptible in artificial light or daylight.

Hydrogen has a wide range of flammability (4% to 75% by volume) and ignition temperatures in air. Weak ignition sources, such as a hot surface or an electrostatic spark, are often sufficient to ignite a combustible hydrogen-air mixture.

1.18 ENVIRONMENTAL CONDITIONS

The weather hindcast for Freeport on the 10 October were obtained via the UK's Meteorological Office. There are no records available for *Hilli*'s engine room temperature.

The maximum temperature recorded in Freeport on 10 October 2003 was 30.6ºC. The minimum was 23ºC. The temperature at 1900 was 27.1ºC, with 78% relative humidity. It is reasonable to expect that in the confined engine room the temperature and humidity would have been at the upper end, or in excess, of those recorded.

1.19 CHEMICAL INDUSTRY RELATED ORGANISATIONS

1.19.1 Chemical Industries Association

The Chemical Industries Association (CIA) is a leading trade association for the chemical and chemistry-using industries. Its membership is both national and international and represents manufacturers, supplier, consultant and service providers. The CIA is the UK's main representative association for the chemical industry.

1.19.2 British Association for Chemical Specialities

The British Association for Chemical Specialities (BACS) is the UK trade association that represents the interests of companies operating in the field of speciality and performance chemicals. Membership of BACS embraces manufacturers, marketers and professional consultants. BACS shares non-confidential technical data and disseminates relevant information from a variety of sources.

1.20 POST ACCIDENT REPORTS

Following the accident, a number of investigations were conducted and reports written. These include:

- Two brief summaries by Grand Bahama Shipyard Ltd.
- Northlands Industries Inc's report on behalf of Harris Pye Marine Ltd.
- West Atlantic Marine Ltd's Survey Report on behalf of the owners' P&I Club.
- Internal report by Golar Management (UK) Ltd.

SECTION 2 - ANALYSIS

2.1 AIM

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

2.2 CAUSE OF THE ACCIDENT

The most likely cause of the accident was the ignition of hydrogen gas that built up in the starboard boiler steam drum. The hydrogen accumulation occurred because of inadequate ventilation arrangements to release the gas to atmosphere, as it evolved during the chemical cleaning procedure. As the steam drum door was opened, air was drawn in and combined with the hydrogen gas to produce a mixture between the hydrogen's Lower Explosive and Upper Explosive Limits. This potentially explosive gas was not ventilated to atmosphere, nor was the confined space of the steam drum tested for toxic or flammable gases in accordance with normal practice. As the non-intrinsically safe, halogen lamp was passed into the steam drum, either the high temperature of the halogen bulb or lens glass, or an electrical spark from the lamp, ignited the gas and caused the explosion.

2.3 GENERATION OF FLAMMABLE GASES DURING CLEANING OPERATIONS

It is well known throughout the chemical cleaning and marine industries that reactions may occur between certain acids, i.e. chemicals used for cleaning and component materials, scale and other contaminants, which may result in flammable gases being generated.

Where contaminants are present then this may lead to the evolution of hydrogen gas at a much higher rate than can be expected from just the acid/steel reaction alone. In this case the degree and composition of scaling and contamination was not recorded and therefore its contribution to the degree of hydrogen evolution cannot be determined.

2.3.1 Calculation of the possible amount of hydrogen present

Southampton University's report at **Annex O** clearly explains how hydrogen gas can evolve when using sulphamic acid to clean steel structures such as boilers. A conservative estimate was made of the amount of hydrogen gas that was likely to have evolved through contact with the steel in the starboard boiler. This estimate, which did not consider the interaction of other possible contaminants, was based on the assumption that there was no effective ventilation and the inhibitor was 95% efficient. The report determined that, at the point of opening the steam drum, there would have been about 2.7m^3 of hydrogen present, giving a hydrogen air/mix of about 55%. This is well within the hydrogen LEL and UEL range of 4 -75%, i.e. an explosive mixture existed in the steam drum.

2.3.2 Evidence of hydrogen

All the physical evidence also points to the presence of hydrogen in the steam drum: there were no other known flammable gases present in the engine room at the time; the boiler fuel systems were fully isolated; and there was no LNG cargo on board.

When the steam drum was opened, there were no unusual smells or vapours. The overseer noticed a small blue spark as the halogen lamp was placed inside the steam drum, but as the gas ignited there was no visible flame. There was very little evidence of scorching in the areas surrounding the steam drum. The only real evidence of burning was to Mr Walton's clothing because he was in line with the steam drum door and received the full force and heat from the explosion, which caused his injuries. The overseer, on the other hand, was very close to Mr Walton; while some of his clothing was burned, he received far fewer heat-related injuries, suggesting the flame and heat duration was localised and of short duration.

All these factors are consistent with the properties of hydrogen, and of a hydrogen explosion/fire as described at paragraph 1.17.

2.3.3 Awareness of the risk of flammable gas accumulation during cleaning

Mr Walton's own instructions **(Annex H)** relating to the use of sulphamic acid specifically stated that:

> *"The acid cleaning process can generate flammable/hazardous gas – **do not perform hot work when acid is in circulation**.*"

It is, therefore, reasonable to assume that Mr Walton was fully aware of the possibility that a flammable gas, including hydrogen, could have been present when the steam drum door was opened. Although there was no equipment to test for the presence of hydrogen, Mr Walton would have been aware of the risk of explosion when a heat source was introduced into the flammable atmosphere.

It is possible that he did not appreciate the risk in this case, believing that the steam drum had been safely ventilating the evolving flammable gases during the cleaning process.

2.3.4 Warnings on Product and Material Safety Data Sheets

It is reasonable to expect that the chemical provider's Product and Material Safety Data Sheets and instructions for use, should reflect the explosive risk of hydrogen being evolved. Scrutiny of the four main chemical suppliers' documentation shows that only Nalco's Product Data Sheet **(Annex L)** specifically mentions the risk of hydrogen gas being generated, and gives advice on precautions to be observed.

Product instructions normally invite the user to read the appropriate Product and Material Safety Data Sheets. If the risk of producing hydrogen is highlighted, users will be better prepared, and are more likely to identify the need to put suitable control measures in place to reduce such risks.

New European legislation on the management of risks from chemicals, called REACH (Registration, Evaluation, Authorisation of Chemicals), is due to enter force later this year (1 June 2007). The communication requirements of the legislation should ensure that end users have the information that they require to use chemicals safely. Information relating to health, safety and environmental properties, risks, and risk management measures is required to be passed both down and up the supply chain.

2.4 BOILER VENTILATION ARRANGEMENTS

To prevent the build up of potentially explosive mixtures, there must be an effective means of ventilating the boiler while it is being chemically cleaned.

Mr Walton and the overseer understood the need to ventilate; the cleaning procedures from the various chemical providers all state the need for effective, large bore ventilation arrangements, as did Mr Walton's own documentation. What is less clear is if and how Mr Walton ventilated the boiler.

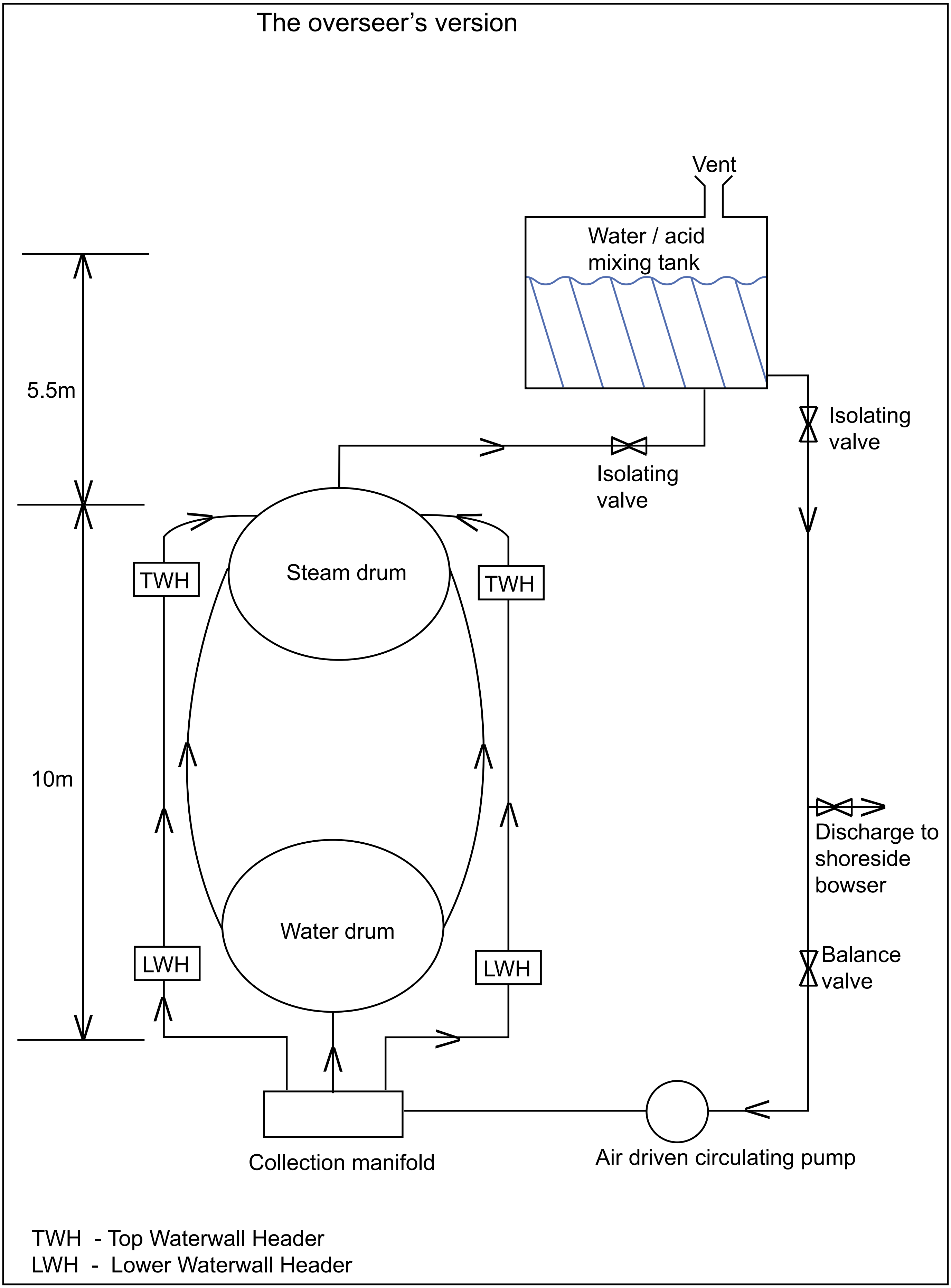
During the acid/water circulating phase, a small percentage of gases become entrained in the mixture, and will be released to atmosphere as the mixture returns to the non-gastight, water/acid mixing tank. It is not possible to assess how much will be released by this method, and this point is covered in the University of Southampton's report at **Annex O**.

Mr Walton's report at **Annex A**, following the boiler clean at El Ferrol, did not describe any dedicated ventilation arrangements. It is unclear what arrangements Mr Walton made to ventilate the boiler during the cleaning operation at GBSL. None of the ship's staff, Golar's Technical Superintendent, HPML personnel or the overseer were able to confidently state how the boiler was ventilated, either in El Ferrol or at GBSL. Additionally, none of those interviewed recall checking any ventilation arrangements, before or during the clean, or removing any venting arrangement following re-instatement of the boiler, after the clean was finally completed.

The overseer could not recall any dedicated ventilation arrangements. He was not concerned by this because he believed - mistakenly - that the acid/water circulation was the reverse to that which was actually arranged. He thought that the circulating pump was taking its suction from the water/acid mixing tank and delivering it back to the tank, via the top of the steam drum, as illustrated by the schematic at **Figure 15.** With this arrangement in place, he believed that the evolved gases were being driven from the top of the steam drum and discharging to atmosphere from the top of the water/acid mixing tank. This interpretation is understandable because the generic system drawing given by Mr Walton to the overseer does show this configuration. It might have been that Mr Walton presented the diagram as an alternative method, but did not fully explain the configuration in use at the time.

There are only two probable connections that would have been made to ventilate the boiler. The first would have entailed connecting a flexible hose to the second safety valve's 100mm bore flange **(Figure 12)** on the steam drum, and leading it to a position on the upper deck. This is considered unlikely. Most of those interviewed could remember only one hose fitted to the safety valves, and this would have been the gravity feed hose from the water/acid mixing tank.

The only other likely option would have been to connect a small bore hose to the steam drum air release cock arrangement **(Figure 16)**. This could have been fitted either to the goose neck, or directly to one of the flanges if the goose neck had been removed. In each case, the hose would have been led vertically, and secured, to allow the gases to escape to atmosphere.



Schematic of the overseer's interpretation of the boiler cleaning water/acid circulation

Figure 16

Starboard boiler – steam drum air cock arrangement

Had a hose been connected, there are a number of reasons why this might have been ineffective: the internal bore of the air release pipework was small, at 20mm; it was possible that it was of insufficient bore, even if unobstructed, to carry away the volume of gases being generated; it might have been that Mr Walton simply overlooked opening one or both of the valves; it was possible that the hose collapsed because of poor securing arrangements, causing the hose to "crimp" and create a blockage that prevented ventilation; and finally, a door might have been closed on the hose, or another object inadvertently placed on it, causing a restriction.

Unfortunately, none of the photographs taken after the accident show the air cock system, or the safety valve arrangements, so it is not possible to confirm whether or not ventilation hoses were fitted. There is evidence that HPML workers had been placed at strategic points around the cleaning system to address acid leaks, should they occur, but there is no evidence to suggest that anyone was allocated to check the venting arrangements.

Further evidence of inadequate ventilation was provided by the witnesses who reported there was a distinct suction as air was drawn in from outside, when the steam drum door was opened (see paragraph 1.6.3). Had the steam drum been freely ventilating, air would have been drawn in from the ventilation arrangement as the water in the boiler was being pumped out. In this case, there would not have been suction on the steam drum door as it was opened.

It can therefore be concluded that the ventilation arrangements were inadequate to prevent the build up of the explosive hydrogen/air mixture. This was because they were either obstructed, or were not fitted at all.

2.5 OPENING THE STEAM DRUM

2.5.1 Reason for opening

The steam drum was opened to assess the effectiveness of the chemical clean. While the relationship between Mr Walton and the overseer was amicable, there were differences in opinion regarding the effectiveness of using sulphamic acid. Although it appears that Mr Walton had not used Unitor Descalex before, he had often used sulphamic acid, while the overseer had not.

Mr Walton was also concerned that the overseer had recommended stopping the acid/water circulation well before the 8 -12 hour period stated in Unitor Descalex's instructions. This recommendation was based on the indications from his wire wool test (paragraph 1.6.3), which suggested that the boiler steel was being dissolved by the acid. Mr Walton, on the other hand, was not used to testing the effectiveness of the inhibitor, and might have doubted the interpretation of the test. However, he took the overseer's advice to stop the circulation, and instructed the HPML night shift workers to open the steam drum.

Opening the steam drum at this point was consistent with both the Unitor and Drew Marine procedures[1] at **Annexes I and J** respectively. Indeed, it should have been safe to do so if the boiler had been properly ventilated. Additionally, if the atmosphere in the steam drum had been tested for toxic and flammable gases, any ineffectiveness in the ventilation would have been identified.

Each case needs to be considered separately, and procedures will vary depending on the complexities and the extent of chemical cleans. However, in this case it would have been far safer to discharge the acid/water mix fully from the boiler, and then refill the boiler with fresh water to purge gases to atmosphere. The ventilation terminations could then have been tested with a suitable hydrogen gas detector, had one been provided, to confirm that there was no hydrogen gas present. On completion, the water could have been drained to a level below the steam drum door, the door opened, and the atmosphere tested to verify the absence of toxic or flammable gases.

2.5.2 Confined space regulations

Mr Walton and the overseer were both familiar with the safety procedures relating to entering confined spaces. Indeed, Mr Walton had recently completed the GBSL safety induction course that covered this subject.

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[1] Mr Walton was using the Unitor Descalex product to descale the boiler, but was following the Drew Marine procedure for SAF-Acid

The starboard steam drum was very clearly a confined space, and should have been subject to the restrictions relating to naked lights as laid down in paragraphs 10.2.3 and 10.2.4 of GBSL's H&S Manual. The latter reference specifically lists portable electric lights as a source of ignition. As such, the atmosphere inside the steam drum should have been subject to the restrictions at paragraph 10.4.4 of GBSL's H&S Manual: a Naked Light Certificate should have been issued before a portable light was placed inside the confined space.

It is possible that Mr Walton thought it was safe to inspect the boiler because he believed that either the generation of gases was minimal, or that these should have been expelled through the ventilation system.

Nevertheless, it is difficult to reconcile Mr Walton's actions and the overseer's lack of concern over using a non-intrinsically safe lamp to illuminate the untested, potentially explosive atmosphere of the steam drum. With no testing equipment readily to hand, it may be that they considered the risk of explosion to be minimal when compared with the delay that would have been incurred if GBSL had been required to formally verify that the space was gas free. However, the ship's staff had a certified explosimeter available which could have been used to test for hydrocarbon flammable gases (it would also register hydrogen, but not accurately), but this option was apparently not considered.

It was also possible that Mr Walton did not consider the confined space regulations to be applicable, because he only intended to put his arm into the steam drum and so his respiratory system would not be at risk. GBSL has since defined the meaning of "entry" in its Safety Management System as:

> "*… is considered to have occurred as soon as any part of the entrant's body breaks the plane of an opening into the space".*

While this specific definition was not documented at the time, the introduction of the non-intrinsically safe lamp into an unproven atmosphere was a serious error of judgment, and was contrary to GBSL's procedures **(Annex N)** and good practice.

2.6 IGNITION SOURCE

The halogen lamps supplied by HPML were not intrinsically safe. The main purpose of the lamps was to illuminate the boiler while it was being repaired. This was when hot work was taking place and therefore the lamps did not need to be intrinsically safe for that purpose. It was not considered that they could have been inadvertently used in the confined space of the steam drum, and they were not intended for that purpose.

Because neither Mr Walton nor the overseer had torches available to them, the lamp was used to light up the steam drum because it was close at hand.

Annex P identifies that various conditions, including open flames, hot surfaces, friction, electrical spark and a weak electrostatic spark from a human body can cause ignition of hydrogen/air mixtures.

There was no “hot work” in progress, and only Mr Walton and the overseer were in the vicinity of the steam drum. Neither of them smoked, so the possibility of ignition from a cigarette or open flame can be discounted. It is highly likely that the halogen lamp was the source of ignition as the explosion occurred immediately after it was placed into the steam drum.

The halogen lamp was badly damaged in the explosion **(Figure 10)**, and has since been disposed of. Because of the damage to the lamp, post accident investigators were unable to determine whether the electrical terminal block was faulty, or whether there were other electrical faults, which might have caused an ignition spark. There was also anecdotal evidence that the lamp might not have had an intact lens, although it has not been possible to verify this.

Tests by investigators, on an identical lamp, found that the stable surface temperature of the glass lens was 170ºC, and the temperature of the bulb, with the lens removed was 206ºC.

Hydrogen has a wide ignition temperature range in air (paragraph 1.17), and it is considered most likely that the ignition was caused by either the hot surface of the lens or bulb, or by an electrical spark from a faulty connection.

2.7 RISK ASSESSMENTS

Thorough and complete risk assessments are an integral part of a company’s procedures in ensuring it fulfils its Health and Safety obligations. By identifying the risks, appropriate control measures can be put in place to minimise risks to personnel and equipment.

While HPML had contracted Mr Walton to produce risk assessments as part of a separate, ongoing contract, these had not been presented. There were none to support either the cleaning procedure of 10 October 2003, or earlier HPML work conducted by Mr Walton.

None of the GBSL or HPML staff, Golar’s on site Technical Superintendent, or the overseer, asked to see Mr Walton’s risk assessments, or the Method Statement covering the chemical clean of *Hilli’*s boilers. Therefore, no-one knew if all the risks had been identified, or whether appropriate control measures were in place or had been considered.

Had risk assessments been presented, it is possible that the need to check the boiler venting arrangements would have been identified. Also, it is probable that the need to test the steam drum atmosphere for both toxic and flammable gases, with suitable test equipment, would have been highlighted. Had this been the case, the necessity for following the procedures set out in the GBSL Health and Safety Manual would also have been apparent. The Confined Space requirements would have been invoked, and it is most unlikely that the accident would have happened.

As it was, all those involved seemed to have accepted that Mr Walton was an expert in his field and that it was unnecessary to carry out any checks relating to the method of cleaning the boiler or of related safety procedures.

The chemical cleaning overseer was in a position to identify and advise against unsafe working practices in relation to the clean. It was he who proposed changes to Mr Walton's procedure. Indeed, the clean was stopped on the overseer's recommendation because there was evidence that the boiler steel was being attacked. It was following this, that the steam drum door was opened leading to the explosion. However, there is no evidence that the overseer had risk assessed any aspect of the clean or his own actions. Had he done so, there is a chance that he would have been prompted to invoke the confined space procedures and reduce the chances of the accident happening.

2.8 CONTROL OF THE CHEMICAL CLEAN

Harris Pye Marine Ltd had previously worked with Mr Walton when he was involved in post boiler repair chemical cleaning. However, HPML had minimal involvement with the chemical clean itself, other than providing the equipment and manpower to assist in its rigging. As a sub-contractor of HPML, it is surprising that there was no close scrutiny of Mr Walton's processes, and no-one appears to have appreciated the significance of the lack of a Method Statement or risk assessments to support the clean.

Golar's Technical Superintendent had an overview of the cleaning procedure because he had been briefed by Mr Walton. However, other than checking that the cleaning equipment did not present a health and safety hazard, the superintendent did nothing more to involve himself in the cleaning process.

The ship's crew provided some domestic-related support to the HPML team. They generally monitored the progress of the boiler work, but were not involved in any great detail other than witnessing key events such as pressure testing of the boiler to prove the integrity of the repairs. There was no involvement in assessing or monitoring the cleaning procedure. Unfortunately, the ISM system in force at the time has been replaced, so it has not been possible to assess what guidance was available to the crew on their level of responsibility in relation to contractors' work.

Had Mr Walton attended the morning Project Meetings, it is possible that a greater degree of control would have resulted by identifying, for example, the need to comply with confined space routines.

2.9 SIMILAR ACCIDENTS

There are numerous reports of boiler explosions relating to mal-operation, fuel leaks and inadequate purging procedures. Despite anecdotal reports of explosions occurring following chemical cleaning operations, scrutiny of the MAIB, IMO and HSE accident databases have found no evidence of these.

2.10 FATIGUE

2.10.1 Mr Walton

Despite Mr Walton suffering from diabetes and hypertension, he was considered to be fit by those who knew him well. Mr Walton was well rested on the evening of 9 October 2003. On the day of the accident, he had been working for about 14 hours, with a short break in the afternoon, in temperatures of over 30ºC and in humidity as high as

78%. The climb from the engine room, lower plate level, to the water/acid mixing tank position was about 20m and was up steep ladders. It is possible that he was feeling tired at the time of the accident, and that this affected his decision-making. However, there is no hard evidence to support this.

2.10.2 The overseer

The overseer had been travelling for about 24 hours before he landed at Grand Bahama at 2400 on 9 October 2003. Tired from travelling, he arrived at his hotel a short time later and had about 7 hours rest before arriving at GBSL on the following morning. The overseer stated that he felt alert throughout the day and there is no evidence to the contrary.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES

The following safety issues have been identified by the investigation. They are not listed in any order of priority.

1. The hydrogen gas that evolved as a result of the chemical clean accumulated in the starboard boiler steam drum because it was inadequately ventilated to atmosphere. [2.2, 2.4]

2. With the exception of Nalco's "Sea Shield" Safe Acid 79125, Product Description, none of the main chemical cleaning Product Data or Material Safety Data Sheets identifies the risk of evolving hydrogen gas. [2.3.4]

3. There was misunderstanding regarding the circulation of the water/acid mixture. This led to confusion over the ventilation requirements. [2.4]

4. There is no evidence that anyone checked the ventilation arrangements, if they had been installed, during the period of the chemical clean. [2.4]

5. The workers who opened the steam drum did not appreciate the importance of the suction they felt as the door was opened, and the implication this had on the effectiveness of the ventilation arrangements. [2.4]

6. The cleaning sub-contractor had no equipment to accurately test for the presence of hydrogen, and it was not normal procedure to do so. [2.3.3, 2.5.1]

7. Boiler cleaning procedures stated that the steam drum door was to be opened for inspection purposes following the chemical clean, once the water/acid level dropped below the door. This assumed the boiler was properly ventilated. [2.5.1]

8. A non-intrinsically safe, halogen lamp was introduced into the untested confined space of the steam drum, contrary to the Grand Bahama shipyard Ltd's safety procedures and the routines well known to the boiler cleaning sub-contractor. [2.5.2, 2.6]

9. No consideration was given to testing the steam drum atmosphere after the steam drum door was opened. [2.4, 2.5.2]

10. Neither the boiler cleaning sub-contractor, nor the overseer had risk assessments to identify the risks associated with the chemical clean, and no-one was aware of any formal control measures that were in place. [2.7]

SECTION 4 - ACTION TAKEN

4.1 HARRIS PYE MARINE LTD

Following the accident, Harris Pye Marine Ltd has completely reviewed its chemical cleaning procedures. The company now only uses personnel who have been trained and certified to an agreed standard by the chemical suppliers, Eazychem.

Permit to Work procedures are now in force. The company has established the use of written Method Statements, circulation diagrams, ventilation procedures, risk assessments and the mandated use of intrinsically safe lighting and hydrogen detectors. Cleaning procedures have been revised to reflect that boilers are to be filled with fresh water to purge gases before opening steam drums.

4.2 GOLAR SHIP MANAGEMENT

Since the accident, Golar's technical management transferred from Golar Management (UK) Ltd to Barber Ship Management which is based in Norway As a result, the ISM documentation has been replaced. The current version clearly details the crews' responsibilities with regard to the use of contractors.

As a result of the management change, many records have been rationalised, and documentation relating to post-accident actions is no longer available. However, the company's accident report recommended that:

- Ships' crews be reminded of the need for vigilance with regard to noticing non-safety equipment being used by shore workers in hazardous areas.
- The company's internal report be circulated throughout its fleet.

4.3 SBC-INTER APS

SBC-Inter ApS has established the routine use of hydrogen detectors for testing boiler cleaning ventilation terminals and boiler drums.

4.4 GRAND BAHAMA SHIPYARD LTD

The Grand Bahama Shipyard Ltd replaced its Health and Safety Manual with the Safety Management System on 12 May 2005. The new document contains revised instructions relating to confined and enclosed spaces and hot work routines. These are supported by a comprehensive list of related definitions.

4.5 MARINE ACCIDENT INVESTIGATION BRANCH

At the time of final publication of this report, the Marine Accident Investigation Branch will circulate a two-page account of this accident and the principle lessons to be learned from it. Among the issues the MAIB will stress is the importance of strict adherence to Confined Space routines and the need for risk assessments to support potentially dangerous maintenance tasks.

SECTION 5 - RECOMMENDATIONS

Nalco, Unitor, Drew Marine (UK) Ltd and Eazychem are recommended to:

M2007/127 Review their respective inhibited sulphamic acid, chemical cleaning procedural guidance and Product Data Sheets to:

- Reflect that hydrogen can be produced during the chemical cleaning process.
- Stress the importance of checking ventilation arrangements to ensure they are unobstructed during chemical cleaning.
- Advise that the boiler ventilation terminals fitted during cleaning, be tested for the presence of hydrogen.
- Advise that the boiler is emptied and refilled with fresh water, to purge it of gases, before opening the steam drum door.

M2007/128 Include the risk of hydrogen generation when formulating Material Safety Data Sheets to comply with the European legislation on the management of risks from chemicals (Registration, Evaluation, Authorisation of Chemicals) which is due to enter force on 1 June 2007.

The Maritime and Coastguard Agency, Health and Safety Executive, The Chemical Industries Association, British Association of Chemical Specialities, The Institute of Chemical Engineers, The Chartered Institution of Building Services Engineers and the Institute of Marine Engineering , Science and Technology are recommended to:

M2007/129 Promulgate to their membership and surveyors, where appropriate, the following safety issues, which have been identified in this investigation report:

- The risk of hydrogen generation when using sulphamic acid to clean steel structures.
- The need to ensure that ventilation is effective and unobstructed during chemical cleaning.
- The importance of Method Statements and risk assessments.
- The need for strict adherence to confined space entry routines.

The Maritime and Coastguard Agency is recommended to:

2007/130 Review the content of the Code of Safe Working Practices, to:

- Reflect the risk of hydrogen being generated when using sulphamic acid to clean steel structures.
- Recommend testing for hydrogen when conducting confined space entry routines following any chemical clean.

Marine Accident Investigation Branch
March 2007

Safety recommendations shall in no case create a presumption of blame or liability