

SCANDINAVIAN STAR

Fire on board 070490-080490

FIRE INVESTIGATION



Preliminary study

Malmö, Sweden, 2009-07-09

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Document information

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1 Introduction

This fire investigation has been performed by Pierre Palmberg and Henrik Georgsson, Fire Protection Engineers Lund University. Pierre Palmberg and Henrik Georgsson have performed this investigation on their own initiative as independent experts within the field of fire and risk technology. The project has been carried out as an internal project i.e. without compensation from any client. The object of the project has been to provide an adequate basis for decision concerning further investigation of the fire aboard the Scandinavian Star.

This report is a developed and translated version of the preliminary study presented and officially announced in 2006-08-15 by Pierre Palmberg and Henrik Georgsson. This report will undergo yet another thorough review, including assessment of the testimonies made, the conclusions drawn and further analysis of available photo and video material, this autumn (2009).

2 Facts and documentation

The following documentation has constituted the basis for this preliminary study:

- Norges Offentlige Utredninger (NOU): Scandinavian Star – ulykken, 7. april 1990, Hovedrapport NOU 1991:1A and vedlegg NOU 1991:1B, Oslo 1991.
- SoS-rapport 1993:3: Branden på passagerarfärjan Scandinavian Star den 7 april 1990 (the National Swedish Board of Health and Welfare).
- Excerpts from SOLAS 60 as printed in the Swedish Maritime Administration's statute book SJVFS 1970:13.
- Testimony from Ingvar Brynfors – Gothenburg Rescue Service (Sweden), Fire Ground Commander for the first rescue action aboard the Scandinavian Star.
- Testimony from Police Inspector Agne Knutsson – The Swedish Police Service, the first Police Officer aboard the Scandinavian Star after the fire.
- Post-mortem report concerning Erik Mörk Andersen denoted "Likåbning SS 80/90 dato 100490" drawn up by expert M.D. Leif Jørgensen and Senior Physician Leif H Bostad, Rikshospitalet – Retsmedisinsk Institut, Oslo.
- Observer report from Scandinavian Star 1990-04-07 – 1990-04-09, Olle Wennström – Fire Protection Engineer (Sweden).
- I-R Logg (Rescue action log) Scandinavian Star 1990-04-07, Gothenburg Rescue Service (Sweden).

3 Ship specifications

In the table below a short description of the ship and its equipment is presented.

Technical specifications for M/S Scandinavian Star	
Year of production	1971
Number of decks	8
Length	141,60 m
Width	21,9 m
Height measured from keel to main deck (car deck)	7,75 m
Height measured from keel to sun deck	19,00 m
Draught	5,50 m
Cruising speed	21,5 knots
Passenger capacity	1152 passengers including 100 crew members
Number of passengers at the time for the accident 1990-04-07	383 passengers and 99 crew members
Applied regulations concerning the construction of the ship	SOLAS 60
Fire resistance class applied to main fire sections (3)	A 60
Ventilation system	Mechanical supply/exhaust system with manually operated fire dampers
Operation mode of the ventilation system in case of fire	Manual shutdown of fans and fire dampers

Table 1. Technical specifications for M/S Scandinavian Star.

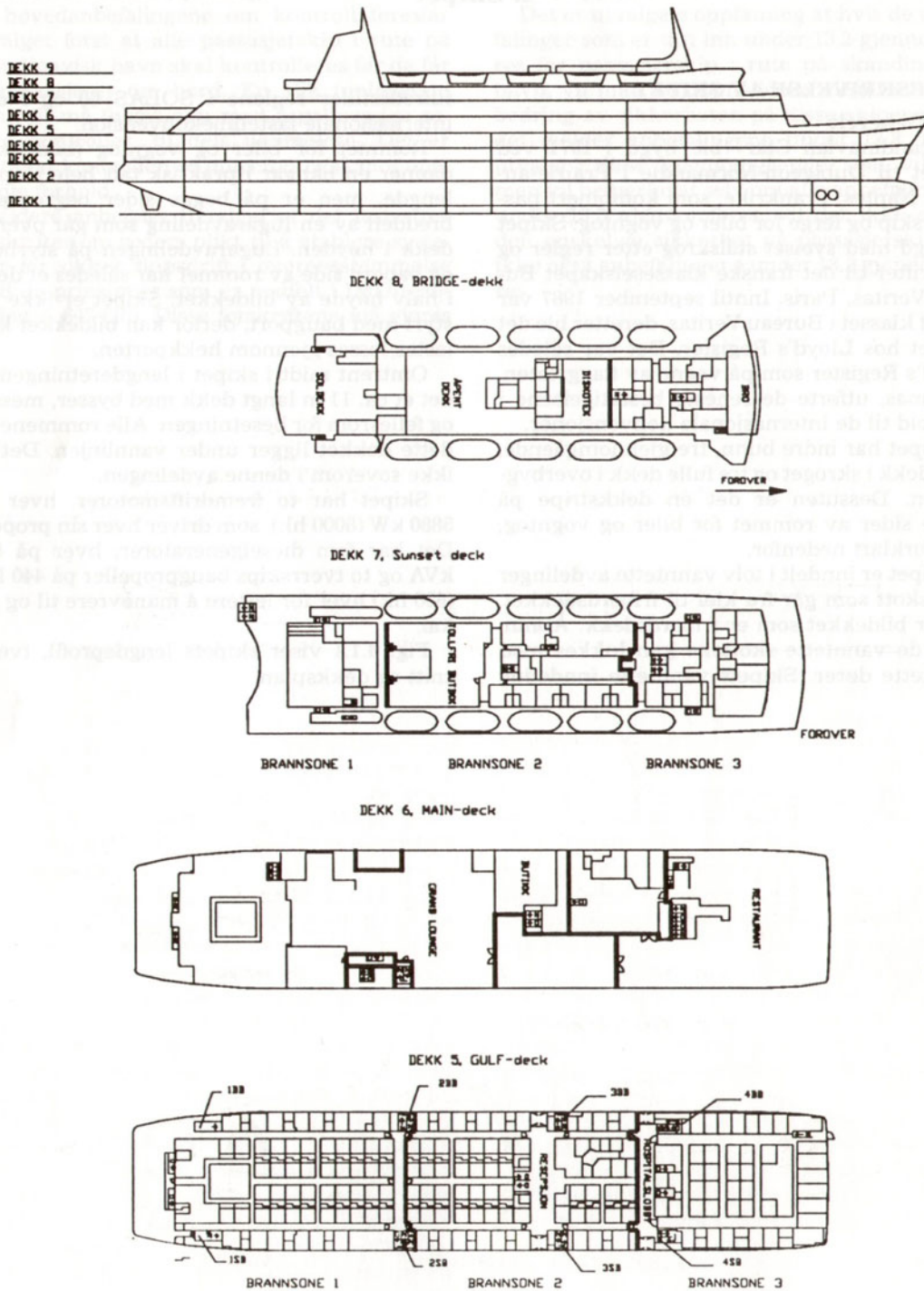


Figure 1. Cross-sectional view of the ship along with plans for deck 5, 6, 7 and 8. Main fire sections are represented by thick black lines.

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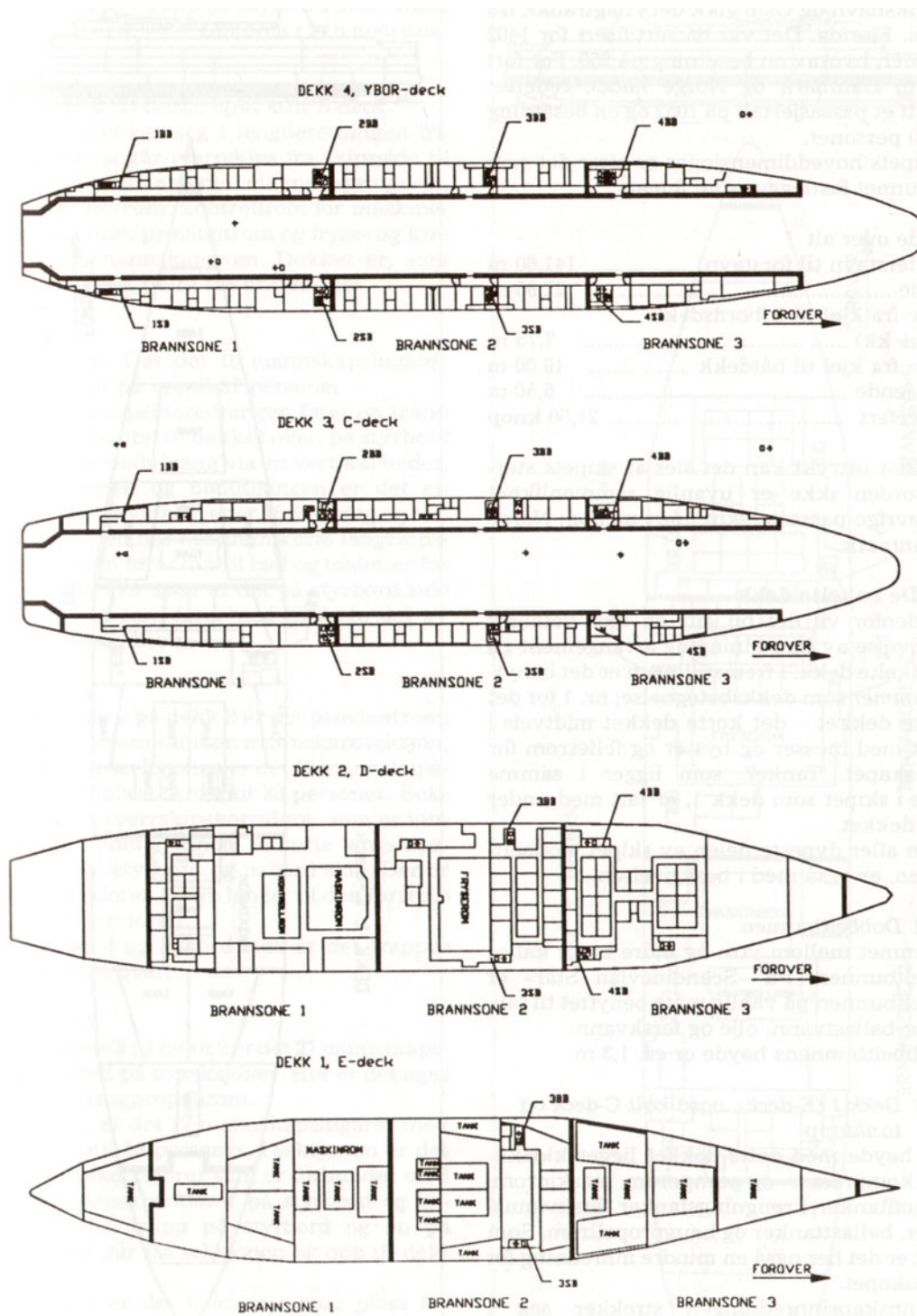


Figure 2. Plans for deck 1, 2, 3 and 4. Main fire sections are represented by thick black lines.

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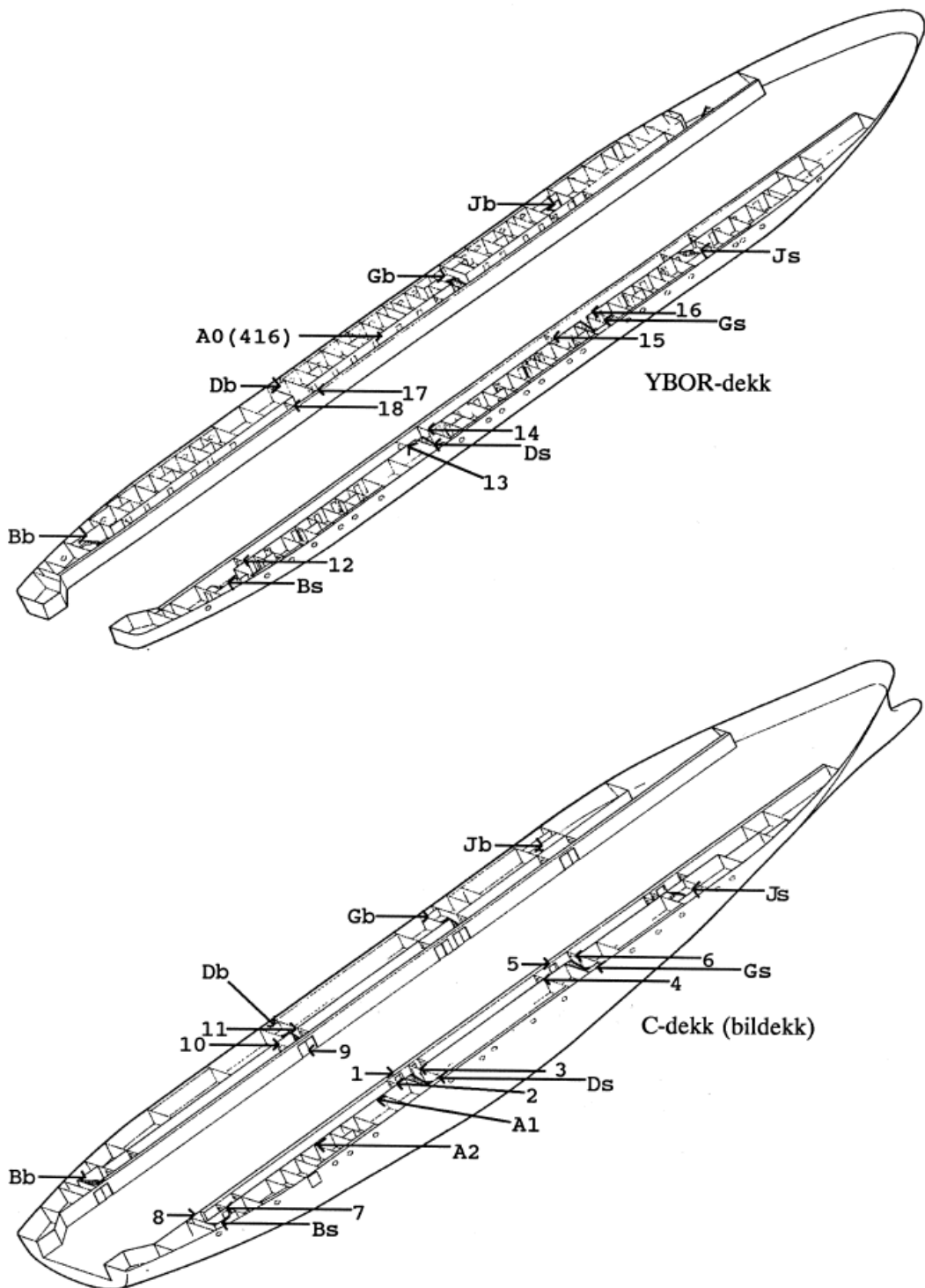


Figure 3. Overview showing door and staircase notations for Ybor deck (deck 4) and C deck (deck 3).

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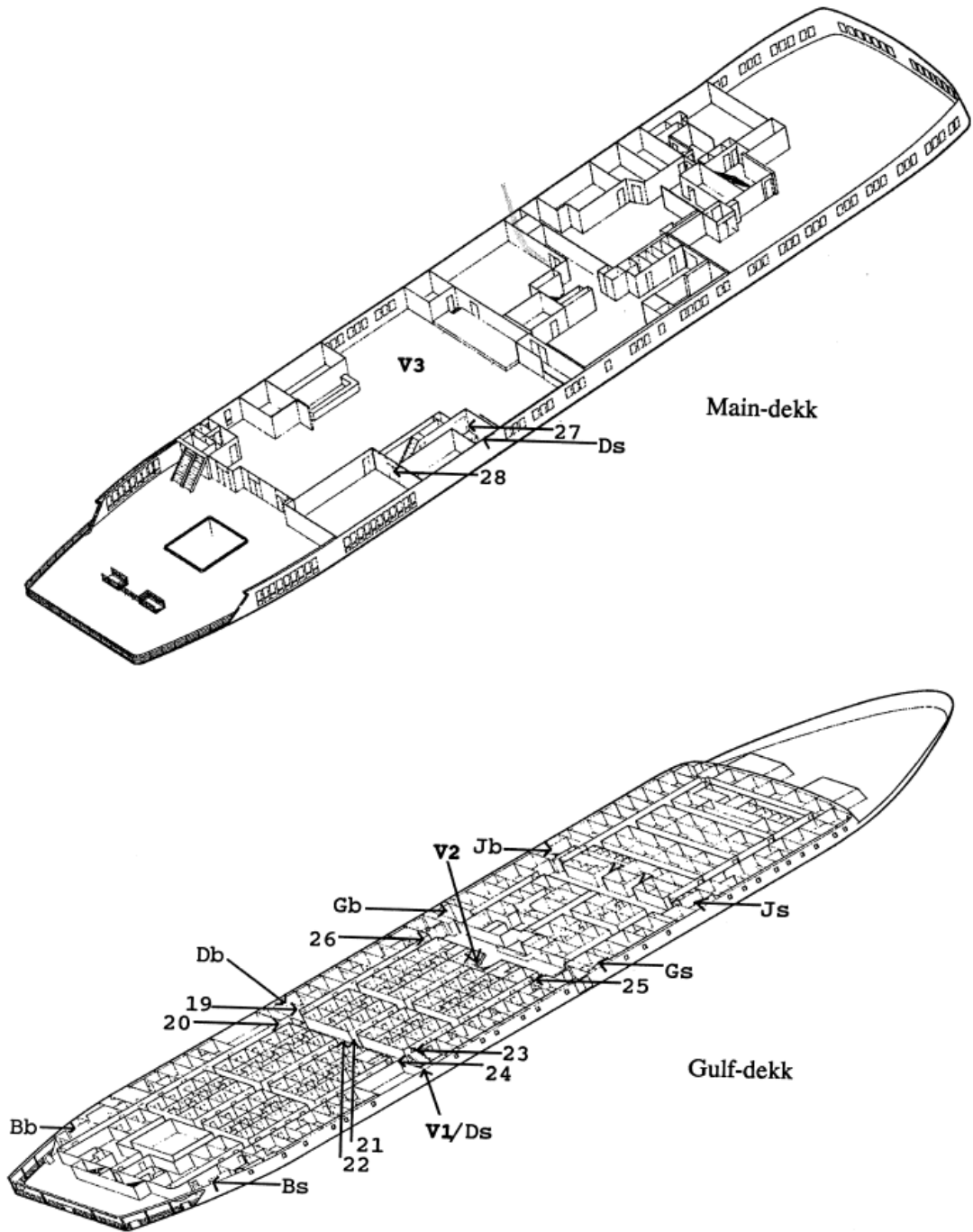
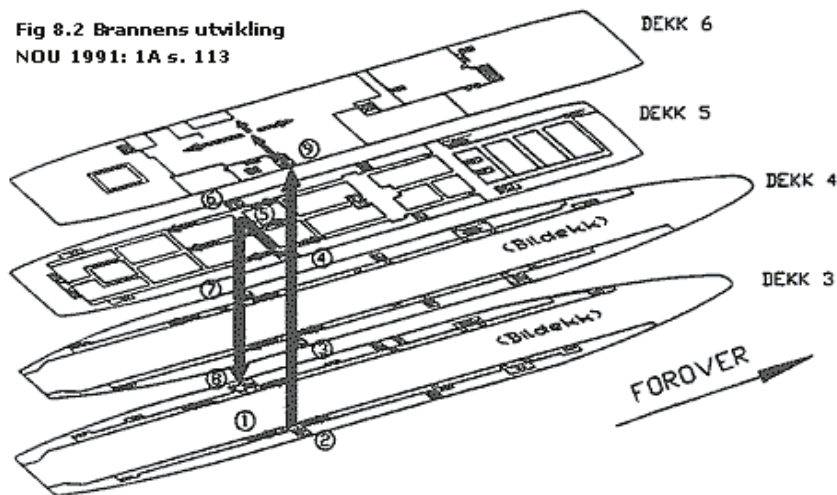


Figure 4. Overview showing door and staircase notations for Main deck (deck 6) and Gulf deck (deck 5).

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4 Course of events

The course of events during the first part of the fire on the 7th of April 1990 is described in Figure 5 below. These events represent what was later on denoted as "The Main fire". In the following sections of this report these events are denoted as "Fire No. 2".



Fire spread timeline for fire no. 2 (positions are denoted with numbers)

1. The fire starts here at approx. 02:00 (hh:mm). 2-8 minutes later the heat release rate reaches 200 kW. This point in time is set to the starting point for the catastrophic fire.
2. The fire is spreading rapidly to this staircase and further upwards.
3. The smoke reaches deck 3 approx. 1 minute after the fire start and spreads to the adjacent corridors ahead and astern the staircase. The fire door ahead the staircase remains open.
4. The smoke reaches deck 5 after approx. 2-3 minutes and starts to spread into the adjacent corridors.
5. The fire spreads from starboard to port through this crossing corridor.
6. On the port side the fire spreads downwards through the staircase.
7. A smaller amount of smoke spreads to the corridors on the port side of deck 4. All passengers in this section were evacuated.
8. The fire spreads down to deck 3 where the fire door leading to car deck is in open position.
9. The fire also spreads into the restaurant section on deck 6 through an open fire door on the top floor of the staircase.

Figure 5. The spread of the main fire (Fire No. 2) throughout the ship. Note that the description of the course of events is a direct translation of description as printed in the NOU 1991:1A report.

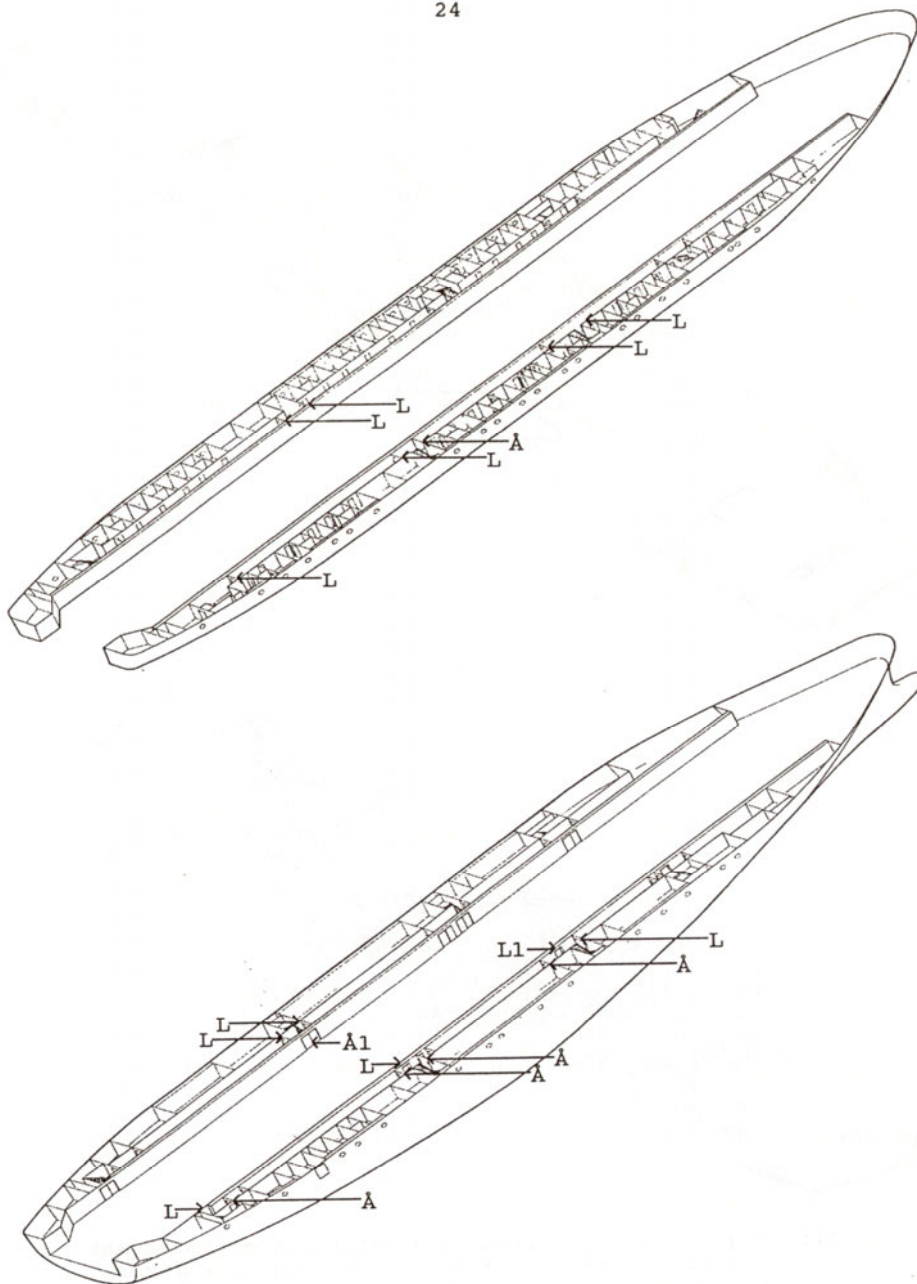


Figure 6. Drawing that shows closed and open fire doors on deck 3 (lower drawing) and deck 4 (upper drawing) which allows fire to spread as described in Figure 5. "A" denotes an open door and "L" denotes a closed door. "A1" denotes that the door is almost fully open and "L1" denotes that there is a leakage caused by either poor sealing or a slit between the door and the doorframe.

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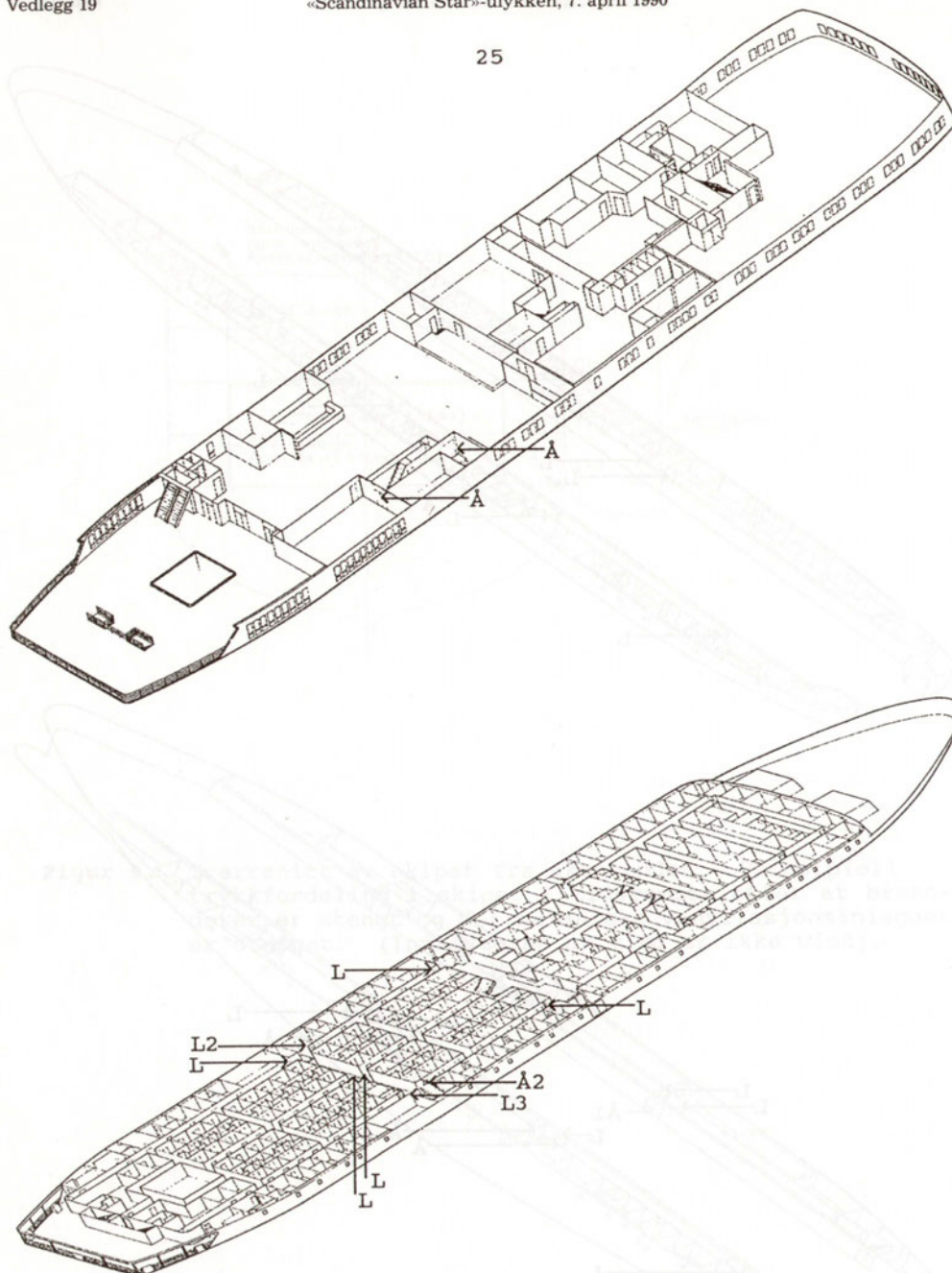


Figure 7. Drawing that shows closed and open fire doors on deck 5 (lower drawing) and deck 6 (upper drawing) which allows fire to spread as described in Figure 5. "Å" denotes an open door and "L" denotes a closed door. "Å1" denotes that the door is almost fully open and "L1" denotes that there is a leakage caused by either poor sealing or a slit between the door and the doorframe "Å2" denotes that the door has been open for a period of time during the fire. "L2" denotes either that the leaking conditions for the door is uncertain or that the door has been shut for a period of time during the fire. "L3" denotes either that the leaking conditions for the door is uncertain or that the door has been shut during the starting phase of the fire.

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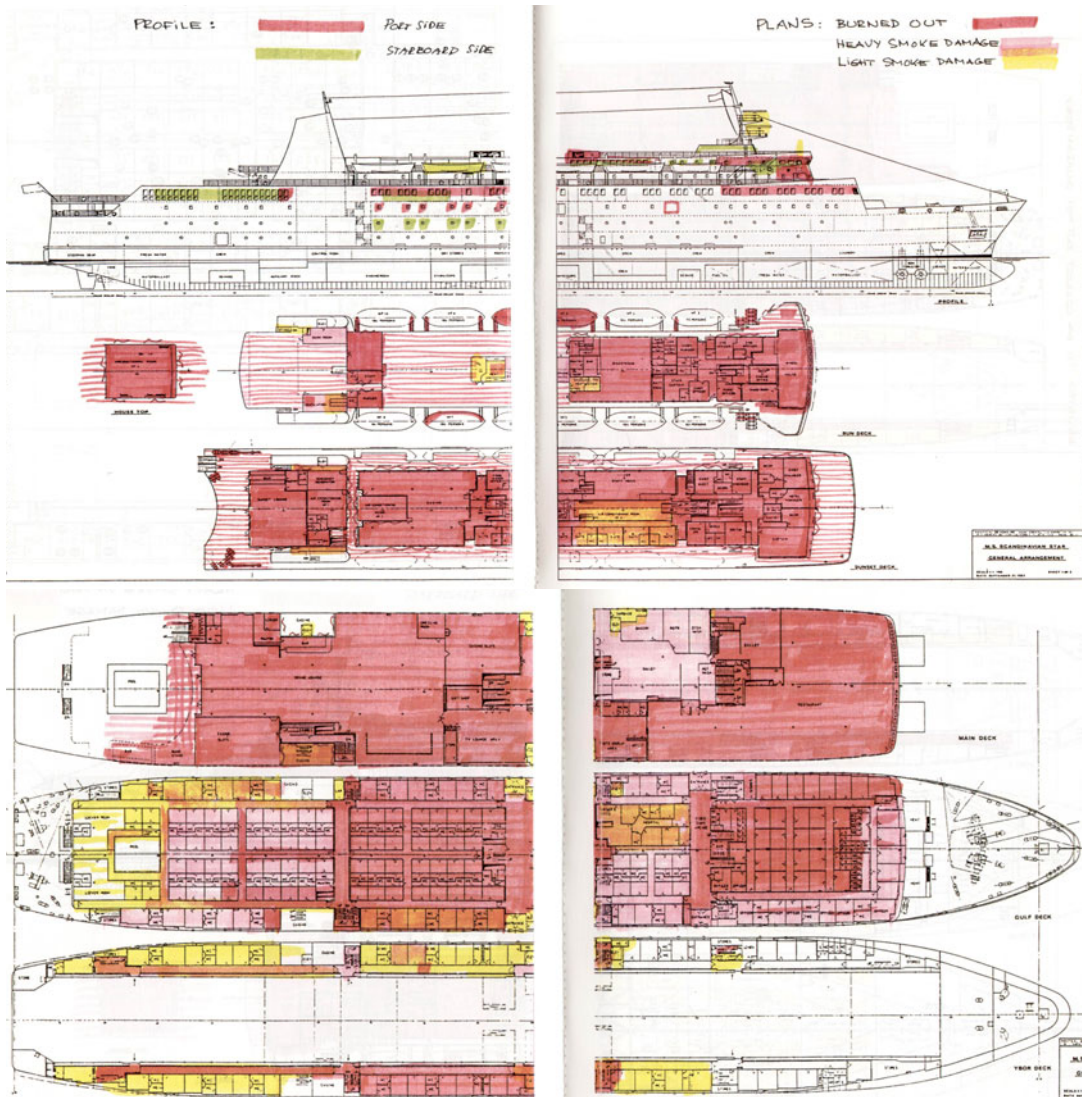


Figure 8. Drawings that show reported damages due to fire on each deck respectively, see also chapter 5.5.1.

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5 Analysis of the fires

5.1 Fire no. 1

Fire no. 1 started around 01.55 am on the 7th of April 1990 outside cabin 416 on deck 4 (Ybor/Caribbean deck). This fire was discovered early and it was at that time of small magnitude and could therefore easily be put out by passengers and crew members.

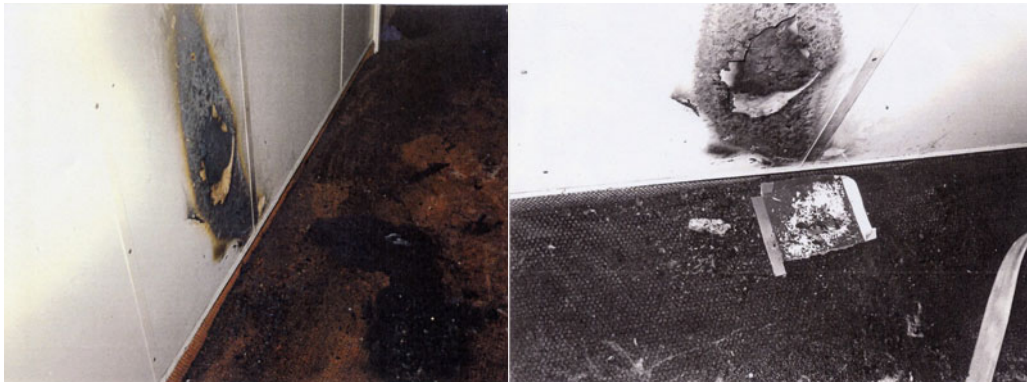


Figure 9. Pictures showing the starting location for fire no. 1. The picture on the right includes the piece of cardboard that was used to create a pilot flame.

5.1.1 Conclusion

Fire no. 1 was of no importance for the following chain of events. It is also clear that fire no. 1 was not accidental but was an attempted arson, see Figure 9. According to SOLAS 60 the captain is obligated to activate the evacuation alarm, leading to a total evacuation of the ship, when a fire is detected on board. If the evacuation alarm had been activated at this point it is highly plausible that the number of casualties due to the subsequent fire (no. 2) would have been much lower.

5.2 Fire no. 2 – The main fire

Fire no. 2 started around 02.00 am on the 7th of April 1990 outside cabin 219 on deck 3 (C deck/A deck). This fire is officially denoted as “The main fire”. No fire extinguishing measures are initiated by the captain at this point. The fire accelerates rapidly upwards throughout the ship as described in Figure 5 above.

According to eyewitness testimonies, door no. 5 (A 60) between car deck (deck 3) and staircase G_s (3 SB) on the starboard side of the ship was open about 10-15 cm and that door no. 9 (A 60) between car deck (deck 3) and staircase D_b (2 BB) on the port side of the ship was almost completely open (approx. 1 m) during the main fire, see Figure 3 and Figure 11.

Eye witnesses state that the ventilation system was running normally during the starting phase of fire no. 2 and that the fire at this time was to be considered as normal. Eye witnesses also state that the ventilation system, after 10-15 minutes, was forced towards maximum flow which resulted in an acceleration of the fire into a scenario which is to be considered as unnatural. The increased ventilation flow drives the fire downwards through staircase D_b (2 BB) to car deck (deck 3) up to a point in time where the ventilation system is shut down completely. The fact that the ventilation system was shut down lead to a change of pressure conditions in the passenger cabins, from overpressure to underpressure. This change of pressure conditions drives highly toxic smoke into the cabins. After about 10 minutes critical conditions in terms of CO (carbon monoxide) and HCN (hydrogen cyanide) concentrations are a fact.



Figure 10. Three photographs showing damages in the hallway on deck 3, on starboard side of the ship, astern of staircase D_s (2 SB). The door opening, visible to the right in the picture on the left, leads in to cabin 219. Fire no. 2 (the main fire) was started in this hallway.



Figure 11. Photograph showing a car damaged by fire. The car was parked just nearby the open sliding door no. 9 (A 60), see Figure 3, on the car deck. The air velocity trough this specific fire door opening has been measured to 20 m/s (during a full scale test on board a sister vessel) without the thermal effects from a fire. Note that this velocity refers to cold air. At a smoke temperature of 600°C the velocity increases by approximately a factor 3. This indicates the large effect that the ventilation system would have on the main fire.

According to eyewitness testimonies a flashover occurs, in the rear part of the restaurant/lounge area on deck 6 (main deck), approximately 30-40 minutes after the fire started. During this phase the fire consumes all combustible material in this part of the ship.

When the fire brigade arrives, approximately 3,5 hours after the fire started (approx. 5.30 am), a fully developed fire is in progress astern in the ship. However, at this time, the parts ahead in the ship on deck 6, including kitchen and restaurant, along with the parts ahead on deck 7 and 8, are not affected by the fire. Around 11.30 a.m. permanent smoke ventilation of the stern and middle parts of deck 6 is established, by breaking windows and the use of side openings in the reception lobby on deck 5.

5.2.1 Conclusion

According to eyewitness testimony, the ventilation systems are running as normal when fire no. 2 starts. After 10-15 minutes, the ventilation is forced, using the exhaust fans for car deck (deck 3/C), towards maximum flow capacity, resulting in the movement of hot smoke towards the strategically open fire door.

Full scale tests carried out by SINTEF aboard Scandinavian Star's sister ship "Jupiter" shows air speed at normal room temperature of approx. 20 m/s across sliding door no. 9 (A 60) between car deck (deck 3) and staircase D_b (2 BB) on the port side. In a fire situation, this air speed has probably been approx. 60 m/s caused by the fact that the invoked gas mix sucked down trough the staircase had a temperature of at least 500-600°C and thus had a density of approx. 1/3 of the density of air at room temperature.

Given that a number of fire doors, see Figure 6, were left opened along with that the ventilation system at first was operating normally and then was controlled so that all fans on car deck evacuated air, close to ideal conditions for rapid fire spread were given. This is also the only possible operation for the ventilation system that allows smoke to be sucked down trough D_b (2 BB) in opposite direction of the normal flow direction.

To create these ideal conditions for rapid fire spread requires extensive knowledge regarding fire dynamics, the ship and its technical systems, the location of the control devices as well as the functionality of all these systems is needed. Furthermore the arsonist/arsonists must have access to a number of locked rooms to be able to control the systems in question.

Fire no. 2 was started in fire zone 1 on deck 3 at approx. 02.00 on April 7th 1990. Fire no. 2 resulted in the death of 159 persons and extensive damage to the ship in fire zone no. 1 and 2.

5.3 Fire no. 3

Eyewitness testimonies states that fire no. 3 was started at approx. 11.00-12.00 am on the 7th of April 1990 in the 300-section/fire zone 2 on deck 4 (Ybor/Caribbean deck). The fire started, and was most likely fuelled by hydraulic oil spraying out of the hydraulic system at elevated pressure and was ignited. Available documentation indicates that the hydraulic oil most likely has been ignited by using a bed as a pilot flame, see Figure 12. This hydraulic system is not intended to be running when the ship is at sea since it only controls the vehicle lift on car deck. Manoeuvring the hydraulic pump can only be done using the controls located in a separate and locked room on car deck.

The leaking hydraulic pipe (indicated by a blue arrow in the photograph below on the right) is sharply bent horizontally towards the bulkhead (cabin wall). The other pipes, set in the same ceiling section as the leaking hydraulic pipe, are unaffected by the fire.

Note that only some parts of the ceiling section (indicated by a yellow arrow) that, prior to the fire, was covering the entire pipe zone has collapsed despite the fact that the entire corridor was involved in this fire which indicates that it was destroyed by hand before the fire.



Figure 12. The two photographs show the location for the start of fire no. 3 (the hydraulic fire). On these photographs, the bed (indicated by a red arrow) that most likely has been used to ignite the hydraulic oil is visible. The blue arrow indicates the hydraulic pipe in question. The other pipes, set in the same ceiling section as the leaking hydraulic pipe, are unaffected by the fire. Note that only some parts of the ceiling section (indicated by a yellow arrow) that, prior to the fire, was covering the entire pipe zone has collapsed despite the fact that the entire corridor was involved in this fire which indicates that it was destroyed by hand before the fire.

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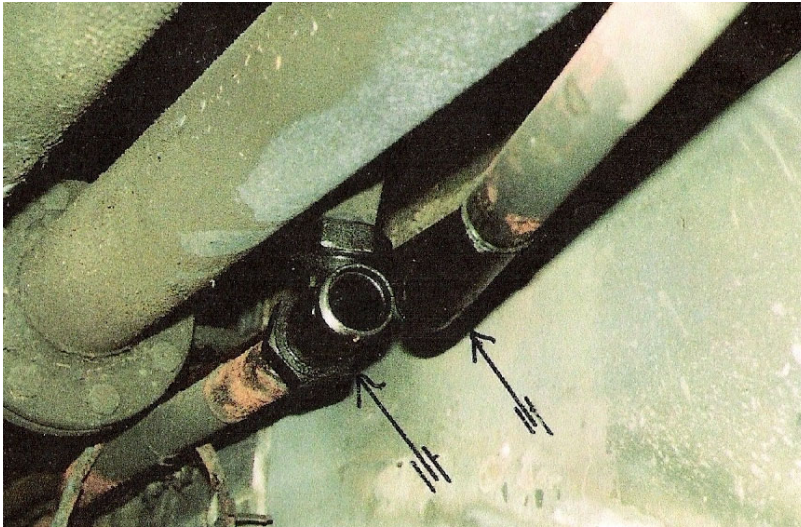


Figure 13. Photograph showing the connection closest to the horizontal bend in the hydraulic pipe in question.

5.3.1 Conclusion

A hydraulic pipe is constructed and mounted in bulkheads to withstand the very high pressures they are designed for during normal operation. A hydraulic pipe like that, so heavily affected by fire to the extent that it starts leaking oil in a connection, should be bent down on a very long section (notably longer than the distance between the true fixation points since the fixations most likely can't withstand the fire any longer than the hydraulic pipe and its connections) and in a soft arc vertically down towards the cabin sole.

The look of the hydraulic pipe hence indicates that it most likely has been bent to its current position by mechanical damage carried out by human hand and that fire 3 thus most likely was arson. Fire no. 3 resulted in extensive damage on the ship in fire zone 2.

Available documentation regarding fire damage on the ship along with the fire scenario calculations carried out by SINTEF indicates that this fire didn't break through the fire compartment division (A 60) towards fire zone 3, see also Figure 8 and chapter 5.6.1.

5.4 Fire no. 4 and 5

These two arsons was attempted in or close by staircases B_s (1 SB) and B_B (1 BB) respectively in the stern part of the ship on deck 3. The starting times for these fires are unknown but it is most likely that they were started quite some time before the ship reached Lysekil. The effects of these fires are uncertain but were most likely moderate.

5.4.1 Conclusion

Fire no. 4 and 5 were attempted arsons but have no documented significance on the further course of events.

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5.5 Fire no. 6

The fire in the stern parts of the decks 6, 7 and 8 (part of fire no. 2, fire zone 2) is reported, by the rescue services personnel, to be put out at approx. 11.30 am on April 7th 1990.

The official report, regarding the fire damages on the ship (see Figure 8) shows that the front parts of the middle fire zone (zone 2) on deck 5, is, to some extent, only lightly smoke damaged, and in other parts heavily smoke damaged and that the kitchen part on deck 6 (separate fire compartment in fire class A 60) is heavily smoke damaged. This clearly indicates that the fire (fire no. 2) wasn't completely developed in these parts.

Fire no. 6 starts in fire zone 3 some time after the ship has arrived at Lysekil at 21.17 pm on the 7th of April 1990. Fire no.6 involves the front parts of decks 5, 6, 7, and 8. Note that the first group from the rescue services was lowered from helicopter on to the bow on deck 7 and established command centre in the front, upper part of the ship in connection with the initiation of the fire rescue operations (approximately 3,5 hours after the start of fire no. 2). This clearly indicates that these parts of the ship were not involved in fire no. 2. The fire wasn't extinguished until on the evening of April 8th 1990.



Figure 14. Photograph showing the restaurant in the front part of deck 6. The heavy fire damages are most likely the effects of fire no. 6.

5.5.1 Conclusion

Available documentation regarding the fire damages on the ship indicates that it is most unlikely that the documented damages in fire zone 3 is an effect of natural fire spread from fire zone 2 (fires no. 2 and 3). The fact that the upper front part of the ship was used as a command centre for the rescue operation, also shows that this part of the ship was unaffected by the fire before the ship had arrived at Lysekil. This is further confirmed by the fact that permanent smoke ventilation of the parts affected by fire in the middle and stern parts of the ship was established already around 11.30 (see also chapter 5.2).

The heavy smoke damages in the kitchen are most likely the consequence of the poor integrity of the fire door (A 60) between the kitchen and staircase (between the reception on deck 5 and stair lounge on deck 6) and hence there has been a substantial leakage of smoke. The fact that the fire in fire zone 2, on deck 6, astern of the kitchen, was relatively easily extinguished probably depends on the flashover earlier in the fire scenario (fire no. 2) which consumed the major part of the combustible material in this part of the ship. During this fire rescue operation, the rescue service clears the windows on deck 6 and opens up the side openings on deck 5, thus securing permanent smoke ventilation in this part in order to prevent flashover and hence facilitating further rescue operations and preventing fire spread to fire zone 3.

The fact that the stairs between the reception on deck 5 and the stair lounge on deck 6 was open has also contributed to the much less extensive fire damages in the front part of fire zone 2 on deck 5. This, along with the rescue operations mentioned above shows that it is highly unlikely that the documented damages in fire zone 3 are the effects of natural fire spread from fire zone 2.

Fire no. 6, hence was most likely arson, set in fire zone 3 on deck 5 when the ship had arrived at Lysekil. Fire no. 6 resulted in extensive damage on the ship in fire zone 3.

6 Summarizing discussion and conclusions

The conclusions of this preliminary study are summarized below along with added comments.

1. Fire no. 1 has no significance on the further course of events. Fire no.1 was an attempted arson. According to SOLAS 60, the captain should at this point have activated the evacuation alarm and evacuated all persons aboard to outside decks. If this had been done the number of casualties would most likely have been considerably lower.
2. Fire no. 2 started in fire zone 1 on deck 3 at approximately 02.00 on April 7th 1990. Fire no. 2 resulted in the loss of 159 human lives along with extensive damage on the ship in fire zones 1 and 2.
3. The current state of the hydraulic pipe indicates that it most likely has been bent as shown by mechanical force from human hand and that fire no. 3, hence was arson. Fire no. 3 resulted in extensive damage on the ship in fire zone 2.
4. Fire no. 4 and 5 were attempted arsons but have no documented significance on the further course of events.
5. Fire no. 6 was most likely arson set in fire zone 3 on deck 5 when the ship had arrived at Lysekil. Fire no. 6 resulted in extensive damage in fire zone 3.
6. The post-mortem report shows that the suspected arsonist Erik Mörk Andersen died in the main fire (fire no. 2) and consequently it is impossible that he started the subsequent fires. By logic this also makes it highly unlikely that he started the first two fires (fires no. 1 and 2).
7. The public investigation made up till now (Norges Offentlige Utredninger (NOU): Scandinavian Star – ulykken, 7. april 1990, Hovedrapport NOU 1991:1A samt vedlegg NOU 1991:1B, Oslo 1991) only considers events covering the main fire (fire no. 2). This preliminary study indicates that it is of utter importance to investigate the full chain of events (fire no 1 through 6) completely in order to initiate a renewed crime investigation etc. The purpose of such further investigation is primarily to clarify the following:
 - The effect of the ventilation system on the fire scenarios.
 - To what extent fire impact on hydraulic pipes can lead to a deformation of the type, with resulting leakage, that occurred during fire no. 3.
 - To what extent fire no. 6 might be the result of natural fire spread between fire zones 2 and 3, alternatively show that this fire definitely was arson.
 - If there is a natural explanation to the fact that the hydraulic system was operating.
 - Why the other pipes in the same piping section as the damaged hydraulic pipe weren't damaged although they obviously were subjected to an equal fire exposure.
 - Why the ship had a list of 7-9 degrees approximately 30 minutes after the start of fire no. 2 since no water had been used for fire fighting operations or sprinkler systems nor were there any leaks in the hull.
 - Other related events that hasn't been investigated.

7 Suggested plan of action for further work

Below a general plan of action for further work is suggested.

1. Fire scenario calculations with a proper CFD-model regarding all fire scenarios. The project organisation for this should consist of two separate work groups with all the necessary competence in the field of fire engineering, performing and auditing the work done respectively. The purpose of these calculations is to scientifically secure a timeline for all fire scenarios and their consequences.
2. Full scale tests regarding fire impact on a section of hydraulic pipes (as a complement to the CFD-calculations when necessary). The project organisation for this should consist of two separate work groups with all the necessary competence in the field of fire engineering, performing and auditing the work done respectively.
3. Full scale tests regarding the effect of the ventilation system on the fire scenarios (as a complement to the CFD-calculations when necessary). The project organisation for this should consist of two separate work groups with all the necessary competence in the field of fire engineering, performing and auditing the work done respectively.
4. When results from the tests and calculations above are present a group consisting of experts in the field of fire engineering, with the aim of supporting police and other affected authorities in the further work, should be designated and given a complete assignment specification without limiting factors that might compromise the result of the investigation.
5. The final report should be presented in full for all affected governments and affected authorities as well as the public in the respective countries.
6. The final report should be publicly published in full along with a popular (short) version.

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