INVESTIGATION REPORT
ON
M/S CELEBRATION GENERATOR ROOM FIRE
11JAN00

MARINE SAFETY OFFICE MOBILE
INVESTIGATOR: LIEUTENANT JERRY A. HUBBARD
OCMI: CAPTAIN JERZY J. KICHNER

SUBJECT: M/S CELEBRATION (LI), L8314134, GENERATOR ROOM FIRE ENROUTE MONTEGO BAY FROM NEW ORLEANS, LA, ON 11JAN00.

PRELIMINARY STATEMENT

At approximately 2350 on 11Jan00 the M/S CELEBRATION, operated by Carnival Cruise Lines, experienced a fire in the generator room. The fire was extinguished using the Halon fixed fire-fighting system. There were 1586 passengers and 667 crewmembers on board, with no reported injuries. The vessel departed New Orleans, LA, on 09Jan00 for a seven day western Caribbean cruise to Montego Bay, Grand Cayman, and Playa del Carmen/Cozumel, and was 100 miles northwest of Montego Bay at the time of the incident. Electrical power and propulsion were lost. The #1 generator was brought back on line at 0405, supplying partial electrical power, and the vessel continued under its own power to Montego Bay, where the passengers disembarked. Company representatives and engineering personnel then boarded the vessel and continued on to Mobile, AL, for repairs.

The cause of the fire was the failure of the four bolts securing the fuel oil (F/O) injection pump for cylinder A2 of diesel generator #3. These bolts were tested, and the cause of their failure was determined to be inadequate tightening of the four nuts securing the pump to the engine block. This allowed the pump to vibrate, resulting in progressive fatigue fracture of the bolts. The inadequate tightening is a result of two factors: (1) proper torque for this type bolt, in this application, is 171 ft-lb. The manufacturer service manual requires 147 ft-lb; (2) the nuts used were lock nuts with plastic inserts, which increases the friction between the studs and nuts during tightening. This reduced the torque applied to the nut by an estimated 20-50% than if a standard non-locking hexagonal nut had been used. (A detailed explanation of the test results can be found below, under the section titled **"<u>Conclusions</u>"**).

The pump is operated by a cam, which repeatedly strikes a plunger at the base of the pump internally. This repeated striking motion, coupled with the inadequate tightening of the nuts, caused the bolts' failure. The pump then became dislodged from the engine block, breaking the fuel supply line causing fuel being introduced under pressure to spray out freely, creating a flammable vapor, which then came in contact with the exhaust manifold and ignited. The fuel pump covers were blown off the engine, allowing the fuel oil to spray into the generator room, possibly finding an additional ignition source.

The fuel used is a heavy oil that is preheated and has a flash point of 176 F (80 C), and an ignition point of 662 F (350 C). The normal exhaust manifold temperature is approximately 700-750 F. The crew had received a low temperature alarm on cylinder A2, investigated it, and discovered a leak on the F/O pump fuel supply line prior to the fire.

Figure 1: Stern of the M/S CELEBRATION moored at AMI in Mobile, AL

They were responding to the situation by starting #2 generator, to shift the load, when the fuel supply line completely severed and the fuel oil vapors ignited. The crew then activated the Halon system, which extinguished the fire. A fire team was sent into the space to investigate. The smoke, which was described as heavy, caused the #2 and #1 generator to stall, resulting in a complete loss of electrical power. The emergency generator came on-line, but is not designed to support the main engines, which resulted in a complete loss of propulsion. The emergency generator only supports critical systems, such as emergency lighting and the navigation system. Approximately twenty minutes later, the emergency generator overheated and was shut down. The vessel went on emergency battery power at that time. The emergency generator cooling system was repaired, and brought back on-line approximately one hour later. No general alarm was sounded after the incident and the passengers were not alerted. The Captain made an announcement concerning the situation over the ship's public address system. (A detailed chronology of these events can be found below, under the section titled **"Findings of Fact"**).

FINDINGS OF FACT

Vessel Description

Owner/Operator: Celebration Cruises, Inc./Carnival Cruises, Inc.
Flag: Liberian
Class: Lloyds
Official Number: L8314134
Service: Passenger
Gross Tons: 47,262
Propulsion/Horsepower: Diesel reduction /31970 Brake HP
Length: 734 ft
Date of Build: 1987 in Malmo, Sweden

Environmental Conditions

Visibility: Good at 12 miles
Weather: Clear
Winds: NE at 5 kt
Air Temp: 75
Seas: 4 ft

Crew Involved in the Incident

Master: Donato Giuseppe
Staff Captain: Pier Paolo Scala
Chief Engineer: Duce Mario
2nd Engineer/Watch Leader: Carrino Salvatore
3rd Engineer: Saltalamacchia-Gianfranco

Fire Fighting Equipment

1. The Auxiliary Engine Room is located on deck 1 between frames 96 and 112 *(See Diagram 1)* and is protected by a Halon 1301 System, consisting of four 154.2 KG bottles, each with one nozzle. The system is activated at a Remote Release Station located in the passageway, immediately outside the Engine Control Room on deck 2, and adjacent to the door leading down to the engineering spaces. There is a separate Halon system and Remote Release Station for the Main Engine Room, Auxiliary Engine Room, and Purifier Room. The Remote Release Station consists of a cabinet and status indicator panel. When the panel door is opened, an electronic horn and rotating beacon are activated only in the compartment served by that panel. This is the only location where the Halon systems can be activated.

2. Two pilot gas bottles within the cabinet, plus main and reserve actuation cylinders activate release of the Halon. The ventilation system in the space protected by the Halon system can be secured two ways, manually or automatically. It can be secured manually by pushing a button on the outside

of the Remote Release Station panel door. Automatic ventilation shut down is provided by activation of a pressure switch inside the Remote Release Station panel door, when the panel door is opened. A Halon Alarm Panel is located on the Bridge and is also activated when the Remote Release Station panel door is opened**.**

3. Per the vessel's system description manual, the Auxiliary Engine Room is 1860 cubic meters, requiring 582 KG of Halon. There are four bottles at 154.2 KG each, for a total of 616.8 KG of Halon available.

Fire Fighting Crew

The vessel has designated crewmembers to serve as fire fighting teams who are trained to wear a self-contained breathing apparatus (SCBA). The Captain summoned the Alpha Team to the marshaling area in response to the fire. The Alpha Team is a designator meant only for the crew, and is intended not to alert the passengers of their purpose or situation. The six-person team responded and a two-person team entered the Auxiliary Engine Room.

Ventilation

The ventilation system in the Auxiliary Engine Room consists of two supply fans and one exhaust fan. At the time of the fire, the two supply fans were on high, and the exhaust fan on low. (Detailed information on this system is found, below, under the section titled "*Post Casualty Analysis*").

Watertight Doors

1. There are 20 hydraulically operated watertight doors divided into six groups. They can be operated from the Central Control Panel on the Bridge, the Emergency Stations, or locally.

2. To isolate the Auxiliary Engine Room, Group 2 and 3 must be activated to close door #4 and #5, respectively. Watertight door #4 separates the Main Engine Room and Auxiliary Engine Room at frame #96. Watertight door #5 separates the Auxiliary Engine Room and the Purifier Room at frame #112 ***(see Diagram 1 for illustration)***.

Auxiliary Generators

1. The auxiliary generators are WartSila Vasa 32 V-engines. They are 12 cylinder turbo-charged, four-stroke diesel engines with direct fuel injection. The fuel oil (F/O) injection pumps are mounted to the engine block using a four studs and nuts arrangement. They are operated by a cam roller, which pushes a plunger up and down to feed the fuel ***(see Diagram 2 for illustration)***.

2. The F/O pumps and piping are located in a closed space, which is heat insulated for using heavy fuel oil. While the engines are normally run on heavy fuel oil, they are started using diesel fuel. The heavy fuel oil is blended in over a 30-45 minute period. This is to facilitate starting, and to keep the system clean. To ensure flow, the heavy fuel oil is preheated to 275 F (135 C). Diesel fuel is again blended in at shut down to prevent the cool heavy fuel oil from clogging the fuel lines.

3. There are 6 cylinders on each side of the engine. Each cylinder has one F/O pump. There is a cover for each three pumps, with two covers on each side of the engine. These covers fit into a slot with four threaded knobs at the top to secure the cover. Each cylinder has both a direct reading gauge and a remote reading in the Engine Control Room for cylinder exhaust temperature. The exhaust manifold is located at the top and center of the engine between the cylinder banks.

DIAGRAM 1

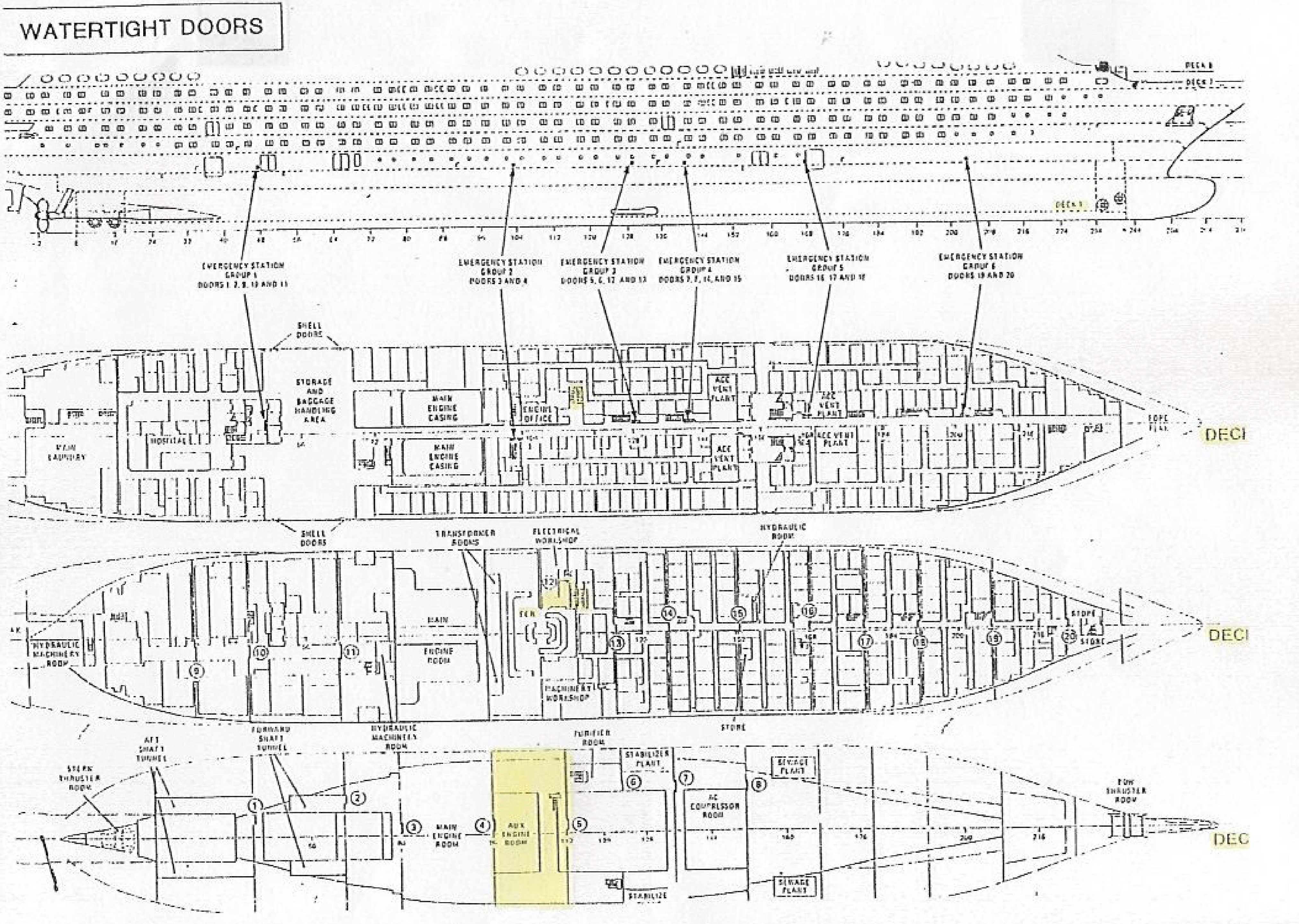
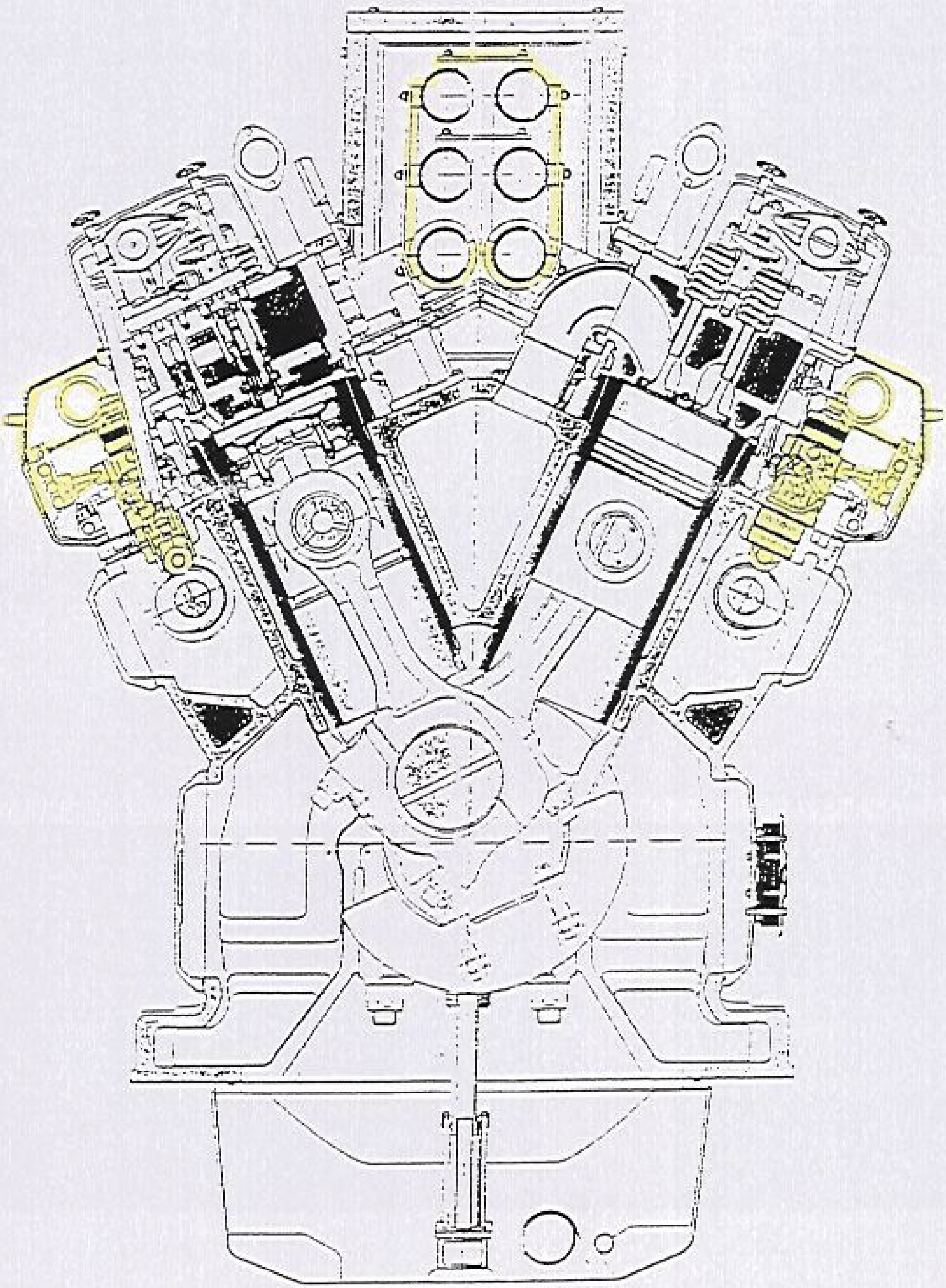

WATERTIGHT DOORS
EMERGENCY STATION GROUP 1 DOORS 1, 2, 9, 10 AND 11
EMERGENCY STATION GROUP 2 DOORS 3 AND 4
EMERGENCY STATION GROUP 3 DOORS 5, 6, 12 AND 13
EMERGENCY STATION GROUP 4 DOORS 7, 8, 14, AND 15
EMERGENCY STATION GROUP 5 DOORS 16 17 AND 18
EMERGENCY STATION GROUP 6 DOORS 19 AND 20
SHELL DOORS
STORAGE AND BAGGAGE HANDLING AREA
MAIN ENGINE CASING
ENGINE OFFICE
A/C VENT PLANT
HOSPITAL
MAIN LAUNDRY
TRANSFORMER ROOMS
ELECTRICAL WORKSHOP
HYDRAULIC ROOM
MAIN ENGINE ROOM
MACHINERY WORKSHOP
HYDRAULIC MACHINERY ROOM
STORE
AFT SHAFT TUNNEL
FORWARD SHAFT TUNNEL
STERN THRUSTER ROOM
PURIFIER ROOM
STABILIZER PLANT
AUX ENGINE ROOM
AC COMPRESSOR ROOM
SEWAGE PLANT
BOW THRUSTER ROOM
DECK
DECI

DIAGRAM 2

Cross-section of Wärtsilä VASA 32, V-engine



Chronology of the Fire

1. At 1754 on 09Jan00 the vessel departed New Orleans, LA, enroute Montego Bay, Jamaica. On the evening of 11Jan00, the Oiler, Second Engineer (2/E) and Third Engineer (3/E) were on watch, with the 2/E acting as Watch Leader. Generators #1 and #3 were on-line.

2. While at position N 19-17.0, W 079-45.0, approximately 100 miles northwest of Montego Bay at 23:38:43 local time, the 2/E was in the Engine Control Room and received a low temperature alarm on cylinder A2 of #3 generator. Cylinder A2 indicated a low temperature of 667 F (353 C), with the normal temperature being 743 F (395 C). He directed the 3/E to investigate. It took approximately 20-30 seconds for the 3/E to arrive at the generator.

3. At 23:39:00 the 2/E received a high temperature alarm on cylinder A1, indicating 817 F (436 C), with 747 F (397 C) being the normal temperature. The 3/E confirmed the readings on the gauges at the cylinders, removed the F/O injector pump cover for cylinder A2 to investigate, and discovered what he described as a drip from the weld in the supply line feeding the pump.

Figure 2: F/O supply line for affected pump. Notice break at welded connection on the flange.

(The 3/E was questioned thoroughly concerning his description of the leak as a drip, not a spray. The pressure on this line was 72-87 PSI). The 3/E stated that he had replaced the cover, taking a couple of turns on the knobs to secure the cover in place, and notified the 2/E by radio. He recommended the 2/E start #2 generator and shift the load from #3 generator.

4. The 2/E started #2 generator and, with the cooperation of the Chief Electrician, was shifting the load from #3 to the #2 generator. The Chief Engineer (C/E) and Staff Chief Engineer (SC/E) were notified, as per SOP, and they responded. The 3/E reported to the Engine Control Room to assist.

5. At 23:42:36 they received a F/O oil pressure alarm for #3 generator. It was 42 PSI (2.9 bar), with 72-87 PSI (5-6 bar) being the normal range. At 23:42:51 they received a F/O pressure alarm for generator #1 at 70 PSI (4.81 bar), slightly below normal. This indicated that the leak at the F/O injector pump on cylinder A2 on generator #3 was affecting the overall pressure supplied by the main F/O pump. The main pump supplies all three generators. The leak on #3 generator was sufficient enough to drop the overall pressure in the supply lines and cause the alarms.

6. At 23:43:06 they received a low-pressure alarm indicating 29 PSI (2 bar) of F/O pressure to all generators. At 23:43:41 alarms for #3 generator indicated low temperatures for several cylinders. At 23:44:32 diesel generator #2 (DG2) circuit breaker closed, indicating generator #2 had the load.

7. At 23:45:41 they received an alarm indicating #3 generator had shut down. The 2/E reported hearing a loud bang, and generators #1 and #2 also began to lose power and shut down. At 23:45:55 they

suffered a complete loss of electrical power, resulting in a loss of the main engines.

Figure 3: Damaged electrical panel directly adjacent to #3 generator.

8. After a 10-second delay on the main switchboard, the emergency generator started, providing emergency lights and power to the essential navigation systems. The C/E arrived in the Engine Control Room on deck 2. He opened the door to the ladder leading down to the engineering spaces on deck 1, which is located just outside the Engine Control Room and opposite the Remote Releasing Station for the Halon, and was faced with a thick black wall of smoke. He immediately deemed it impossible to enter; and, with the SC/E at his side, they turned to activate the Halon system.

9. Concerned for the crew, the C/E asked the 2/E where the Oiler was, and he was assured he was not in the engineering spaces. Using the key to open the Remote Release Station, the SC/E activated the Halon system. The alarm log indicates this happened at 23:48:29. It was believed that the fire was immediately extinguished, but an entry by a fire team would be needed to confirm it.

10. With the vessel on emergency power, all Officers had reported to the bridge. The C/E spoke with the Captain who summoned the Alpha Team to the marshaling area on deck 3, which is a loading dock in the immediate vicinity of the a ladder leading down to the engineering spaces. The Staff Captain (S/C) and the Safety Officer (S/O) also reported to the marshaling area. The Alpha Team was dressed out and ready when they arrived, which was within 10 minutes of initial notification.

11. The Alpha Team went below, and two of the six-person team entered the Auxiliary Engine Room. They confirmed that the fire was extinguished, and used portable CO2 extinguishers to cool hot spots. With the Halon system expended, there was no fire protection. A two-person fire watch was maintained in the Auxiliary Engine Room in the event of a re-flash. The S/C stated that the watertight door (WTD) between the Auxiliary Engine Room and Purifier Room was open when Alpha Team arrived.

Figure 4: Fire damage to temperature monitoring equipment on #3 generator.

12. With the vessel on emergency power, an announcement was made via the public address system to inform the passengers that there had been a fire, that it was extinguished, and that they were working to restore power. After approximately 20 minutes, the Chief Electrician was sent to check on the emergency generator, and reported to the C/E that it was steaming. The C/E ordered the Chief Electrician to shut it down. The vessel was only on battery power at this point, and restoring the emergency generator was the C/E's priority. Estimated life of the batteries was one hour. The C/E called for the First Engineer (1/E) to investigate the steaming emergency generator, due to his expertise in machinery. Due to the steam, the C/E concluded it was not an electrical problem.

13. The 1/E reported the emergency generator had overheated, and he determined that the louvers allowing cooling air to flow in did not open. This caused the generator to overheat, requiring a supply of water to refill the radiator. A bucket brigade was assembled to transport water from the fresh water tank to the radiator. Once the radiator water supply was replenished, the emergency generator was restarted. Unsure of the damage from the overheating, they monitored it closely for a few minutes and then shut it down to inspect it. After gaining some assurance that it was not damaged, they restarted it and allowed it to run continuously with a crewmember standing by.

14. With the emergency generator on-line, they had power to the lube oil pump, and starting air pressure to support starting #1 generator. Generator #1 was then started; however, it shut down because of a lack of air supply, due to the air filters being clogged by soot from the fire. The emergency generator, due to possible damages from overheating, was then shut down while the filters for generator #1 were cleaned. The emergency generator was later restarted to support the restart of #1 generator, which was brought on-line at 0405 without further incident. Generator #1 supplied power to the port main electrical bus, and the emergency generator shut down automatically.

Figure 5: Fire damage to the air intake and overhead above #3 generator.

15. Further inspection revealed damaged wiring on generator #2 and extensive damage to generator #3, rendering both inoperative. The vessel's power supply was now limited to the output of the starboard shaft generator and generator #1. This limited power supply excluded the use of the air conditioning, fin stabilizers, and bow and stern thrusters. Damage to the control air system delayed starting the main engines, which also required heavy fuel oil heated by the auxiliary boiler. Repairs were made, F/O was heated, and the #1 generator was shifted from diesel fuel to heavy fuel oil. At 0620 the main engines were brought on-line on the first attempt. The electrical load was shifted from the #1 generator to the starboard shaft generator. The #1 generator was shut down and placed on standby. The crew then focused on restoring equipment affecting the comfort of the passengers. The vessel continued the voyage to Montego Bay without further incident.

16. The passengers disembarked in Montego Bay on 12Jan00. Company officials and manufacturing representatives

boarded the vessel to conduct an assessment. The CELEBRATION arrived in Mobile, AL, on 15Jan00.

Investigation Analysis

1. MSO Mobile Port State Control (PSC) personnel boarded the vessel at the Mobile Ship Channel sea buoy, and conducted a modified fire fighting/CVE exam and ISM check. This included all fire screen doors, WTDs, STCW, licenses, fire/smoke detectors, spot check of life rafts/boats, and navigation bridge equipment. Checks of the Safety Management System (SMS) were made and compared to the actions taken by the crew. (The results can be found below, in the section titled **"Conclusions"**).

2. An investigative team joined the vessel at Atlantic Marine in Mobile, AL, and conducted extensive interviews with the crew, Lloyds, and a Flag State representative. Multiple visits were made in follow-up interviews to secure additional information and documents.

3. Four bolts were discovered sheared off on the F/O injector pump for cylinder A2 of #3 generator. These bolts were sent to Lucius Pitkin, Inc., in New York, NY, for testing. Included were a random sample of other F/O injector bolts from the other generators. All of these bolts on all three generators were replaced as a precaution. The C/E was questioned concerning problems or the replacement of these bolts. He did not recall any previous failure of a F/O pump or a requirement to ever retighten these mounting bolts. When pump maintenance is due, the pump is removed and replaced with a new or rebuilt pump, which occurs every 10,000 hours.

Figure 6: Fuel oil injection pump on #1 generator. Notice supply line coming from bottom left side and coiled injection line to cylinder on top. Cylinder head is immediately adjacent and above the pump with the exhaust manifold above the cylinder head. These pumps are normally protected by heavy metal covers, which are removed in this photo. There is free communication of air around the cylinder head and between the pump and exhaust manifold.

4. All four F/O injection pump covers were found dislodged from generator #3 and strewn about the deck. It is believed that the pressure created by the fuel oil vapor ignition by the exhaust manifold blew the four covers off the engine. Analysis of the F/O properties and the exhaust manifold temperature show them sufficient to ignite the F/O vapors.

5. The C/E stated that the normal operating ventilation condition for the Auxiliary Engine Room is both supply fans running at high speed, and the exhaust fan running at low speed. This condition maintains a positive pressure in the space for maximum engine efficiency. Good airflow is essential for engine/generator cooling. Looking at the position of the supplies and exhausts, there is good mixing of air with minimal "dead spaces." Most of the supply air is directed forward towards the generator intakes. The air would mix with the existing air in the space and be warmed by the diesel generators, which would cause it to rise towards the overhead and eventually be drawn out by the exhaust fan. The space is estimated to be 65,685 ft^3. The combined capacity of the supply fans is 75,432 ft^3/min

- more than one complete air change per minute. As a term of reference, 46 CFR Subchapter D requires one complete air change in less than 3 minutes for pump rooms handling Grades A, B, or C cargoes.

Examination of the Halon system and ventilation was made to determine if there was a positive or negative pressure within the Auxiliary Engine Room and how that related to the WTDs being open. Empirically, it is difficult to determine if positive pressure
(> atmospheric) existed within the Auxiliary Engine Room. From a practical standpoint, it is advantageous for the ship to have positive pressure in the Auxiliary Engine Room (or any space that had internal combustion engines that scavenged combustion air from within the space), since it would increase the efficiency of the diesel generators. An attempt is made below to account for the airflow into and out of the Auxiliary Engine Room. What is undefined for this system is the relative pressure in the adjacent spaces (Main Engine Room & Purifier Rooms), due to the WTDs being open, and allowing mass to enter/exit the system. It is normal operating procedure to keep a positive pressure (> atmospheric) in the main propulsion space. The dead head pressure (zero flow, max pressure) for the supply fans into the Auxiliary Engine Room is ~ 0.3 psi (pressure difference between intake & exhaust).

Mass/Flow balance for Auxiliary Engine Room: Assume that the space is an open system at constant temperature and pressure.

Material balance:

Accumulation within the system
= 0 ft^3/s

2 supply fans on hi speed
2(628 ft3/s) = +1257 ft^3/s

1 exhaust fan on low speed
-423 ft^3/s

2 diesel generators on line
2(176 ft3/s) = -353 ft^3/s

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Net (should be equal to zero)
+480 ft^3/s

To balance the system out, either there is another output for the system (a door open into a space with a lower pressure) or there is some positive pressure (> atmospheric) in the system, and the flow rates from the supply fans are actually lower than optimum. With regards to the latter case, as pressure accumulates within the system, initially during fan start up, the flow rate for the supply fans begins to decrease, and the flow rate of the exhaust fan begins to increase, until some equilibrium for the system is reached.

Considering other evidence, it is most likely that a combination of both cases existed - the WTDs at either end of the Auxiliary Engine Room were open, and that some positive pressure (as compared to adjacent spaces) existed within the space. Whether the doors at either end of the space served as entrances or exits for air depends upon the pressure in the adjacent spaces. Both adjacent spaces were supplied with forced ventilation. There was very little smoke damage in the adjacent spaces, however, since the doors were so low, most of the smoke would have been near the overhead.

6. The maintenance records for #3 generator were reviewed. The fuel injection pump for cylinder A2 on diesel generator #3 is scheduled for maintenance every 10,000 hours. This was last accomplished at 37,061 hours. There were 9,773 hours of operation on the pump since its last maintenance, leaving 227 hours till next maintenance was due. The last maintenance performed on this pump was April 12, 1998, and it was

replaced, as scheduled, at that time. The manufacturer, WartSila, calls for maintenance every 16,000 hours, which only calls for replacing the pump. No maintenance is performed on the pump itself. Pumps are sent to a repair facility for overhaul.

7. The maintenance records for the emergency generator were examined. The detailed history shows "Replaced two new radiator heaters, gaskets for emergency diesel alternator," and tested OK on 15Nov99 as the last maintenance. The C/E stated that the generator is test run weekly, usually in Montego Bay or Cozumel.

8. MSO Mobile Inspections personnel investigated other possible ignition sources, in addition to the exhaust manifold. It is their opinion that there was no electrical ignition sources involved, based on their inspection of the electrical sources in the immediate area.

9. The manufacturer's normal procedures were followed in starting generators #1 and #2, and in attempting to shut down generator #3. The generators are started using diesel and then F/O is blended in over a 45-60 minute period. The F/O is preheated to 275 F (135 C). Prior to shut down, the generators are shifted to diesel to flush the heavy F/O from the system.

10. It should be noted that on 13Aug97, the USNS BOB HOPE (CG053430) was being outfitted, and the WartSila WN-25 engines were tested. The CELEBRATION has WartSila Vasa-32 engines. During the testing of the WN-25s on the BOB HOPE, the F/O injector pump mounting bolts suffered the same type failure as the CELEBRATION. CWO John Catanzaro of MSO Mobile Inspections Department, formerly assigned to MSO New Orleans, witnessed this failure. A review of MSO New Orleans files has no details, other than a description in MSIS. CWO Catanzaro recalled a technical bulletin being issued by WartSila; however, WartSila (New Orleans) has no record of any technical bulletin for the WN-25 or Vasa-32 concerning F/O injector pump mounting bolts. The Military Sealift Command (MSC), operator of the BOB HOPE, and American Bureau of Shipping (ABS) were asked to search their records for any information on this incident, with negative results.

CONCLUSIONS

1. The crew's response to the fire was adequate. There were no language barriers detected in the interviews. All of the engineering crew directly involved spoke Italian.

2. The fire detection and fixed fire fighting systems worked, as designed.

3. Checks of the Safety Management System (SMS) indicated that the C/E and SC/E could not act on their own judgment in discharging Halon. Various steps are required. These steps include securing the ventilation, however, this is done automatically when the Remote Releasing Station cabinet door is opened. Manual 13, Section 7, of their SMS contains a flowchart for "Fire Out of Control – Engine Room Fires," which shows the Captain having the ultimate authority for releasing the Halon. The C/E releasing the Halon was not in accordance with their SMS. The C/E did secure the ventilation and ensure the space was not occupied before discharging the Halon.

4. The C/E gave no orders for the WTDs to be closed. The Staff Captain, who was directing the Alpha Team, stated that WTD #5, between the Purifier Room (aft) and the Auxiliary Engine Room, was not closed when the team arrived on scene. We found no crewmember that could verify that the

WTDs were closed. The WTDs and Halon system are not connected in any way. The WTDs not being closed is not in accordance with the SMS (Manual 13 Section 7).

5. Ventilation was secured in all engineering spaces (fore and aft) due to loss of power, thereby enhancing the effect of the Halon in the Auxiliary Engine Room. The main F/O pump supplying F/O to all three generators was shut down, due to loss of power, which secured the supply of F/O to the broken lines and stopped the leak. This loss of power, which secured the air and fuel supply to the fire, was a benefit.

6. Replacement of the F/O injector pump for cylinder A2 was within the prescribed time frame. Cylinders A5 and A6 were overdue by 352 and 104 hours, respectively. This must be tempered against the fact that the manufacturers recommended replacement is due at 16,000 hours, not 10,000 hours.

Figure 7: Affected F/O pump mounted on workbench for inspection. Notice roller on bottom of piston for cam operation.

7. The testing of the F/O injector pump mounting bolts and nuts conducted by Lucius Pitkin, Inc., in New York, NY, concluded the following:

a. There was no evidence of any pre-existing metallurgical defects with the four bolts or fuel oil supply lines.

b. The bolts exhibited no damages from shear loads, tensile overloads, or overtorquing.

c. The bolts failure occurred by way of progressive fracture in the nature of low-stress, high cycle fatigue.

d. The fatigue fractures initiated from one side of the thread roots, and progressed across 75%-85% of the bolt cross sections, indicating they had been subjected to relatively low cyclic bending loads.

e. Fretting/pounding marks were evident on the bolt shank and nut fraying surfaces, indicating oscillations occurred during operation, which induced cyclic stresses in the bolts.

f. It is apparent that the fatigue fracture of the bolts occurred due to inadequate pre-load. The service load exceeded the pre-load and subjected the bolts to a cyclic load, which, over time, resulted in the fracture.

g. In general, fasteners should be pre-loaded to at least 80% of the yield load of the fastener. This would have equated to 171 ft-lb of torque applied to the steel nut of these bolts.

h. According to the service manual for these F/O injector pumps, these bolts would have been torqued to 147.6 ft-lb, or 69% of the yield load of the fastener.

i. In addition, the bolts were

tightened using lock nuts with plastic inserts, which increased the friction between the bolt and the nut during tightening. This increased friction reduces the torque applied to the nut by an estimated 20-50%, than if a standard, non-locking hexagonal nut had been used.

j. In summary: inadequate tightening of the nuts securing the F/O pumps resulted in vibration of the entire pump assembly. Fatigue cracks started at the bolt thread roots and promulgated across the bolt until it could no longer withstand the applied load from the cyclic cam action, causing the pump to become dislodged from the engine and breaking the fuel oil supply lines.

8. There is a direct path for the F/O vapors to make contact with the exhaust manifold, and this air space is common to all four F/O injector pump covers. All four fuel oil injector pump covers on #3 generator were blown off the engine, which supports the theory that the exhaust manifold ignited the fuel oil vapors, and it flashed in and around the cylinder heads of the engine. Had the ignition not occurred under these covers, the covers, likely, would not have been blown off and strewn about the deck.

9. The fuel oil was RMG 35, purchased from BP Marine in New Orleans, and distributed by John W. Stone Oil Distributors via the barge S-14. The flash point of the fuel oil is 176 F (80 C), and ignition point is 662 F (350 C). The normal operating range of the exhaust manifold is 752 F (400 C) at 100% load. Normal operating load is 70%-80%. The exhaust manifold is the likely source of ignition, however, there were other electrical sources, and it can not be determined with certainty. There was a spray pattern of F/O on the bulkhead, indicating that there was F/O spraying freely in the vicinity of the broken F/O supply line, which may have found another ignition source. The spray pattern on the bulkhead covered approximately a 3 x 8 foot area immediately adjacent to electrical panel and steam lines.

10. There is no Engine Room watch routine for removing the F/O injector pump covers and inspecting the pumps. The covers are removed for inspection, as needed, such as in response to a temperature alarm. The C/E stated that there is no consistent frequency for temperature alarms. When the alarm is received, the crewmember on watch in the Engine Control Room dispatches another crewmember to investigate.

11. The four F/O injector pump covers are each secured by four bolts. These bolts have large knobs, requiring no tools to secure or release the covers. Each generator was missing at least 6 of the 16 bolts, with some covers missing 3 of the 4 required. The remaining bolts were stripped and incapable of securing the covers. The F/O leak and fire may have been contained to the cylinder head space of the engine, had these covers been secured, rather than spraying freely over a large area.

12. The crew believes that the emergency generator overheated, due to the louvers not opening to allow airflow. However, the louvers worked in every test run after the overheating and shut down. No deficiencies were found in the operation of the louvers, and there were no repairs made. MSO personnel witnessed the operation and testing of this equipment.

<u>RECOMMENDATIONS</u>

1. The covers for the F/O injector pumps must be in good condition, and secured with all four fasteners each time they are opened. This fire may have been contained in the top of the engine, if the covers had not blown off. The WartSila representative confirmed

that the purpose of the covers is to contain leaks, and keep the area clean.

2. Vessels of same class should be examined for:

a. louvers on the emergency diesel generator operating properly;
b. proper bolts, nuts, and torques on all fuel injector pumps; and,
c. the condition of all F/O pump covers and their fasteners.

3. MSO Mobile Port State Control Branch issued two requirements:

a. improve the description of the steps necessary in fighting a fire in the engine room; include two different procedures: one for fighting a minor localized fire, and another for large fires requiring the fixed fire fighting system; and,

b. state clearly the C/E's authority to discharge the fixed fire fighting system.

4. With the above modifications made, the watertight doors should be secured, as required by the SMS, before discharging the Halon. Had the adjacent spaces not lost ventilation due to loss of power, it may have effected the efficiency of the Halon system in the affected space.

5. No crewmember was in the vicinity of the emergency generator after it went on-line and then overheated. An engineering watch should be maintained over the emergency generator while it is running. There are no warning indicators for this generator in the Engine Control Room, and it was fortunate that the crewmember shut it down before it was severely damaged. It was critical to restoring partial power to the vessel and safely returning to port.

6. The weekly test run of the emergency generator should be logged.

7. WartSila should conduct a review of records to ensure there is no trend in failure of the F/O injector pump mounting bolts, regardless of the engine model. The pumps are under a heavy cyclic load.

8. WartSila should review the service manual and consider the torque listing for the nuts that secure the F/O injection pumps. Lucius Pitkin proposes 171 ft-lb for this type bolt in this application. In addition, the use of self locking nuts with plastic inserts must be considered in computing the proper torque.

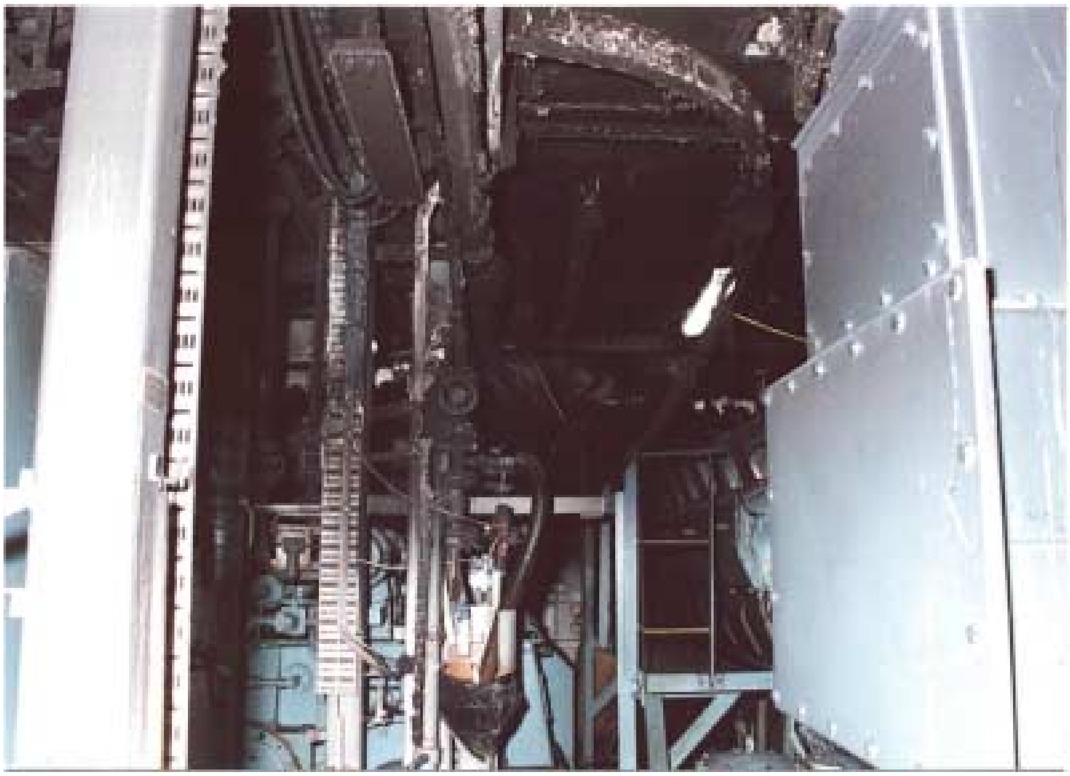
If you have any questions or concerns, contact Marine Safety Office Mobile, Investigations Department, at 334-441-5207.

Forward bulkhead of auxiliary engine room looking starboard.

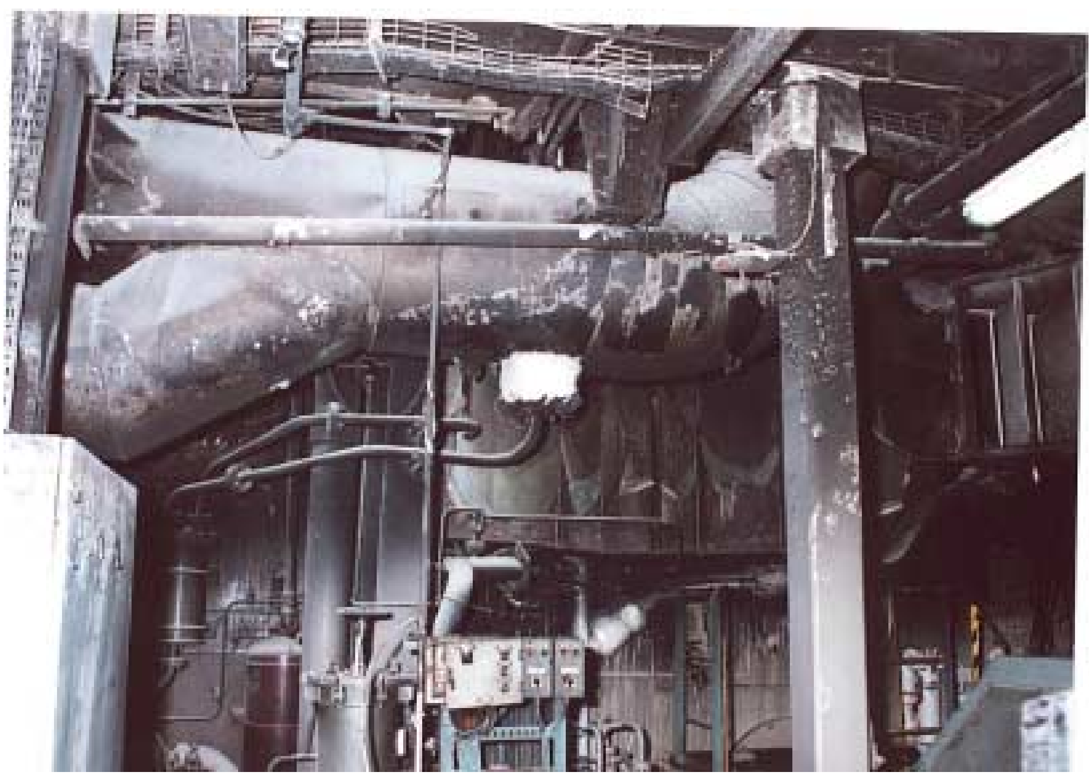
Forward starboard corner of Generator #3.
Fire started in this area.

Overhead above Generator #3.

Port side of Generator #3 looking aft.

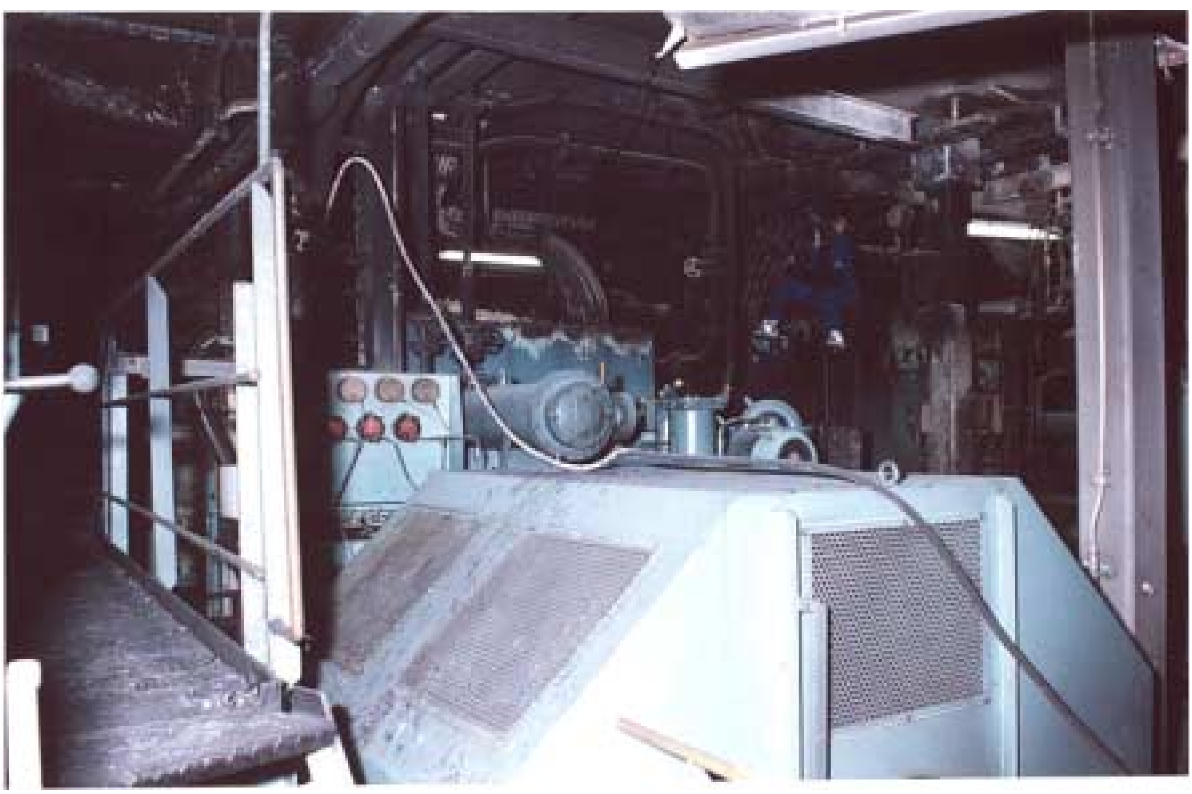


Machinery between Generators #3 and #2 with damage overhead looking forward.



Aft starboard corner of Generator #3.

Port side of Generator #3 looking aft.



Machinery between Generators #3 and #2 looking aft.