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U.S. Department of Transportation
United States Coast Guard

AD-A158 737

COMMANDANT'S INTERNATIONAL TECHNICAL SERIES

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VOLUME VIII

Fire Aboard the M.S. SCANDINAVIAN SEA

on March 9, 1984

Technical Assessment

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USCG CITS-85-1-1

85 8 28 091

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
	AD-A158 237	

4. Title and Subtitle
Fire Aboard the M.S. SCANDINAVIAN SEA on March 9, 1984.
Technical Assessment

5. Report Date
January 1985

6. Performing Organization Code

7. Author(s)
Staff

8. Performing Organization Report No.

9. Performing Organization Name and Address
Marine Technical and Hazardous Materials Division, USCG.
Human Performance Division, Bureau of Technology, NTSB

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Commandant (G-MTH-4/13)
U.S. Coast Guard
2100, Second Street, S.W.
Washington, DC 20593

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
This technical report was prepared as background material for the Marine Board of Investigation that examined the SCANDINAVIAN SEA FIRE of March 9, 1984.

16. Abstract
The forward third of the passenger vessel SCANDINAVIAN SEA was destroyed by a fire which began while at sea off the Florida coast on March 9, 1984. This report provides a technical assessment of the vessel and the fire and supplements the report of the Marine Board. The fire scenario, particularly in the initial stages is examined in detail. Principles of construction and histroy of structural fire protection requirements for passenger ships are discussed. The stability of the vessel at various times during the firefighting operations has been calculated and suggestions for avoiding unsafe stability conditions have been listed. Background information on flammability of shipboard cable is included.

17. Key Words
Fire, Passenger Ship, SCANDINAVIAN SEA, SOLAS, Structural Fire Protection.

18. Distribution Statement
Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLAS	UNCLAS	70	

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THE COMMANDANT OF THE UNITED STATES COAST GUARD
WASHINGTON, D.C. 20593

May 29, 1985

TO UNITED STATES MARITIME INTERESTS:

FIRE ABOARD THE SCANDINAVIAN SEA

The attached report was prepared by the technical staffs of the U.S. Coast Guard and National Transportation Safety Board (NTSB) as background material for the Marine Board of Investigation that examined the March 9, 1984 fire aboard the foreign flag passenger vessel SCANDINAVIAN SEA.

The detailed technical assessment of the fire origin and spread shows how a fire can develop even on a modern vessel built to all of the latest international safety standards.

The stability problem that developed during the two days of firefighting is examined in some depth and observations are included on ways to avoid potential problems with similar casualties in the future. In addition, the SCANDINAVIAN SEA is thoroughly examined for compliance with U.S. and international standards including an evaluation of the effectiveness of these standards.

Appended to the report is a thorough review of the history of international fire protection requirements for commercial vessels as well as a review of the development of electrical cable flammability standards in the United States and abroad.

While the attached report was prepared for a specific casualty, it contains a great deal of background information that is not available in any other document. I commend the report to your attention in the interest of maritime safety.

Toward our common goal of safety at sea,

J. S. GRACEY
Admiral, U.S. Coast Guard

Fire Aboard the M.S. SCANDINAVIAN SEA on March 9, 1984
Technical Assessment

Prepared for the M.S. SCANDINAVIAN
SEA Marine Board of Investigation

By

Marine Technical and Hazardous
Materials Division
U.S. Coast Guard

and

Human Performance Division
Bureau of Technology
National Transportation Safety Board

INTRODUCTION

This report was prepared for the M.S. SCANDINAVIAN SEA Marine Board of Investigation by the Marine Technical and Hazardous Materials Division (U.S. Coast Guard) and the Human Performance Division, Bureau of Technology (National Transportation Safety Board). It includes a technical assessment of the fire and related stability problems, the method of construction and the standards to which the vessel was built.

CONTENTS

I. Vessel Information

A. Background

The SCANDINAVIAN SEA was built at the Upper Clyde Shipyard, Clydebank, Scotland in 1970 as a combination passenger, roll on - roll off cargo and ferry vessel. She was registered in the United Kingdom as the M. S. BLENHEIM until sold to Scandinavian World Cruises in 1981. Prior to her first arrival at a U.S. port in February 1982, a plan review was conducted to verify compliance with the 1966 Fire Safety Amendments and the 1960 Convention for the Safety of Life at Sea . A control verification inspection was conducted and a certificate was issued by OCMI Jacksonville on 10 February 1982. The vessel was reviewed regularly after that time, the last control verification inspection having been done 17 January 1984.

B. Vessel Particulars

Registry	Bahamas
Classification Society	Det norske Veritas
Gross Tonnage (Mark submerged)	10,736.84 tons
Gross Tonnage (Mark not submerged)	9588.52 tons
Length	149m (490 ft)
Beam	20m (65.7 ft)
Passengers	580 berth 527 deck Not to exceed 1033 combined.
Crew	204
Propulsion	Twin screw diesel
SOLAS 1974 Safety Certificate	Issued by Det norske Veritas Dated 14 January 1983

II. Fire Scenario

A. The Accident

The SCANDINAVIAN SEA is shown in Photograph 1. The corresponding diagrammatic configuration of the various deck locations in the fire area is shown in Figure 1. Only the forward third of the vessel is shown in Figure 1 since this is the area of primary interest in this casualty. Figures 2 through 5, are the schematic diagrams of the decks sustaining fire damage. Figure 5 is the "A" deck where the fire originated and Figures 2, 3, and 4 are decks above this deck.

Fire was detected aboard the SCANDINAVIAN SEA at approximate 1930 e.s.t. (local time) on Friday, March 9, 1984 while the vessel was 5 miles east of Port Canaveral. Smoke was first detected on "A" deck in the passageway by a passing crew member. (The fire patrol was not scheduled to come on duty until 2000). The alarm was manually sounded, immediately after which an automatic heat detector indicated on the bridge alarm panel that there was a fire on "A" deck. Fire dampers were closed remotely from the bridge. The origin of the smoke was determined by a crew member to be a fire in room 414 on "A" deck. The fire was observed to be on the deck towards the back of the room.

FIGURE 1
MV 1

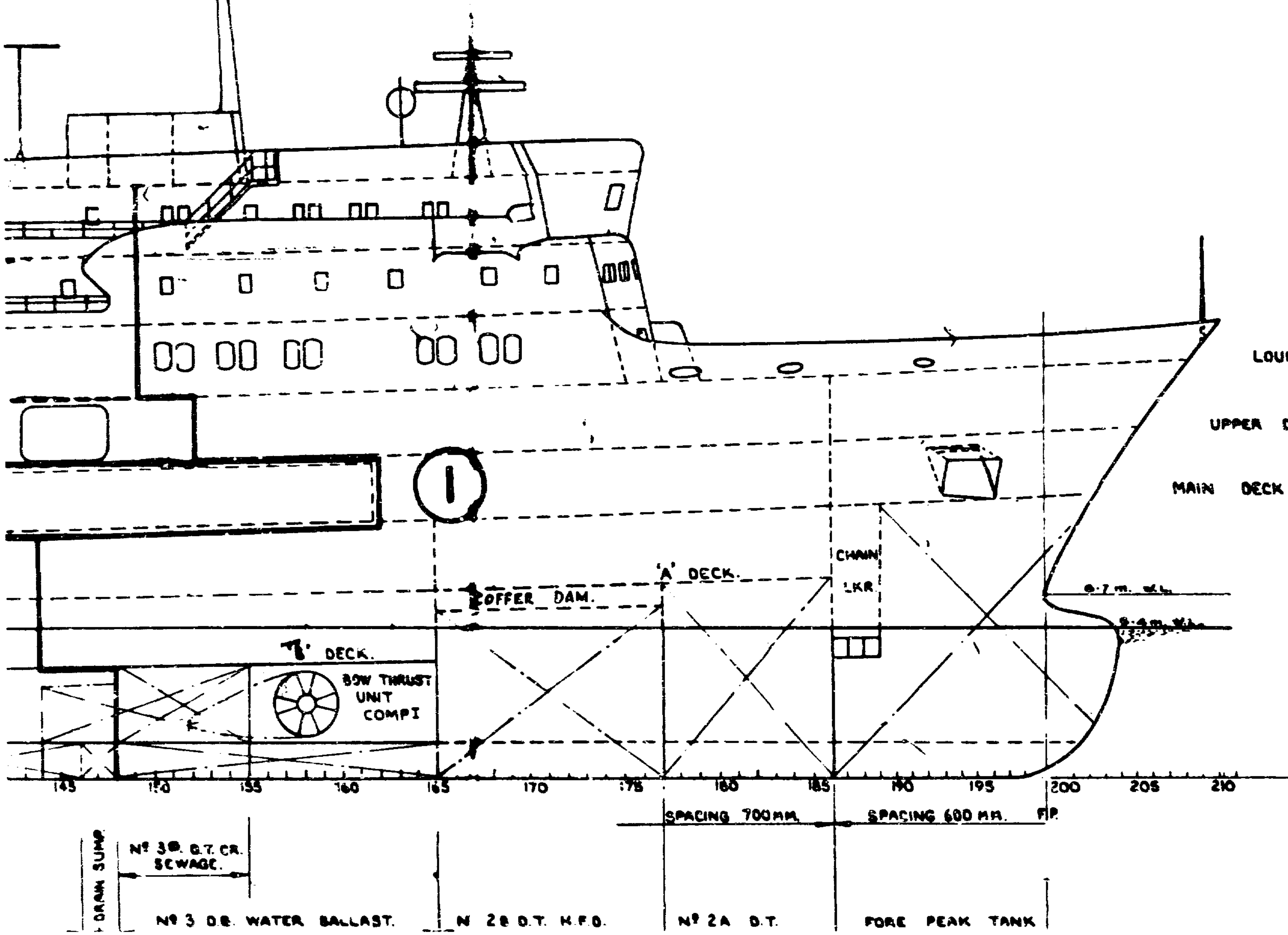

LOUNGE DECK.
UPPER DECK.
MAIN DECK.
'A' DECK.
COFFER DAM.
CHAIN LKR.
'B' DECK.
BOW THRUST UNIT COMPT
145
150
155
160
165
170
175
180
185
190
195
200
205
210
SPACING 700 MM.
SPACING 600 MM.
FP.
DRAIN SUMP
Nº 3 D.B. WATER BALLAST.
N 2 B D.T. H.F.O.
Nº 2A D.T.
FORE PEAK TANK

FIGURE 2
LOUNGE DECK

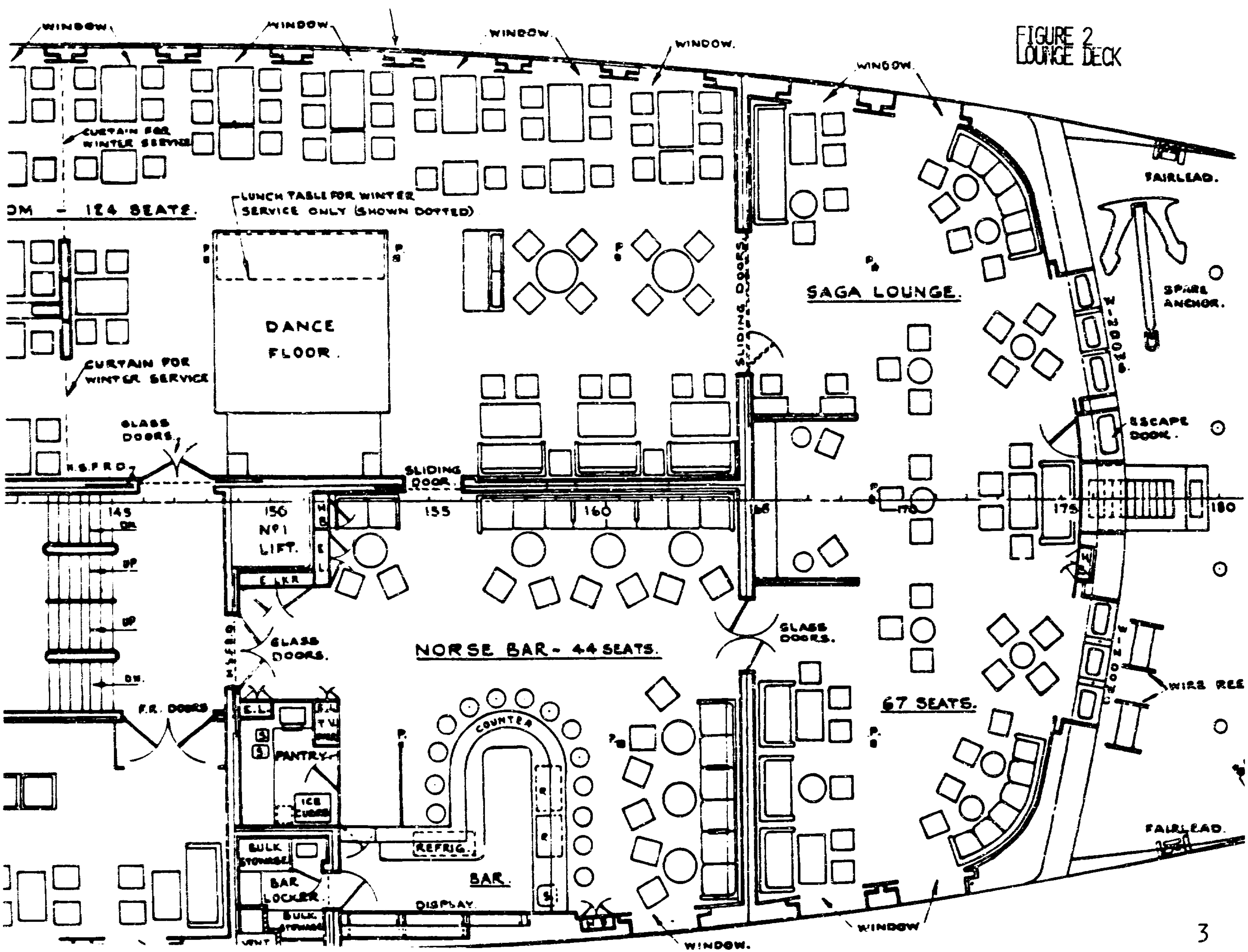
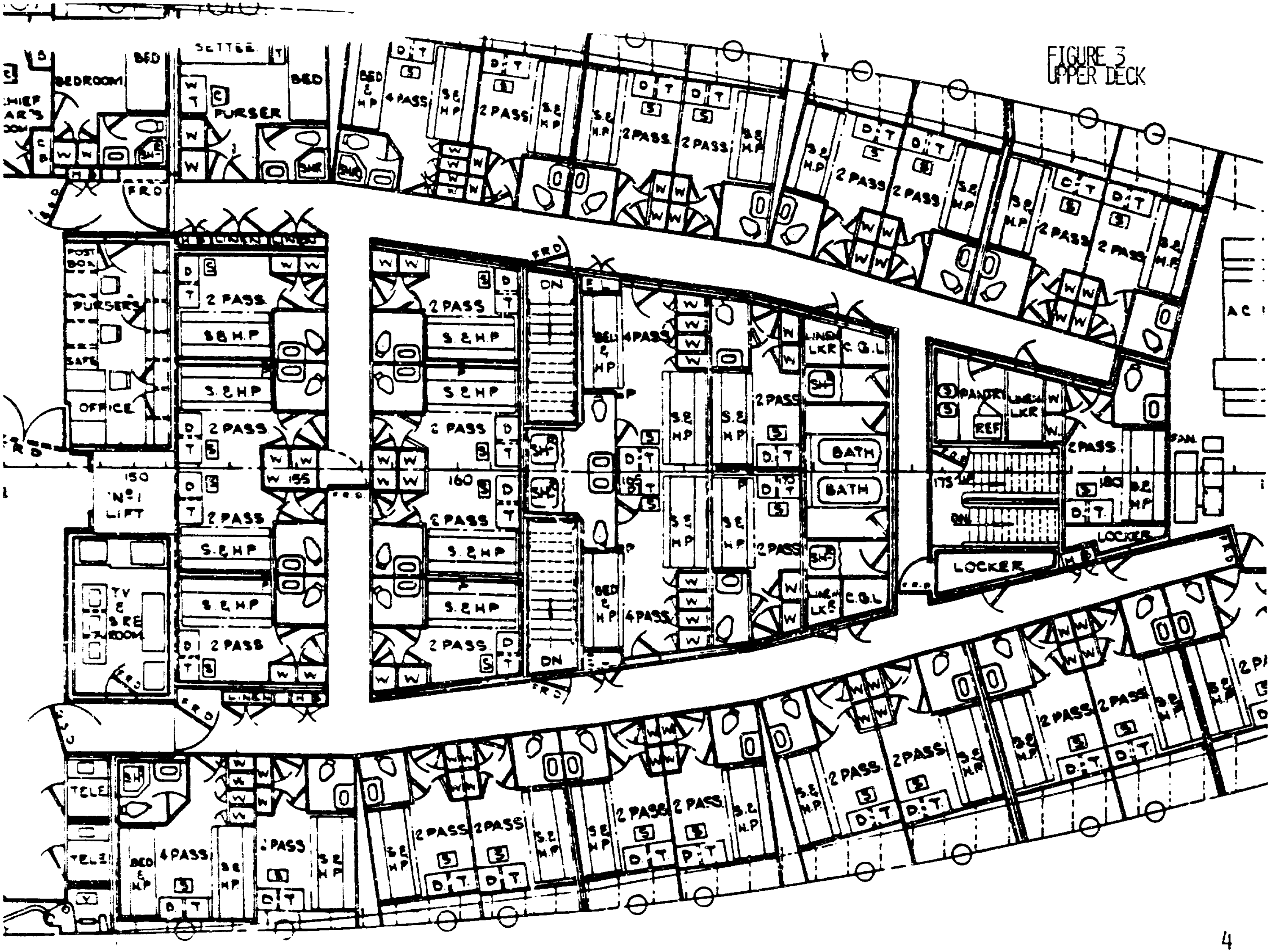


FIGURE 3
UPPER DECK



TOURIST ACCOMMODATION - 28 OFF 2 BERTH CABINS & 4 OFF 4 BERTH CABINS = 72 PASSENGERS

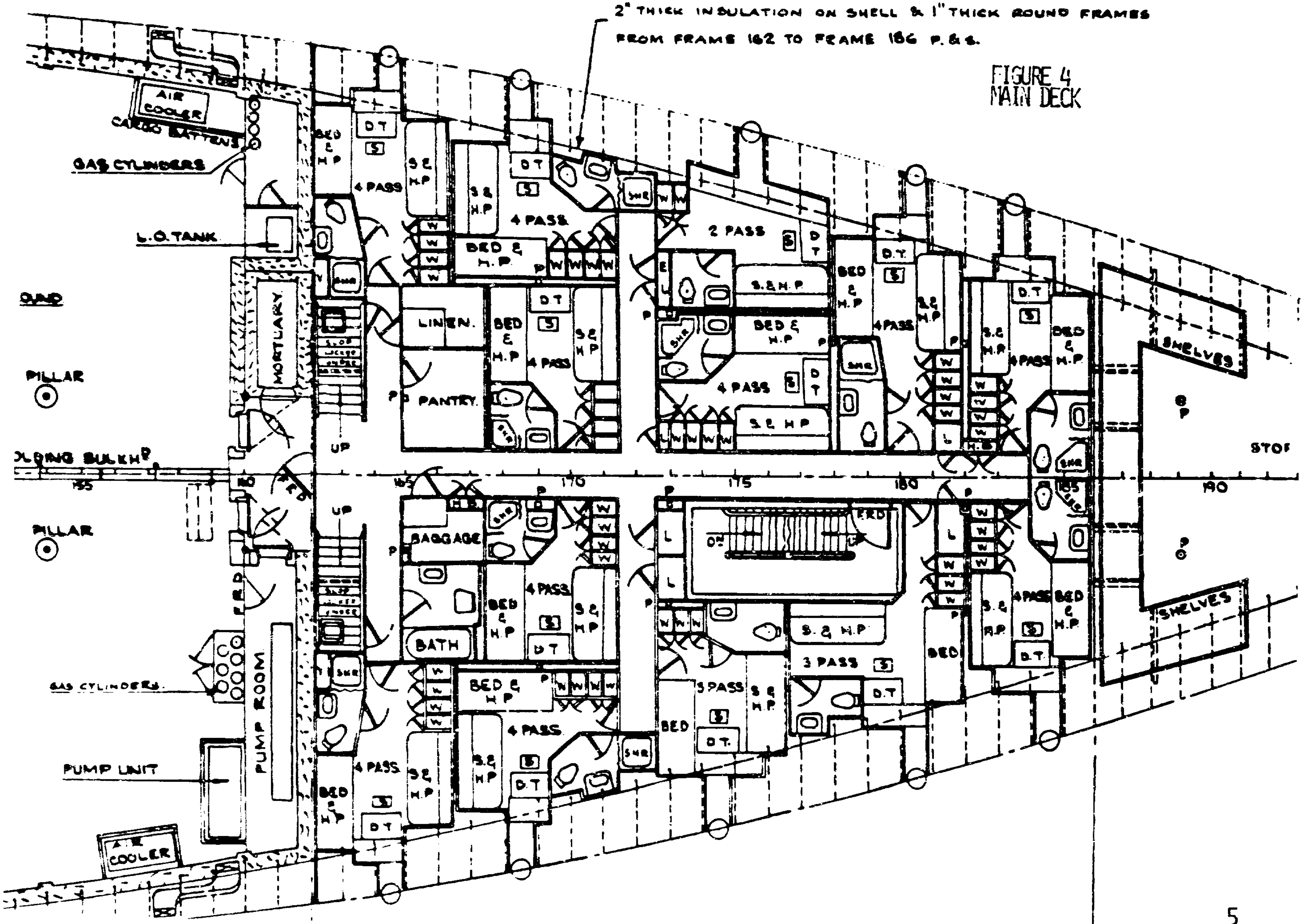
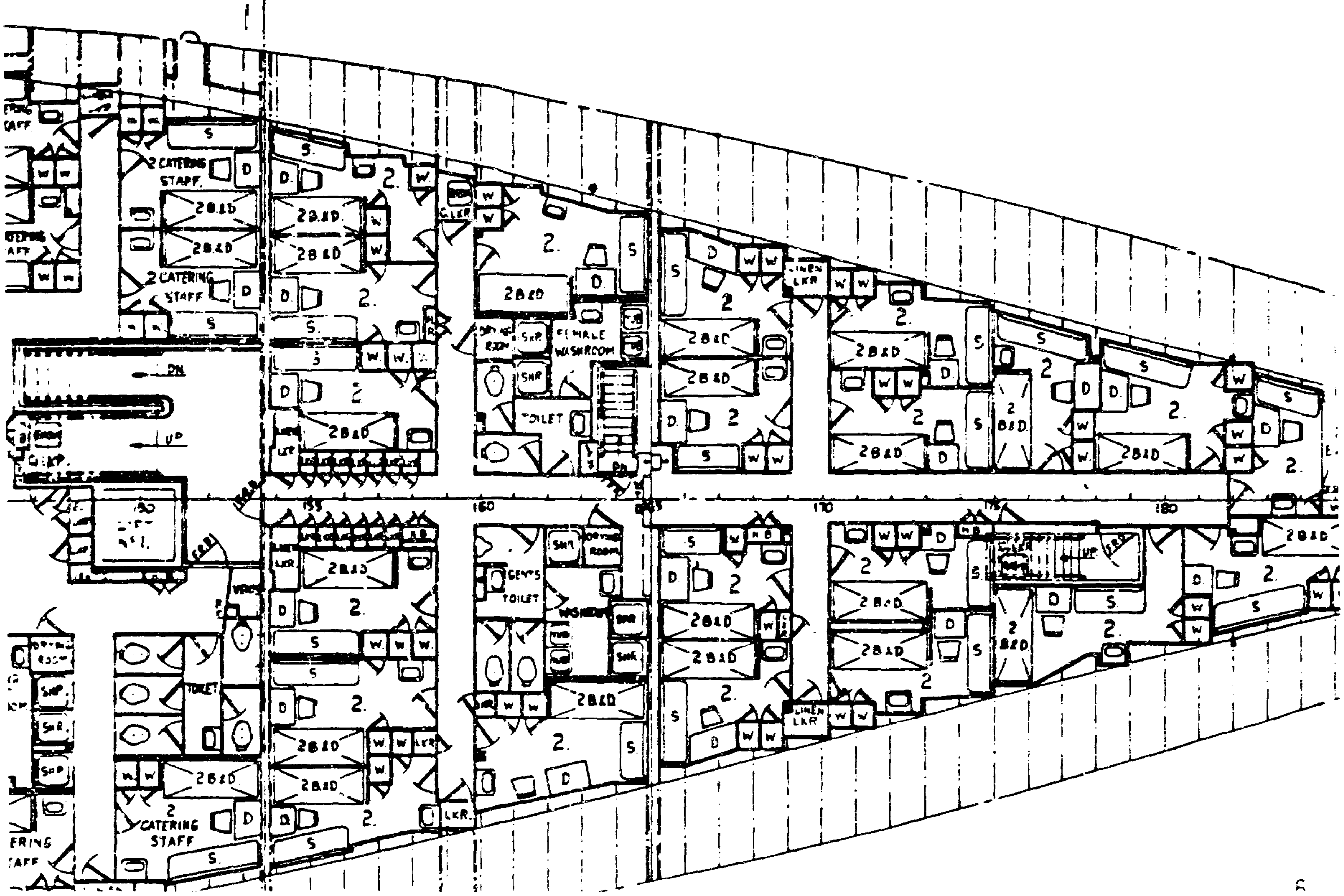


FIGURE 4
MAIN DECK

TOURIST ACCOMMODATION. 21 OFF. 2-BERTH CABINS. 42 PERSONS.
CATERING STAFF ACCOMMODATION DURING WINTER TRADE.

FIGURE 5
"A" DECK



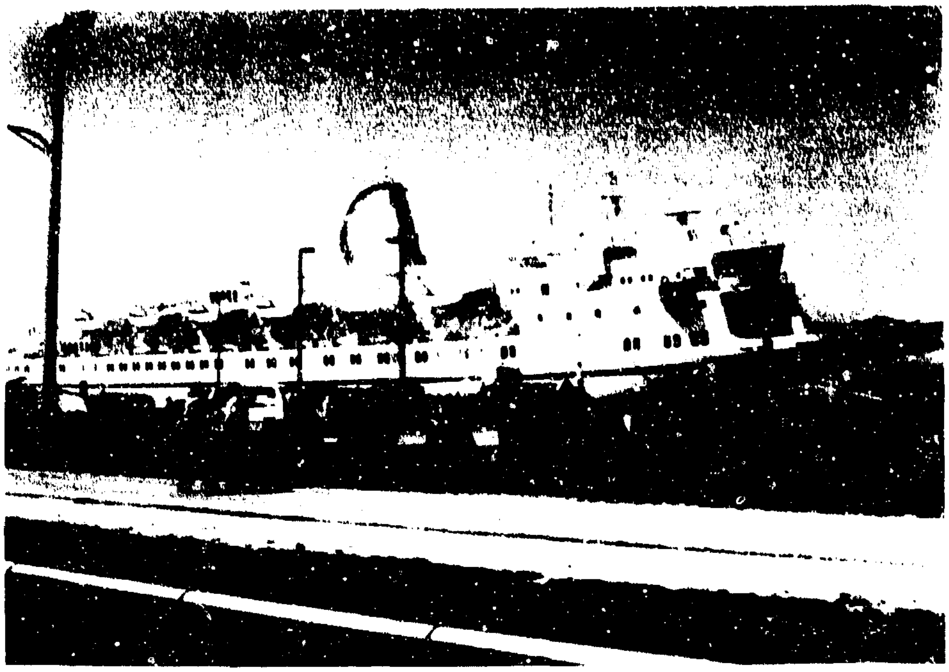


Photo 1 - SCANDINAVIAN SEA

Firefighting operations were immediately started with hand extinguishers, the first of which failed to operate. The vessel's fire brigade then attacked the fire with a hose connected aft of frame 153. The first hose failed but a second was quickly brought to bear on the fire. The brigade was driven back by heat but effectively sealed off the forward third of "A" deck from the fire door at frame 153 forward. The hoses in the cabinets at frames 168 and 174, both of which were immediately adjacent to room 414, were not used.

The ship arrived back at Port Canaveral at 2035 hours and disembarked all 744 passengers and 202 crewmembers. There were no injuries or deaths associated with the fire. The fire continued to burn until about 1600 hours Sunday, March 11 at which time the fire was officially declared to be extinguished. At various times during the firefighting operations the firefighters reported that the fire was under control but it flared up again each time. At 2300 hours Friday, some passengers were even allowed aboard to retrieve luggage. Photographs of the fire and firefighting operations are shown in Photographs 2 and 3.

Main entry into the vessel for firefighting operations was provided through the door shown in Photograph 3 that led to the upper deck. This door provided entrance to the vessel two decks above where the fire was reported to have originated.

Firefighting operations were delayed at various times as a result of a list that developed as large quantities of water were pumped into the vessel to extinguish the fire and to cool decks above "A" deck. Photograph 4 is a view from the stern showing the list.

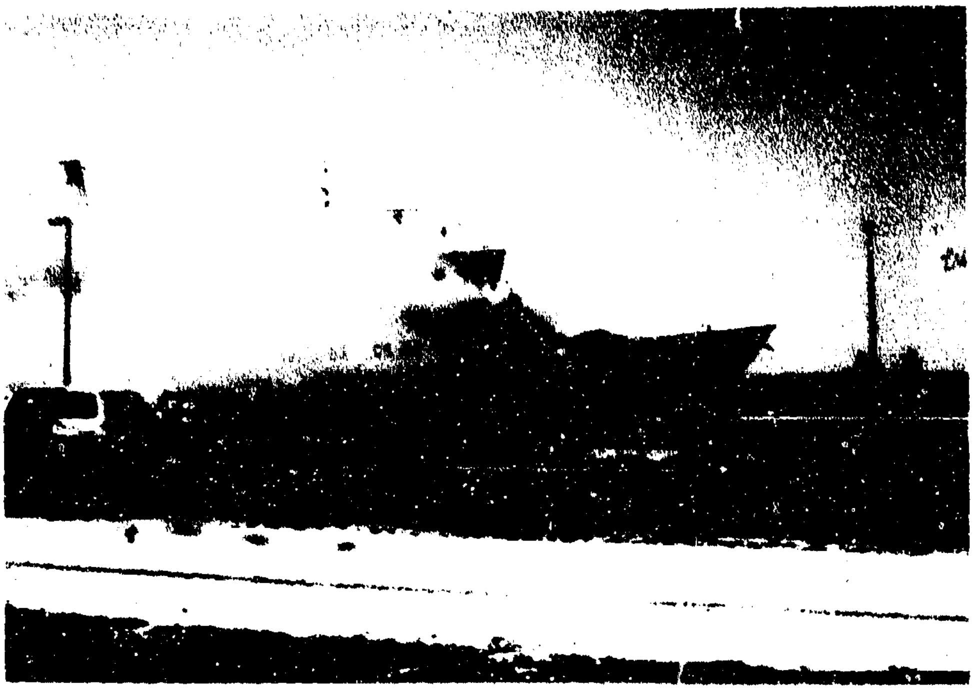


Photo 2 - Fire aboard the SCANDINAVIAN SEA

Photo 3 - Firefighting Operations

B. Investigation

Investigation of the cause and origin of the fire started on Monday afternoon March 12, 1984 with interviews of various crew members. Mr. Camile Jean, one occupant of room 414 on "A" deck where the fire was reported to have originated, reported earlier (Tuesday, March 6) that the lights above the bed did not work and the electrical outlet near the desk did not have power.

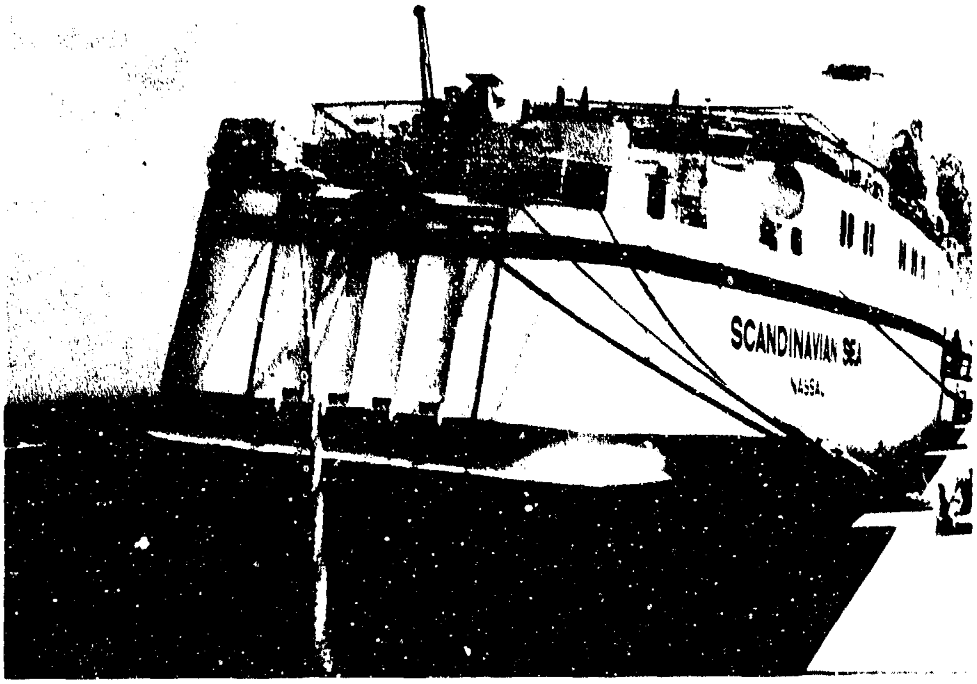


Photo 4 - SCANDINAVIAN SEA listing to starboard

On the evening of the fire at approximately 1800 hours, Mr. Jean reported to the steward that the lights above the bed and his radio still did not work. The steward went with Mr. Jean to investigate the electrical problem. He reported that both the lights and the radio were operational. Earlier in the week an order had been made up for repair of the problem by the electrician. However, no record was found that repairs had been made and testimony by the electrician indicates no repairs had been made to the room.

An on-the-scene investigation of the fire also started on Monday morning, March 12. Entrance to the vessel was made through the main embarkation door that leads to the upper deck. Fire damage forward of this door on several decks above "A" deck was extensive. The extent of this damage is illustrated by the passageway shown in Photograph 5 which is the upper deck passageway on the starboard side looking forward.

Most of the cabins along this passageway as well as the cabins on the decks above the fire origin were gutted by the fire. The port side passageway on the upper deck was similarly destroyed by fire. The electrical panel as shown in Photograph 6, located at about frame 167 (reference Figure 3), is illustrative of the damage.

In room 414 there was about 8 to 16 inches of water depending on the location in the room. This variation was due to the list of the vessel as a result of the large amount of water on board from firefighting operations. Inside the doorway to this cabin there was a portable fire extinguisher blocking the door open.

Photo 5 - Upper deck passageway, starboard side forward

For orientation purposes in the discussion of the investigation as to the cause of the fire, consult Figure 5. In addition, a larger diagram of the room of fire origin has been prepared that is close to scale and is shown in Figure 6. Descriptions of items in the room of origin are referenced to this drawing. This cabin is approximately 6'6" X 10'11".

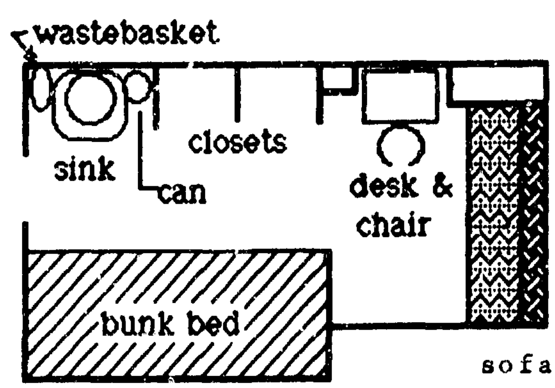


Figure 6 - Schematic of room 414

Photograph 7 is a view of the area under the sink in room 414. In the upper left corner of this photo is a wastebasket filled with debris and next to the broken partition (part of closet wall) is a metal one gallon can. The wastebasket and can are illustrated beneath the sink in Figure 6.

Photo 6 - Burned out electrical panel upper deck passageway

Photograph 8 is a close-up of the area around the gallon can. The black stick next to the gallon can is the remains of a broom handle that was not completely consumed by the fire.

Photograph 9 shows the burn pattern in the corner of the room under the sink on the bulkhead above the wastebasket.

The remains of the radio (speaker frame) are shown in upper left part of Photograph 10 just above the water line. The approximate location of this radio relative to the desk is shown in Figure 7 below.

Since electrical problems had been reported in cabin 414, particular attention was directed to detecting evidence of arcing. Photograph 11 is the remains of the outlet near the desk area where the radio was reported to be plugged in and did not work. This outlet was located about three feet above the deck and about two feet around the corner from the desk alcove. Photograph 11 shows the remains of the electrical wiring that leads to this receptacle. The wires had the appearance of having melted through with no signs of arcing.

Photo 7 - Cabin 414 under sink

Photo 8 - Close-up of area under sink

Photo 9 - Burn pattern in corner of room under sink

Photo 10 - Remains of radio and other debris

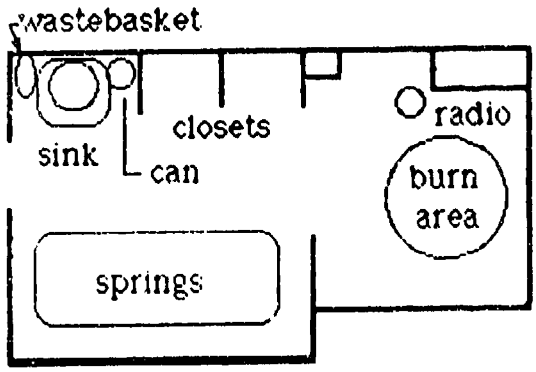


Figure 7 - Schematic of room 414

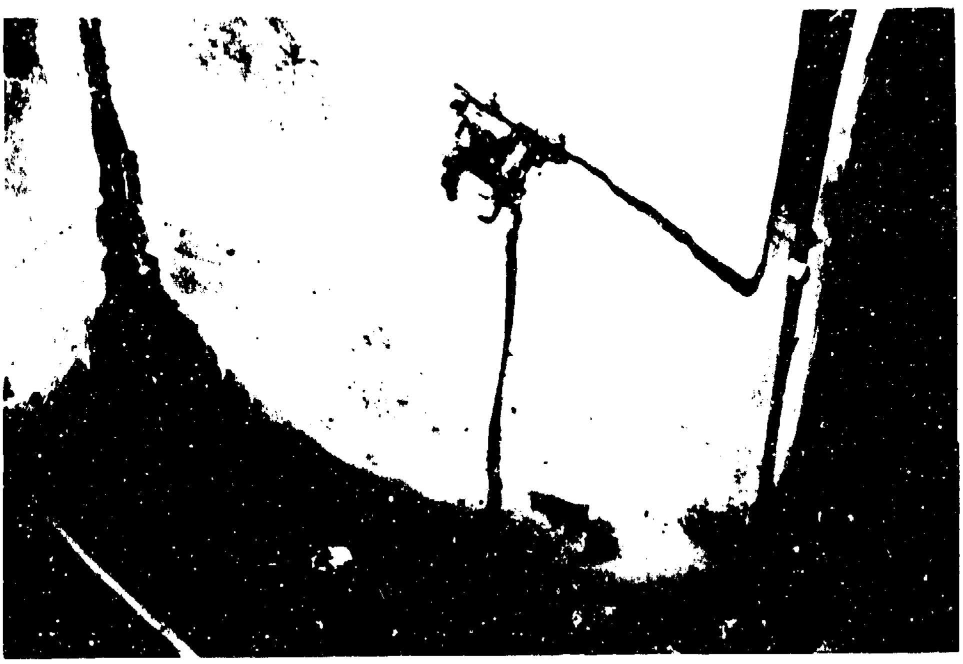


Photo 11 - Electrical cutlet

The electrical wiring for the light fixture in the center of the room is shown in photograph 13. There was no evidence of electrical arcing.

A large piece of luggage was found on the deck of this room. This piece of luggage was located on the debris (springs) of the bunk bed.

Photo 12 - Remains of electrical leads for outlet

Photo 13 - Electrical leads to light

The wastebasket and gallon can were removed from the room and the contents examined. The gallon can contained a hardened "quick dry" cement material with about 1/4 inch of water on the top.

The wastebasket was filled with various items. On top was burned ash debris that appeared to have fallen in during the fire. Immediately underneath this debris (ash) was a partially burned towel having a rum like odor. This was removed and placed in a plastic bag until a sealed metal evidence container could be obtained. Two beer bottles were also found in the basket along with cigarette butts. The wastebasket was not seriously burned as is evidenced in the photographs. Most of the burn damage was at the top or rim of the container. The materials in the wastebasket and the condition of the wastebasket are shown in Photograph 14.

Photo 14 - Wastebasket and contents

Some of the radio parts were also extracted from the flood area in room 414 for examination. This consisted of the case and pieces of drive or gearing mechanisms. Further investigation of this room could not be carried out until the water was pumped from it and lights brought in for a detailed examination.

On Thursday, March 15, 1984 the water was pumped from "A" deck permitting a better examination of room 414 as well as adjoining rooms.

The plumber (Burgos) testified that when he went to extinguish the fire in room 414 he observed a flame in front of the sofa on the deck. In order to investigate this further it was necessary to remove 6 to 8 inches of debris from the floor before this area could be examined. Underneath the debris the deck was covered with a red patterned carpet with a rubber backing. The carpeting, after removal of debris and cleaning is shown in Photograph 15, which is the area under the sink where the wastebasket was located. Most of the carpeting in room 414 was intact with pattern and coloring very visible. There was little fire damage. Underneath the carpeting the deck was covered with a vinyl asbestos tile.

Photo 15 - Unburned carpeting under sink

In the back of room 414 the carpeting in front of the sofa was burned away in a circular pattern about 3 feet in diameter as shown in Photograph 16. The remains of red carpeting can be seen in this photograph of the left edge of the burn pattern. This is shown as the white area at the left of Photograph 16 where a small piece of carpeting has been removed. Where the carpeting has been burned away in the circular pattern the underlying tile has been discolored or scorched by the heat. This was the only area in this room where the carpeting had burned through to the floor tile.

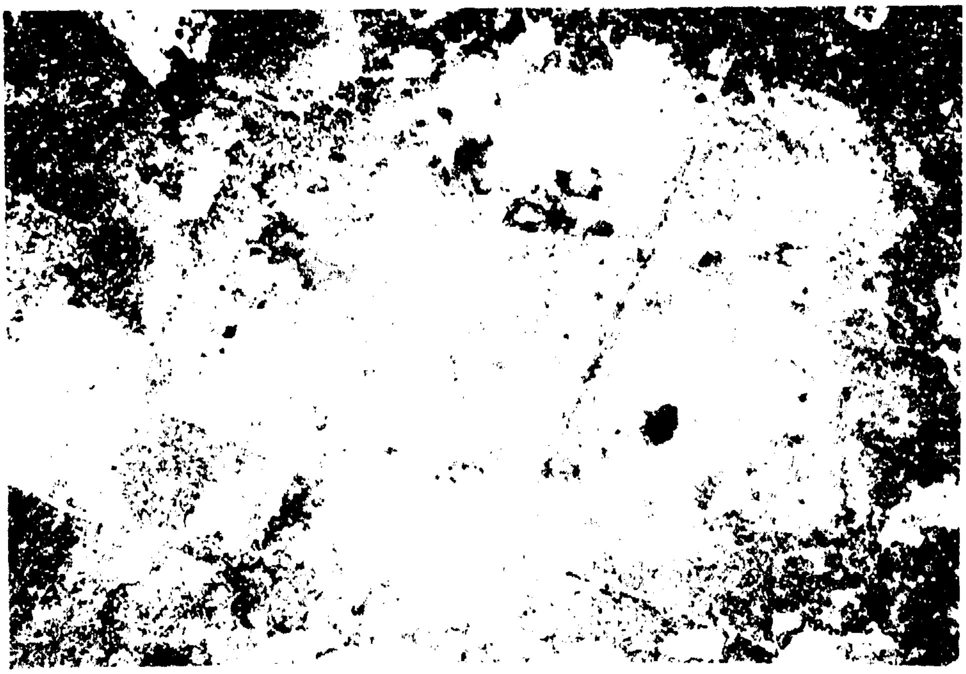


Photo 16 - Circular burn pattern in carpet in cabin 414

C. Fire/Smoke Spread

The ship was divided into six main vertical zones (MVZ) by fire resistive "A" class bulkheads, decks and fire doors. The construction materials used to divide the spaces in these zones were mainly asbestos board covered on both sides with a thin surface finish of melamine. The doors to cabins and other spaces were of similar firo resistive construction. A small amount of wood paneling and framing was used on the lounge deck in the restaurant and casino area.

The overheads (ceilings) of the accommodations, passageways and public spaces were suspended about 18 inches below the deck above. The ceilings were asbestos board panels covered with melamine. The concealed space between the ceiling and the deck above contained electrical cables, pipes and ventilation ducts.

Extensive fire damage occurred on "A" deck, the main deck, the upper deck and the lounge deck. These decks, forward of the fire door at frame 153 (see Figure 5), were eventually gutted in several areas. Some smoke and water damage also occurred aft of this position.

Fire spread from deck to deck principally due to heat conduction through the steel decks and structural members over an extended period of time and by direct transmission of smoke, heat and flames through an open door. Within decks, open cabin doors permitted fire access to cabin contents, which provided the major source of fuel for the continued growth and spread of the fire. Overhead transmission of fire through "feed-throughs" for electrical heating and ventilating systems appears to have been impeded except for a few isolated locations in secondary bulkheads. The vast majority of these "feed-throughs" were sealed with tightly fitting asbestos board. One of the few exceptions is shown in Photograph 17 which is an overhead pipe on "A" deck in the port passageway at frame 169. It is not likely that this unsealed penetration contributed to the initial fire spread. Fire could not reach this area until it had burned through an asbestos board ceiling, through a fire resistant "B" class passageway bulkhead and traveled approximately 6 feet horizontally to reach the penetration.

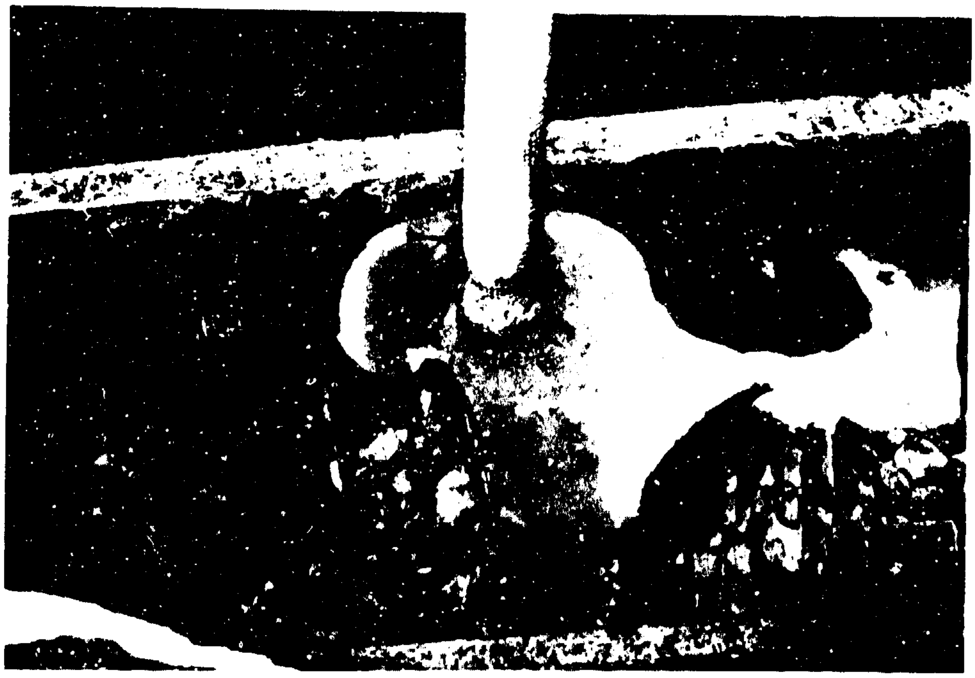


Photo 17 - Opening in an overhead through which fire spread

As the ship returned to port, the crew fought the fire and "confined" it to the area forward of frame 153 on "A" deck. The small localized fire initially confined within a single space eventually spread extensively. The door was left ajar, permitting the fire to spread beyond the room of origin. If closed, the room structure would have been expected to "confine" it for at least one half hour because of the fire resistant bulkheads. Apparently the door to room 414 was blocked open during the initial stages of the fire by one of the fire extinguishers originally brought to the room.

The crew, as part of the search for occupants, opened cabin doors and failed to close them upon completion of the search. The fire did not spread aft of the stairway fire door located at frame 153 on "A" deck but there was some heat and smoke damage aft of this door on "A" deck, and above. As is typical in ship fires where combustion air is limited, smoke production was heavy. The high fire load of 8.8 lb/sq. ft. contributed to the amount of smoke produced. Smoke deposits were evident throughout the entire vessel. A primary contributor to this extensive smoke spread was a partially open fire door at frame 153. Two hoses passed through this door by the fire brigade during the initial firefighting efforts prevented the door from being closed. This door opened into a stairtower with access to all decks. Therefore the smoke could easily spread to other decks. Considering the extensive periods of time during which there was no active firefighting, it is surprising that the flames did not also spread through this open door. Smoke and fire spread through doors where hoses had been laid may have been minimized by the fitting of hose ports with pivoting steel covers at the lower corner of the door. U.S. regulations for passenger vessels, 46 CFR 72.05-25(a)(6), permit hose ports in fire doors other than those in main vertical zone boundaries. SOLAS makes no provision for hose ports.

All fire doors that were activated from the bridge had automatic closers. The location of these doors is shown on Figures 2 through 5. Fire propagation as determined by heat and fire damage suggests that the stairtower fire door at frame 179 on "A" deck, was left open early in firefighting operations. A fire hose had also been left in this door opening. This open door probably aided transmission of heat and combustible gases to the deck above.

The effects of leaving cabin doors closed or open is well demonstrated by photographs of room 417 (across the passageway from room 414) and rooms 405 and 408. Room 417 had minimal fire damage as shown in Photograph 18 even though it was only about 2.5 feet across the passageway from the room of origin. Actual heat damage was limited to the corner of the room at the ceiling adjacent to the passageway. The door to this cabin was kept closed and prevented the spread of fire into this area. Furthermore, construction detail prevented the fire from spreading through the overhead area into this cabin. There was, however, considerable smoke damage.

Photo 18 - Room 417 showing heat damage

In stark comparison is the nearly total gutting of rooms 405 and 408. Both of these rooms are further from 414 than 417. The burn pattern on the carpet in the doorway of room 405 provided evidence that the door was left open in this room. The carpet was burned about 12 inches into the room in a "V" pattern.

The upper deck and the lounge deck (casino area) were significantly buckled by the heat generated from the fire on the deck below. In fact, fire damage in the casino and restaurant areas show that the fire spread as a result of ignition of the carpet on the hot deck. Photograph 20 shows an area in the restaurant on the port side where the carpeting was ignited spreading the fire through the restaurant and casino area. The deck in the restaurant was later cut through by firefighters in an effort to extinguish the fire in the cabin below. Photograph 21 also shows the restaurant, but further towards the center of the vessel. This photo demonstrates the extensive fire damage in the restaurant area that was next to the casino.

Photograph 22 was taken in the casino area next to the restaurant. Although it is not evident from this photograph, char depth on the table and chair legs was progressively less as one went from the port to the starboard side of the vessel on this deck. Likewise the depth of burn in the carpet followed the same pattern.

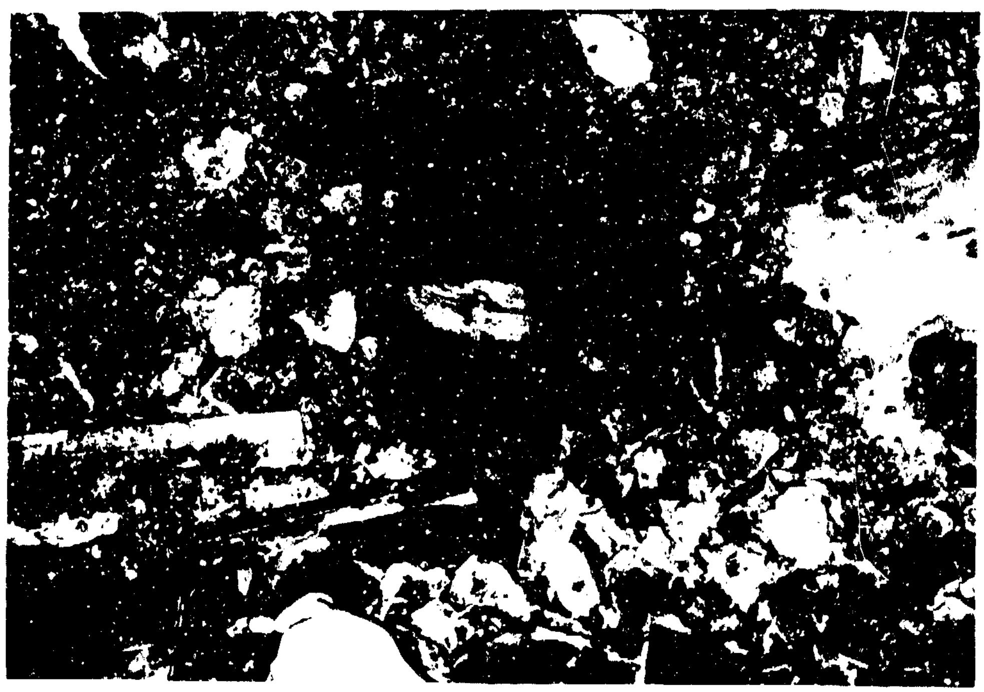


Photo 19 - Room 405

Fire also spread from the casino upwards into a closet on the boat deck as a result of heat conducted through an uninsulated steel structural element at frame 156. Minimal damage resulted from the spread of fire into this closet. A small hole was burned in a wooden floor panel. Heat damage was limited to the closet in room 308. This damage is shown in Photograph 23. This area was analyzed in some detail since a local

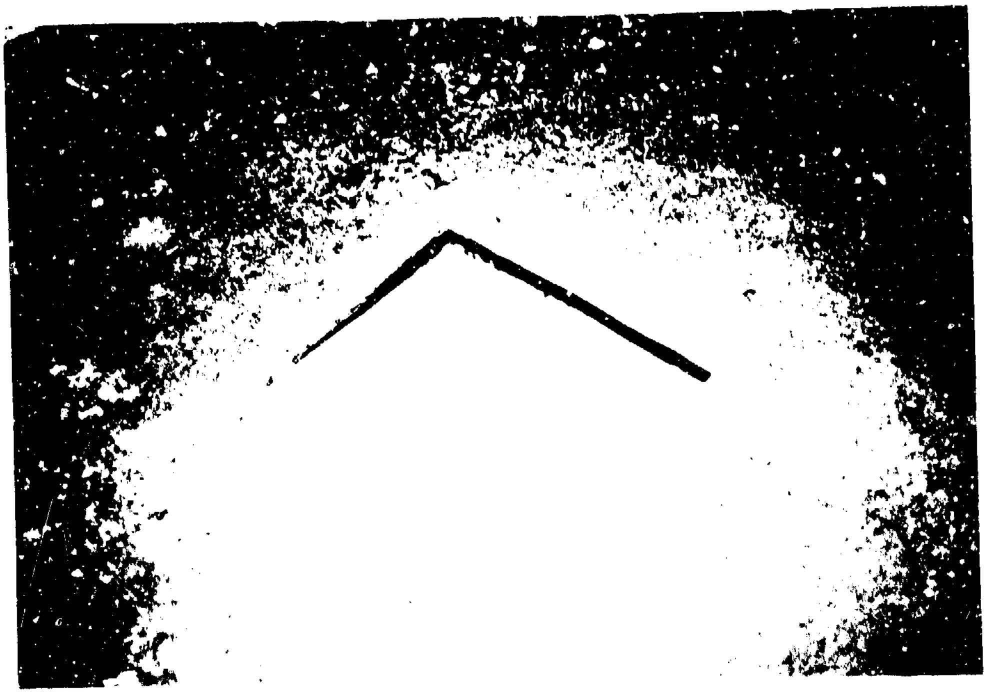


Photo 20 - Deck in restaurant

Photo 21 - Restaurant Lounge deck

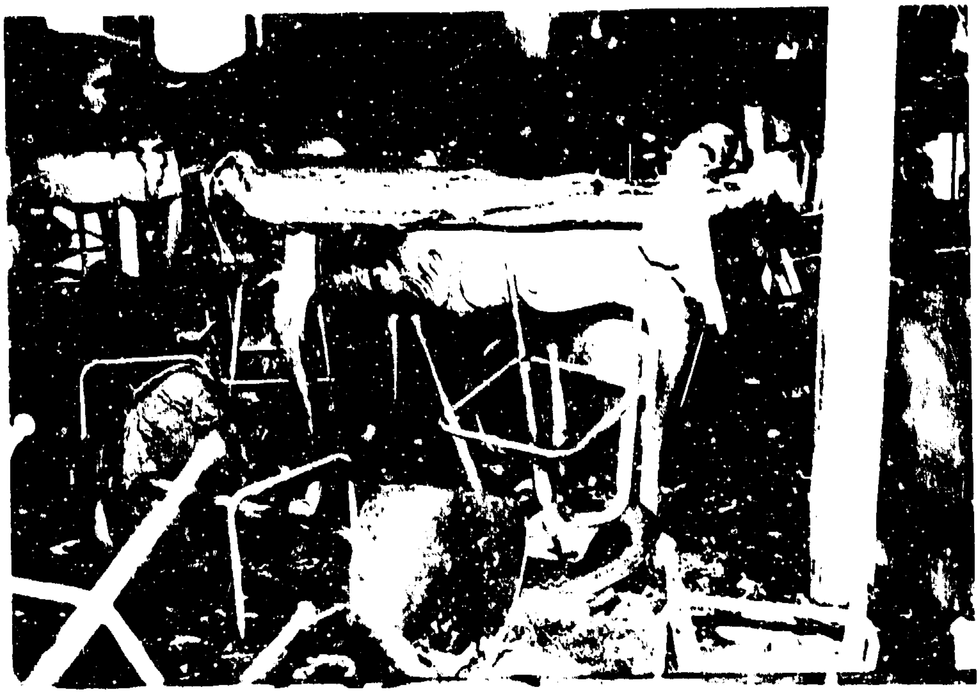


Photo 22 - Casino area portside of restaurant

fire investigator was convinced that this separate fire was set. The circular pattern is due to the fact a pair of shoes were sitting on top of this wooden flooring in the closet.

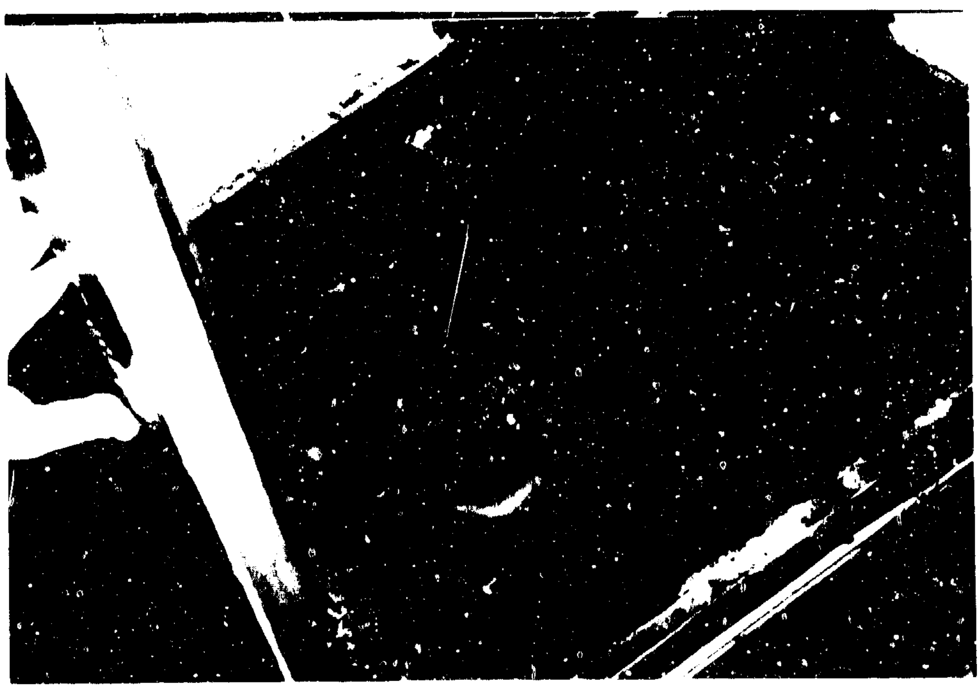


Photo 23 - Burn pattern in room 308 (boat deck)

A steel structural element encased in wood framing was identified in a doorway between the restaurant and the casino, directly below the closet. Heat from the combustion of framing and other combustibles in the casino area was conducted to the closet via the uninsulated metal structural element.

The electrical wiring insulation in the overhead space contributed fuel to the fire. Due to extensive blocking with asbestos board where the wiring went between various spaces, it does not appear that this contributed extensively to fire spread.

D. Analysis of Cause of Fire

There were a number of factors that suggested that this fire started with the aid of a flammable liquid. First, the construction of the vessel was mainly non-combustible consisting of fire resistive asbestos board and steel. The combustibles were mainly cabin furnishings, clothing and personal effects, and the melamine interior finish on the asbestos board bulkhead and ceiling panels. Second, it is difficult to get carpeting to burn through to the deck from a fire above. Thirdly and more significantly, it is most unusual to get the circular burn pattern (about 3 feet in diameter) noted in Photograph 16 without the aid of a flammable liquid. Fourth, the burn pattern in the corner above the wastebasket (Photograph 9) indicates the fire burned from below and not from above. Fifth, there was no evidence of electrical arcing or other cause of the fire in spite of complaints of electrical problems in this cabin.

The towel found in the wastebasket was sent to the State Fire Marshall's Laboratory for analysis for alcohol. This analysis, by gas chromatography, did not identify alcohol or any other accelerant. This is not a surprising finding as there were extensive amounts of water used to extinguish the fire. Alcohol is water soluble and would have been diluted below the detection limit. The rum like smell of alcohol is not due to the alcoholic content but due to other components. Consequently, a sample was sent to the Bureau of Alcohol Tobacco and Fire Arms for gas chromatography/mass spectrometry analysis for non-ethanol component residues characteristic of rum and similar beverages. The findings there were also negative. Although none were found in room 414, bottles of 151 proof rum which is flammable were evident in many crew spaces aboard the vessel.

The burn pattern in the corner under the sink and the circular pattern on the deck deserve further explanation. First, the burn pattern under the sink shows signs of burning from the wastebasket upward; that is, there is a typical "V" pattern. Another interesting factor is that the towel was not completely consumed, suggesting that material from the corner of the room fell into the wastebasket and limited the availability of oxygen to continue the combustion process.

The second burn pattern, that of the carpeting, is the strongest evidence of a fire initiated with the aid of an accelerant. As noted earlier, it is difficult to get wool carpeting to burn on the deck without some additional factor such as a fire on the deck below. When a fire begins in a room the heat rises so that the radiative flux to the deck or in this case to the carpet is low and generally insufficient to ignite the type of carpeting installed on ships. This would be particularly true of a heat conductive non-combustible deck material such as steel. In this instance the carpeting was laid over vinyl tile. Carpeting can be burned and frequently is in home fires where the floor is wooden or in fires of intense heat with high fuel loading and sufficient oxygen. It can also become involved if there are thermoplastics that melt and drip or run onto the deck covering. In this particular fire one could postulate that the circular pattern in front of and under the sofa could conceivably be due to the melting of the polyurethane cushions of the sofa or the chair.

To determine the probability of this, the sofas in other rooms were examined to determine the construction. It was determined that they were constructed of wood frame, foam rubber (probably butadiene) seat and a polyurethane back (note: a chemical analysis of these materials has not been done to confirm these observations on material identifications). The only material in this combination that has the potential to melt and pool is the polyurethane. However, it could not have pooled and created the circular pattern shown in Photograph 16 because the burn pattern is too far forward in the room. Since the back cushion of the sofa was polyurethane, if it had melted and dripped, one would expect the carpet to be burned away along the back wall of the room resulting in a linear burn pattern and not the circular pattern found.

Soot samples were collected from 4 locations.

1. upper deck in passageway outside cabin 644,
2. cabin 738 on upper deck,
3. cabin 720 on upper deck and
4. from clock in lobby of upper deck (frame 148)

Analysis of these samples was carried out using a computerized pyrolysis/mass spectometry technique. Based on a computerized library of soot spectra, this analytical technique is used to identify the polymer from which the soot was formed. Basically, when polymeric materials burn, the combustion process is incomplete and the smoke or aerosol that is generated contains components or fragments of the original polymer. These fragments make it possible to identify the polymer from a "fingerprint".

The results of this analysis show that soot from locations 1, 2, and 3 were the result of burning wool, nylon, PVC and a cellulosic material. The analysis of the sample from location 4 showed that it was the result of burning wool, nylon and cellulosic materials. The carpeting material on board the ship was reported to be a blend of 80% wool and 20% nylon. Other sources of the wool and nylon may be the clothing and bedding that was consumed in the fire. The source of PVC was the electrical wire insulation and molding in the cabins. The cellulosics can be accounted for by the clothing and wood furnishings.

Based on this evidence it is probable that the fire initiated with the aid of a flammable liquid on the carpeting in front of the sofa. Furthermore, the investigation suggests that a fire may also have originated in the wastebasket under the sink with the aid of a towel soaked in rum or some other flammable fluid. However, the wastebasket could have been a secondary ignition source, being ignited after the fire was in process.

III. Construction/Arrangement

A. Applicable Fire Safety Standards

Vessels on international voyages are subject to the safety requirements in the International Convention for the Safety of Life at Sea, the requirements of their national administrations and in the case of foreign vessels carrying 50 or more overnight passengers from U.S. ports, U.S. public law. A table summarizing the convention documents follows this paragraph. A more complete history of international fire protection requirements can be found in Appendix A.

Convention/Amendment	Application Date
SOLAS 1929	7 Nov 1936
SOLAS 1948	19 Nov 1952
SOLAS 1960	26 May 1965
1966 SOLAS Amendments	Not ratified
1967 SOLAS Amendments	Not ratified
SOLAS 1974	25 May 1980
1981 SOLAS Amendments	1 Sep 1984
1983 SOLAS Amendments	1 July 1986

The SCANDINAVIAN SEA was built in 1970 and, being British flag, had to meet the fire protection requirements of the United Kingdom, Board of Trade, the minimum international standards for new vessels of the International Convention for the Safety of Life at Sea, 1960 (SOLAS 60), and to trade in the United States, Public Law 89-777.

In 1968, Public Law 89-777 required passenger vessels embarking U.S. nationals from U.S. ports to comply with the 1966 Amendments to SOLAS 60. These amendments, which make changes to the requirements for fire door construction, fire dampers, immediate availability of fire pumps, trained fire patrol, alarms, fire drills, wiring, ventilation ducts, release mechanisms and fireman's outfits for existing as well as new vessels never came into force as SOLAS Amendments but were unilaterally enforced by the United States on foreign as well as domestic vessels.

Additional amendments to SOLAS 60 were proposed in 1967, three years before construction of the SCANDINAVIAN SEA. These 1967 Amendments were similar in many respects to the U.S. regulations for passenger vessels and were intended to apply to new construction. They prescribed a single method of fire resistant construction for all passenger vessels. Like the 1966 Amendments, the 1967 Amendments were never ratified by enough governments to enter into force internationally. Unlike the 1966 Amendments, the U.S. did not mandate compliance with the 1967 Amendments for foreign passenger vessels trading in U.S. ports. They eventually became part of SOLAS 1974 which entered into force for new ships after 25 May 1980. The 1966 Amendments also became part of SOLAS 1974, most of them in a section applicable to existing passenger ships. Although the SCANDINAVIAN SEA was not required to meet the 1967 Amendments by either international or U.S. law, it appears to have been built to meet those requirements.

B. Principles

The principles that guided development of the 1967 Amendments are stated in Regulation 93 as follows:

(a) division of ship into main vertical zones by thermal and structural boundaries;
(b) separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries;
(c) restricted use of combustible materials;
(d) detection of any fire in the zone of origin;
(e) containment and extinction of any fire in the space of origin
(f) protection of means of escape or access for fire-fighting
(g) ready availability of fire extinguishing appliances

The detailed requirements for accomplishing these goals are contained in the 1967 Amendments. Regulation 2 of SOLAS 1974 and of the 1981 SOLAS Amendments contains essentially the same principles.

C. Vessel Fire Loading (i.e. combustible contents and construction materials).

The intensity and duration of a fire depends on the amount of combustible material, the burning rate of the material and the oxygen available. Lack of ventilation, such as would be typical of a ship, tends to prolong the burning and confine the heat so that fire barriers are more likely to be breached in the long run.

The amount of combustible material in a space which can contribute to a fire is called the "fire load." Fire load is expressed in equivalent pounds of wood per square foot of floor area. Attempts have been made to relate fire loading to the standard time-temperature curve used for approving bulkheads. Although it has been estimated in the literature that under optimum air flow conditions, a 10 lb/sq. ft. fire load of wood or similar combustibles equates in severity to a 1 hour standard fire test, the tests conducted aboard the S.S. NANTASKET in the 1930's used a fire load of 5 lb/sq. ft. in developing standards for structural fire protection aboard passenger vessels.

The primary source of fuel for the propagation of the fire on the SCANDINAVIAN SEA was interior finish, furnishings, electrical cable and materials brought into the habitable space. In an effort to determine their significance, the quantity of fuel in a cabin was estimated. The following table is an estimate of the type and amount of these fuels with the corresponding heats of combustion of each material. Since the heats of combustion of materials vary, the total BTU content of each material has been converted to an equivalent amount of wood having a heat of combustion of 8000 BTU/lb.

Material	Quantity(lb)	Heat of Combustion BTU/lb	BTU(k)	Equivalent Wood (lb)
wood	200	8000	1600	200
paper	10	8000	80	10
clothing	80	8000	640	80
melamine	140*	8000	1120	140

Material	Quantity(lb)	BTU/lb	BTU(k)	Equivalent Wood (lb)
polyurethane	4	12000	48	6
trash can	5	8000	40	5
butadiene	8	16000	128	16
vinyl tile	68	4000	272	34
polyester	20	15000	300	38
wool	40	9000	360	45
		TOTAL WOOD EQUIVALENT		574 lb

*exposed side of panel only.

The deck area in cabin 414 where the fire originated is about 65 square feet. This gives a fire loading of approximately 8.8 lb/sq. ft. Although the estimate of 200 lb of wood in this space appears high, Photograph 24, which shows a typical bed frame, is indicative of the quantity of wood in the furnishings used aboard the SCANDINAVIAN SEA.

Examples of typical fire loads based upon various surveys are: clerical office, 5.8 lb/sq. ft.; general office, 7.3 lb/sq. ft.; conference room, 4.2 lb/sq. ft; library, 30.2 lb/sq. ft.; family room, 2.7 lb/sq. ft.; bedroom, 4.3 lb/sq. ft.; hospital room, 1.2 lb/sq. ft.; naval vessel accommodations, 2.4 lb/sq. ft.; and nursing home patient room, 2.6 lb/sq. ft. No data has been found on dormitories, hotels or motels which might be used for comparison. However, the 8.8 lb/sq. ft. fire load on the SCANDINAVIAN SEA appears to be quite high when compared to a residential bedroom or nursing home patient room which were estimated at 4.3 lb/sq. ft. and 2.6 lb/sq. ft. respectively.

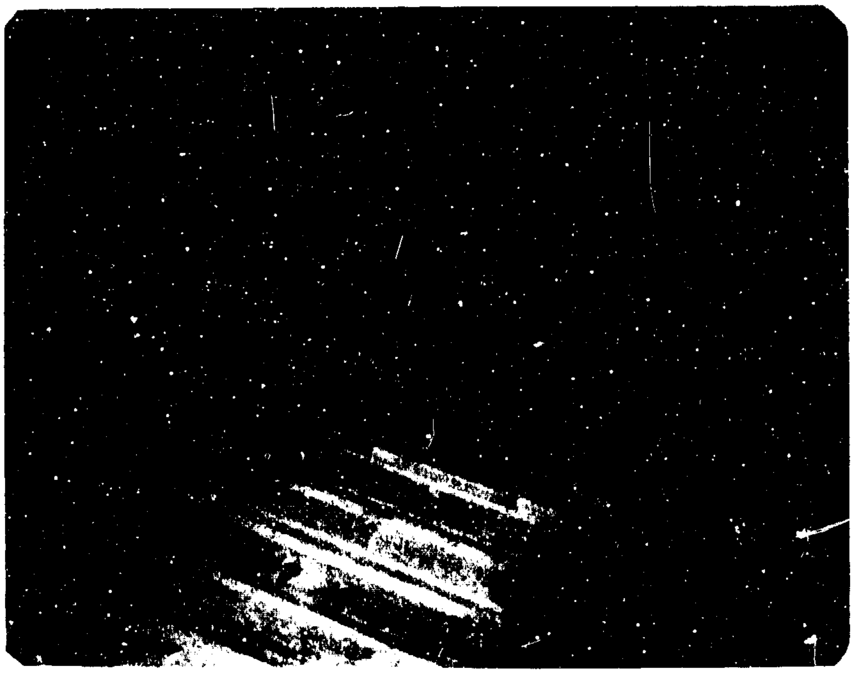


Photo 24 - Bed frame

The fire load of room 414 was also estimated as if it had been limited to "furniture and furnishings of restricted fire risk" as described in Regulation II-2/3.23 of the 1981 SOLAS Amendments. If that standard were applied, case furniture would have been non-combustible and freestanding furniture would have had non-combustible frames. This would have eliminated all of the wood and possibly the polyurethane cushions, reducing the total amount of combustibles to an equivalent of 368 lb, for a fire load of 5.6 lb/sq. ft. This is much closer to the fire load of similar occupancies. It should be remembered that furnishings are restricted only where bulkhead and deck ratings are reduced.

D. Electrical Installation

The electrical installation on the SCANDINAVIAN SEA was typical for the period when she was constructed. In accommodation spaces, electric cable was installed in a bundled configuration in metal cable hangers above the asbestos board ceiling panels. Cables were run behind the bulkhead panels to flush mounted fixtures (lights, switches, and receptacles). From the existence of modern marine cable types, it is evident that the original installation had been supplemented with additional circuits and equipment or that some original cable had been replaced. Cables originally installed were typical for ships of the period, as they were designed to be self-extinguishing when tested in a single cable configuration. This has minimal significance for cables installed in bundles, as the close proximity of the cables provides reinforcement to maintain a cable fire. Such an installation can be expected to propagate fire when installed in a cable bundle. Some cable added at a later date was designed to be resistant to fire propagation in a bundled configuration. Cable performance during the fire was as expected, with insulation and sheathing materials contributing to the fire propagation along with the interior finish, furnishings, and materials brought into the spaces.

A brief history of cable performance during a shipboard fire condition and of the development of shipboard cable standards is attached as Appendix B.

E. Portable Fire Extinguishers

The area of fire origin on A-Deck between the bow and the first main vertical zone bulkhead was equipped with 6 portable fire extinguishers; three 13.5kg dry chemical type, and three 10 liter pressurized water type. (The 1982 Fire Control Plan identifies the water type extinguishers as soda-acid type.) This exceeds SOLAS 74 requirements with respect to extinguisher size and location. The fire extinguishers throughout the ship bore tags indicating that they had recently been serviced.

The number provided also exceeds the carriage requirements of Title 46 of the Code of Federal Regulations, Subchapter H, which requires only one Type A size II extinguisher in each main passageway in each main vertical zone. Each of the water extinguishers and the dry chemical extinguishers (assuming they were charged with a monammonium phosphate dry chemical) would have the extinguishing potential of an USCG approved Type A, size II extinguisher.

Since excess extinguishers were provided, the spare charge carriage requirements of 46 CFR Subchapter H would have been met.

F. Smoke And Toxicity Considerations

1. Smoke

Shipboard fires are typically very smoky, even in sparsely furnished naval ships. Control of smoke development is essential. Dense smoke reduces visibility of passengers and crew members. In passenger ships, where occupants are often confused by the unfamiliar layout, the increased disorientation can quickly become disastrous. Inhalation of smoke which usually contains carbon monoxide and other toxicants dulls the senses which can cause inappropriate escape activity. Spread of smoke away from the point of origin by ventilation or other openings may result in confusion and wasted time on the part of the ship's officers in determining where to send the fire brigade. It can also result in faulty judgement as to when a fire is beyond the control of the crew and in premature abandon- ment. In normal fires, the heated smoke filled air rises while cooler fresh air is drawn in at lower levels, a phenomenon commonly referred to as "stack effect." Unlike buildings, ships are subdivided into many air tight areas and do not have openings for air infiltration at lower levels, so the free entry of clean air is normally quite limited. When attacking a shoreside fire, the fire department will often cut holes in the roof of a building to accelerate the stack effect process. This allows improved visibility so that the seat of the fire can be located.

For ships, where fresh air cannot freely enter at lower levels, the air must enter from above and mix with the smoke; a fire quickly becomes oxygen limited. Oxygen starved fires tend to produce even more smoke. Shipboard fires are among the most difficult to fight, primilary because of the amount of smoke.

A great deal of research is being done on smoke movement, smoke knockdown, and visibility through smoke. Several areas of interest include use of the ventilation system to exhaust the fire area while pressurizing all surrounding areas with fresh air; the use of sprinklers to knock down smoke; and use of special cameras that see through smoke. While these measures show some promise, all would be costly. An approach that is within the scope of existing technology and regulations is to reduce the amount of combustible and smoke producing material. Tests have been conducted by the Coast Guard Research and Development Center to evaluate the "Smoke/Gas Hazards of Furnishings." The report, CG-D-27-84 dated November 1983 indicates that combustible furniture was a major contributor to smoke generation and could project large amounts of smoke and fire gases over a considerable distance within a very short time. Alternative furniture and carpet materials were found to have an important effect.

The existing regulations provide for two categories of staterooms, those of minor fire risk and those of moderate fire risk. In a stateroom designated category 6 (which is an accommodation space of minor fire risk), furnishings such as case furniture, chairs, draperies, carpets, and interior finish materials are restricted to minimize fire risk. By electing to restrict combustible contents, builders may use class "B-0" bulkheads between category 6 spaces. If the builder does not restrict contents, then the staterooms are designated category 7 (accommodation spaces of moderate fire risk), and are required to be separated by class "B-15" bulkheads. Since virtually all approved bulkhead panels are rated "B-15", there is not much economic advantage to the builder to restrict combustibility of furnishings to allow use of the less resistant "B-0" panels.

Coast Guard regulations limit smoke development for combustible interior finish materials but not for furniture, draperies, electrical insulation or deck coverings. As indicated earlier, the soot analysis showed that carpet, fabric and electrical insulation contributed smoke to the fire. At present, IMO does not have a standard for smoke development although regulation II-2/34.7 requires that finish materials not be capable of producing excessive quantities of smoke and toxic products. Coast Guard approval of interior finish materials includes testing to ASTM E-84, which is used to measure surface burning and smoke development characteristics of building materials.

Fire retardant melamine interior finishes perform favorably in the test and there are a number that meet the requirements in 46 CFR 164.012 for a flame spread rating of 20 or less and a smoke development rating of 10 or less. The Coast Guard research reported above found that these finish materials make a small contribution to the smoke and gas hazard when compared to the combustible stateroom contents tested. Smoke development and flame spread for those that are not Coast Guard approved vary greatly and both flame spread and smoke can have ratings of several hundred. By comparison, red oak produces ratings of 100 in the ASTM E-84 test, while asbestos board produces ratings of zero.

2. Toxicity of Fire Products

The predominate cause of death in fires is smoke inhalation and not the results of thermal burns. Even though this fact has been recognized for a number of years, smoke toxicity is not one of the criteria for the selection of construction materials for buildings or for marine vessels. Various laboratory test methods using animals have been developed to determine the toxicity of smoke from materials under specified thermal conditions. Studies using these laboratory test methods show that the toxicity is dependent on the temperature profile to which the sample is exposed, on ventilation conditions and on sample orientation.

The two test methods of primary use are; (1) the National Bureau of Standards method and (2) the University of Pittsburgh method. In the NBS method, two smoke toxicity values are determined for each material, one for the flaming mode and one for the non-flaming combustion mode. The absolute values of the toxicity of the materials tested by the two methods may be quite different. These differences are due to the fact that each method decomposes the material differently and exposes the animals differently. In addition, the animal of choice is also different in each method. In both test methods the toxicity of smoke from a given material is expressed as the LC50. The LC50 is defined as the amount of material that must be burned to produce death in 50% of the animal population within a specified exposure time.

Both of these test methods have been used to evaluate the toxicity of smoke from materials that are generically the same as several of those that were involved in the SCANDINAVIAN SEA fire. However, it must be recognized that just because a material is generically the same as some other material does not mean that the two materials will have the same toxicity. Minor additives can and sometimes do produce major changes in toxicological response. For example, the toxicity of polyurethanes may be quite different depending on the presence and type of fire retardant additive, the polyol and the isocyanurate used. Consequently, the only way that one can be assured that the toxicity of two materials is the same is to know that the formulations are the same or to test them. For those materials which have not been evaluated, the chemistry of the polymer will give some clues as to the type or principal toxicant(s) expected but will not guarantee that the toxicological response is due to the principal toxicant deduced from the chemistry.

With these caveats, the toxicity of materials generically the same as those found on the SCANDINAVIAN SEA, as determined from the two toxicity test methods, are tabulated below. A listing of the principal toxic products is included in the last column of the table. Polyvinyl chloride is included in the toxicity table since it was one of the principle components found in the soot analysis. The floor tiles were vinyl, however, they did not burn in many areas. The only major source of this smoke was the polyvinyl chloride used as electrical insulation. There could also have been a small amount of vinyl clothing or luggage involved in the fire.

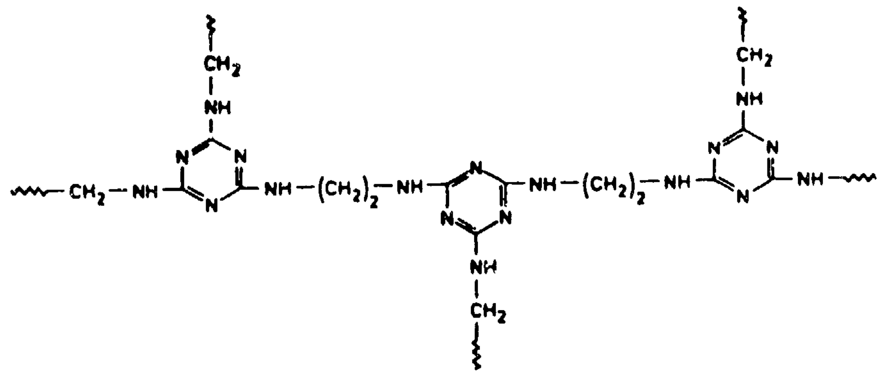
MATERIAL	NBS LC50 mg/l	UNIV. PITT. LC50 gm	TOXICANT(S)
wood	22.8NF* 39.8F**	63.8	CO/irritants
cotton***			
wool	25.1NF 28.2F	3	CO/HCN
PVC	20NF 17.3F	7	HCl/CO
Polyurethane	17 to 40	8 to 14	CO/HCN/irritants
polyester(fiber fill)	27.6NF	ND	CO/irritants
melamine	ND****	ND	CO/HCN
butadiene	ND	ND	

* Non-flaming
** Flaming
*** Similar to wood but slightly more toxic
**** Not Determined

As noted in the above table for the materials of interest, the Pittsburgh method for measuring smoke toxicity provides a larger spread in toxicity, that is, materials are spread over a broader range.

Melamine and butadiene have not been tested in either toxicity test procedure. In fact, the material identified as a butadiene has not been confirmed as such by analytical measurements. This must be done prior to theorizing about its toxicity.

The Coast Guard research on smoke and gas hazard of furnishings mentioned earlier found that the bulkhead finish material contributed little smoke in relation to the stateroom contents. However, because of the large amount of melamine used on the SCANDINAVIAN SEA and the unavailability of toxicity text data, melamine was examined to determine its potential for toxicity. Melamine is a condensation product of formaldehyde with urea. Depending on the application, it is mixed with various fillers such as cellulose, wood flour or stone powder. The chemical structure can be represented as follows:



melamine resin

As can be seen from the chemical structure of melamine, the C-N group, which can lead to the production of hydrogen cyanide, constitutes a high percentage of the molecular weight of melamine. Consequently, it is likely that some hydrogen cyanide will be produced. It is highly unlikely that theoretical yields of hydrogen cyanide (52%) based on nitrogen content will result except under specific conditions that may or may not exist in the fire environment. The soot analysis did not detect any hydrogen cyanide, although a significant amount of melamine burned. However, most of the hydrogen cyanide may have escaped as a gas without leaving deposits. Based on the above formulation, thermal decomposition is likely to occur according to the following equation:

$$C_6 N_6 H_5 \xrightarrow[O_2]{\Delta} HCN + NH_3 + CO + \text{other products}$$

It is reported that when melamine undergoes thermal decomposition, ammonia, methylamine and other products are produced. Hydrogen cyanide was not listed in the literature, but is sure to be a product. The question of how much is produced in the fire environment, however, can only be determined by doing the specific toxicological studies.

According to laboratory fire tests using ASTM E-84, melamines perform favorably in the fire environment. However, melamines do burn and contribute smoke and toxic products. Since toxic products are the primary cause of death in fires, and melamine is a nitrogen containing product, its toxicity is a problem to contend with. As a minimum, the analysis for hydrogen cyanide in the smoke should be done followed by exposure of animals to verify the analytical findings.

On the positive side, there were no deaths and no permanent injuries reported by passengers, crew or firefighters due to smoke. Had there been significant quantities of highly toxic byproducts, injuries to firefighters who spent long hours exposed to these products would have been likely.

IV. STABILITY PROBLEMS RESULTING FROM FIREFIGHTING EFFORTS

A. Background

Firefighting began at sea with the crew using the firemain system . Water was introduced onto "A" deck forward of frame 153. The vessel arrived with a list of one to two degrees. Following arrival at the pier, shoreside firefighting support began introducing water. Little if any water was removed from the ship throughout these efforts. As firefighting continued, the vessel continued to list to starboard. The list was approximately 10.8 degrees at the conclusion of the effort. Throughout the firefighting effort there was speculation as to the risk to the vessel due to the introduction of firefighting water. The on-scene commanders attempted to assess the potential for capsizing but little information was available for making such an assessment. Clearly the ability for an on-scene commander to determine the effects of firefighting efforts on the stability of a vessel, at sea or at pierside, is desirable.

The stability of the vessel during the firefighting effort was evaluated for the following three conditions:

Condition 1 - The arrival condition according to the Chief Mate.

Condition 2 - The vessel with firefighting water on board as described by the NTSB investigator.

Condition 3 - A hypothetical condition to assess the effects of additional firefighting water.

For details of the Stability Analysis refer to Appendix C.

B. Observations:

1. The vessel, at the time firefighting efforts were stopped due to excessive list, was in little danger of capsizing. It must be noted that there were some portlights on "A" deck which were almost submerged at the time firefighting efforts were stopped. These portlights were a potential source of flooding and were monitored closely by the firefighting team. Since access to the cabins where the portlights were located was, at best, difficult, the decision to stop firefighting efforts was probably a wise one. For the condition which was reconstructed for the purpose of analysis, calculations show the angle of equilibrium to be 5.5 degrees. The maximum righting arm was 3.25 feet at approximately 52.5 degrees. The available righting energy to this angle was 141.1 foot degrees. The angle of vanishing stability was 87.0 degrees, leaving a residual range of stability of 81.5 degrees (Righting Arm 2 in Appendix C).

2. The vessel would have listed further had additional firefighting without dewatering occurred, but still would not have been in immediate danger of capsizing, so long as the port lights mentioned above remained intact. Calculations show the vessel heeling to approximately 27 degrees with one hour's worth of firefighting at 5000 gallons per minute without dewatering. The maximum righting arm was 1.7 feet at approximately 52.5 degrees. The available righting energy to this angle was 54.4 foot degrees. The angle of vanishing stability was 78.0 degrees, leaving a residual range of stability of 51.0 degrees.

3. Had free water accumulation continued beyond this point, the longitudinal extent of the free water on each deck would have increased resulting in an increase in heel and free surface. Although the free

surface for a given compartment is independent of the volume of water in it, the heel angle is not. The limiting factor for heel in this case (as in most passenger vessels) is the downflooding which occurs when the "water interface" moves transversely across a stairway.

4. Penetrations in the superstructure envelope, made during the course of firefighting to allow firefighting water to drain off the vessel, could minimize stability problems resulting from firefighting efforts. This could significantly reduce heeling moments. Care would need to be taken to avoid penetrating a potentially important water or fire boundary in carrying this out.

5. Shipboard fires should be fought so as to minimize the degradation of stability as the effort progresses. When a choice exists, fight the fire as low in the vessel as possible and dewater as high as possible. This has the effect of lowering the center of gravity or at least minimizing the rise. The extent of longitudinal flooding should be limited as much as practicable. The degradation of stability due to free water depends on several factors. Among them are the length of the flooded compartments, the angle of heel of the vessel, the height of the compartment above baseline and the percentage to which the compartment is full (i.e. 10%, 20%, etc.). This percentage affects the equilibrium heel but not the free surface correction. In general, limiting the longitudinal extent of the flooding is most readily accomplished and is very effective.

V. Structural Fire Protection Design Assessment

A. Compliance with U.S. and SOLAS Fire Safety Standards

As stated earlier, the SCANDINAVIAN SEA was required to meet the provisions of SOLAS 1960 as well as the 1966 Fire Safety Amendments Annexes I through IV for service while embarking U.S. nationals in U.S. ports. Prior to her first arrival at a U.S. port in 1982, preliminary fire control plans were submitted to Coast Guard headquarters for the required review. The owners submittal stated that the vessel met the requirements of SOLAS 1960 for Method I vessels as well as the requirements of the 1967 SOLAS Amendments. This greatly exceeded the minimum U.S. requirements for foreign vessels at the time which permitted any of the three Methods of construction under SOLAS 1960 as well as the 1966 Amendments. The 1967 Amendments are nearly the same as the regulations for U.S. flag passenger vessels.

In general, the following construction materials were used:

Passageway Bulkheads - 3/4" asbestos cement panels
Cabin Division Bulkheads - 5/8" asbestos cement panels
Ceilings - 3/8" asbestos cement panels
Structural insulation - mineral wool
Ducting and Hull Insulation-fibrous glass/mineral wool
Decks - steel
Linings - 3/4" and 5/8" asbestos cement panels
Interior finish - melamine plastic laminate
Furnishings - wood and foam plastic
Floor covering - 72% wool/28% nylon carpet

The preliminary vessel plans were reviewed at Coast Guard Headquarters in 1981 to determine compliance with 1967 SOLAS Amendments and Method I of SOLAS 1960. Potential discrepancies concerning fire insulation of the wheelhouse and means of escape were noted. These discrepancies were satisfactorily resolved in a later submittal. Following this review, the plans were forwarded to MSO Jacksonville for use during a Control Verification examination. This examination was completed on 10 February 1982 and a Control Verification Certificate was issued.

After the fire there were several different opinions over the method of construction of the vessel. Since the standards applicable to any particular construction detail may vary depending upon the method of construction and the convention or amendments to which a vessel is built, it is important that the convention and construction method be known. A letter from the owners stated that the SCANDINAVIAN SEA was of Method I construction and met the 1967 Amendments. The Coast Guard inspection reports indicated Method II in some cases and no Method in others. In a letter dated 3 August 1984 the classification society, Det norske Veritas, indicated that the SCANDINAVIAN SEA was constructed according to Method III and pointed to their "initial" report of 18 January 1982 and plan number 744/628/P as documentation. The report was not received by the Coast Guard. Nothing was found in the plan to indicate that the vessel was of Method III construction. A telex dated 5 November 1984, from a former managing director of DFDS, confirmed that the vessel was of Method I construction and built to the 1967 Amendments.

The definitions for the three methods of construction as defined in Regulation 34 of SOLAS 1960 are as follows:

> Method I. The construction of internal divisional bulkheading of "B" Class divisions (as defined in paragraph (d) of Regulation 35 of this Chapter) generally without the installation of a detection or sprinkler system in the accommodation and service spaces.
>
> Method II. The fitting of an automatic sprinkler and fire alarm system for the detection and extinction of fire in all spaces in which a fire might be expected to originate, generally with no restriction on the type of internal divisional bulkheading in spaces so protected.
>
> Method III. A system of subdivision within each main vertical zone using "A" and "B" Class divisions distributed according to the importance, size and nature of the various compartments, with an automatic fire detection system in all spaces in which a fire might be expected to originate, and with restricted use of combustible and highly inflammable materials and furnishings; but generally without the installations of a sprinkler system.

In general Method I construction consists of noncombustible fire resistive construction. Sprinklers or fire detectors are not required but may be installed. Method II construction allows unlimited combustible construction materials and compensates by requiring a sprinkler system throughout to detect and suppress fires. Method III construction is similar to Method I but allows limited combustible construction materials and compensates by requiring a fire detection system throughout and limiting combustible furnishings.

A ship is normally built to meet one particular set of construction requirements but may meet more than one. For example, a Method I ship with sprinklers throughout would still be a Method I ship. It could also be considered to be of Method II construction without combustible construction materials. A Method I ship with a detection system would appear to be Method III but still be Method I.

The 1967 Amendments settled on a single method of construction which most closely resembles the old Method I with the addition of detectors. Since there is only one type of construction possible for passenger ships built to the 1967 Amendments and later conventions (SOLAS 1974, 1981 Amendments, 1983 Amendments) a method of construction does not need to be specified. This may be the source of the confusion. It is surmised that the owners elected to specify the 1967 Amendments long before they were required internationally. Therefore, there was no need to specify a method of construction. Governments which continue to apply the earlier treaty require that a method of construction be identified. Fortunately, vessels meeting the 1967 Amendments would automatically qualify as meeting Method I construction in nearly all respects.

After the fire the plans were reexamined and it was verified that the plans for the SCANDINAVIAN SEA did in fact meet the 1967 Amendments in nearly all respects. Therefore the owner's claim that the vessel was constructed to the 1967 Amendments and the Method I requirements of SOLAS 1960 and the 1966 Amendments appears correct. In this review category numbers of spaces had to be arrived at by trial and error since they were not identified. It was concluded that all staterooms were category 7 spaces in which bulkheads have higher fire ratings but furnishings are unregulated. Also, ratings of "B" class bulkheads were not identified on any plan and could not be verified. In several areas the plans neglected to identify fire resistance of boundaries or identified an insulation value more or less than appeared to be required. No discrepancies were identified in the area that burned.

It is often difficult to determine by observation alone which construction method or convention was used for a particular vessel. Since the active fire protection systems are the most visible characteristics of a method of construction, there is a tendency to assume any ship with sprinklers is Method II, any ship with detectors is Method III and any ship with neither is Method I. It is the construction rather than the protection system that should be the primary factor in determining method. Therefore, the Coast Guard inspection reports which do not indicate any method of construction for the SCANDINAVIAN SEA are correct for a vessel built to the 1967 Amendments. Those indicating Method II are mistaken. Although there were sprinklers in the cargo spaces, Method II construction requires sprinklers throughout and usually would have combustible construction throughout. The DNV report is also mistaken. The ship had detectors throughout and may, by coincidence, meet most of the requirements for Method III but it was not "constructed according to Method III" as stated in the DNV letter, and certainly the furnishings are not of restricted combustibility as would be required for Method III. In order to avoid conflicts such as this it would be useful to require a copy of the original specification or other document to prove the construction at the time of the initial control verification inspection.

In addition to the plan review, a spot check was made of the vessel after the fire. Also samples were taken for testing. The test results are reviewed in the next section of this report.

In most respects the structural fire protection was found to be in agreement with the plans. In the fire area, the only exception was the limited use of combustible material in several bulkheads on the lounge deck. As stated earlier this nearly led to spread of the fire to the boat deck. This combustible construction was not shown on any plan. It could not be determined when the combustible material was installed. Since the ship was initially built to the 1967 Amendments, combustible construction was not permissible. A review of the plans shows that the Board of Trade did a thorough plan review and required a number of changes to comply with the 1967 Amendments. Regulation 1(a)(iii) of the 1967 Amendments and of SOLAS 1974 requires any alterations to comply with at least the regulations previously applicable to the ship.

DNV has been the cognizant classification society since the vessel was built, and should have been aware that the SCANDINAVIAN SEA was built to the 1967 Amendments and therefore that combustible materials (bulkheads) are not permitted. Apparently they were not aware and instead thought the ship was constructed to Method III. Under Method III of SOLAS 1960, but not the 1967 Amendments, an administration may approve combustible bulkheads provided they have fire retarding properties equal to "B" class bulkheads. It is possible that the wood bulkheads were fire retardant, although no supporting data is available, and that the classification society allowed them, believing that the ship was of Method III construction. However, some of the wood found in the lounge area was used as grounds (furring) to support other structures. Method III construction prohibits wood grounds. Also as noted earlier, Method III construction is not in conformance with the 1967 Amendments.

One area which was not fully in compliance with the convention was the placement of draft stops. Draft stops are required to subdivide spaces behind ceilings, panelling or linings to a maximum length of 14 meters. Ceiling spaces above all large open areas had draft stops properly distributed. However, ceiling spaces above several passageways which exceeded 14 meters in length were not shown on the plans as being provided with draft stops. A spot check of the vessel verified the absence of these draft stops. The passageways in the fire area on "A" deck were not required to have draft stops. Their absence was not a factor in the initial fire spread. On the decks above "A" deck where draft stops were required but not installed in the passageways, it is not likely that the lack of draft stops contributed to the fire spread since the fire did not originate in or spread lengthwise via the ceiling spaces above these passageways.

B. Performance of Structural Fire Protection Materials

Several samples of materials were taken to spot check against U.S. and international fire test methods. Noncombustibility tests using 46 CFR 164.009 were conducted on the core of the ceiling panel, the insulation between layers of spiral-wound duct, wood chipboard from a bulkhead in the Saga lounge, and several structural, fiberglass and sound insulations. The core passed the test, the chipboard failed badly as expected, and the insulation samples passed most tests although some samples failed by small amounts. Except for the chipboard which should not have been installed, the failures were for the most part within the limitations of the apparatus being used at the time by various administrations. Compared to the heavy fire load on this vessel, the contribution to combustibility of these items was insignificant. Several reports were circulated at the time of the fire that the fire spread behind panellings feeding on polyurethane insulation. Polyurethane insulation is not permitted in the accommodations area of passenger ships like the SCANDINAVIAN SEA and none was found in the fire area. Foam insulation is permitted in refrigeration spaces and was found in one unidentified space aft. The test results are summarized as follows:

Sample	Furnace ΔT (°C)	Surface ΔT (°C)	Wt. Loss %	Flaming (Sec.)
ceiling panel core	5.7	10.12	15.17	0
Spiral duct insulation	11.1	0	4.40	0.6
Wood chipboard	253.8	258.9	74.32	670
Structural Insulation	15.4	24.3	11.5	3.8
Insulation from penetration closures	51	73.5	9.86	16
MVZ insulation	21.3	34.0	4.81	0
Fiberglass	12.6	7.76	1.95	0
Sound insulation	8.7	7.76	3.49	0
Beam insulation	74.4	88.1	8.92	3
Structural Insulation	56.3	85.7	8.85	5

The carpet was tested using both the flooring radiant panel test (ASTM E-648) and the new IMO flammability test (Resolution A. 516). The flooring radiant panel is the test most commonly used by the carpet industry in the United States. The carpet sample had an average critical radiant flux (CRF) of 0.70 watts per square centimeter for a sample which included an integral pad. This is much better than the current U.S. standard for buildings which permits a CRF of 0.22 or 0.45 depending on the occupancy. The IMO flammability apparatus obtained a Critical Flux at Extinguishment (CFE) of 0.70 watts per square centimeter on the carpet without the attached pad. The fact that the CRF and CFE are the same is coincidence. The CRF was measured with a horizontally oriented carpet specimen which had a foam pad. The CFE was measured with a vertically oriented carpet specimen without a pad. The orientation and the pad both affect the result. In both test methods the heat flux (radiation) decreases from a high of 5 or 1.1 watts/cm^2 to a low of 0 or 0.1 watts/cm^2 respectively over the length of the specimen. At a high heat flux nearly all carpets burn while at a low flux the heat input is insufficient to keep most types of carpet burning. The object is to determine the lowest heat flux at which a specimen continues to burn after being ignited at the hot end. Carpet obtaining a critical flux below a preset level should not be used in certain occupancies. Comparative results for a typical 100% wool carpet as presently required on some passenger ships are CRF 0.87 w/cm^2 and CFE 2.25 w/cm^2.

The carpet was also analyzed to identify the fibers. This analysis found the carpet to be 28% nylon and 72% wool. Measurements indicated that the pile height was 7mm, that the foam pad was 5mm thick, and that the weight was 5.24 lb/yd^2 (2.84 kg/m^2) without the foam pad. All of these figures differ from the data submitted by the owner's representative which indicated that the carpet was 20% nylon and 80% wool with pile heights of 6mm, 8mm or 10mm and fitted with a wool felt underlay. The data submitted by the owners representative indicated that the installed carpet was tested according to method BR-72 and approved by the Danish Ministry of Housing for staircases and fire escapes. Although the data submitted appears to have been for the wrong carpet, this difference is not considered to have affected the outcome of the fire.

The fact that the carpet did not burn to any great extent on "A" deck indicates that it did not significantly spread that fire. That the carpet did burn and contribute to the fire on other decks illustrates that heat conducted through the deck must also be considered for shipboard carpet. This is usually not a factor in buildings since conduction through floors of buildings is insignificant. The soot sample analysis confirms that the carpet was a major contributor to smoke. It should be noted that the carpet on the SCANDINAVIAN SEA was not required to meet any test method because of the high level of bulkhead and deck fire resistance provided.

The ceiling panels were subjected to a surface flammability test using ASTM E-84, which is currently specified in 46 CFR 164.012 for surface finish materials on U.S. vessels. The samples tested produced an average flame spread of 24.4 and average smoke contribution of 176 on the exposed side of the panel. On the back side (the side facing upward into the concealed ceiling space), the flame spread results were much more divergent. Flame spread numbers of 86 and 139 were obtained on 2 samples and the smoke numbers for the samples were 116 and 112. This far exceeds what would be permitted on a U.S. ship, but does not violate SOLAS which sets no limits. The limits for U.S. Coast Guard approvals are a flame spread of 20 and a smoke development of 10. For comparison purposes an asbestos cement board produces flame spread and smoke results of 0 and red oak produces results of 100 for both flame spread and smoke.

All of these samples were taken from a passageway. SOLAS 1960 and the 1967 Amendments both require exposed surfaces in passageways as well as surfaces in concealed spaces to have low flame spread characteristics. Regulation 105 (e) reads as follows:

> "All exposed surfaces in passageways or stairway enclosures and surfaces in concealed or inaccessible spaces in accommodation and service spaces and control stations shall have low flame spread characteristics."

Although there were no uniformly accepted international test standards for surface flammability at the time the SCANDINAVIAN SEA was built, it is obvious from the results obtained in the ASTM E-84 test that one side of the ceiling panel did not comply with the requirement to have low flame spread characteristics. The results with the IMO test were similar. In this test the exposed side of the panel did not propagate flame at all while the side in the concealed space spread flames more than most similar materials. The only surface flammability data available on material originally installed aboard the vessel indicates that it was a wood veneer which got a class 1 (very low) rating when tested to British Standard 476, Part 1, 1953, Section 2. The report indicated that there was very little smoke produced. Since no wood veneer was found in the fire area or in most other parts of the vessel, it is believed that this veneer was limited to the Captain's quarters.

A simulation of a bulkhead panel fire endurance test was also done on a 3/8" ceiling panel. This panel failed the temperature transmission test after 13.8 minutes but remained in place throughout the one hour test and may have qualified as B-0.

C. Evaluation of SOLAS Effectiveness

Compliance with the requirements of SOLAS served to limit the fire growth. However, fire spread appears to have been facilitated by open doors and lack of a well coordinated fire attack. The only area where construction not in compliance with SOLAS contributed to the fire spread was the wood door frame on the lounge deck noted earlier. This allowed fire to spread to a small closet on the boat deck but it did not spread beyond the closet.

All active fire protection equipment that was utilized operated properly, although several hoses in the firemain system failed. Most of the hose was of the unlined linen type. SOLAS is not explicit in regard to hose materials. Since such hose when wet very quickly rots, testing is not normally advisable unless hose drying facilities are available. For this reason, unlined linen hose cannot be used on U.S. flag vessels. The fire detection system operated quickly even though a quick acting smoke detection capability was not a part of the system.

Remote controlled dampers appear to have closed properly when operated from the bridge. Some flexible ducting in the ventilation system burned, but there were no reports of significant smoke spread through the ventilation system.

The local land-based fire department was hampered by the incompatibility of hose threads. SOLAS is silent on this point except that international hose connection adaptors are required to permit joining of pumping capabilities of a stricken vessel and that of assisting forces. Since the threads were different and no hose adaptors were provided, the shoreside fire departments could not take their own hose aboard to use on the ship's fire main. International shore connections would not have solved this problem because they depend upon the hoses already aboard the vessel which, although meeting SOLAS requirements, were less than adequate in this case.

The fact that the vessel survived and no lives were lost is a tribute to its construction, which was basically SOLAS Method I. Although the fire damage was severe, it was restricted to one main vertical zone. Despite long periods of time with no active firefighting, the main vertical zone boundaries prevented fire spread. The only way the fire spread was through unclosed (or opened) fire doors and over an extended period of time by conduction through steel decks. In addition, the breakage of windows during firefighting provided additional oxygen for the fire.

A large quantity of smoke was produced and it appears that it was generated from furnishings, bulkhead linings (exposed and unexposed sides), electrical cable, etc. SOLAS does not limit smoke producing material nor in any way attempt to control smoke production other than the basic limitation that construction materials be noncombustible and that exposed surfaces have low flame spread characteristics. Note that combustible materials with low flame spread do not necessarily have low smoke production rates and low toxic gas production rates; in fact, chemicals added to combustible materials to reduce flame spread rates can result in higher smoke and/or toxic gas production rates. At the Twenty-ninth session of the Fire Protection Subcommittee of IMO in February 1984, the Subcommittee removed the issues of smoke and smoke toxicity from its work program, and has no plans for any further consideration of these issues. It was felt that the expertise on these matters resided outside IMO.

The SOLAS standards in 1960 and 1974 covered low flame producing qualities with the specifics to be determined by each Administration. An international flammability test has since been developed but no limit criteria are yet available. There is presently no IMO test for smoke production; however, the International Organization for Standardization (ISO) is in the process of developing one. An international standard is desirable, especially one acceptable to IMO. The U.S. test for smoke is a part of the test for flame spread. If the IMO flammability test were to be adopted by the U.S. as a replacement for 46 CFR 164.012, there would no longer be any smoke limitations on construction materials used on U.S. ships; this would be a step backward. Tests for both flammability and smoke are critical to safety and should not permit materials which have greater flame spread and/or smoke development characteristics than those presently accepted for U.S. vessels.

The crew performed in a manner consistent with the level of training required by SOLAS. Basically, routine fire and boat drills must be conducted. Typically, these vary depending upon the interest of the ship's officers and crew. Had the crew drills included instructions on closing of doors in the event of a fire there may have been better performance in this fire. IMO is addressing improvement of training through the International Convention on Standards for Training, Certification and Watchkeeping. This includes participation in an approved firefighting course by officers and crew.

The SCANDINAVIAN SEA was studied to determine its degree of compliance with the new ship requirements of SOLAS 1974, the 1981 SOLAS Amendments, and the 1983 SOLAS Amendments, even though it was not required to meet these standards. SOLAS 1974 is similar in most respects to the 1967 SOLAS Amendments to which the SCANDINAVIAN SEA was built. If the ship had been built to SOLAS 1974, there would have been no fire protection changes necessary other than correction of a few previously noted items that were also violations of the 1967 Amendments. The 1981 SOLAS Amendments are much more detailed than SOLAS 1974. However, in an examination of the plans and in an abbreviated inspection of the SCANDINAVIAN SEA, there was only one area noted where the ship did not satisfy the additional requirements of the 1981 Amendments. The amendments require fire alarm pull boxes at all exits. While the SCANDINAVIAN SEA had a large number of pull boxes, they were not located in all cases at the exits. This probably would not have changed the sequence of events in this casualty. Only one requirement could be identified in the proposed 1983 SOLAS Amendments that would have changed the way the SCANDINAVIAN SEA was built. This was a requirement for smoke detectors in passageways, stairways, and escape routes. Such detectors, although not required on the SCANDINAVIAN SEA, were aboard the vessel, but not yet installed. If smoke detectors had been installed in the passageway outside room 414, it is possible that the fire would have been detected earlier and that firefighting activities could have started earlier and been more effective.

APPENDIX A

History of International Fire Protection Requirements

The development of Structural Fire Protection requirements can be traced to casualties in the early twentieth century. The sinking of the S.S. TITANIC on April 14, 1912 heightened public concern for safety of life at sea, and the heavy death toll experienced in this tragedy was a primary cause for the calling of an international conference. In 1914, the first International Conference on Safety of Life at Sea was held in London. The recommendations of the conference concerned vessel subdivision and minimum requirements for lifesaving devices; however, no mention was made of structural fire protection requirements. Because of the onset of World War I, the provisions of this convention were never fully implemented.

In 1929, a second conference promoting safety of life at sea was held. The purpose of this conference was to continue development of an international standard for the safety of passenger vessels as originally begun in 1914. On May 31, 1929 the "Convention for the Safety of Life at Sea" was completed. Only one segment of this Convention specifically addressed structural fire protection requirements. Regulation XVI required the fitting of fire-resisting bulkheads above the weather deck. The purpose of this requirement was to confine any outbreaks of fire into zones which would not exceed 40 meters in length. This figure was apparently chosen to coincide with every second watertight bulkhead. The fire-resisting bulkheads were required to be constructed of "metal or other fire-resisting materials effective to prevent for one hour, under the conditions for which the bulkheads are to be fitted in the ship, the spread of fire generating a temperature of 1500°F at the bulkhead."

Seven years elapsed prior to the Convention's ratification by the United States. Impetus towards the ratification of this document and the development of structural fire protection regulations occurred in 1934 when the U.S. flag passenger vessel MORRO CASTLE burned off the coast of New Jersey, causing the death of 124 persons. Public reaction to this tragedy convinced the U.S. Senate Committee on Commerce to create a special technical committee of civilian experts on vessel design to investigate the MORRO CASTLE tragedy and to develop recommendations for life safety standards aboard U.S. vessels. This Technical Committee on Safety at Sea was divided into groups assigned to deal separately with the various elements of life safety at sea. The investigation of fire protection measures was assigned to the Subcommittee on Fireproofing and Fire Prevention under the leadership of George G. Sharp, a prominent naval architect. In its report the Subcommittee noted "The first problem confronting the committee was the question as to what general method of fire control might be the most practical combination of effectiveness and simplicity. Past experience having demonstrated the vulnerability of complex automatic and manually controlled systems of detection and extinction, widely spaced fire doors, etc., it was agreed that, if possible and economically practicable, the most foolproof solution to the problem would be construction of such nature that it would confine any fire to the enclosure in which it originated." The Subcommittee had for consideration the 1929 SOLAS Convention which required "fire-resisting bulkheads;" however, a precise definition or standard test for "fire-resisting bulkheads" was not included in the Convention requirements.

To develop a comprehensive definition for "fire-resisting bulkheads," the Subcommittee decided to conduct a series of full-scale shipboard fire tests to evaluate different methods of construction. A test ship, the S.S. NANTASKET, was procured from the Reserve Fleet on the James River. In mid-1936, numerous fire tests were conducted which singled out the performance of one type construction utilizing steel plate and asbestos composition panels. This construction technique was recommended by the Marine Section of the National Fire Protection Association (NFPA), and included two types of "fire-resistive" bulkheads. Class A-1 bulkheads, intended for use as fire-screen or main vertical zone bulkheads, and Class B bulkheads for stateroom boundaries. Class A-1 bulkheads were metal bulkheads which were lined or insulated effectively to maintain structural integrity and prevent the spread of fire to the unexposed side of the test panel when subjected to a standard fire test for one hour. Class B bulkheads were incombustible materials which could maintain structural integrity and prevent the spread of fire to the unexposed side of the test panel when subjected to a standard fire test for thirty minutes. The standard fire test also recommended by the Marine Section of the NFPA was the laboratory fire endurance test used by the National Bureau of Standards. This test had been adopted as a standard test method in 1918 (ASTM E-119).

During the S.S. NANTASKET tests, temperatures were recorded to compare the flame temperatures in the test rooms to the temperatures in the standard laboratory test furnace. Initially, the tests were conducted using clothing and typical furnishings as a fuel source. Very poor combustion occurred, and cord wood was then substituted as a fuel in the remainder of the tests. To approximate the B.T.U. content of the clothing and furnishings, a fuel load of 5 lbs./ft^2 was used. With this configuration, temperatures equivalent to those generated in the standard laboratory test were noted.

Based upon the test results, the Subcommittee reported to Congress, "It would be impossible to fireproof a modern passenger ship by the methods used ashore." During the NANTASKET testing, it was determined that certain materials commonly used for building construction "... gave off such quantities of fumes that it was found impossible to approach even a minor fire to extinguish it. During the course of the experiments, a form of construction was developed in which combustible material was eliminated to such an extent that combustion cannot be sustained by any part of the ship's structure."

As a result of the recommendations presented by the Subcommittee in Chapter IV of Senate Report No. 184, the United States Congress ratified the 1929 Convention for the Safety of Life at Sea, and amended the United States Code to require U.S. passenger vessels to employ "fire-retardant material in their construction so far as is reasonable and practicable." Although it was not clearly defined, the type construction that was utilized in the S.S. NANTASKET tests was intended.

Under the authority of 46 U.S.C. 369, the Secretary of Commerce promulgated order #42 on July 17, 1940, creating Part 144 of Title 46 of the Code of Federal Regulations (Subchapter M). Paragraph 144.4(a) of Subchapter M required interior boundaries to be "constructed of Class A-1, A, or B fire-retardant materials." Class A-1 bulkheads were required to be steel, lined or insulated with sufficient incombustible materials to prevent the average temperature on the unexposed side of the test bulkhead from rising more than 250°F or any single point temperature from rising more than 325°F in one hour when subjected to the standard fire test. Class A bulkheads were required to be steel and to withstand the standard fire test for one hour with no temperature rise limitations. Class B bulkheads were required to be incombustible materials capable of withstanding the standard fire test for 30 minutes and to be capable of preventing the aforementioned temperature rise limitations for 15 minutes. The terms "fire retardant" and "incombustible" were used without precise definition. Unfortunately, there were materials that could be considered fire-retardant and which, in certain configurations, could pass the standard fire test, but did not have the equivalent noncombustibility properties of steel or asbestos board panels. Because of the lack of a specific test method, materials were approved which had the potential to greatly contribute to the fuel load of a protected space. It was not until the end of World War II that a specific test was developed to classify materials as incombustible. In 1949, the Coast Guard adopted standard 46 CFR 164.009 for incombustible materials based upon research conducted at the National Bureau of Standards by N.P. Setchkin and S.H. Ingberg.

During World War II, the need for lighter-weight ships' superstructures had brought about the use of aluminum bulkheads on U.S. Naval vessels. After the war, aluminum bulkheads were proposed for staterooms aboard passenger vessels. It was argued that aluminum bulkheads would be an acceptable substitute for the heavier asbestos composition panels although the aluminum panels might not withstand the standard fire test. The basis for this argument was the fact that aluminum, which has a very high thermal conductivity, will dissipate heat rapidly; secondly, it was suggested that the intensity of the fires in the NANTASKET tests was due to the cord wood fuel source and, as such, did not represent actual conditions. It was maintained that the typical contents of a stateroom could not constitute a fuel load capable of producing a fire equivalent to the standard laboratory test, or even to cause melting of the bulkheads. In 1947, a full scale aluminum stateroom burnout test was conducted in conjunction with the naval architecture firm of Gibbs & Cox, Inc. and the National Bureau of Standards. The stateroom test was conducted in a mock-up stateroom using typical furnishings and the personal belongings of three passengers as a fuel source. This test verified the results of the NANTASKET tests, and showed that a fire involving only typical stateroom furnishings is capable of generating the same temperatures as the laboratory fire test furnace. The stateroom test also showed that uninsulated aluminum bulkheads cannot provide the same degree of fire protection as asbestos composition panels.

The new maritime technology developed during World War II was the cause for a third International Conference on the Safety of Life at Sea during April of 1948, to upgrade the 1929 SOLAS Convention. The United States proposed the incorporation of fire protection techniques contained in 46 CFR Subchapter M. Because the materials used for U.S. flag construction were not available world-wide, and because several nations felt that active fire protection systems were equivalent to passive fire protection, three alternate methods of shipboard fire protection appeared in the 1948 Convention. Method I was the technique proposed and employed by the United States. Method II, proposed by the United Kingdom, advocated the use of sprinklers with no restriction on the combustibility or fire endurance of compartment bulkheads. Method III, proposed by France, made use of a limited amount of fire-resisting bulkheads in conjunction with a fire detection system. The 1948 Convention came into force in the United States on 19 November 1952. To implement this document, and to also revise the passenger vessel inspection regulations into one subchapter, the Coast Guard withdrew Part 144 and created a new Part 70 (Subchapter H -

Passenger Vessels) in Title 46 of the Code of Federal Regulations. The regulations written for this new subchapter are basically those in effect today.

In the new Subchapter H changes were made regarding bulkhead fire endurance ratings. The old Class A-1 bulkheads became "A-60," the Class A bulkheads were changed to "A-0," and the Class B bulkheads became "B-15." Two new categories of bulkheads were created. Class "A-30" bulkheads were an intermediate Class "A "bulkhead. Class "B-0" bulkheads were created because the former Class B bulkhead panels had an inherent fifteen minute fire endurance rating; however, unless certain joints systems or "H-posts" were used, heat transfer through the joints occurred. It was felt that if these bulkheads with inferior joints were installed next to spaces with very low fuel loads such as toilet spaces, a "B-0" rating would be acceptable.

The 1948 Convention was followed by a later convention in 1960. SOLAS 1960 made a number of minor changes to the 1948 Convention but there were no significant or conceptual changes. This convention came into force on 26 May 1965.

Traditionally, international treaties that affect shipping safety standards apply to ships built after the treaty has come into force. This approach is predicated on the premise that older ships will become uneconomical, go out of service and be replaced with new ships, eventually resulting in replacement of the older fleet.

In the mid-sixties there was a series of disastrous passenger vessel fires - the LAKONIA, the VIKING PRINCESS, and the YARMOUTH CASTLE. The VIKING PRINCESS and the YARMOUTH CASTLE carried U.S. passengers on a regular basis and 90 U.S. citizens died as a result of the YARMOUTH CASTLE fire.

As parties to the 1929, 1948, and 1960 Safety of Life at Sea (SOLAS) treaties the United States was required to accept passenger vessels of other flags without hindering their movement, even though the vessels didn't meet the standards required for U.S. flag vessels.

The heavy loss of life aroused the attention of the maritime countries, and in May 1966 a special meeting of the Maritime Safety Committee of the Inter-Governmental Maritime Consultative Organization (IMCO) was called at the request of the United States to consider measures for improving the fire safety of passenger ships.

The Committee first directed attention to the problem of fire safety in older passenger ships, and after thorough consideration of the problem, agreed upon a series of proposed amendments to the fire safety regulations in the 1960 Safety Convention and upon recommendations related thereto. Summarized, these amendments raised the level of all vessels to at least that of SOLAS 1948.

In November 1966, representatives and experts from 46 countries met at the special IMCO Assembly convened to consider solely this subject; this Assembly adopted the proposed amendments and recommendations submitted by the Maritime Safety Committee. These amendments, known as the 1966 Amendments, were scheduled to enter into force one year after they had been formally accepted by at least two-thirds of the Contracting Governments to the 1960 Safety Convention. However, Assembly Resolution A/ES.III/Res.108 invited all governments concerned to take immediate action to put the above fire safety measures into effect at the earliest possible date.

The main part of the amendments is the addition of a new Part G to Chapter II of the Convention, which contains specific provisions for improvements to be made to different groups of existing ships - ships built prior to the coming into force of the 1948 Safety Convention, ships which comply with the 1948 Convention and ships built to the standards of the 1960 Safety Convention. As might be expected, the requirements proved to be more onerous for ships built before 1952, when the 1948 Convention came into force, than for those ships built since then and which already complied fully with either the 1948 or 1960 Conventions.

These improvements call for the structure of ships to be constructed of steel, separation of accommodation spaces from machinery, cargo and service spaces, protection of control stations, stairways and lifts, reduction of the amount of combustible material used in accommodation spaces and the installation of automatic sprinkler or fire detection systems. Under these provisions old passenger ships are required to be brought into close conformity with one of the methods of fire protection laid down in the 1960 Safety Convention.

There were three groups of ships which could be categorized by the international conventions to which they were built.

Group I - This is the oldest group of ships and was built to either a nations individual standards or was built to comply with the 1929 Safety of Life at Sea Convention.

Group II - This represented the largest number of ships, those built in accordance with the requirements of the 1948 Safety of Life at Sea Convention. This convention utilized three methods of fire protection.

Group III - This group of vessels was comparatively small. These vessels were built to the 1960 Safety of Life at Sea Convention which had just entered into force in 1965. This convention also utilized the three methods of fire protection.

For the first time an amendment retroactively required upgrading construction details of existing passenger vessels. The first provision in general required that Group I ships be brought up to the 1960 Standards. This in essence eliminated the so called grandfather clause which permitted older ships to continue in operation without applying the detailed standards of the latest convention as they would apply to new ships.

Group II ships which were built after the 1948 Convention and prior to the 1960 Convention were required to comply with several additional measures such as:

- engine and boiler room skylights be capable of being closed from outside the space

- remote control for pumps from outside of the space in which they are located

- pressure be maintained on the firemain at all times

- a special alarm be fitted in the crew quarters for advance warning of the firefighting crew

- fitting of a public address system throughout the passenger spaces for the ships officers to communicate with the passengers in the event of an emergency.

The last three requirements were also applied to the Group III ships.

The United States complied with the recommendation of Resolution A/ES.III/Res.108 and the 1966 Fire Safety Amendments were made a requirement for foreign flag passenger vessels to embark U.S. passengers at U.S. ports. P.L. 89-777 became law on 6 November 1966. As a result of this approximately 45 foreign flag passenger vessels ceased trading with the United States. It effectively did away with the ability of pre-1948 vessels, including the original QUEEN ELIZABETH and QUEEN MARY to trade in the United States.

Enforcement of P.L. 89-777 was the responsibility of the U.S. Coast Guard. In the first year of enforcement compliance with the 1966 Fire Safety Amendments was determined by reviewing a certificate which stated that the vessel was in compliance. This certificate was issued by the vessels flag state or its duly authorized representative.

After it was discovered that there were often considerable variations in interpretation of convention requirements and that in certain instances the vessels did not comply with the 1966 Fire Safety Amendments, the Coast Guard began inspecting vessels upon arrival at a port and issuing a control verification certificate. This certificate stated that the vessel was in substantial compliance with the 1966 Amendments. In 1968, a British passenger vessel, the CARMANIA arrived in Port Everglades, Florida. It was boarded by a Coast Guard team and found not to be in compliance. The vessel was not permitted to load U.S. passengers. To facilitate subsequent vessel reviews, a new procedure was developed to minimize such inconveniences. Plans were submitted in advance of a vessel's arrival in a U.S. port. After a review where technical problems were identified, the vessel's owner and flag state were notified. The list of deficiencies or problem areas along with appropriate plans were forwarded to the Coast Guard inspection office at the port where the vessel was expected to call. The vessel was then examined to verify that outstanding discrepancies had been corrected. This procedure was followed in the case of the SCANDINAVIAN SEA.

After older passenger ships had been addressed, the next task was the improvement in fire safety of future passenger ships. The Maritime Safety Committee requested the IMCO Sub-Committee on Fire Protection to develop a new system of fire protection, taking into account the best features of the existing three methods of fire protection and having full regard to the maximum use of incombustible material and the appropriate use of automatic sprinkler and detection systems.

The Sub-Committee, after intensive work, succeeded in developing new regulations for fire protection, fire detection and fire extinction which were to apply to future passenger ships carrying more than 36 passengers. At its meeting in February/March 1967, after careful consideration, the Maritime Safety Committee adopted the proposed amendments to the 1960 Safety Convention which became the 1967 Amendments, Resolution A. 122(V).

The proposed 1967 Amendments contained a single unified system with two variants of structural fire protection, with and without automatic sprinklers. They addressed fire detection and fire extinction in accommodation, machinery and cargo spaces and spaces containing motor vehicles with fuel in their tanks. Extensive changes were also made to the provisions for fire safety measures in machinery spaces, fireman's outfits, muster lists, fire patrols, etc.

The proposed new regulations (to which reference has been made in the preceding paragraphs) introduced a number of important changes in the 1960 Safety Convention requirements, the most significant of which was the adoption of a single unified system of structural fire protection which replaced the existing three methods.

Lack of progress in obtaining acceptance by the required two-thirds of the contracting governments led to yet another convention, SOLAS 1974. One of the primary purposes of this convention was to consolidate the accumulated amendments and convention requirements into a single document which could be ratified by a sufficient number of governments to enter into force. The 1974 Convention, from a fire protection standpoint, consist essentially of boiler plate from SOLAS 1960, detailed construction requirements from the 1967 Amendments for new ships and a section, Part F, which applies the bulk of the 1966 Amendments to existing ships. Another important change was inclusion of a simpler method of amending the technical provisions of the treaty (tacit amendment procedure). Had this improved mechanism been in place in 1966, the 1966 and 1967 Amendments would have come into force approximately two years following their adoption by the Maritime Safety Committee, over ten years sooner than their actual coming into force through SOLAS 1974.

The scope of the development of SOLAS 1974 was limited to formatting and consolidation of existing conventions and proposed amendments. It was felt during these deliberations that advances in the state of the art required upgrading of the convention. The first set of amendments to SOLAS 1974 was adopted by the Maritime Safety Committee on 20 November 1981. Known as the 1981 Amendments, the changes to structural fire protection primarily impacted cargo ships and tankers. They entered into force on 1 September 1984. A second set of Amendments was adopted by the Maritime Safety Committee on 17 June 1983. Known as the 1983 Amendments, the changes to structural fire protection were mostly of a minor nature. As of the beginning of 1985, there are no additional amendments anticipated in the near future.

APPENDIX B

Cable Flammability

The first shipboard application of electric cable was in 1879. Since that time, there have been many evolutionary changes in cable usage, design, and material. Unfortunately, it has only been in recent years that there has been a greater awareness of the damage to lives and property caused by fires propagated by cables. In the United States, shipboard cable changes have primarily been initiated by Navy cable engineers and by the Marine Transportation Committee of the Institute of Electrical and Electronics Engineers (IEEE), with the assistance of the Insulated Cable Engineers Association (ICEA). Internationally, the International Electrotechnical Committee (IEC) has been the primary standards organization for the development of shipboard cable standards.

For merchant vessel cable, design emphasis has historically been placed on the harsh ship construction environment (nearby welding, pulling cable through bulkheads, and subjecting cable to constant mechanical abuse), as well as on the shipboard environment (clamped assemblies, large cable bundles, and exposure to a wide range of temperatures, high humidity, and oil). For naval cable, additional considerations have included longitudinal water propagation resistance, overload conditions, and circuit integrity under fire conditions. Recently, the Navy has also had to explore smaller diameter, lighter weight cable constructions in order to conserve space and reduce topside weight. It has only been during the past fifteen years that several disastrous shipboard fires have focused attention on the fire propagation aspects of typical marine cable installations.

In the 1970's, significant cable fires occurred on the aircraft carriers USS FORRESTAL, USS SARATOGA, and USS KENNEDY, and on the British submarine HMS WARSPITE. In the recent Falklands conflict, the destroyer HMS SHEFFIELD, hit by an Exocet missile, experienced a cable fire that contributed to the loss of the vessel. The problem of cable fires has not been unique to ships. On March 22, 1975, a major cable fire occurred in the cable-spreading room of the Brown's Ferry Nuclear Plant. In casualties such as these, cableways have been blamed for spreading relatively small and confined fires and generating dense black smoke and toxic and corrosive products of combustion, compounding the firefighting problem.

Prior to 1977, the most common method for testing the flammability of marine cable was a gas burner test on a single vertical cable. Typically, a specified cable length is subjected to a gas flame for a specified duration, and the gas then turned off. The flame must extinguish itself before reaching a specified height. Similar requirements appeared in IEEE Standard No. 45, "IEEE Recommended Practice for Electric Installations on Shipboard", and IEC Publication 92-3, "Electric Installations in Ships", the standard referenced by many classification societies, including Det norske Veritas. Prior to May 1980, the Navy flammability test also used a single vertical cable sample, but heated the sample with an electric heating coil and used spark plugs to ignite the evolved gases. Both the distance of cable burn and the time of afterburn were used to determine flame retardancy. While these tests predicted the capability of a single cable to be self-extinguishing, they did not predict cable performance in a bundled configuration, where the close proximity of the cables provides reinforcement to maintain a cable fire.

During the last decade, the wire and cable industry has made major advances in materials, construction techniques, and flammability evaluation procedures. In the United States, standards that include testing for flame propagation resistance in a typical installation were developed. The first was IEEE Standard No. 383-1974, "IEEE Standard for Type Test of Class IE Electrical Cables, Field Splices, and Connections for Nuclear Power Plants." The IEEE Marine Transportation Committee subsequently adopted this method for fire evaluation in IEEE Standard No. 45-1977. The U.S. Coast Guard regulations in effect at that time referenced the cable requirements of the IEEE-45 "currently in effect". However, the regulations also permitted U.S. Navy cable that did not meet the stringent IEEE-45 flammability requirements. In May 1980, the U.S. Navy adopted the IEEE-383 flammability requirements in Amendment 2 of military specification MIL-C-915E. The Coast Guard Electrical Engineering Regulations published April 8, 1982, and effective for vessels contracted for after May 31, 1982 require shipboard cable to meet the IEEE-45 flammability requirements. The only exceptions are for special purpose cables, such as coaxial cables, that are recognized in both IEEE-45 and the 1981 Amendments to SOLAS 1974.

The IEEE-45 test attempts to simulate a real cableway fire situation in evaluating propagation parameters of a typical cable installation. In this test, six eight-foot lengths of unarmored cable of the same type and size are arranged in a single layer in an eight foot vertical tray, with a separation of one-half cable diameter between each cable. A ribbon type gas burner is mounted horizontally behind the tray, 18 inches from the bottom, with the burner face 3 inches behind the closest surface of the cables. Air pressure and propane gas flow are adjusted in accordance with the standard. The resultant flame is approximately 14-16 inches high, has a temperature of approximately 1750°F., and has a heat input of approximately 70,000 Btu/h. During the test, the flame is allowed to burn for 20 minutes, and any afterburn is allowed to continue. The cable may be destroyed in the area of flame contact, but must not propagate the flame. The cable is considered to be flame retardant if, after the fire has extinguished itself, the damage to the cable (blistering or charring of the jacket) does not reach the top of the eight foot samples. At this time, IEEE-45 does not address toxicity, smoke, or corrosive gas generation.

Internationally, the shipboard cable flammability problem was addressed in IMCO Resolution A.325(IX), which was adopted on November 12, 1975. Paragraph (e)(ii) of Regulation 23 states: "All electric cables shall be at least of a flame retardant type and shall be installed so as not to impair their original flame retarding properties." This requirement has now been adopted in the First Set of Amendments to SOLAS 1974 (1981 Amendments), which became effective September 1, 1984.

The IEC Technical Committee 18 is developing guidance on how to meet the SOLAS Amendments. The most recent proposal indicates that shipboard cables should be qualified using a suitable test procedure for cables in a bunched configuration, for example IEC Report 332-3, or that special precautions should be taken. These special precautions consist of utilizing fire stops along cable runs and in other selected locations, or applying a fire protective coating to the cable installation.

As recent experience has shown, shipboard cable standards of the past and the present do not adequately address cable performance in a shipboard fire.

Shipboard cables typically generate large quantities of black smoke and noxious fumes which impede firefighters efforts to locate the fire, extinguish the flames, and escape to safer areas. Shipboard cables of the early 1970's, whether on a U.S. or foreign flag vessel, naval or merchant marine, can also be expected to propagate fire when bundled in a typical shipboard installation.

On a U.S. flag vessel built today, the risk of fire propagation has been significantly reduced due to the Coast Guard's requirement to use flame retardant cables. Internationally, the cable fire propagation problem has been recognized, and solutions are close at hand. Due to the 1981 Amendments to SOLAS 1974, there will soon be flame retardant cable installations on new construction world-wide. Then the international community can move on to the more complex issues concerning the smoke, toxic gases and corrosive products generated during a shipboard fire.

APPENDIX C STABILITY

A. Overview of Method

B. Assumptions

C. Details of Method

D. Enclosures

1) Righting Arm Curves
2) Load Condition 1 with Attachment
3) Load Condition 2
4) Load Condition 3
5) Calculation of Displacement and Centroids of Free Water Load Condition 2
6) Calculation of Displacement and Centroids of Free Water Load Condition 3
7) Discussion of Computer Programs for Calculating Centroids of Free Water.
8) Description of Compartments and Soundings used in the stability assessment

APPENDIX C STABILITY

A. Overview of Method

The displacement, draft, trim and KG were calculated using the Chief Mate's loading figures. Using these parameters, the associated righting arm curve was then developed (Righting Arm Curve 1 on enclosure 1).

The displacements and centroids were calculated for the amount of free water reported to be on board the vessel during the firefighting efforts. These were summed along with the displacement and centers of gravity from Condition 1 to produce Condition 2. Stability calculations were then made for the vessel in this condition. The righting arm curve was corrected for free surface and plotted as Curve 2 on enclosure 2.

To assess the decrease in stability due to additional firefighting without dewatering, the displacements and centroids for quarter full compartments in all compartments reported to be slack were calculated. The weight of the water in this third hypothetical condition was calculated to be 1630 tons. These displacements and centroids were summed along with the Condition 1 values to produce Condition 3. Righting Arm Curve 3 is that curve corrected for free surface values. For a more detailed discussion see the "Details of Method" Section of this report. The particulars for the free water calculations and for the vessel conditions are also attached to this appendix.

B. Assumptions

The digitized hull form was based on the Lines Plan provided by the Marine Board. Note that all stability calculations assume the vessel watertight to the lounge deck per the Trim and Stability booklet. Good agreement was found with both the hydrostatics and the righting arms across the range of drafts and displacements.

Information on drafts was provided from several sources. They were not in agreement. One set was taken by the NTSB Investigator and three others were taken by a USCG Inspector at various times during the firefighting efforts. Attempts to verify the drafts provided against the condition of the vessel at various times met with only limited success. Therefore, the Chief Mate's loading condition sheet (attachment to enclosure 2) was used to estimate the vessel's initial condition.

The NTSB Investigator provided a set of compartment "soundings". These "soundings" were taken from the high water marks in the vessel a day or two after the fire was out. It should be recognized that these soundings were approximate, but were the best figures available. These "soundings" and the 10.8 degree maximum list recorded formed the basis for calculation of the volume of firefighting water. It was further assumed that this water was the only firefighting water on the vessel.

Early in the firefighting effort, water was pumped into the chain locker, bow thruster room and boatswain's stores. The purpose of this was to submerge the forward bunker tanks so that maximum cooling by sea water could be effected. All calculated conditions assume these compartments to be pressed up.

In defining Condition 3 (1630 tons of free water) it was assumed that the compartment breadths for capacity and free surface purposes were the mean half breadth. This assumption was made since in this vessel, as in most passenger ships, the construction is such that downflooding occurs though stairways located on centerline. In calculating these displacements and centroids then, a volume was assumed which would fill our half breadth compartments fifty percent full. These assumptions allowed several parameters to be fixed in order to quantify the effect of additional free water on stability. Once these parameters were defined, Table 8 in Section 5 of "Principles of Naval Architecture" was used to calculate the free surface correction for the various angles of heel.

The additional free water added in going from Condition 2 to Condition 3 (1100 tons) corresponds to approximately one hour's worth of firefighting water at 5000 gallons per minute with no dewatering being done.

The effects of the wind and seas on the vessel at pierside were negligible. These factors probably account, however, for a portion of the difference between the reported heel angle and the one calculated in Condition 2.

The free surface correction for the vessel's tanks was negligible. It was calculated to be 0.03 feet and was ignored.

C. Details of Method

In order to evaluate the stability of the vessel, the relationship between the amount of water onboard based on high water marks found by the NTSB Investigator and the corresponding heeling and righting moments at the maximum reported list angle was assessed.

Displacements and centroids for the water onboard were determined. Initial attempts involved the use of the tank calibration option of the Stability Analysis of Arbitrary Forms program (STAAF II). These attempts were unsuccessful, however, because of errors in the STAAF II program itself. Two programs were then written to calculate displacements, volumes and centroids. These programs were used repeatedly to calculate those parameters for the several loading conditions. The details of the programs as well as those for the free water in loading Conditions 2 and 3 can be found in enclosures 7, 6, and 5, respectively.

The vessel's stability particulars were calculated per the Chief Mate's departure condition and adjusted for crew and passenger changes, fuel burnoff and fresh water usage. Details of this condition as well as the Condition 1 Righting Arm curve derived from running the U.S. Navy's Ship Hull Characteristics Program (SHCP) on this condition can also be found in enclosures 1 and 2.

In order to assess the effects of the free water on the vessel, a program was generated to calculate the displacement and centroids of the contained volumes based on the information provided by the NTSB Investigator's soundings and reported heel angle. These figures were then summed and used to calculate a new condition (Righting Arm Curve 2) for the vessel. This condition was run using STAAF II to find the equilibrium heeling angle and righting arm curve. Table 8 of Section 5 of "Principles of

Naval Architecture" was used to find the Free Surface Corrections for the slack compartments. These corrections were applied to the righting arm values found above and the resultant curve was plotted. This curve is shown as Righting Arm Curve 2 in enclosure 1.

To verify the righting arms and equilibrium heel angle values, the "no list" righting arm values were found using SHCP for free surface. Generally good agreement was obtained with the values calculated using STAAF II.

With a reference established for the effects of added water, the effect of adding additional water to the vessel was studied. A volume of water, which would give a half full compartment, was assumed in each compartment which had been reported to contain water. As mentioned in the assumptions, it was assumed that the maximum breadth for each compartment was the average half breadth.

This resulted in using one fourth of the total volume of the compartment for Condition 3 water volumes. The displacement of each of these slabs was calculated and then summed to compute a total displacement for the slabs. In that the total displacement was about 1500 tons, the TCG which had been calculated for Condition 2 was used to estimate the angle of heel to which this much water would bring the vessel. The corresponding point on the uncorrected (for free surface) curve was approximately 14.6 degrees.

Using this angle, another program was generated to calculate the centroids of these new water volumes given the volume and 14.6 degree heel angle. These figures were summed and added to the arrival condition particulars to achieve new LCG, TCG, and VCG figures for Condition 3.

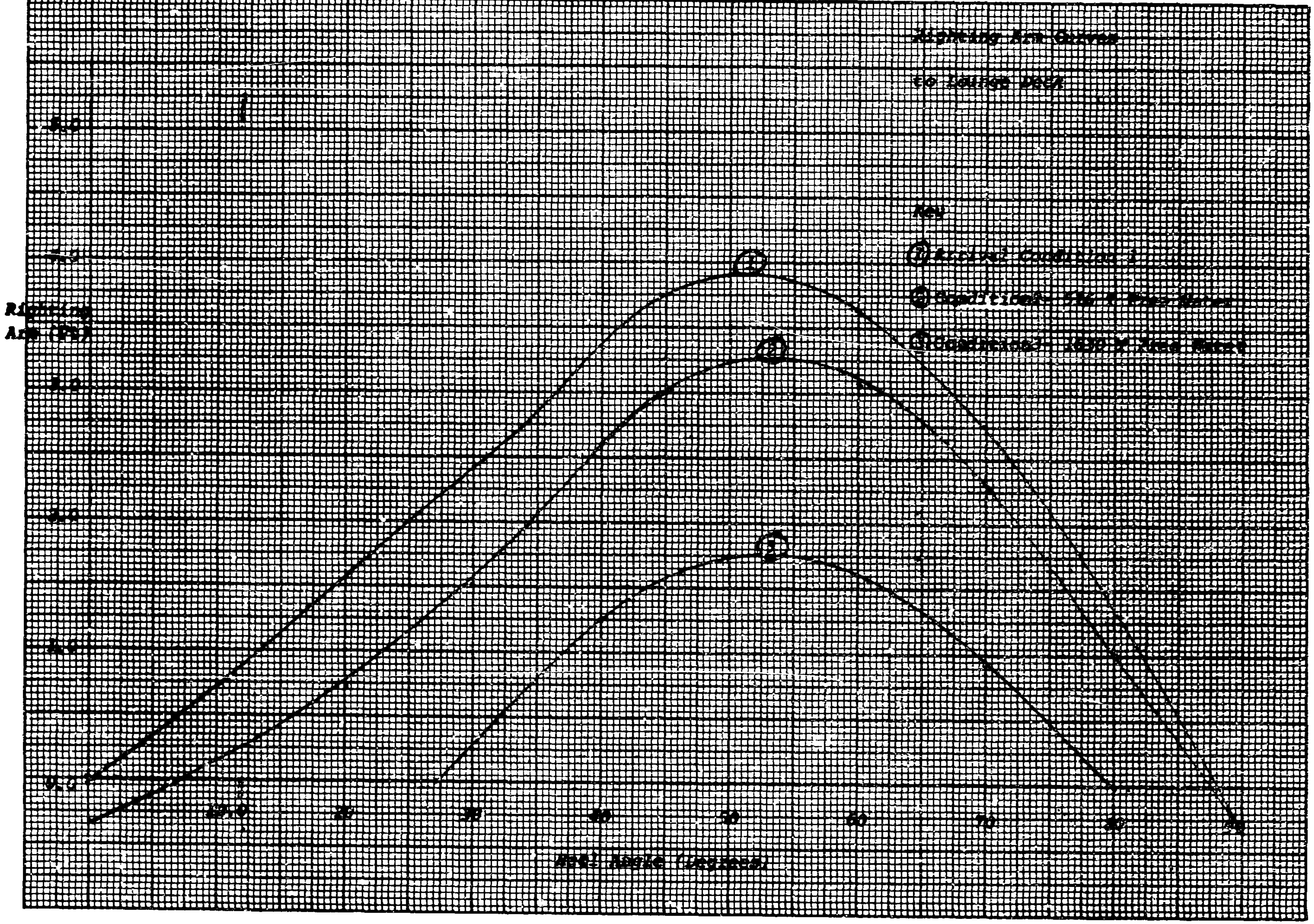
As in Condition 2 case, STAFF II was run with these parameters and a new equilibrium heeling angle and righting arm curve were found. This angle proved to be 26.8 degrees. This Condition 3 curve was again corrected for free surface and plotted as Righting Arm 3 in enclosure 1.

As in the Condition 2 work, the righting arms were calculated using SHCP. The equilibrium heeling angle was about 27 degrees and again generally good agreement was found with the righting arm values from STAAF II.

For further details on either of the programs used to find displacements and centroids, and on the compartment descriptions and soundings, consult enclosure 7.

Enclosure (1)

M.V. Scandinavian Sea



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Enclosure (2)

STABILITY TEST M/V Scandinavian Sea

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Condition 1 - Arrival at Dock with No Free Water

Data for Tanks: Liquid	Sound'g	Net Inertia of Free Surface	Inertia Feet⁴/Ton	ITEMS (Include list of tanks completely empty)	Weight Tons	C. G. Above Base: Lever	Vertical Moments Ft-tons	C. G. From M. P.: Feet Aft	After Moments Ft-tons	Feet Fwd	Forward Moments Ft-tons
				Mates Departure Condition Metric	9303.9		77889.19				584,902.66
				per attached sheet							
				Deduction for burnoff, ~~passengers~~, crew and fresh water	131.1		1315.1				8,372.6
					9172.8		76574.09				576,530.06
				Convert to English Units	9028.4		247,267.99				1,861,692.74
				VCG FT		27.4					
				LCG FT FWD AP						206.2	
				LCG FT AFT FP						242.2	
				Draft (ft)	19.19						
				Trim (ft) by stern	2.21						

NOTE: Furnish tank sounding tables and plan of sounding tube locations unless previously submitted.)

MATES DEPARTURE CONDITION

3/9/84 SCANDIAVIAN SEA

ITEM	Disp. Tons	Ht above BL	Mom. about BL	Dist fm A.P.	Mom. about A.P.	Mom of Inertia
F. PK.	72.	5.23	376.6	133.16	9587.5	25.9
5 ENCL.	41.6	0.78	32.45	78.92	3283.07	-
7 ENCL.	57.7	0.65	37.51	49.38	2849.23	-
HEEL TKS.	50.	2.21	11.05	55.24	2762.	23.8
10 TW. P.	71.1	7.98	567.4	6.94	493.4	176.5
10 TW. S.	63.7	7.98	508.3	6.73	428.7	158.9
10 D.P.	23.4	6.	146.4	6.27	146.7	20.0
10 D.S.	20.0	6.03	120.6	5.86	117.2	15.8
10 D.C.	103.1	4.85	500.	5.62	579.4	70.2
A. PK.	35.4	6.14	217.4	-0.91	-32.2	144.1
2 B. P.	40.	5.	200.	118.07	4722.8	13.6
2 B. C.	43.	3.4	146.2	117.81	5065.8	23.6
2 B. S.	22.	5.	110.	118.07	2597.54	13.6
6 B. P.	35.	0.74	25.9	69.89	2446.2	108.6
7 A. P.	38.	0.57	21.7	54.23	2060.7	81.3
7 A. S.	26.	0.57	14.8	54.23	1410.	81.3
7 B. P.	40.	0.56	22.4	46.13	1845.2	88.8
7 B. S.	35.	0.56	19.6	46.13	1614.6	88.8
SETTL. TK.	18.	3.84	69.1	83.72	1507.	7.5
DAY TK.	20.	3.84	76.8	83.72	1674.4	8.1
2 A. P.	25.	4.29	107.25	125.35	3133.75	9.4
9 DEEP	62.	2.66	164.9	14.35	889.7	200.
SETTL. TK.	6.	3.27	19.6	83.75	502.5	3.7
DAY TK.	7.	5.44	38.08	83.72	586.04	3.7
5A. DB. P.	28.6	0.70	2002.	79.58	2275.99	28.9
5A. DB. S.	34.7	0.69	23.94	79.60	2762.12	16.7
M. E. CL.TK.	41.6	0.65	27.04	79.70	3315.52	41.4
LUB. TK.	45.	0.67	30.15	65.02	2925.9	12.3
L. SHIP.	7949.	9.05	71938.45	63.19	502297.3	
PROV./ STORES	150.	6.05	907.5	91.88	13782.	
PAX	80.	14.05	1124.	69.37	5549.6	
CREW	20.	8.53	17.06	86.15	1723.	
	9,303.9		77,889.19		584,902.66	1,459.5

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Enclosure (3)

STABILITY TEST M/V Scandinavian Sea

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Condition of Condition 2 - 516 Tons Free Water and Estimated 10.8 Degree List

Data for Tanks: Liquid	Sound'g	Net Inertia of Free Surface	Inertia Feet⁴/Ton	ITEMS (Include list of tanks completely empty)	Weight Tons	C. G. Above Base: Lever	Vertical Moments	C. G. From M. P.: Feet Aft	After Moments Ft-tons	Meters Feet For'd	Forward Moments
				Mates Departure Condition Metric Units	9303.9		77889.19				584902.66
				Deduction for burnoff, passengers, crew,							
				and fresh water	131.1		1315.1				8372.6
				Net Metric	9172.8		76574.09				576,530.06
				Calculation of VCG							
				Convert to English Units	9028.4		247,267.99				1,861,692.74
				Add Free Water	516.0		11,543.23				
				Total	9544.0		258,811.22				
				VCG (ft)		27.12					
				Calculation of LCG	9544.0						1,861,692.74
				LCG FT FWD of AP						206.2	
				AFT of FP				242.3			
				Moment about FP					2,187,388.6		
				add Moment for Free Water					37,782.0		
									2,225,170.6		
				LCG				233.2	ft aft of FP		
				Calculation of TCG	9544.0						
				Water's Moment about			3821.0				
						.4005					
				Even Keel Draft 20.05 ft							
				Trim 3.12 ft. by bow							

NOTE: Furnish tank sounding tables and plan of sounding tube locations unless previously submitted.)

True Heel Angle = 5.63° Star Board

Enclosure (4)

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Calculation of Condition 3 - 1630 Tons Free Water and Estimated 14.6° List

Data for Tanks: Liquid	Sound'g	Net Inertia of Free Surface	Inertia $Feet^4$/Ton	ITEMS (Include list of tanks completely empty)	Weight Tons	C. G. Above Base: Lever	Vertical Moments Ft.-tons	C. G. From M. P.: Feet Aft	After Moments Ft.-tons	Feet Forward	Forward Moments Ft.-tons
				Mates departure Condition corrected for	3028.4		247,267.99		2,183,890.53		
				burn off passenger, crew and							
				fresh water deductions							
				and free water and moments	1630.0		56,412.55		153,073.63		19,499.67
					10,658.0		303,680.54		2,336,964.16		
				VCG (ft)		28.49					
				LCG (ft) aft FP				219.27			
				TCG (ft) to STBD						1.83	
				Even Keel Draft 22.09 ft							
				Trim 14.25 ft by bow							
				True Heel Angle = 27.64° Starboard							

NOTE: Furnish tank sounding tables and plan of sounding tube locations unless previously submitted.)

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STABILITY TEST M/V. Scandinavian Sea

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Listing at 10.8 degrees to Starboard
Condition 2 - With 516 Tons of Free Water

Data for Tanks: Liquid	Sound'g	Net Inertia of Free Surface	Inertia ft⁴/Ton	ITEMS (Include list of tanks completely empty)		Weight Tons	C. G. Above Base: Lever	Vertical Moments Ft-tons	C. G. From M. P.: Feet Aft	After Moments Ft-tons	Feet Fwd (off c)	Transverse: Forward Moments Ft-tons
				Compartment	A-1	52.58	24.5	1288.21	53.2	2795.7	11.4	600.99
					A-2	14.24	26.0	370.67	107.0	1523.8	21.9	312.00
					A-3	20.11	21.3	428.95	155.0	3117.1	28.6	575.15
					B-1	23.88	17.2	411.45	112.7	2691.3	17.6	420.53
					B-2	5.20	13.9	72.33	138.4	719.5	20.1	104.31
					C-1	71.11	3.9	280.17	86.9	6176.6	0	0
					C-2	74.58	2.6	196.15	129.1	9624.6	0	0
				Lounge		31.25	47.9	1495.63	133.0	4155.9	24.8	775.63
				Upper-1A		8.01	39.6	317.20	50.6	405.6	20.4	163.24
				Upper-1B		17.80	39.5	703.18	82.7	1471.2	25.2	448.56
				Upper-1C		9.56	39.3	375.71	103.6	990.2	26.6	254.30
				Upper-2		.56	38.2	21.41	120.3	67.5	31.1	17.42
				Upper-3		.25	38.0	9.50	162.4	40.6	32.1	8.03
				Main		3.48	31.6	110.04	73.2	254.9	24.5	85.23
				Boat		1.92	56.7	108.92	92.8	180.1	29.4	56.41
				Chain Locker		82.13	23.0	1886.53	30.8	2532.1	0	0
				Bosun's Stores		99.67	34.8	3466.57	10.4	1035.6	0	0
				TOTALS		516.33		11543.23		37782.00		3821.80

NOTE: Furnish tank sounding tables and plan of sounding tube locations unless previously submitted.)

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STABILITY TEST M.V. Scandinavian Sea

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Listing at 14.6 degrees to Starboard

Condition 3 - Worst Case 1630 Tons of Free Water (Half Full Compartments)

Data for Tanks: Liquid	Sound'g	Net Inertia of Free Surface	Inertia Feet³/Ton	ITEMS (include list of tanks completely empty)	Weight Tons	C. G. Above Base: Lever	Vertical Moments Ft.-tons	C. G. From M. P.: Feet Aft	After Moments Ft.-tons	Feet For'd	Forward Moments Ft.-tons
				Compartment A-1							
				A-2	312.45	24.7	7726.9	121.9	38081.4	9.3	2896.4
				A-3							
				B-1	141.75	15.4	2178.7	116.0	16440.2	10.2	1451.5
				B-2							
				C-1	124.97	7.2	896.0	100.9	12609.5	7.5	934.8
				C-2							
				Lounge	222.04	49.6	11006.5	132.1	29322.6	18.8	4165.5
				Upper-1A							
				Upper-1B							
				Upper-1C	293.88	40.5	11910.9	87.1	25596.9	15.2	4452.3
				Upper-2							
				Upper-3							
				Main	127.85	33.3	4254.2	58.1	7431.9	10.1	1296.4
				Boat	225.16	58.1	13088.6	88.9	20023.5	19.1	4302.8
				Chain Locker	82.13	23.0	1886.5	30.8	2532.1	0	0
				Bosun's Stores	99.67	34.8	3466.5	10.4	1035.6	0	0
				TOTALS	1630.0		56,412.6		153,073.6		19,439.7

NOTE: Furnish tank sounding tables and plan of sounding tube locations unless previously submitted.)

U. S. GOVERNMENT PRINTING OFFICE 16-36870-6

GPO 958024

Enclosure (7) DISCUSSION OF DISPLACEMENT & CENTROID PROGRAMS

Two methods were used to make these calculations. The first involved a program written in BASIC on the WANG system while the second was written for an HP-41C calculator. The programs differed slightly in their input/output and in the centroid calculating technique used, but essentially yielded displacement, VCG, TCG, and LCG of the individual compartments for a given amount of water. Details have been avoided but a short discussion of the techniques follows.

Briefly, in the BASIC program the inputs were tank geometry, water wedge geometry and height of water at the hull at the forward and after faces of the water wedges. The algorithm used intergration to find volumes and centroids and then VCG, TCG, and LCG for each of them. In that the program used a coordinate system which was oriented parallel to the ships hull, a trigonometric correction was required to pull these values back into the ship's coordinate system.

The HP-41C calculator program took a slightly different approach. Here it was necessary to look at the volumes, displacements and centroids for tanks which contained a given volume of water at a given list angle. These two values, (the volume and the list angle) as well as the tank geometry were input and the program used an algebraic method to find centroids and convert them into TCG, VCG, and LCG. Since the program worked in a coordinate system which was parallel to the ships coordinate system, no trigonometric calculations were required and the outputs were usable directly in the calculation of TCG, VCG, and LCG for the ship.

Description of Compartments and Soundings Used

Compartment	Frame Boundaries Fwd	Aft	Sounding and Location
A-1	186	165	2.67' aft at hull
A-2	165	144	2.95' aft
A-3	144	123	5.45' aft
B-1	165	144	3.00' fwd
B-2	140	136	3.00' aft
C-1	165	155	Full
C-2	146	136	6.73' aft
Lounge	175	149	3.07' aft
Upper 1A	186	166	2.73' aft
Upper 1B	166	156	3.16' aft
Upper 1C	156	149	3.23' aft
Upper 2	149	141	0.68' aft
Upper 3	131	121	0.43' aft
Main	186	162	1.25' fwd
Boat	170	150	1.0' aft
Chain Locker	189	186	Full
Boatswain's Stores	202	186	Full

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F