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WORLD MARITIME UNIVERSITY
Malmö, Sweden

FIRE PROTECTION ONBOARD

Enhance Fire Safety by Design

By

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A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of

MASTER OF SCIENCE

in

MARITIME ADMINISTRATION & ENVIRONMENT PROTECTION

2000

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **Fire Protection Onboard: Enhance Fire Safety By Design**

Degree: **Master of Science**

This dissertation studies an approach of improving fire safety onboard: safety by design. Statistics and analysis of fire onboard are given in order to shows the situation and the trends in ship fires. The author then briefly reviews some major fire casualties on board ships and lessons learned from these casualties.

The traditional ways of fire protection fall into three areas: structural fire protection, fire detection and fire extinguishing. The design of fire detection and alarm systems should be in such a way that the fire can be discovered and located quickly and efficiently. Fire-extinguishing devices should be capable to extinguish the minor fires and control the spread of large fires. The agents used should be suitable for the types of fire.

Halon systems used be the most efficient extinguishing systems, however it could not be used after 1 January 2000. Alternative to halon system is still a major concern. The water mist fire suppression system is one of them and both the advantages and disadvantages are discussed in chapter 6.

Engine rooms are the most likely spaces of fire. More than half of the ship's fires occurred in this area. Safety by design concept could have great impact on the overall safety of engine rooms and other machinery spaces.

Smoke control is a new area and caught much concern in recent years. The majority of people killed in ship fires were due to smoke exposure. Smoke control is an extremely important study from saving human lives' point of view.

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LIST OF ABBREVIATIONS

CCS	China Classification Society
CTL	Constructive total loss
ER	Engine room
HVAC	Heating Ventilating and Air Conditioning
ILU	Institute of London Underwriters
IMO	International Maritime Organization
MSC	Maritime Safety Committee
NKK	Japanese Classification Society
SOLAS	International Convention on Safety of Life at Sea
USCG	United States Coast Guard
WMU	World Maritime University

Chapter 1

Introduction

1.1 Fire safety on board

Fire at sea is much different from fire on land. If a fire breaks out in an office building, there is a danger, but there is always a chance of escape. When you get out of the building, you are safe. At sea it is totally different because the ship is surrounded by water and in most case, far from land. The only escape is by means of a lifeboat or a life raft. Bad weather may still make you in great danger even you have been evacuated from a blazing ship onto a lifeboat.

Many of the greatest maritime tragedies have involved fire, especially fire onboard passenger ships: the Morro Castle, the Lakonia, and the Scandinavian Star are all examples. Hundreds of lives were lost in these accidents.

Fire is one of the major causes of total loss. Statistics shows that fire and explosion amounts to one fourth of the maritime casualties of total loss. Many amendments to SOLAS Conventions are adopted by IMO in recent years. However, the direct application of the SOLAS regulations does not ensure a safe ship.

Technology and equipment on board ships are so different today compared to what they were only a few decades ago. Ship building industry develops very fast. A large cruise ship has more in common with a five-star multi-storey hotel. A high-speed passenger craft could be compared to an airplane with regard to safety measures (Manum, 1994).

Fire on ships is extremely dangerous to human lives. We must increase fire safety by improving the design of the ship and using new technologies. The crew in the first place should be provided with a safe ship by design. This would then lead to as low as reasonably possible risk levels being able to be maintained throughout the operational life of that ship. (Matthewson, 1994)

1.2 Philosophies of fire protection

What is going to be protected during a ship fire, especially what are the priorities? It is recognized that human lives, property and the environment should be given the top priorities.

In the past the order of priorities was given in just the written order above. Nowadays the last two items may change place. It is well accepted that human lives are always the highest priority to protect on board, not only concerning ships fire incidents but also other incidents such as grounding and collision. One can say that most of the SOLAS regulations on fire protection are dealing with the protection of human lives.

The environment protection comes up to the second place due to the growing consciousness of protecting environment. The phase out of the use of halon, the famous ozone depleting substance on board, is a good example of this. We cannot extinguish a ship fire but at the same time pollute the air or the sea.

Protecting the property, the ship, is on the third priority. The uses of fire detectors, alarms and fire extinguishers are to protect human lives and at the same time protect the ships as well. However, protecting the ship is more difficult than protecting human lives. In many fire casualties, the fire goes beyond the control of crew's capacity. That is why there are lots total losses from fire and explosions.

Another question is: how to protect? The priorities of protection measures may be kept as the following order:

1) prevent fire form developing;
2) detect a fire (early);
3) contain the fire;
4) alarm;
5) evacuation;
6) deployment / fire-fighting / smoke ventilation. (Manum, 1994)

1.3 Principles of fire protection on board

Traditionally fire protection on board can be divided into 3 groups:

1) structural fire protection
2) fire detection
3) fire extinction

Structural fire protection is also called passive protection due to its passive characteristics. The purposes of structural fire protection are to slow down the spread of fire on board and give people the time to escape or, at the worst situation, reach the life rafts or wait for the rescue vessels. Details are discussed in Chapter 4.

Fire detection and fire extinction are active protection. Their purposes are very clear: to detect a fire and extinguish it.

SOLAS 74 gives 8 basic principles of fire protection on board ships in more details in Chapter II-2, Regulation 2. These principles are as following:

1) division of ship into main vertical zones by thermal and structural boundaries;
2) separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries;
3) restricted use of combustible materials;
4) detection of any fire in the zone of origin;
5) containment and extinction of any fire in the space of origin;
6) protection of means of escape or access for fire fighting;
7) ready availability of fire-extinguishing appliances;
8) minimization of possibility of ignition of flammable cargo vapour.

No. 1), 2), 3) and 6) are actually the principles of structural fire protection, 4) and 5) refer to fire detection and extinction.

1.4 Concept of Safety by Design

The statistics shows that the reason for the majority of fire incidents can be broadly categorized as the failure of (Matthewson & Beck, 1994):

1) the human element to respond adequately to events; and / or
2) the provisions and arrangements in the ship as designed.

It is recognized widely that human errors amount to 80% of the maritime casualties. Some even believe it should be 100% because the ship is designed, built and operated by man. It sounds right, but if all the accidents at sea are caused by human errors, the only thing we need to do is training, to improve the personnel's capacity. There is no need to improve the ship's design, no need to use the new technologies and high-tech equipment on board and lots of money may be saved. Unfortunately it is not the case.

Taking Estonia disaster as an example, there are a lot human errors involved in this accident, but the direct reason of the vessel's sinking is the failure of her bow door. The ship was built in 1970s and at that time such type of bow door design was very popular and widely used. It was unfair to say it was a human error and the designers should be responsible for the large number loss of lives. At the time of the ship was built, no one had the experiences of such type of design on a new type of ship: ro-ro passenger ships. This was exactly an example of the importance of Safety by Design.

There are two ways to improve fire safety onboard: training of personnel and safety by design. Fire drills onboard may be including in training. They have the same purpose: making the crew familiar with the procedure and fire equipment.

Training is important. The personnel onboard shall be qualified with adequate training and certificates, and fire drills should be carried regularly. However, in many cases it was just impossible and impracticable to have a real fire and boat drill, especially on passenger ships such as "Dara" (See chapter 3). Training seafarers is not an easy job, but it is possible. How about training passengers? Impossible!

Training and Safety by design are the two ways to reduce human errors. It is difficult to say which one is more important. They should be treated equally. Many of the equipment onboard are design to avoid human errors.

When a fire disaster occurred, it was always considered in the first place whether the ship was appliance with SOLAS regulations. However, from Chapter 3 we can see, in many cases it happened on ships where all the rules and regulations were fulfilled when they were built. Improvement in the overall fire safety of ships and therefore safety of life at sea will not be achieved solely by the fully appliances with existing or new prescriptive regulations.

The interpretations to SOLAS regulations and other international conventions are so different from one flag state to another. The regulations themselves have many void words. And more important, SOLAS convention is a minimum standard. To improve the overall fire safety level, more considerations beyond the convention need to be taken during the design stages of the ship. Ship designers must have regard of, and knowledge of, fire fighting and fire protection, so that the advantages of fire fighting and fire protection systems may be utilized to the full extent.

The concept of Safety by Design includes not only the traditional types of fire protection, i.e. structural fire protection, fire detection and fire extinction, but also many other fundamental methods.

As an example, which has mentioned in paragraph 1.3, the first priority of fire protection is to prevent fire from developing. This may include part of the concept of structural fire protection, i.e. the restricted use of combustible materials. But these are not enough. Preventing fire from developing has a much wider sense. Multi-engine, twin propeller installations are very common on board modern ships. Due to the limited space the fuel supply pipe of one engine passes over the other engine and the failure of a connection results in an engine room fire. Such events are not uncommon, which should be avoided at the design stage of that ship.

Another interesting example is a designer reduces the number of smoking rooms on a cruise ship. He achieves the purpose of preventing fire from developing in such a simple way.

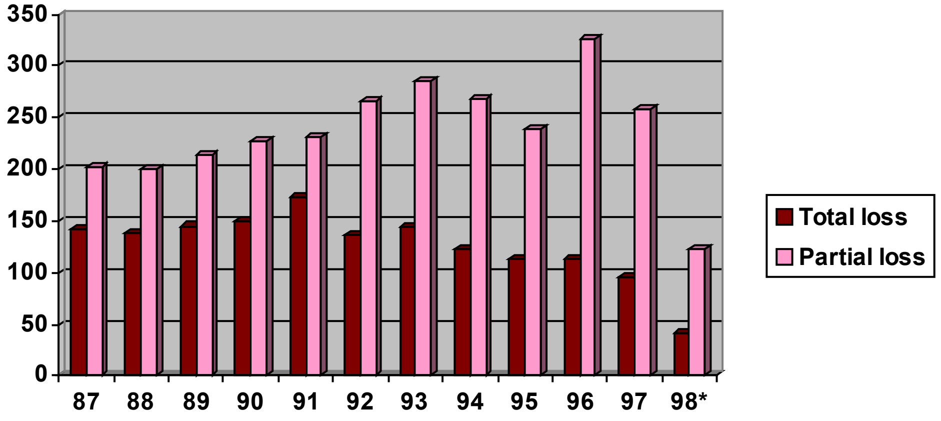
In Chapter 3 some major fire casualties will be discussed, which may show the importance of safety by design by real cases. Before that, let’s start with the analysis of fire on board.

Chapter 2

Analysis of fires on board

2.1 Total loss and major partial loss

Figure 2.1 shows the number of total loss and major partial loss of all ships over 500gt from 1987 to June 1998. The statistics used in this section are based on the Casualty Statistics for marine insurance from the Institute of London Underwriters (ILU).



Total and major partial losses by Number of Casualities all ships over 500 gt (* 98 until June)

Figure 2.1[**]

The total number of total loss is 1515, and partial loss 2841.

Figure 2.2 gives the total losses by tonnage in the period 1987-1997. Even the number of total loss in 1996 is the highest, the tonnage of total loss is not so high comparing to other years.

[**] Source of Figure 2.1~2.3,2.5,2.7~2.10: Rushbrook's Fire Aboard (3rd edition).

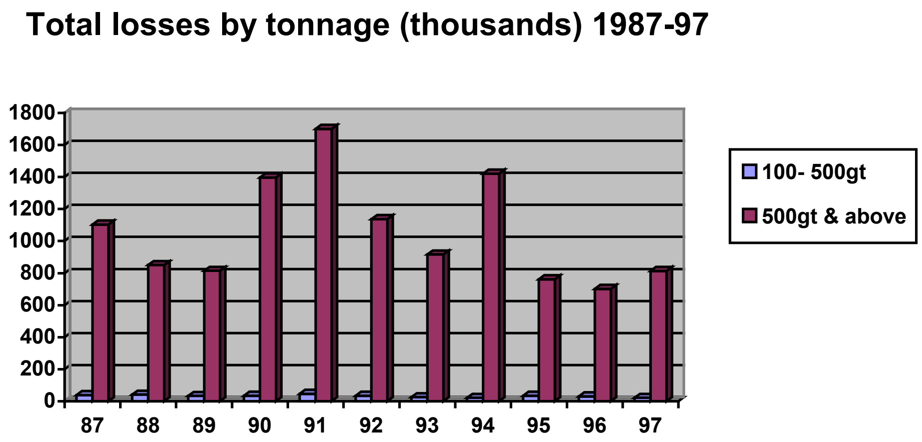

Total losses by tonnage (thousands) 1987-97

Figure 2.2

2.2 Fire and explosions

Within the same period, the number of total loss and major partial losses caused by fire or explosion are shown in Figure 2.3.

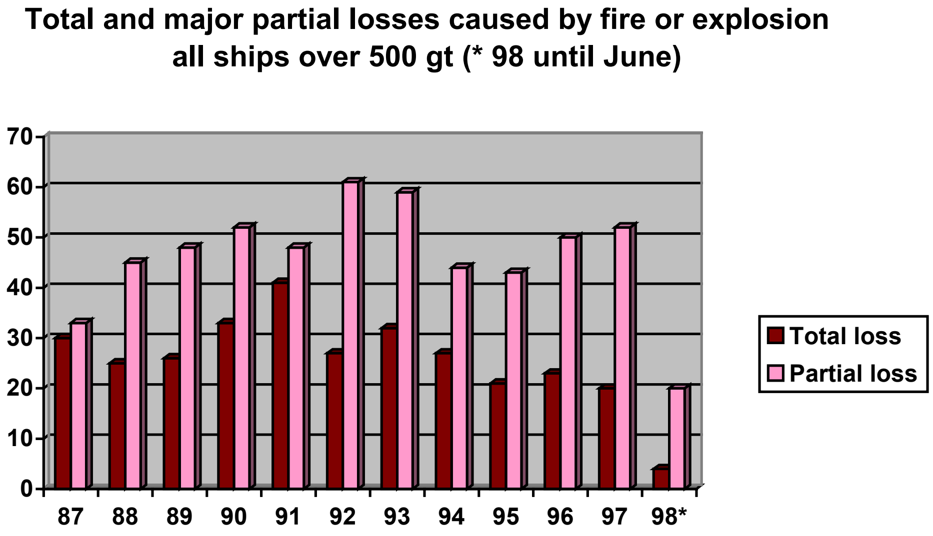

Total and major partial losses caused by fire or explosion all ships over 500 gt (* 98 until June)

Figure 2.3

2.3 Causes of loss

In the ILU Casualty Statistics (1998), the causes of maritime accidents may be divided into the following groups: 1) collision or contact; 2) fire or explosion; 3) grounding; 4) machinery; 5) weather; 6) others. Table 1.1 lists the number of total loss by group of causes and year and the percentage of each group is shown in Figure 2.4. It is shown that fire together with explosion amounts to 21% of the maritime casualties of total loss, and 33% of the total loss are due to the bad weather. The percentage of casualties caused by fire and explosion is higher than those caused by collision or grounding.

Table 2.1 Cause of total loss of ships over 500gt

Year	87	88	89	90	91	92	93	94	95	96	97	98	Total
Coll./cont.	13	7	19	18	15	18	10	12	12	12	12	6	154
Fire/Expl.	30	25	26	33	41	27	32	27	21	23	20	4	309
Grounding	19	13	17	17	20	19	16	8	9	11	12	3	164
Machinery	6	9	8	10	10	9	8	5	5	2	6	1	79
Weather	50	53	58	47	60	33	55	38	31	33	22	16	496
Others	25	31	17	24	28	31	23	32	35	32	23	12	313
Total	143	138	145	149	174	137	144	122	113	113	95	42	1515

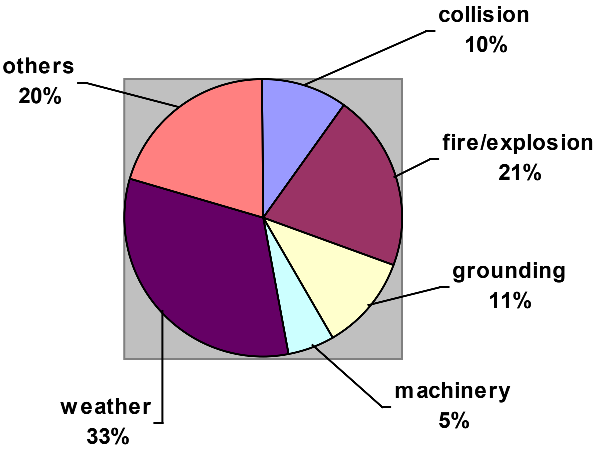


Figure 2.4

2.4 Vessel age

Figure 2.5 shows the occurrence of fire expressed as tonnage affected by fire with respect to the age of the casualty. Figure 2.6, source from ILU Casualty Statistics 1998, shows the total loss as percentage of all ships (over 500gt) according to age of ship in 1987-1997. In Figure 2.5, the numbers of sinking vessels are separate form total loss, while in ILU statistics they are included in the numbers of total loss. In Figure 2.5 the major losses caused by fire or explosion are also considered.

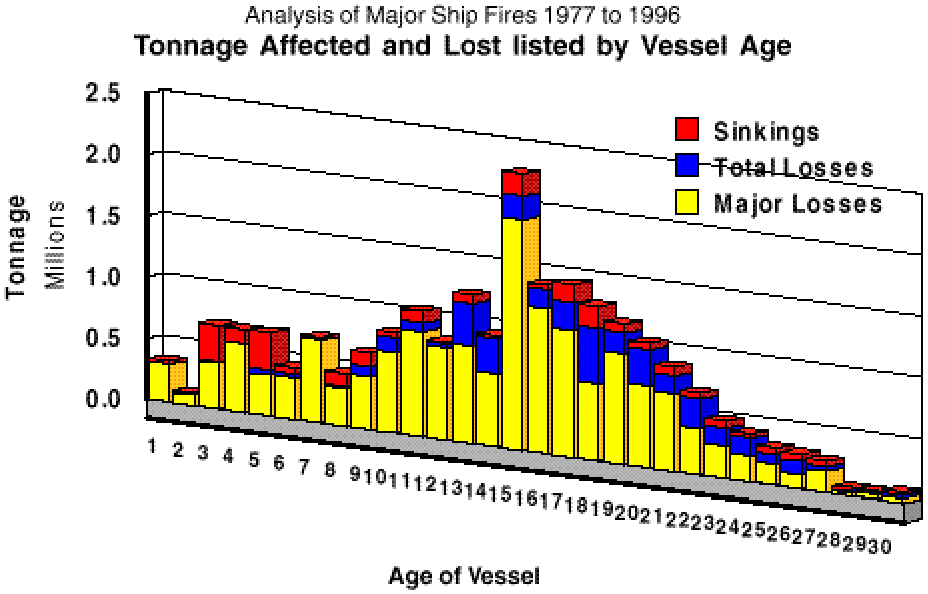


Figure 2.5

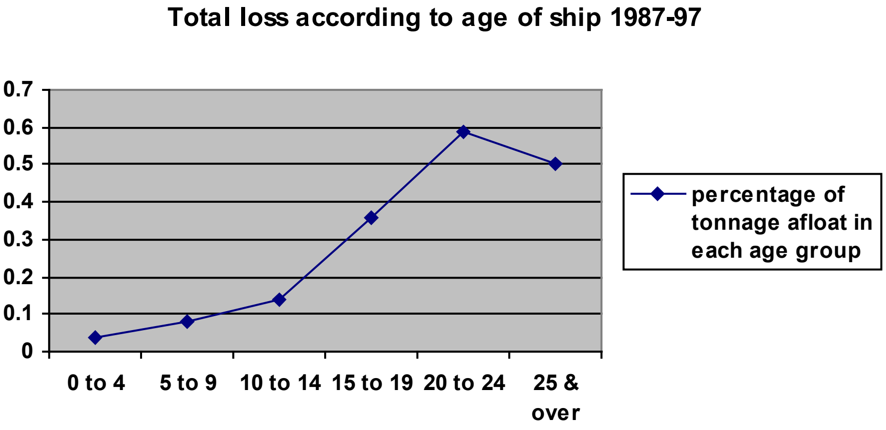


Figure 2.6

Comparing these two figures, the most dangerous age group for the possibility of total loss is the group of 20 to 24 years, while the most dangerous age group for the possibility of total loss caused by fire, if the same age groups are used as in Figure 2.6, is the group of 15 to 19 years, and it keeps almost the same number of total loss in the next age group. In Figure 2.5, except year 16, the curve is more stable than the curve in Figure 2.6. That is to say the fires are likely to happen on board every age of ship which lead to major or total loss, and the possibility does not changes a lot with the ship's age.

2.5 Vessel type

Figure 2.7 shows the gross tonnage lost by fire and sorted by vessel's type in the period of 1977 to 1996. Tankers account for the greatest loss of tonnage as a result of fire and explosions. Over a twenty-year period, tankers constitute approximately 50% of the vessels lost in fire and explosion.

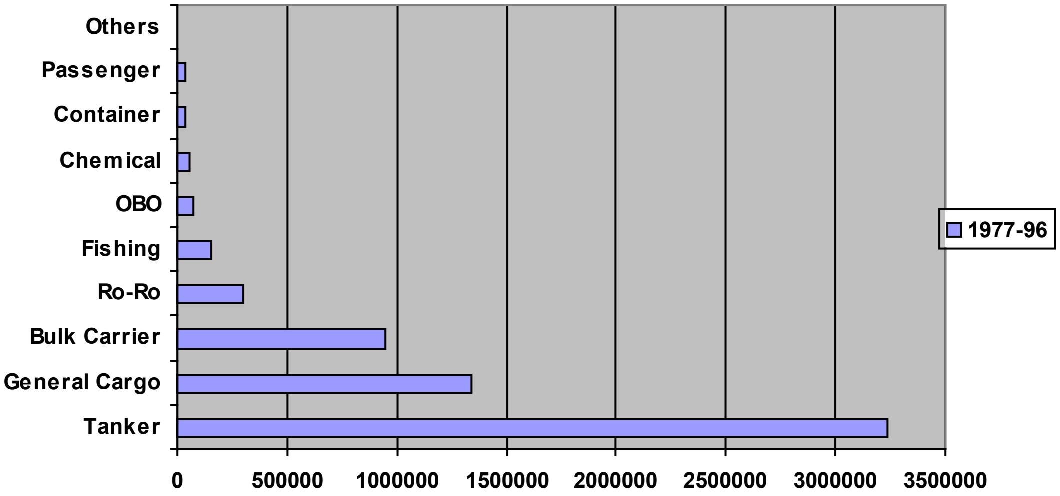


Figure 2.7

2.6 Location of fire

Figure 2.8 shows the number of casualties which have occurred in the period 1977 to 1996, graphed by vessel type and sorted by location of fire. The same information is shown in a pie in Figure 2.9. There is a greater likelihood of more serious fire occurring in machinery spaces, followed by cargo spaces and accommodation areas. If the tonnage lost is concerned, which is shown in Figure 2.10, fire in oil tanks is another major source and a small number of such fires lead to a large number of tonnage lost.

From Figure 2.10 we can find the largest blocks are oil tanks on tankers, engine rooms on tankers, general cargo ships and bulk carriers. It is obviously that the most fire-dangerous type of vessel is tanker and the place of highest fire risk on board is the engine room. The analysis of engine room fires will be continued in Chapter 7 where the engine room design is discussed.

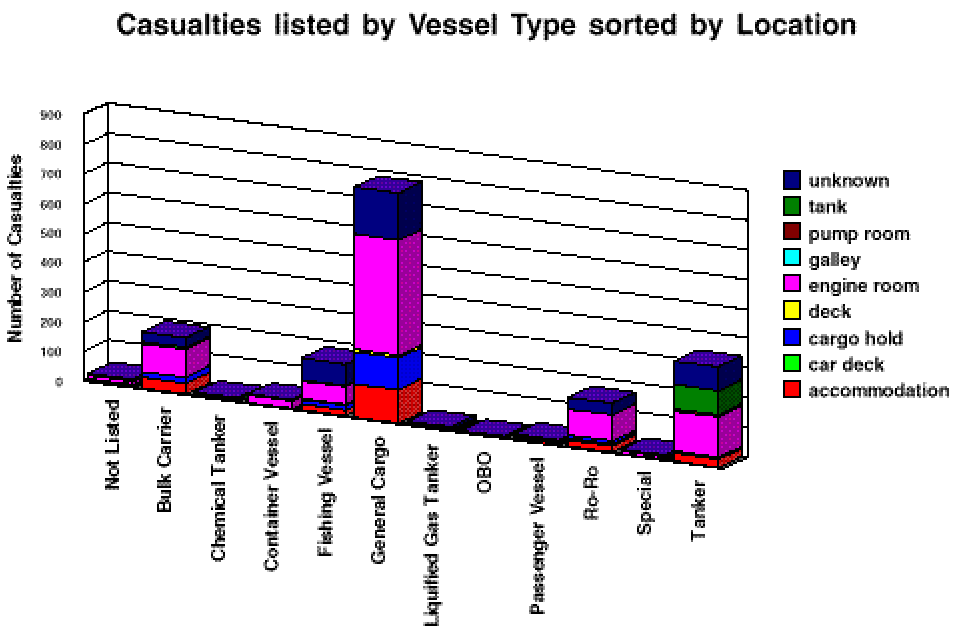

Casualties listed by Vessel Type sorted by Location

Figure 2.8

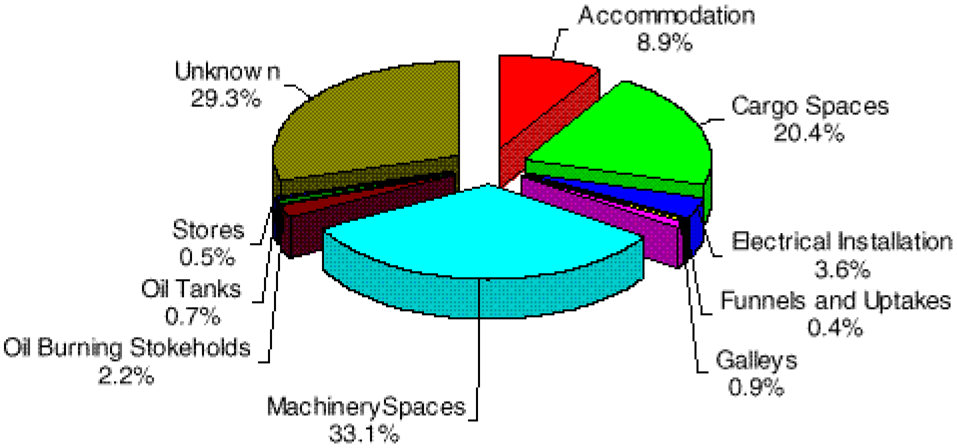


Figure 2.9

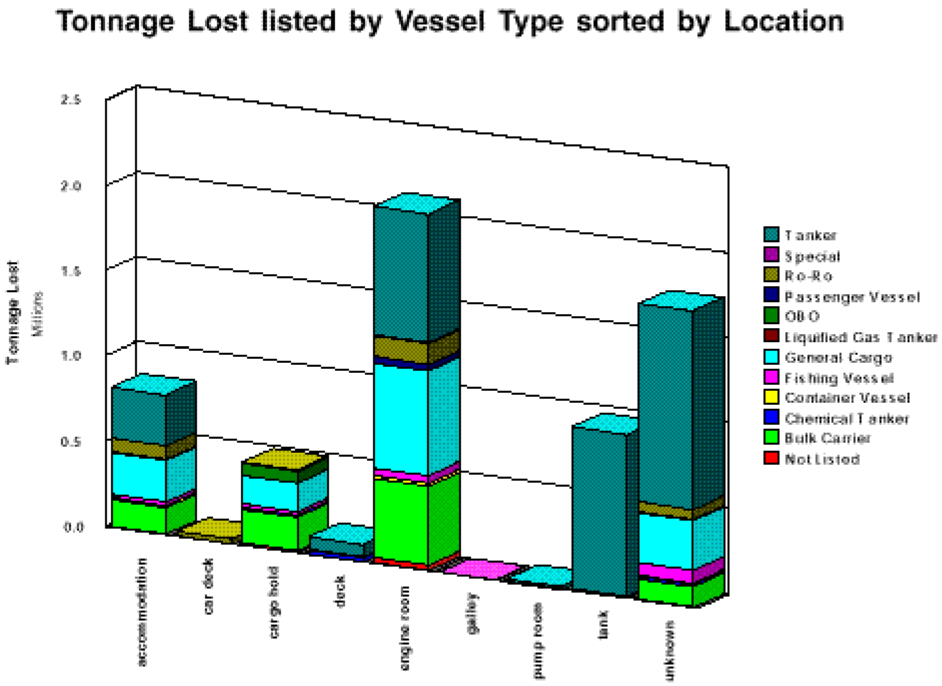


Figure 2.10

2.7 Rank in maritime casualties

Another survey of total loss accidents in merchant shipping over a period of 25 years was carried out by Mr. Mendiola and Achutegui. The results appeared in the IFE Journal (January 1999). It states fire ranks second in maritime casualties.

The analysis considers ships over 500grt of 15 different flags, running on any rout of navigation and trade. Totally 1,500 ships of different types and tonnage are considered. All the ships are suffered total loss. The result shows that fire together with explosion amounts to 25% of maritime casualty returns: 20.3% for fire and 4.3% for explosion in details. Stranding, which including stranding in fine weather, in gale or fog and stranding due to engine failure, rank the first, taking about 30% of the total.

The analysis took many circumstances into account and the results were in the following order:

Stranding	30.3%
Fire	20.3%
Water-leaks	13.4%
Gales	10.5%

Collisions	9.9%
Explosions	4.3%
Cargo failure or shifting	3.9%
War	3.2%
Struck object	1.6%
Others	2.6%
Total	100% (1,500 ships)

Detail information may be found in the article “Fire Ranks Second in Maritime Casualties” which is available in Appendix B.

Chapter 3

Fire Casualties and Lessons Learned

3.1 Morro Castle

The Morro Castle, a ship of 11,520 gross registered tons with accommodation for 490 passengers, was built in 1930 for the American Ward Line. Fitted with turbo-electric drive, she was considered to be the finest and most luxurious vessel yet placed in the coastwise service. The vessel was 508 ft overall, and she had three decks devoted to passenger accommodation.

In common with the then current world practice, the ship was constructed with large quantities of highly combustible linings and furnishings in the passenger and crew accommodation. Plywood partitions and linings were extensively used in the staterooms, dining saloons, lounges, cabins and other public rooms. Luxuriously equipped throughout, the ship had a "fire load" which was obviously of a high order.

As in most casualties, no single event was responsible for the severity of the fire and the disaster. The master died or possibly was poisoned by a crew member (later convicted for another murder) who started the fire on the evening previous to the outbreak of the fire. The chief officer in charge was relatively inexperienced.

The fire broke out at about 0245h on September 8th 1934 in a locker containing over 100 blankets which had been cleaned with a flammable liquid. The locker was situated in the writing room on the promenade deck. The ship's stewards unsuccessfully attempted to fight the fire using portable extinguishers. There was a long delay in rigging the fire hoses. The hoses had to be brought from two decks below because the master had ordered them to be removed following a lawsuit against the Company by a passenger who had been injured on a wet deck after other passengers had been playing with a fire hose.

The fire spread rapidly along highly polished paneling in the writing room, corridors, salon, stairways and other passenger accommodation. By 0256h, every stateroom was transmitting a fire alarm to the monitoring panel in the wheelhouse. However, the writing room, dining room, the ballroom and the library were not fitted with fire detectors and most of the telephones were unserviceable. There was a further delay because the acting chief officer had to run to the engine room, five decks below, to order an increase in pressure on the fire main. The acting master therefore gave the signal to "stand by the lifeboats". The fire was driven aft as the acting master proceeded straight into the wind of approximately 20 knots until 0300h when he called for the vessel to be turned towards the shore.

The ship was thrown into darkness and the gyro-compass, electric steering apparatus and the stand-by hydraulic system were all out-of-action by 0310h. The acting master then steered the ship using the engines and headed towards the shore on a zig-zag course. An SOS was transmitted at 0318h. Shortly after 0321h, the anchor was dropped and a signal was given to abandon ship. Only six of the twelve lifeboats were launched. Little assistance was given to the passengers.

Of the 548 persons on board, a total of 124 lost their lives - 89 passengers and 35 members of the crew. Many of the rescued suffered from burns and other injuries.

The main lessons to be learnt from the *Morro Castle* fire, which could be improved by design, are the following:

1. Linings should be of a fire-resisting nature.
2. Doors to compartments should be self-closing.
3. Automatic fire alarms should be installed throughout (or sprinklers fitted).
4. Fire doors should be capable of being closed by remote control.
5. Staircases should be totally enclosed, and fitted with self-closing doors.
6. Self-closing smoke-stop doors should divide all long corridors.
7. Emergency generators should be carried.
8. All escape routes should be clearly indicated.

In addition to the above, other lessons in relation to human elements are:

1. Crews should be trained in fire-fighting.

2. The action to be taken in case of fire should be clearly laid down, and urgently brought to the notice of both passengers and crew.

3.2 Dara

Dara was a passenger ship owned by British India Steam Navigation Company, sailing between Bombay and Karachi with a number of other stops along the way. She was built in 1948, 5029 gross tons, and was constructed especially for the trade in which she was employed at the time of her loss.

Her ports of call were for the most part less than twenty-four hours apart. The ship had berths for 78 first and second class passengers, the bulk were unberthed and "camped out" on the open deck or in the specially constructed 'tween decks. Her certificate allowed the ship to carry up to 948 unberthed passengers. There were 132 crew, 78 first and second class passengers and 537 unberthed passengers aboard when she caught fire on her fateful last voyage.

Dara had had a regular fire and boat drill in Bombay before leaving on the voyage and embarking passengers. The crew were mustered at fire and boat stations, fire hoses led out and charged and the offshore boats launched. However, this was far from ideal since in any real emergency the ship would be filled with passengers who must be cared and provided for, and the large number of unberthed passengers made the situation much worse. There was no way of simulating such conditions at the drills.

Dara was a small vessel compared to her relatively large number of passengers carried. She had 16 lifeboats but there was simply not enough deck space to accommodate so many boats easily. Twelve of the boats were nested one above the other, with only a single set of davits and falls for each pair. Launching those boats under the best of circumstances was awkward, and under conditions of actual emergency could be very difficult if not impossible.

On 7 April 1961, the sea and weather suddenly changed at about 1200h when the passengers embarked and disembarked at Dubai. Dara was struck twice by a Panamanian freighter named Zeus due to the sudden change of weather. It caused slight damage to the vessel but the master of Dara felt his vessel would be safer at sea and he decided to get underway. The wind was blowing in gusts of up to force 9 attended by heavy rain and lightning. About 1645h a severe explosion shook the ship. Everybody thought that the explosion had come from the engine room, because the power had also failed. In fact, from the after investigation, the place of explosion was in the port alleyway of the upper deck just above the engine room. It was estimated that the explosion was caused by about 20 pounds of explosive charge. It was thought to be the work of terrorists but that was never firmly established.

After the explosion, fire spread rapidly with no effective means of fighting it. Many design failures could be found in this disaster:

1. The fire main was not charged because of the smoke in the engine room and the failure to activate the fire pumps.
2. The emergency system did not extend to the bridge and chart room forcing the crew to rely on electric torches.
3. The CO2 room was located just above the engine room and close to the place of explosion. The crew could not enter the CO2 room because of the flame and smoke around it. There was no other way of control.
4. There was no steam for the ship's whistle to send out the second abandon signal on the general alarm.
5. Most of the lifeboats could not be launched.

In all 238 persons died in this disaster.

3.3 Meteor

The M.S. Meteor was a passenger vessel built in 1955 in accordance with the requirements of SOLAS 48. A combination of Methods II and III were adopted but a sprinkler system was installed only in the dining rooms and lounges on the Promenade Deck and throughout the passenger accommodation.

In 1968 the vessel was "upgraded" in compliance with the new Part G of Chapter II in the SOLAS Convention adopted in 1966. The vessel also had in force a "Control Verification for Foreign Vessel", issued by the United States Coast Guard and valid until November 4, 1971.

On May 22, 1971, on her return voyage from Alaska to Vancouver, whilst in the Strait of Georgia about 60 miles from Vancouver, fire broke out in the crew accommodation on "B" Deck. It was at 0235h when the look-out on the forecastle noticed a smell of smoke coming from the forward deckhouse. The look-out raised the alarm but he was unable to penetrate beyond "A" Deck in the crew accommodation because of thick smoke and "gusts of flame" coming from "B" Deck.

At about 0235h the bridge was manned by the first mate and the pilot, when a smell of smoke was noticed and shouts were heard. The seriousness of the situation was not realized and, "in order not to frighten passengers unnecessarily the fire alarm was not given". The first mate immediately called the master and tried to find the chief officer but he was not in his cabin. Upon the mate's return to the bridge, about two minutes later, flames were already bursting out of the doors on the starboard side of the forward deckhouse. The fire alarm was switched on but did not function.

When the master reached the bridge he ordered the ship's whistle to be sounded in order to warn the passengers and crew. He neither heard any sound from the warning panel on the bridge, nor did he see any warning lights on the panel.

The second engineer was on duty in the engine-room when the look-out informed him of the fire and that water would be needed on deck. The fire pump was started at approximately 0244h, 9 minutes after the first alarm.

Because of the tremendous heat in the early stages of the fire, the fire-fighters were unable to penetrate into the burning corridors via the stairways.

It took about five hours to bring the fire under control and the ship got under way at 0700h, reaching Vancouver at 1227h, but final extinction was not achieved until 1815h on Sunday May 23.

Sadly 32 members of the crew died in the fire and many more were injured and shocked. None of the passengers suffered any injury.

The cause of this fire was not known but it could well have started in one of the crew's cabins and smoking in bed might have been responsible.

There are a number of lessons to be learned from this tragic fire, which if taken to heart might mean that the victims had not died entirely in vain. These are as follows:

1. Sprinkler systems should be installed on board all large passenger vessels — in crew's quarters as well as in passenger accommodation.

2. Automatic fire detectors should be installed. These should be of the type which detect smoke rather than heat.

3. Strict attention should be paid to smoke-stopping so that the area of fire and smoke spread be limited. Staircases should be fully enclosed.

4. All bulkheads, divisions and ceilings in accommodation areas should be constructed of non-combustible materials giving at least 30 minutes fire protection.

5. Conventional paints and varnishes should not be used internally in accommodation or machinery spaces. If surfaces have to be painted then only fire retardant material should be used.

6. The use of polystyrene or polyurethane in furniture should be banned for shipboard use. Table tops or bench surfaces should be constructed of Melamine decorative laminates — if not of natural timber.

7. On no account should there be any delay in raising the alarm when the presence of fire has been notified. It is quite inexcusable that an officer should leave the bridge in order to inform senior officers. There is a case for having a separate warning system to sound only in the crew's quarters but this must be operated from the bridge without any delay.

8. Only by constant and realistic exercising can a crew avoid the delays which occurred in this fire. It took 9 minutes before the engine-room was informed of the fire and the engineer instructed to start the pumps. The watertight doors were not closed until 40 minutes after the discovery of the fire. With proper training and procedures these two functions would have been completed within, at most, two minutes of the initial alarm.

All these lessons learned are related to fire safety design.

3.4 Cunard Ambassador

The Cunard Ambassador was built in compliance with 1967 Amendments to SOLAS 60. On 12 September 1974, the vessel, with a full crew complement of 298 persons, was bound for New Orleans to pick up passengers. At about 0525 hours a fire broke out in the main engine room. Smoke detectors were fitted in the machinery spaces and the signals were sent to both bridge and engine control room.

The main engines were stopped, the general alarm sounded and the machinery space fans were stopped. The emergency alternator started automatically and supplied emergency lighting. The alternator also supplied power to the emergency fire pump but the pump's starter was adjacent to the pump sited in the distiller room. Attempts to enter this room were unsuccessful because of the smoke and the intense heat.

The vessel had emergency lighting but no water for fire-fighting. At about 0800h the USCG firefighters got onboard. Water was supplied from a USCG cutter. The fire was finally extinguished on September 15 and the vessel was towed into port. Although no lives were lost and the fire was confined to one vertical zone, the vessel was declared a constructive total loss.

Lessons learned from this accident may be as follows (Cowley, 1994):

1) The structural fire protection confined the fire to one vertical zone, but the non-sprinkler construction did not confine the fire to the place of origin or within the spaces protected by the internal fire-retarding structure.
2) The two escape exits should be widely separated.
3) Smoke production is a major problem and the number of breathing apparatuses, although met the SOLAS requirements, were inadequate. In ships with many decks, bellows-type apparatuses are of limited value because of the difficulty of finding a smoke free area in the absence are of fresh air outlets.
4) Viewing ports should be permitted in control rooms contiguous with category A machinery spaces.
5) Fire pumps should be truly independent of the spaces they are intended to protect.
6) Hydraulic pipes in high fire risk areas should have face-to-face steel couplings.
7) Emergency control station should not be sited immediately above machinery space crowns.
8) CO2 was discharged but the effect was reduced by an improperly closed ventilator flap and leaky funnel vent closure plates.

Again, all these lessons are related to safety design.

3.5 The Scandinavian Star

The ship was built as a combination passenger ship and ferry for cars and trailers in 1971, gross tonnage 10,513 tons. The last survey was conducted by Lloyd's Register on 2 to 5 January 1990. This was not long before the fire which occurred on 7 April.

The survey was an ordinary Passenger Ship Safety Survey carried out in compliance with the international rules SOLAS 1960 along with a few additional requirements retrospectively laid down in SOLAS 1974 on behalf of the Flag State, the Bahamas. At that time she was certified to take 1402 persons including a crew of 250.

Most of the crew on board Scandinavian Star were newly engaged due to the fact that the ownership was just changed on March 1990.

On 6 April 1990 the ship left Oslo at 2145 hours with 99 crew and 383 passengers on board. Between 0145h and 0200h the next morning, a small fire was discovered in a pile of bedclothes outside Cabin No.416 on the port side of Deck 4 and was quickly extinguished. Shortly later a second fire started in the aft section of the starboard corridor of Deck 3. The fire was not extinguished and at 0224h the ship sent a Mayday message. Subsequently at 0324h, the captain decided that it was not possible to extinguish the fire and the decision was taken to abandon ship.

Both the two fires were almost certainly started deliberately by the application of a naked flame to bedclothes in the first fire and probably paper and bedding that had been placed at the site on the second occasion (Robinson, 1999).

Two crew and 156 passengers died in this tragedy. Among these, 90 bodies were found in cabins and 49 found in corridors. It was estimated that 8 to 10 minutes after the start of fire, most of the corridors where the people died were filled with smoke. While the ventilation was running, this maintained a positive pressure in the cabins keeping the smoke out. But when the ventilation was switched off, possibly at 0230h, smoke seeped into the cabins. About 25% of the passengers who were found in their cabins were located in the bathroom, often with towels over their faces.

Mr. Alan Robinson, who joined the investigation of the fire, concluded in his case study report the following reasons for the large loss of life:

1) The following deficiencies found in the ship and its equipment:

- workshops and stores had been set up on the car deck

- some of the sprinkler heads on the car deck were blocked with rust
- pressure bottles were stored incorrectly
- there was a defective fire door on the port side of the car deck
- the motorised lifeboats were generally in poor repair
- a fire door was missing from the aft starboard part of Deck 6 and the door
- opening had been fitted with a glazed door
- three alarm bells were missing from the fire alarm system

2) The fire alarm system

The fire occurred while many of the passengers were asleep in their cabins. Consequently the fire alarm system was important in arousing people from their sleep.

As a result of the missing alarm bells it was found that only in about 37% of the cabins was the sound level of the alarm over 68 dB, which was considered to be "probably sufficient". In addition, as buttons had to be held down on the Bridge to maintain the sounding of the alarm, the alarm was not sounded for long enough periods.

3) Composition of materials used in the construction of the accommodation decks

The carpets and cabin furniture were not considered to have been particularly significant in the development of the fire. However the laminated plastic coating on the walls and ceilings of corridors, although only about 1.5mm thick, was significant. Subsequent tests showed that the coating had a calorific value of 48 MJ/m2. SOLAS 1960 did not specify a maximum calorific value for such coating and the material was therefore acceptable. Indeed it is only 3 MJ over the maximum acceptable amount under SOLAS 1974. Nevertheless the material provided an uninterrupted surface in corridors and stairways that greatly assisted the spread of fire. In addition it was also found that the material, when it burned, produced large quantities of carbon monoxide and hydrogen cyanide, both of which were found to have been responsible for causing many of the deaths.

4) Fire doors

The fire doors in general were fitted with magnetic catches and could be closed either locally or from the Bridge. Although most of the doors were eventually closed some in the areas affected by fire, remained open. In particular, as no alarm was ever given from the zone on Deck 3 where the fire started, because no one was there to press the alarm button, the fire door from the zone to stairway 2S was never closed. This allowed the fire to spread to the staircase and hence to other decks. Other doors were also left open. The fact that some doors remained open while others were closed also created draughts which assisted the rapid spread of fire.

5) The ventilation system

The ventilation system aboard the Scandinavian Star may not have been stopped until 02.30 hours. While it was operating it did prevent the spread of smoke into cabins. However during the initial stages of the fire it also played a part in determining the route by which the fire spread, although, as the heat output from the fire increased, the buoyancy of the hot combustion gases became the more dominant factor.

6) The escape routes

Many of the escape routes soon filled with smoke and this affected the evacuation of the accommodation. In addition, the routes involved changes of direction, corridors with dead ends and staircases that were not continuous. An example of the problem that this caused was the aft escape from the starboard corridor on Deck 5. The escape was not at the end of this corridor but about three meters forward set in the outboard bulkhead. In fact there was a door at the end of the corridor but this led only to a small storage cupboard. Some 13 bodies were found at the end of the corridor.

The layout of some of the escape routes meant that passengers unfamiliar with the ship needed the assistance of crew and signposts to find their way quickly. Following the change of ownership, the ship had been put into service without posting emergency notices in a Scandinavian language even though the ship was operating between two Scandinavian ports. In addition as passengers were not issued with boarding cards, they were unable to follow the color coding system used to direct them to their allocated muster station. This led to an uneven distribution between the different muster stations. The assistance offered by the crew is considered in the next section.

7) The manning of the ship and the action of the crew

Following the tragedy, Norway set up a commission, with the participation of representatives from Denmark and Sweden, to investigate the reasons for the tragedy. The ship was not under-manned and the officers possessed the necessary qualifications and certificates but the Commission found that the navigation officers should have had better training in safety matters. It also found that there was a language problem in that many of the Portuguese crew had little or no knowledge of English. However the most serious criticism made of the crew is that they never acted as an organized unit and that no real attempt was made to fight the fire. Furthermore it was found that the alarm was only sounded for a short period of time and that there was no organized waking of sleepers.

The commission made the following recommendations that all ships in passenger traffic should be:

- fitted with sprinkler systems
- fitted with smoke detectors in corridors, stairways, saloons and cabins. The smoke detectors should be connected to indicators on the Bridge and be installed in sufficient numbers and arranged in such a way as to detect smoke as soon as possible and provide adequate indication of the spread of smoke.
- manned with a crew which has attended courses in safety procedures approved by the maritime administrations.
- inspected before coming in to service and then they should be subjected to further periodic scheduled and unscheduled inspections

The Commission also recommended that regulations were laid down governing the duty of ship owners to establish systems for the safe operation of ships.

In conclusion, the tragedy of the Scandinavian Star again illustrates just how important it is to detect a fire quickly, to start fighting it immediately and implement properly organized evacuation procedures supervised by properly trained people.

Conclusion

Most requirements of SOLAS, class rules or national legislations in respect of fire protections were primarily developed from fire experiences and lessons learned from fire casualties. The reviews of fire casualties are very helpful to the fire safety design.

The Dara accident shows exactly the importance of fire safety design. Fire drills are very difficult when passengers are concerned. It is essential and critical to improve fire safety by design on passenger ships. Never leave the problems to intelligence and training of crew.

Almost every review of fire casualties included the failure design in fire structure, detection and alarm systems or fire-extinguishing devices. The Scandinavian Star casualties also highlighted the problem of smoke control. The following chapters will discuss these issues.

Chapter 4

Structural Fire Protection

4.1 Principles of structural fire protection

4.1.1 Basic principles

Structural fire protection is also called passive protection. Even it is passive but it is very important. Many lessons learned from the fire casualties include the importance of structural fire protection. When the fire is beyond control, it is the successfulness of structural protection that contains the spread of fire, prolongs the time needed for evacuation and protects the means of escape.

Generally there are three basic principles of structural fire protection (Stavitskiy et al. 1983):

1) Prevention of the possibility of fire outbreak on board the ship;
2) Containment of fire spread throughout the ship;
3) Protection of means of escape and access for fire fighting.

Comparing to the basic principles mentioned in SOLAS II-2/2.2 (see chapter 1), there are four principles relate to structural fire protection. SOLAS separates the 2nd principle above into two: division of ship into main vertical zones by thermal and structural boundaries, and separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries.

4.1.2 Prevention of the possibility of fire outbreak on board ships

This principle includes many areas. First, the ship's hull, superstructures structural bulkheads, decks and deckhouses shall be constructed of steel of other equivalent material (SOLAS II-2/23.1 and 42.1). Crowns and casings of machinery spaces of category A shall be of steel construction adequately insulated and openings therein shall be suitably arranged and protected to prevent the spread of fire.

Another important way of preventing the possibility of fire outbreak is to limit the application of combustible materials for insulation, grounds, linings, furniture and interior facings.

4.1.3 Containment of fire spread throughout the ship

To contain a fire means whenever there is a fire on board, it should be contained in the initial space for some certain time and the speed of fire spread is limited to the lowest level, in order to obtain the necessary time for the passengers and crew to escape from the dangerous area, and wait for the rescue.

Based on this principle, the ship is to be divided into main vertical fire zones and horizontal fire zones. Machinery and accommodation spaces are to be separated from the remainder of the ship.

4.1.4 Protection of means of escape and access for fire fighting

In case of a ship fire, both passengers and crew should always been evacuated from the dangerous place first, then fire-fighting might be considered. Evacuation is successful only if the stairways or other means of escape are safe and able to use. These escape routes are also the access for fire fighters. Protection of these routes is essential for both evacuation and fire-fighting.

SOLAS provides different regulations of means of escape on passenger ships (Reg. 28), which includes ro-ro passenger ships (Reg. 28-1), and cargo ships (Reg. 45), but the philosophy is the same. Every ship should have at least two means of escape ready for both crew and passengers. Corridors and Stairways should be mainly protected by A Class division.

4.2 Structure and methods of protection

4.2.1 General

The philosophies of ship fire protection have been primarily developed from passenger ship experience (Cowley, 1994). Until November 1952 when SOLAS 48 entered into force, there were no international fire regulations applicable to cargo ships. However, in SOLAS 29 several basic principles of structural fire protection had already been established. It required "fire resisting" bulkheads continuous form side-to-side of the ship spaced not more than 40 m in length. They were to be constructed of metal or other fire resisting material, effective to prevent for one hour. Escapes to the open deck were to be provided from passenger and crew spaces and, within machinery and working spaces, a means of escape independent of watertight doors was required.

After the Morro Castle disaster (see Chapter 3), there were many discussions on how to prevent the spread of fire within the main vertical zones. In United States, United Kingdom and France, three methods were developed and their philosophies were introduced into SOLAS 48 and SOLAS 60. Method I, known as US method, required all enclosure bulkheads within main vertical zones to be of B Class construction and be continued vertically to linings on deck head to prevent spread of fire. Neither fire detectors nor sprinklers were mandatory in Method I.

Method II, known as UK method, required 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. This method did not restrict the type of internal bulkheads.

Method III, known as France method, required a system of subdivision using A Class and B Class divisions, according to the importance, nature and size of the various compartments, and fitted with an automatic fire detection system in all places where there might be a fire.

These three methods did not apply to passenger ships and were replaced by the existing requirements of SOLAS 74 (Chapter II-2, Reg. 25). However they still apply to cargo ships (see 4.2.3).

4.2.2 Passenger ships and Main vertical zones and divisions

For a passenger ship, her hull, superstructures and deckhouses are divided lengthwise into main vertical fire zones by "A" Class divisions (SOLAS II-2/24). For a ship carrying more than 36 passengers, the divisions shall be"A-60" Class divisions. The length and width of main vertical zones may be extended to a maximum of 48 m but the total area of the main vertical zone is not greater than 1,600 m^2 on any deck.

According to fire risk of adjacent spaces, different fire divisions may be chosen. There are three classes of fire division. The most effective fire divisions are A Class divisions which prevent the passage of smoke and flame during one hour and do not heat above the specified limit. Details can be found in SOLAS II-2/3 (see Appendix A). A Class divisions have a metallic core of steel or other equivalent material insulated by noncombustible materials to prevent their heating.

B Class divisions are those which prevent the passage of flame when exposed to 30-minute standard fire test; however, they may not prevent the passage of smoke. B Class divisions may have no metallic core, but they shall be constructed of noncombustible materials only.

C Class divisions are constructed of noncombustible materials but do not need to meet any requirements relative to the passage of smoke and flame nor the limitations relative to the temperature rise. Their purpose is to reduce the ignition potential of the space equipment and structural members, such as linings of the ship's sides, ceilings, partitions, etc. Any bulkhead constructed of a noncombustible material, but not tested for fire-retarding properties is to be regarded as C Class division.

Within a vertical zone, for passenger ships carrying more than 36 passengers, all bulkheads which are not required to be A Class divisions shall be at least B or C Class divisions. For ships carrying not more than 36 passengers, this requirement applies to the bulkheads within accommodation and service spaces. An automatic sprinkler, fire detection and fire alarm system is required to be installed, or an alternative of a fixed fire detection and fire alarm system may be applied to ships carrying not more than 36 passengers (SOLAS II-2/36).

4.2.3 Method of protection on cargo ships

According to the requirements of SOLAS II-2/43 and 52, one of the following methods is required to be adopted in the accommodation and service spaces of a cargo ship:

1) Method IC – The construction of all internal divisional bulkheads shall be non-combustible "B" or "C" class divisions generally without the installation of an automatic sprinkler, fire detection and fire alarm system. However in ships in which method IC is adopted, a fixed fire detection and fire alarm system of an approved type shall be so installed and arranged as to provide smoke detection and manually operated call points in all corridors, stairways and escape routes within accommodation spaces.

2) Method IIC – An automatic sprinkler, fire detection and fire alarm system is required to be fitted for the detection and extinction of fire in all spaces in which fire might be expected to originate, generally with no restriction on the type of internal divisional bulkheads. The system shall be so installed and arranged as to protect accommodation spaces, galleys and other service spaces, except spaces which afford no substantial fire risk such as void spaces, sanitary spaces, etc. In addition, a fixed detection and fire alarm system of an approved type shall be so installed and arranged as to provide smoke detection and manually operated call points in all corridors, stairways and escape routes within accommodation spaces.

3) Method IIIC – A fixed fire detection and fire alarm system is required in all spaces in which a fire might be expected to originate, generally with no restriction on the type of internal divisional bulkheads, except that in no case must the area of any accommodation space or spaces bounded by an "A" or "B" class division exceed 50 m^2. The system shall be so installed and arranged as to detect the presence of fire in all accommodation spaces and service spaces, except spaces which afford no substantial fire risk.

As far as tankers are concerned there is no alternative but to use Method IC.

4.3 Fire integrity of bulkheads and decks

Spaces throughout a ship are classified into categories according to their fire risk. For ships carrying more than 36 passengers, for instance, all the spaces are divided into following 14 categories (SOLAS II-2/26):

1) Control stations
2) Stairways
3) Corridors
4) Evacuation stations and external escape routes

5) Open deck spaces
6) Accommodation spaces of minor fire risk
7) Accommodation spaces of moderate fire risk
8) Accommodation spaces of greater fire risk
9) Sanitary and similar spaces
10) Tanks, voids and auxiliary machinery spaces having little or no fire risk
11) Auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk
12) Machinery spaces and main galleys
13) Store-room, workshops, pantries, etc.
14) Other spaces in which flammable liquids are stowed

The fire integrity of a bulkhead or deck separating adjacent spaces may be obtained by cross-referencing the appropriate categories of the spaces in tables 26.1 and 26.2 in Regulation 26 of SOLAS II-2 (see Appendix A). It is suggested to the designers, where there is doubt as to the classification of a space, it should be treated as a space within the category having the most stringent boundary requirements.

4.4 Means of escape

On board passenger ships, above the bulkhead deck there shall be at least two means of escape from each main vertical zone or similarly restricted space, at least one of which shall give access to a stairway. Below the bulkhead deck two means of escape shall be provided from each watertight compartment or similarly restricted spaces, at least one of which shall be independent of watertight doors. One of the means of escape shall consist of a readily accessible enclosed stairway which provides continuous fire shelter. Any corridor and lobby should have more than one route of escape.

The width of stairways should satisfy the number of passengers and crew who may use the stairways as a mean of escape in emergency. Many reach works had been done to test the width of stairways suitable for the evacuation of large number of persons in a short time. In Regulation 28.5.1 it requires the stairways shall not be less than 900 mm in clear width, and shall be increased by 10 mm for every one person in excess of 90 persons, to a maximum of 1,800 mm. The total number of persons to be evacuated by such stairways shall be assumed to be two thirds of the crew and the total number of passengers in the areas served by such stairways. Again, the designers should not limit their consideration by these SOLAS requirements. On a luxury cruise ship where large scale of theaters, casinos and other public entertainment places are very common, the designer should take the worst situation into account when deciding the width of stairways.

4.5 Protection of stairways and lifts in accommodation and service spaces

The designers should pay much more attention on the protection of stairways and lifts in accommodation and service spaces. Stairways are required to be constructed of steel except where the use of equivalent material is approved. Every stairway or lift is to be lie within an enclosure or trunk constructed of A Class divisions, except that a stairway connecting only two decks need not be enclosed, or stairways may be fitted in an open space.

IMO Maritime Safety Committee accepted three methods of enclosing stairways, which are shown in Figure 4.1, as complying with the regulations in the 1981 SOLAS Amendments relating to the enclosing of stairways serving more than two decks.

In method (a), stairs are completely enclosed. A person may enter the enclosure at any level and proceed to any other level without leaving the enclosure.

In method (b), stairs are completely enclosed, but a person cannot proceed to all levels without having to leave the enclosure.

In method (c), each flight of stairs is closed at one level only and open to a corridor.

There is no doubt that methods (a) and (b) comply with SOLAS requirements, but the stairways in the arrangement of method (c) are not enclosed at each level as required by the 1981 SOLAS Amendments. The arrangements shown in Figure 4.1(b) and (c) do not afford the same degree of protection as that provided by the method (a), which would afford a much safer means of escape and access for fire parties when corridors are filled with smoke or toxic gases (Noble, 1985).

On passenger ships the protection of stairways is very important. Method (c) should not be used in accommodation and service areas. Although all three methods are accepted by MSC, the ship designers should choose the safest way: method (a).

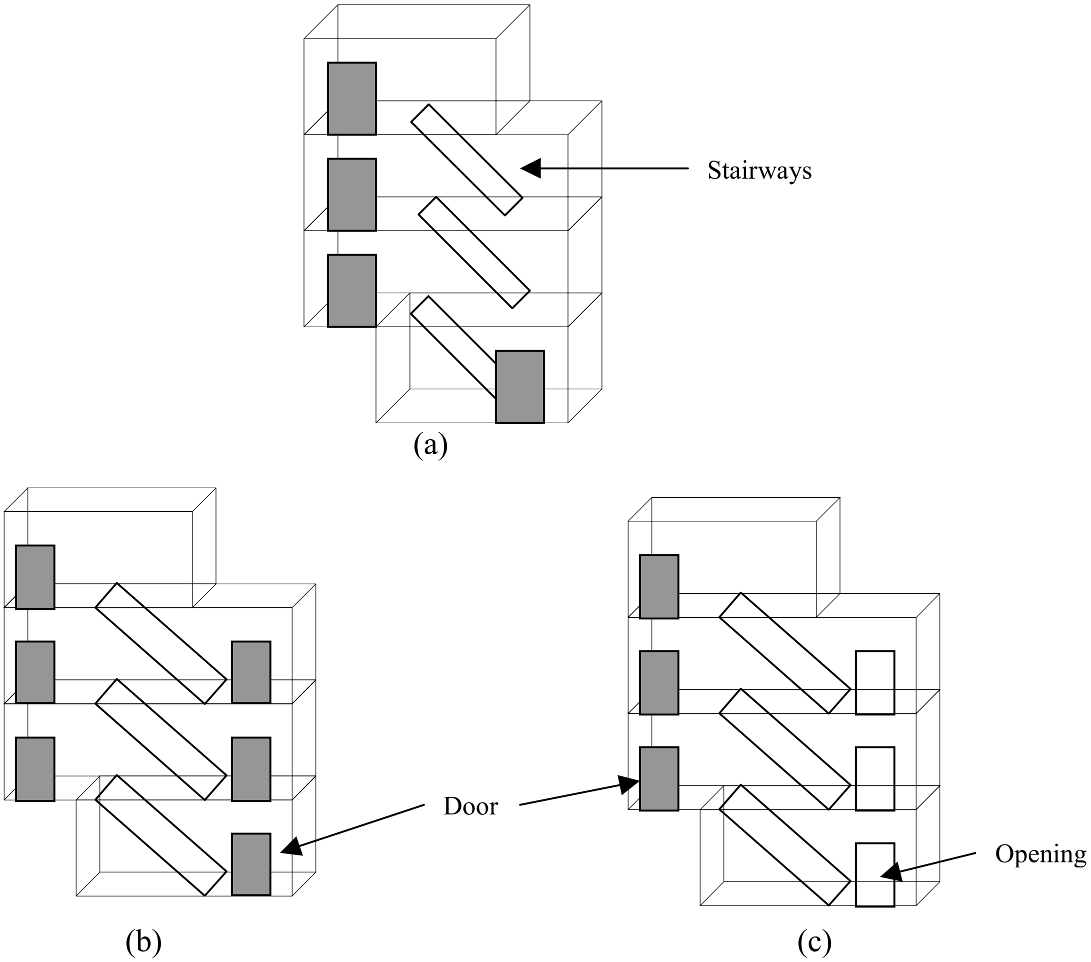


Figure 4.1

4.6 Restricted use of combustible materials

According to SOLAS II-2/34, except in cargo spaces, mailrooms, baggage rooms, or refrigerated compartments of service spaces, all linings, grounds, draught stops, ceilings and insulations shall be of non-combustible materials. Partial bulkheads or decks used to subdivide a space for utility or artistic treatment shall also be of non-combustible material (Reg. 34.1). The exposed surfaces in corridors and stairway enclosures, and of bulkheads, wall and ceiling linings in all accommodation and service spaces and control stations, and the surfaces concealed or inaccessible spaces in accommodation, service spaces and control stations shall have low flame-spread characteristics (Reg. 34.3). Veneers used on surfaces and linings with the low flame-spread characteristics shall have a calorific value not exceeding 45 MJ/m^2 of the area for the thickness used (Reg. 34.5). The total volume of combustible facings, mouldings, decorations and veneers in any accommodation and service space shall not exceed a volume equivalent to 2.5 mm veneer on the combined area of the walls and ceilings (Reg. 34.4). Furniture in stairway enclosures shall be limited to seating. Paints, varnishes and other finishes used on exposed interior surfaces shall not be capable of producing excessive quantities of smoke and toxic products (Reg. 34.7).

In the some Classification Rules, for instance the Rules and Regulations for the Classification and Construction of Sea-Going Ships of China Classification Society, 1991, all these SOLAS requirements are adopted. In compliance with the Rules, in ships of all types permanent deck coverings of more than 5 mm in thickness within control station, accommodation, service and working spaces shall not be readily ignitable. The insulation used in machinery and boiler rooms and in radio rooms is to be only of noncombustible materials, the surface of the insulation being impervious to oil products and their vapors. The adhesives used in conjunction with insulation need not be noncombustible, but they shall be kept to the minimum quantity practicable. Varnishes and paints used for interior decoration of ships are not to have highly flammable base.

Chapter 5

Fire Detection and Alarm System

5.1 Introduction

Fire detection and alarm systems are designed to detect a fire in the earliest practicable stage of its development and to send out alarm signals about the fire. Fire detection and alarm system together with structural fire protection and fire extinguishing system are the most important factors in fire fighting aboard ships and the main elements in SOLAS chapter II-2.

Generally fire detection and alarm system consists of fire detectors, alarm circuits, indicating units with duplicate signals and sources of power.

SOLAS chapter II-2 introduced the requirements for fire-detection and alarm systems, i.e.:

- Regulation 12 requirements for "automatic sprinkler, fire detection and fire alarm system",
- Regulation 13 requirements for "fixed fire detection and fire alarm system",
- Regulation 14 requirements for "fixed fire detection and fire alarm systems for periodically unattended machinery spaces", and
- Regulation 36 (for passenger ships) and Regulation 52 (for cargo ships) requirements for "fixed fire detection and fire alarm systems and automatic sprinkler, fire detection and fire alarm systems".

The Classification regulations for fire detection and alarm systems on board ships are becoming more detailed and stringent. The present Convention and Class requirements for fixed fire detection and alarm systems can be briefly summarized as follows:

Detector requirements include:

1. Specified operating temperature range for heat detectors.
2. Specified upper and lower limits of smoke density for smoke detectors protecting escape routes.
3. Ability to be operationally tested without the necessity to renew any component.

   Control / indicating panel requirements include:
4. Indication of the zone or section in which a detector or manual call point has operated.
5. Facilities to monitor power supplies and system fault conditions.

   Overall system requirements include:
6. Provision of two sources of electrical power.
7. Rationalized segregation of zones with a limit of 50 enclosed spaces permitted in any section.
8. Specified location, spacing and coverage for heat and smoke detectors.
9. Compatibility with the marine environment.

   Additional system requirements include:
10. Rapid detection.
11. Normal variation in machinery operation and ventilation accommodated in the design.
12. In addition to initiating an alarm on the bridge, a responsible engineer officer is to be made aware of an alarm condition. (Finney, 1984)

5.2 Fire detectors

5.2.1 Types of detectors

The faster a fire can be detected, the better are the chances of extinguishing it and thus the lower are the costs of the damage caused. Detectors are the most important parts in the system. The efficiency of each detector determines the efficiency of the whole system. There are mainly three types of detectors commonly used on board ships, namely: heat detectors, smoke detectors and flame detectors.

The ship designers should be very careful when they design the fire detection and alarm systems and choose the right detectors for different places on board, therefore it is very important for the designers to know the advantages and disadvantages of different type of detectors.

5.2.2 Heat detectors:

The detection time for point heat detectors is the sum of time taken for convection currents from the fire to bring hot air to the device and the time taken for sufficient heat to be conducted into the sensing element to operate it. Draughts from ventilation or machinery cooling fans may disturb either process. Heat detectors can only be used where a ceiling will collect a layer of heated air.

The characteristics of heat detectors change slightly depending on their sensing elements. There are many kinds of sensing element. The most used is bimetallic strip. By the principle of their operation there exist three types of heat detectors with bimetallic sensitive elements, namely: maximal (fixed temperature type), differential (rate of rise type) and maximal differential (combined rate of rise and fixed temperature type) detectors.

Maximal heat sensitive detectors operate when a temperature increase of the surrounding air exceeds a predetermined value. Differential thermal detectors actuate on rapid increase of the surrounding air temperature. Maximal differential heat detectors combine the features of the above two types. These types of heat detectors have high thermal inertia, and are prone to false alarms under vibration conditions.

Thermocouples may be used as sensing elements and these kinds of detectors contain a thermal battery having a low inertia and inertia junctions. The shortcomings of these detectors consist in that they do not actuate when rate of increase in the temperature of the surrounding air is rather small, and they are incapable to operate under vibration conditions.

Another type of sensing element is called thermistor. Detectors which use thermistors as sensors may operate in relay mode or weak current mode. The disadvantages of these devices are as follows:

- a need to carefully select thermistors,
- dependence of thermal response on the airflow velocity, and
- supply voltage oscillations.

5.2.3 Smoke detectors

Smoke detectors do not suffer from the thermal inertia of heat detectors and so the detection time depends principally on the time taken for convection currents to bring smoke to the devices. Smoke detectors can operate in the early stage of a slowly growing fire before either heat or flame detectors would operate. They suffer from the same susceptibility to draughts as heat detectors and similarly require to be installed on the ceilings.

There are two types of smoke detectors, one works on optical principles and the other works on ionization principles.

Table 5.1 gives the results of a detector manufacturer's tests using small fires in a 10m × 5m room with a 2.5m ceiling height. During the tests the heat detector was positioned directly above the fire source in the center of the room, and the smoke detectors were 4 m from the center. From the results it shows the good performance of the ionization smoke detector for the fuel fire.

Table 5.1 - Typical response time (in seconds) after initiation of fire

Test fires	Ionization smoke	Optical smoke	Heat
400ºC smouldering cardboard	75	70	_
400ºC smouldering wood blocks	105	110	_
Cotton-fabric-covered polyurethane foam	35	200	270
Waste-paper basket	90	120	_
Petrol + 4% oil	20	130	_
Methylated spirit	_	_	110

5.2.4 Flame detectors

Flame detectors have no delay because the signal will reach the detectors at the speed of light. The only detection delay will be that designed into the system to prevent false triggering.

Flame detectors view a volume of space and so it is unlikely that draughts would take a flame outside the field of a well-sited detector. They can be used on a very high ceiling or in the open air. They are particularly suitable for spaces where flaming fires are likely (in space of large height) as well as in those areas where smoke is generated in the process of work.

Flame detectors operate in different spectral regions, viz.: ultra-violet (UV), infrared (IR) and visible. There are mainly two disadvantages for flame detectors. One is the absence of reliable sensing elements permitting to avoid false alarms. The other is that, comparing to heat and smoke detectors, there should be no objects between the flame and the detector.

5.2.5 Comparison among detectors

Table 5.2 shows the results of detector response tests. It tells the response order after the fire is initiated. These tests were carried on in a 5m × 6m × 2.5m room, when a group of WMU students visited the Rescue Service Center in Helsingborg, Sweden. In the room seven different types of detectors were installed.

Table 5.2 Response time (in orders) of detectors after initiation of fire

Detectors	Gasoline (no smoke)	Oil (small smoke)	Wooden pieces
Maximal Heat	_	⑦	_
Differential Heat	_	⑥	_
Optical Smoke	_	⑤	②
Ionization Smoke	_	④	⑤
UV Flame	②	②	③
IR Flame	①	①	④
Hart (air analyze)	_	③	①

In the first group of tests gasoline was used, where no smoke was brought about. The UV and IR flame detectors responded almost at the same time in a few seconds. The other detectors did not respond within 10 minutes after the initiation.

In the second group of tests there were some smoke emerged from the fire of oil. The flam detectors responded in a few seconds, and then the Hart detector (air analyze type) took action in about 30 seconds. It took respectively 3 and 5 minutes for the responses of the ionization and optical smoke detectors. After 7 minutes of the ignition, the heat detectors responded.

In the third group of tests wooden pieces were ignited, and a lots smoke emerged before the flame come out. It was very clear that the flame detectors responded quickly after the flame come out, but it took some time for the smoke to reach the sensors of detectors. The two heat detectors did not respond due to the small quantity of heat generated from the wooden pieces.

5.3 Fire Alarms

The fire alarm systems usually comprise a fire detection and fire alarm system, a fire announcement alarm system and a warning alarm system.

The fire announcement alarm system is combined with a general alarm system, which gives powerful signals well heard in all ship's spaces.

The warning alarm system is designed to give signals to the spaces attended by people being on their duties and to warn of any intention to discharge a fire smothering gas, e.g. CO2 or inert gas, into the spaces.

Manual alarms are used for giving signals on an incipient fire to the main fire control station by crew members or passengers. Push button alarms are widely used as manual alarms. They are most commonly used on board.

The indicating units are generally centralized on the navigating bridge or other permanently manned location. Since no permanent watch is provided on the bridge when the ship is in harbor, a fire indication alarm should be duplicated in the area where permanent watch is required when in port.

Two sources of power supply should be provided for the fire detection and fire alarm system. The principal source could be the ship's main and the emergency one may be a special purpose accumulator battery, have a capacity sufficient for operation of the system for at least 3 days.

Chapter 6

Fire-extinguishing Devices & Alternatives of Halon System

6.1 General knowledge - Classification of fire

In order to successfully put out a fire, suitable type of extinguishing agent is needed. It will do the job in the least amount of time, cause the least amount of damage and result in the least danger to the crew. The job of picking the proper agent has been made easier by the classification of fire types, or classes, lettered A through D. Within each class are all fires involving materials with similar burning properties and requiring similar extinguishing agents. However, most fuels are found in combinations, and electrical fires always involve some solid fuel. Thus, for firefighting purposes, there are actually seven possible fire classes. Knowledge of these classes is essential to firefighting, as well as knowing the burning characteristics of materials found aboard vessels.

The fire triangle is composed of heat, fuel and air. These three things are needed to make a fire, remove any one of them and the fire is extinguished.

To move into a slightly more advanced theory of fires, there is a fourth ingredient necessary for fire, and the "fire tetrahedron" more accurately demonstrates the combustion process. It contains the four things required for combustion: fuel (to vaporize and burn), oxygen (to combine with the fuel vapor), heat (to raise the vapor to its ignition point) and the chain reaction (the chemical reaction among the fuel, oxygen and heat). Remove any of these four and there is no fire.

Class A Fires—Fires of common combustible solids such as wood, paper and plastic are best put out by water, a cooling agent. Foam and certain dry chemicals, which act mainly as smothering or chain-breaking agents, may also be used.

Class B Fires—Fires caused by flammable liquids such as oil, grease, gas and other substances give off large amounts of flammable vapors and require smothering agents to do the job. Dry chemical, foam and carbon dioxide (CO2) may be used. However, if the fire is being supplied with fuel by an open valve or broken fuel line, the source of the fuel must be shut down first. This action alone may stop the fire or at least make it easier to put out.

In a gas fire, it is important to shut down the source of the fuel. Attempting to put out the fire without shutting down the sources creates an explosive hazard that is more dangerous than the fire itself.

Combination Class A and B Fires—Water fog and foam may be used to smother fires involving both solid fuels and flammable liquids or gases. These agents also have some cooling effect on the fire. In enclosed spaces, CO2 may also be used.

Class C Fires—For fires involving energized electrical equipment, conductors or appliances, non-conducting extinguishing agents must be used such as CO2, Halon and dry chemical. Note that dry chemical may ruin electronic equipment.

Combination Class A and C Fires—Since energized electrical equipment is involved in these fires, non-conducting agents must be used. CO2, Halon, and dry chemicals are best. CO2 reduces the oxygen supply, while the others break the chain reaction.

Combination Class B and C Fires—Again, a non-conducting agent is required. Fires involving flammable liquids or gases and electrical equipment may be extinguished with Halon or dry chemical acting as a chain reaction breaker. In enclosed spaces, they may be extinguished with CO2.

Class D Fires—These fires may involve combustible metals such as potassium, sodium, and their alloys, and magnesium, zinc, zirconium, titanium and aluminum. They burn on the metal surface at very high temperature, often with a brilliant flame.

Water should not be used on Class D fires. It may add to the intensity and cause the molten metal to splatter. This, in turn, can extend the fire and inflict serious burns on those near by.

Combustible metal fires can be smothered and controlled with special agents known as dry powders. Although many people use the term interchangeably with dry chemicals, the agents are used on entirely different types of fires: dry powders are used only to put out combustible metal fires; dry chemicals may be used on other fires, but not on Class D fires.

6.2 Fire-extinguishing agents

(1) Water

Water is the most common medium of attack or containment that the fire brigade uses, initially at least, and the ships have provision to make this possible. It has the following advantages:

- Always available on board
- Excellent cooling properties
- Provides protection for fire party
- Best choice for Class A Fires

The disadvantages are:

- Not to be used on electrical fires
- Can reduce stability
- Can spread Class B Fires
- May damage cargo or equipment

(2) Steam

Like water use on ships, steam is available continuously and in large quantities, provided that there is sufficient fresh water available and the machinery spaces have not been affected by fire. The steam must be generated from fresh water since boilers cannot normally use sea water. It helps fight at a fire by displacing the oxygen form the air and by slowly saturating the cargo as its moisture content condenses. However, it has the following disadvantages:

- Very large quantities are necessary
- Cannot be used on fires which water could not be used
- May cause a vacuum after cooling
- Cause as much damage to cargo and equipment as water

(3) Foam

Foam acts primarily by isolating the source of a fire from the oxygen in the air. It has a number of advantages:

- Great quantities can easily and quickly be generated for filling large area;
- It requires less water and therefore reducing damage to cargo;

- It absorbs heat, helps stop fire spread and forms air-tight blanket over burning liquids;
- It has minimal chance of re-flash;
- It can be used from distance-around corners, from upper decks.

Medium expansion foam is more common on ships than high expansion because it does not require such large generators. It also has other advantages: the equipment necessary is more mobile and can work in more restricted spaces; the foam is wetter and heavier and therefore less affected by air currents.

The disadvantages are: it cannot be used on electrical fires; it may damage or destroy equipment.

(4) Carbon dioxide

Carbon dioxide (CO2) is generally recognized as more efficient than steam for smothering a fire and used widely on board as one kind of fixed fire-fighting installations, especially after the phase out of halon systems.

Carbon dioxide extinguishes fire by reducing the proportion of oxygen in the air to a level where combustion can no longer by supported. The level which must be reached to achieve this varies according to the cargo on fire. In calculating the amount of CO2 required, an allowance is also necessary for that escaping through openings. Carbon dioxide has the following advantages:

- It leaves most cargoes undamaged and unaffected.
- Since it is carried as a liquid under pressure, no pumps are required.
- It causes little damage or corrosion to equipment.

The disadvantages are:

- Some cargoes, such as celluloid, contain or generate oxygen to support the combustion even in an oxygen-free atmosphere, and CO2 will be therefore unable to stop them burning.
- The gas has little cooling effect, and the cargo may therefore remain hot for a long time, with the consequent risk of re-flash.
- The gas displaces oxygen and can kill fire-fighters and people not evacuated.

(5) Inert gas

There are several inert gas systems which use the combustion products of diesel oil. The gas produced, which is heavier than air, consists mostly of nitrogen (about 85%) and carbon dioxide (about 15%). There may also be a few oxygen, unburnt hydrocarbons and oxides of nitrogen. The gas is non-corrosive and non-toxic and does not usually react with the cargo. Its introduction into an atmosphere makes the air so deficient in oxygen that it cannot propagate flame.

(6) Dry chemical

There may be dry chemical extinguishers or installations on board a ship. Dry chemical can knock down flames fast and effectively. However, it has the following disadvantages:

- It has minimal protection against re-flash.
- It is highly corrosive to electronic equipment.
- The agent may cake and solidify in container.

(7) Halon

Halon is a colorless, odorless, high-density, electrically non-conductive gas. It acts by inhibiting the chemical reaction of fuel and oxygen, and has a number of advantages:

- Only a small concentration (5% by volume) is necessary to extinguish a fire, which means a saving in weight and space for storage.
- It has low toxicity.
- It is non-corrosive.
- It is chemically very stable, an advantage for prolonged storage.
- Its obscuration of the atmosphere is minimal, particularly by comparison with CO2.

Halon can become unstable and start to decompose when exposed to flames or hot surfaces above 510°C. The greatest disadvantage is that halon has ozone depletion properties and it cannot be used after 1 January 2000.

6.3 Fire-fighting Equipment on board

6.3.1 Portable equipment

Portable fire extinguishers are used for extinguishing incipient fires and small fires. The agents used in fire extinguishers mainly are foam, carbon dioxide, or dry powder.

The type and number of fire extinguishers to be carried on board are determined depending on the purpose and area of the spaces or output of machinery contained therein. When selecting the type of a fire extinguisher, the designers or persons in charge should also take into account the combustible materials used in the space to be protected, their arrangement in the space, fire risk of the space, ventilation provided, etc. In spaces containing radio navigational or electrical equipment CO2 extinguishers are generally installed, and on open decks foam extinguishers are common provided. On board ships carrying liquefied gases or chemical products powder extinguishers are usually the first choice.

Portable fire extinguishers should be kept at potential fire outbreak points, such as engines, boilers, fuel pumps, oil separators, switchboards, etc. The maximum distance from an extinguisher to a "fire point" is 10 to 20 meters.

The size and weight of portable extinguishers are suitable for one man to carry and operate at any moment. They are effective to small fires. For larger fires semi-portable extinguishers, which are 5 to 15 times of a normal portable extinguisher and fixed on wheels, may be used to protect machinery and working spaces.

In addition to the above fire extinguishers, sand or sawdust impregnated with soda stored in metal receptacles are used for extinguishing small fires of oil leakage or other flammable liquids.

6.3.2 Fixed fire-extinguishing systems

(1) Fire-extinguishing systems using water

There are many types of fixed fire-extinguishing systems using water as medium. Sea water fire main system is the most common fire-extinguishing system on board every type of ships. It is designed for extinguishing fires or cooling ship's structures by water jets or sprays supplied from fire hose nozzles or monitors.

Water spray fire-extinguishing systems are designed for extinguishing fires in machinery spaces, oil fuel bunkers, and cargo spaces for the carriage of vehicles on ro-ro ships.

Sprinkler systems are designed for extinguishing fires in control stations, accommodation and service spaces of passenger ships where structural fire protection within the main fire zones is constructed to Method II.

(2) Foam smothering system

Chemical foam was introduced as a fire-extinguishing medium at the beginning of 20^{th} century. It is still the most efficient medium for extinguishing petroleum products. It was used to combat fires in oil tanks, pump rooms of tankers, as well as engine rooms and other oil-contained machinery spaces. There are mainly two types of fixed foam system used on board: low-expansion foam system and high-expansion foam systems. Low-expansion systems are usually used to protect cargo oil tanks of tankers, while high-expansion systems are used to protect machinery spaces.

(3) Fixed gas fire-extinguishing systems

CO2, steam or inert gas can be used as medium in a fixed gas fire-extinguishing system to protect cargo spaces. CO2 system is used in machinery spaces as well, and became the major fixed system after the phase-out and prohibition of halon system from the beginning of year 2000.

Steam systems were mainly used on steam ships, which formed the majority of the world fleet in the first half of 20th century. Since high capacity boiler installations were provided in these ships, steam was always available for fire-extinguishing purposes. In general, the use of steam as a fire-extinguishing medium in fixed fire-extinguishing systems is not permitted in SOLAS. It shall be used only in restricted areas under specific conditions (see SOLAS II-2/5.4).

Inert gas systems are used to prevent fires or explosions in cargo areas of oil tankers. Since oil cargoes give off gases likely to ignite in mixture with air, the best protection is to maintain the oxygen content in the cargo spaces less than 11% (which does not support combustion) at all the time.

(4) Halon systems

Halon system used to be a very efficient system and used widely on board as the primary fire-extinguishing system for the protection of machinery spaces due to its properties: good extinguishing capabilities, minimum storage space requirements and cost effectiveness. Alternative systems to halon do exist, but few meet many of the criteria that made halon so popular.

The following part of this chapter is mainly focused on a new system -- water mist fire suppression system, which is recognized as an alternative to halon systems.

6.4 Water mist fire suppression systems

6.4.1 Introduction

Water mist fire suppression systems are water-based fire suppression systems, which may be also called fine water spray systems or fog systems, or in SOLAS, pressure water-spraying system. Water mist systems are not new, but they were considered worth developing only after the adoption of Montreal Protocol based on two factors (Mawhinney, 1994):

(1) The need to find an environmentally benign alternative to halon fire suppression agents to suppress flammable liquids, electronic and electrical fires, which water was not a suitable fire-extinguishing agent.

(2) The need to address life safety problems on aircraft and ships in which there are severe limits to the amount of water that can be stored and discharged.

The drop diameter of water mist should be less than 400 microns. Practically it is impossible to create a mist in which all of the drops have the same diameter and smaller then 400 microns. Usually it requires 90% of the volume in the spray is contained in droplets with smaller diameters.

6.4.2 Principles

Halon has been phased out of use as fire suppression agent because of its damage to the ozone layer. Water mist is viewed as a major alternative to halon. In the past sprinkler systems are not preferred because of the concerns about the ship stability and the loss of capacity if freshwater storage was required where sea water could not be used. The improved extinguishing efficiency of water mist reduces the amount of water required, which in turn permits smaller diameter piping.

Comparing to CO2 system, another major alternative to halon system, water mist system doesn't require an airtight enclosure and it has the great advantage of cooling function. Figure 6.1 illustrates the following three major functions that must be considered in the design of a water mist system (Mawhinney, 1994):

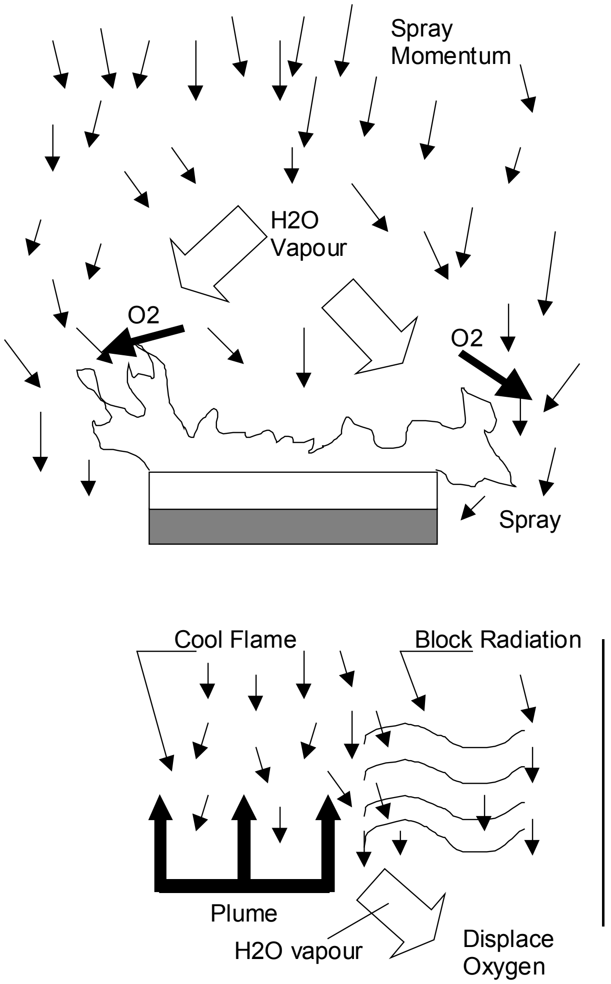


Figure 6.1 Three mechanisms of extinguishing

(1) Cooling

The cooling effect of water mist is a result of the division of water into very fine drops, which increases the total surface area available to absorb heat and maximizes the evaporation rat of the water. The process of evaporation extracts heat from the flame and the plume. If over 60% of the heat being generated by the fire can be absorbed in the flame zone by the evaporation of water drops, the fire will be extinguished (Wighus, 1991).

(2) Oxygen displacement by water vapour

The water vapour displaces normal air and reduces the amount of oxygen in the vicinity of the fire. If the water vapour can be confined to the vicinity of the fire in an enclosure, or directed against the base of the fire by nozzle dynamics, free oxygen will be reduced and the fire will be extinguished.

(3) Radiant heat attenuation

The small water drops suspended in the air reduce radiant heat transfer between the flames and hot gas layer and nearby objects. Heat radiating onto unburned fuel near the flame causes it to volatize and begin burning: it is the transfer of radiant heat to all parts of a compartment that often leads to flashover conditions. Interrupting the radiant heat transfer stops fire growth and spread within the compartment.

6.4.3 Tests in a simulated machinery space

Full-scale tests of a water mist system were carried out in January 1993 at the Royal Danish Navy Emergency School. A mock-up of a ship was used in the tests and the room volume was $225m^3$. Two diesel engines were located in the middle of the room and ventilation conditions were considered to be very high, due to two open doors and a large chimney.

Fire loads consisted of a maximum of $9m^2$ of diesel pools and two diesel sprays. One of the diesel sprays was hidden under an exhaust manifold, while the second was directed onto a hot metal surface. Diesel sprays were operated at pressures of 10 bar and 70 bar, with pre-burn time of 1.5 or 3 min.

The supply system consisted of a 700 liters water tank, nitrogen bottles and a total of 22 nozzles rated at 20 liters/min each. The system was manually operated. The fuel sprays were kept on for 10s after the system was shut down to verify possible re-ignition.

A summary of the test results was shown in Table 6.1. The water consumption rate was between 200 – 400 liters for extinguishments and the average time for extinguishments was 30s. Oxygen concentration readings never dropped below 18% in the room. A rapid knock down of temperature was measured in seconds after the system activated.

Table 6.1 Extract of summary of Test results

Fire characteristics	Ventilation conditions	Time of extinguishments
2 diesel pools and 2 diesel sprays (est. 7MW)	Doors closed, chimney open	25s, no re-ignition
2 diesel sprays – 1050 psi each	Doors closed, chimney open	53s, no re-ignition
3 pools lit in bilge area	Doors open, chimney open	25s
1 diesel pool only (est. 3MW)	Doors open, chimney open	25s
2 lub oil pools (est. 3MW)	2 doors open, chimney open	15s, no re-ignition
All diesel pools lit, 2 diesel sprays (est. 20MW)	2 doors open, chimney open	50s, no re-ignition
All diesel pools lit, 2 diesel sprays (est. 20MW)	2 doors open, chimney open	30s, no re-ignition

6.4.4 Problems and difficulties in design

Despite of the advantages of water mist systems, the possible design difficulties are listed as follows:

(1) Multiple potential fire locations require a large number of nozzles.

(2) Intent to fill entire compartment with mist requires substantial water supply and large amount of freshwater storage.

(3) Lack of space for air cylinder storage.

(4) Air supply cannot be in the compartment being protected, and long pipe runs from a remote location cause significant pressure losses, requiring larger diameter piping.

Water mist systems in current service are additional to the existing requirements. They are designed as local applications, protecting specific risk areas. Total flooding applications are possible in engine rooms and cargo holds. The larger the volume of the space to be protected, the complexity and cost of the installation make it more impractical.

6.4.5 IMO regulations

SOLAS regulation II-2/10 regulates the pressure water-spraying system, and in machinery spaces and cargo pump rooms of tankers the pressure water-spraying system is one of the alternatives for the fixed fire-extinguishing systems in addition to which shall be provided (SOLAS II-2/7, and II-2/63).

IMO has developed the Guidelines for the Approval of Equivalent Water-Based Fire-Extinguishing Systems as Referred to in SOLAS 74 for Machinery Spaces and Cargo Pump-Rooms (Annex to MSC/Circ.668).

Chapter 7

Safety by Design in Other Areas

7.1 Engine room design and arrangements

7.1.1 Analysis of engine room fires

Continuing to the analysis of ship fires in Chapter 2, it was recognized that engine room fires got the highest rank sorted by location. A detailed analysis has been undertaken of fires in engine rooms which occurred during the period 1991 to 1993. Figure 7.1[*] shows engine room fires accounted for almost 54% of all fires occurring between 1991 and 1993. The study of these incidents reveal that they were often initiated by explosion, or result from an uncontrolled release of flammable vapours or fuel into the engine room.

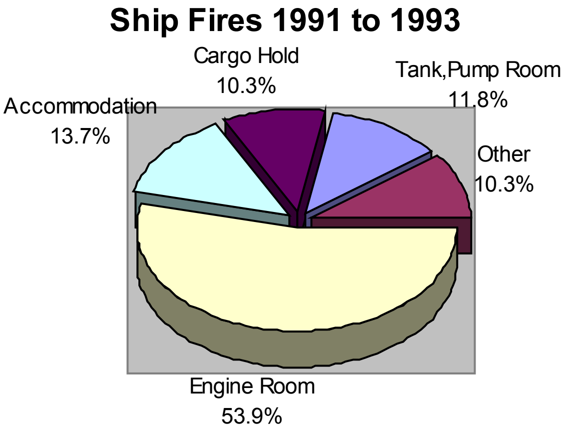


Figure 7.1

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[*] Source of Figure 7.1 ~ 7.7: Rushbrook's Fire Aboard (3rd edition)

Figure 7.2 shows the degree of loss which resulted from engine room fires in the period, grouped by sinking or constructive total loss (CTL), major fires and small incidents. Over 60% of the engine room fires cause major damage to the ship.

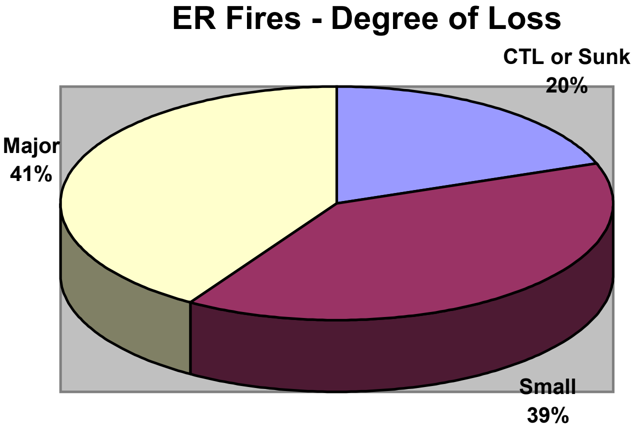

Figure 7.2

Figure 7.3 groups engine room fires by the type of vessel upon which they had occurred. About 42% of all engine room fires occurred on general cargo ships, 16.5% on tankers and 15.8% on ro-ro vessels.

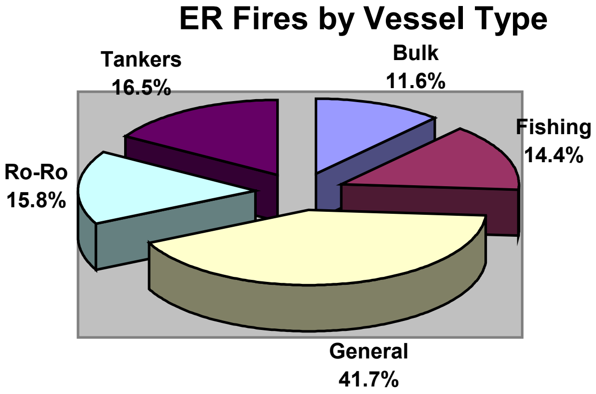

Figure 7.3

Figure 7.4 shows the incidence of fire grouped by severity and sorted by vessel age. There are a considerable number of incidents during the vessel's first year. Except the first year, the peak of incidents happened in the period of year 16 to year 24.

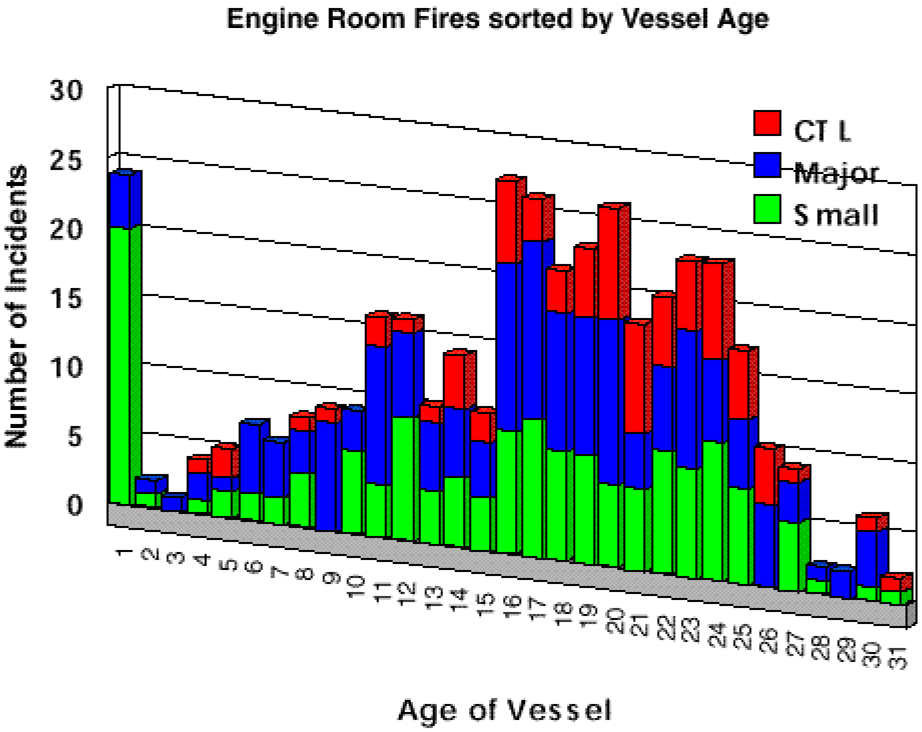

Figure 7.4

In 1994, the Japanese Classification Society NKK published the results of an investigation into 73 fires which occurred on ships of its class in the period of 1980 to 1992. Figure 7.5 shows the causes of the engine room fires and that 57% involved the release of either fuel, lubricate oil or waste oil, 26% resulted from electrical defect, 10% from repair work, welding and the like.

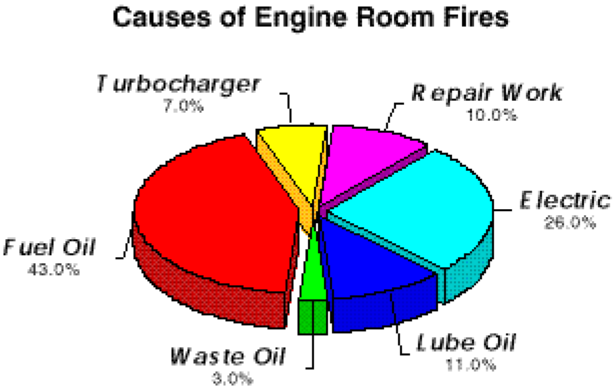

Figure 7.5

Figure 7.6 shows the sources of engine room fires plotted against the equipment's where they have occurred. The majorities were around the main engine and the generators, while a large number of fires occur near boilers and the electrical switchboard.

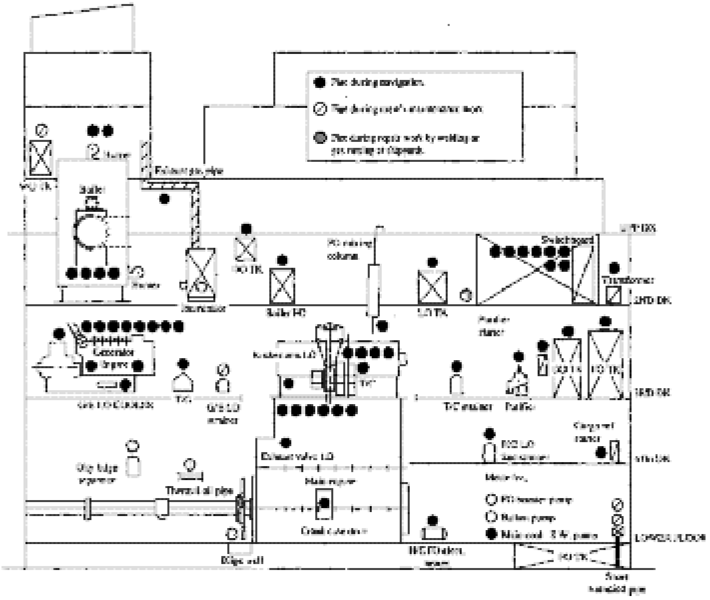

Figure 7.6 The sources of fire in engine rooms

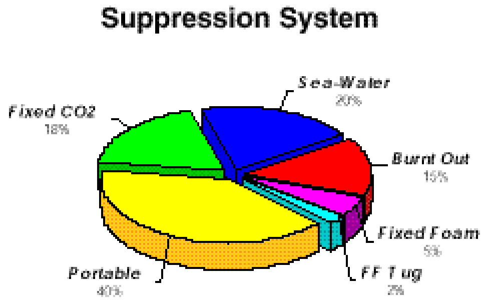

Figure 7.7

Figure 7.7 gives an idea of how the fires were suppressed. About 40% of all fires in engine rooms were extinguished by portable appliances, 20% by sea water, 18% by fixed CO2 and 5% by fixed foam. The other 15% of fires burn themselves out.

7.1.2 Fixed Fire-extinguishing systems in engine room

Which system is better in the engine room: CO2 or water mist system? It should be determined in the design process of the engine room. The advantages and disadvantages of these two types of systems have been discussed in Chapter 6. Here the consideration goes to the extinguishing time of the two systems.

It is obvious that the longer the discharge of CO2 is delayed, the less certain a successful outcome. In the same investigation of NKK, the statistics indicate that the CO2 system will be effective in the first thirty minutes after a fire has been discovered. If the fire has been burning for more than one hour, CO2 is not likely to guarantee a successful outcome than if discharged in the early course of the fire.

Because the discharge of CO2 would result in the certain death of anyone trapped in the engine room, the chief engineer shall make sure that there is no one left in the area before the discharge. Sometimes it is difficult and it takes some time and causes delay. More often the discharge of a CO2 system appears to be a measure of last resort by ship's officers.

The development of water mist systems reduce the amount of water required and the damage caused to the equipment. One of the great advantages of water-based systems is that they can be used immediately and a Master or Chief Engineer is not placed in the unenviable position of when to apply if persons are unaccounted.

7.1.3 Diesel engine and engine room design

One important and key way of improving fire safety in engine rooms is to increase the general safety of the main diesel engines. The highest fire hazard on a diesel engine relates to the fuel lines near to or on the cylinder top area.

It is so common that the failure of components on fuel pipes to diesel engines, especially the poorly designed components on lubricating oil and hydraulic systems, due to the vibration fatigue, leads to a fire. The development of diesel engine continues increasing the power of each cylinder. The fire hazard is increased due to the increase in the amount of high-pressure oil pipelines.

The engines are burning poorer grades of fuel, which will continue to deteriorate in quality. It requires higher pressure for injection under heated conditions well over twice the closed flash point of the fuel. This no doubt increases the fire risk.

In order to reduce the transmission of vibration to the hull structure, engines are mounted on super-critical rubber mountings. It requires all pipe connections between the engine and the hull structure to be flexible fittings. The maximum operational working life affects fire safety of the whole system. The engine manufacturer should not only improve the performance of the engine but the flexible connections as well.

Nowadays multi-engine room design is very popular on a large vessel. Due to the limitation of space, and lack of regulatory guidance, it is not uncommon to observe in a multi-engine room design that the exhaust system of one engine is directly in line to the fuel system of the adjacent engine.

Machinery spaces are becoming more compact. There is a need to assess not only the new developments but also the traditional arrangements, for their impact upon the overall safety, for which the present SOLAS regulations do not stipulate. (Matthewson, 1994)

The introduction of safety by design concept could have great impact on the overall safety in the engine rooms and other machinery spaces. The following issues may be considered:

- fire hazards in engine rooms and its division
- isolation arrangements for the machinery spaces
- tanks within the machinery spaces
- pipe and valve arrangements
- electric cable runs
- machinery space control room

7.2 Smoke control in cabin areas

7.2.1 Introduction

Statistics show that approximately 90% of the persons killed in shipboard fires have perished due to smoke exposure and only 10% due to the heat exposure. It was just the case of Scandinavian Star. The disasters of Scandinavian Star and other passenger ships have further shown that smoke is spread very quickly inside the ship.

After a fire is discovered onboard, the Heating Ventilating and Air Conditioning (HVAC) system should always be shut down first. This may prevent from forcing smoke flow and stop supply of oxygen, however, it does not prevent smoke movement due to smoke buoyancy, stack effect, expansion or draught. If the spread of smoke inside the ship is reduced, the safety will be increased. From saving human lives' point of view, smoke control is a key issue of the application of Safety by Design.

Practice has shown that the fire is extremely difficult to locate in cabin area. Fires in public areas are often easier to locate and thus can be extinguished more quickly. The evacuation of passengers from cabin areas is also more difficult than the evacuation from public spaces, especially at night when people are sleeping. Therefore, smoke control in cabin areas is the major subject to the ship designers.

In the traditional HVAC system, air supply to a cabin comes from an air terminal device which is normally located in the ceiling. There is a smaller positive pressure in the cabins in order to prevent the smoke from entering the cabins. Discharge of air normally takes place partly through bathroom and partly to corridor. There are several air terminal units for exhaust in the corridors, therefore the pressure in the corridor is negative.

In halls and stairwells, the air volume supplied is equal to the air volume exhausted. It is a balanced system, and there is no positive or negative pressure in these areas. The conditions of pressure in cabin, corridor and stairwell are shown in Figure 7.8.

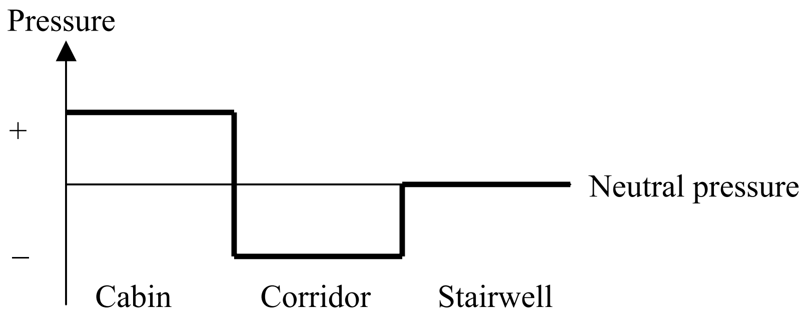

Figure 7.8 Pressure conditions during normal operation

7.2.2 Philosophy of smoke control

The smoke control system may achieve the purpose through the following ways:

(1) Special smoke-extracting fans extract the smoke through grills installed in the ceiling in corridors on the burning deck in the fire zone. This means there will be a negative pressure in the corridor.

(2) All cabins belonging to the fire zone on the deck on fire are to be continuously supplied with air. Supplying air into the cabin creates a positive pressure in these areas.

(3) In order to avoid spread of smoke from the burning zone to adjacent stairwells, these spaces are to be pressurized. (Jenson, 1994)

It should be noted that it is impossible to design a smoke control system which can stop the spread of smoke from any fire. And there is no guarantee that the smoke extraction can be used to absorb all the smoke. The purpose of a smoke control system is to reduce the spread of smoke as much as possible.

Figure 7.9 shows the conditions of pressure where a smoke control system is used. Several full-scale tests have been carried out successfully according to the smoke control philosophy above (Jensen, 1994).

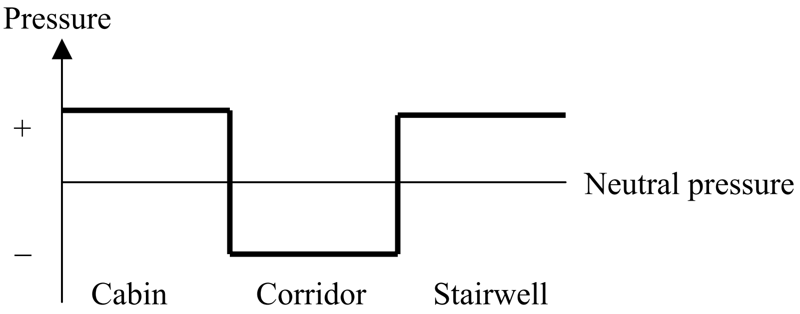

Figure 7.9 Pressure conditions during smoke control mode

Compared to the traditional HVAC systems, smoke control systems are supplemented with only a few components, e.g. smoke extractor fans.

Air supply at the ceiling in the corridor of the burning zone must be avoided in a fire situation. This will result in mixing of air and smoke, which may cause considerable reduction of visibility in the lower part of the corridor.

Supplying air into the cabins, which are not on fires, creates a positive pressure in these spaces. This ensures that the smoke is kept out those cabins not on fire. Furthermore, supply of air into the cabins ensures that smoke will not pass from the burning cabin into other cabins via the exhaust duct system.

The passage of smoke between the cabins via exhaust ducts from the bathroom must also be avoided. In order to keep positive pressure in the cabin, it must be ensured that the air volume which is exhausted via the ducts in the bathroom, is always smaller than the air volume which is supplied to the cabin.

Smoke detectors are to be installed in every cabin. The air supply fan is to be equipped with remote control connected to the control system. In case of smoke detection, the supply fan to the cabin in fire or smoke should be shut down immediately.

In order to maintain the escape routes – stairwells and halls free of smoke, it is a bad design to use a mechanically driven extraction system to remove any smoke that may have entered the stairwells. An extraction system will reduce the pressure level in the escape route. As a result more smoke will be sucked into the escape route. To prevent the smoke from entering the stairwells and halls, an adequate airflow is needed. It means the pressure in the escape routes will be raised.

In connection with the design of the smoke control system, it is important to consider to what extent the fire doors are automatically released into the closed position when a fire is discovered. On the one hand, the closure of fire doors plays a key role in the progress of smoke control; on the other hand, if the doors are closed tightly, which means a higher opening force is needed, it will cause some difficulties for the passengers, especially elders, children or disabled people, to open the doors to the escape routes without assistance.

7.2.3 Smoke control system

Fire experience onboard ships shows that fire in cabin areas can develop extremely quickly, and fires in cabin areas onboard passenger ships often start as smoldering fires (Jensen, 1994). A smoldering fire develops only a small quantity of heat, so usually it cannot be detected by heat detectors before it has developed into a flaming combustion. It may take a long time before the fire is detected. During this time there will be large amounts of smoke containing toxic gases produced. It will be a big risk to the passengers and crew and causes difficulties to the evacuation.

To achieve the best results of smoke control, first, the materials used should be those which produce less smoke during the fire; second, smoke detectors are to be installed all over the accommodation areas, in order to detect the smoke as quickly as possible. The smoke detection system should be capable of activating the smoke control system. After having received and interpreted signals coming from the fire detection system, the smoke control system proposes a preprogrammed control action. If the action does not correspond to the required action, e.g. in case of a fan breakdown, an audible alarm shall be triggered.

The system must allow the crew manually to override the actions operated by the smoke control system at any time.

At last, the control system and all the components activated by the system in a fire situation must be connected to the emergency generator.

Chapter 8
Summary and Conclusion

This dissertation reviews some major fire casualties on board ships and lessons learned from these casualties. Analysis of fire onboard shows the situation and the trends in ship fires.

Fire ranking the second in maritime casualties is not so important that the most important fact is fire and explosion amounts to 20~25% of the total casualty returns (see Chapter 2). There are mainly two ways to improve fire safety on board - training of crew and safety by design. This paper mainly concentrates on the issues of fire safety design.

Both passive and active protections are important. Structural fire protection contains the spread of fire and smoke, and protects the means of escape. It should be well designed at the drawing board stage because it is almost impossible or economically impractical to change ship's structure afterwards.

Active protections include fire detection and alarm systems and fire-extinguishing devices. The selection of detectors should be based on the nature of spaces being protected, and the fire-extinguishing agents used should be suitable for the class of fire.

Engine room design and arrangements, and the smoke control in cabin areas are also discussed, based on the facts that more than half of ship fires occurred in or initiated from engine rooms, and about 90% of the persons died in ship fires were killed by smoke.

Although training and fire drills are not the intent of this paper, it is suggested that special attention should be paid to the first year ships and the ships with large percentage of new crew.

Taking engine room fires as an example, there is a tremendously large number of fires occurred in the vessel's first year (see Figure 7.4). One of the reasons is that the crew are not familiar with the ship equipment and fire-fighting procedures on board a new ship. For the same reason a lot of fire casualties happened on the ships where there were large number of new crew on board, such as the case of Scandinavian Star.

Special attention should be paid to the training and fire drills on these new ships or newly crewed ships. The owners and managers should set up more strengthened procedures and requirements for on-board training and fire drills in order to make the crew familiar with the working environment, especially fire fighting and life-saving equipment and procedures.

Fire safety by design should be implemented at the drawing board stage. The designers should not only follow the SOLAS requirements or class rules and regulations. The overall achievement is to increase the integrated level of fire safety on board. The purpose of safety by design approach is to ensure that the ship is built in such a way that the fire risk onboard is as low as reasonable possible.

The concept of fire safety by design does not mean to increase the amount and level of regulations and conventions. "The first and perhaps the most fundamental defect of the statutory system, is simply that there is too much law."(Robens). When a ship is being built in a shipyard, it is subject to many rules and regulations. The shipyard may have its own standards of ship-building. The state or country has also national regulations of statutory surveys. The ship has a class and should follow all the requirements of that classification society. On top of all these, IMO conventions, mainly SOLAS and MARPOL should be applied. Designers are always confused among the large number of rules and regulations.

It is a major task for the regulatory makers in Maritime Authorities and international organizations to unify and harmonize the different levels of rules and regulations. However, from the ship design's point of view, it is not enough to simply comply with the requirements of IMO conventions. The direct application of the SOLAS regulations does not ensure a safe ship (Matthewson, 1994). The overall safety concept approach should be used from the very beginning of ship's design.

The use of risk assessment in the management of fire safety is a new trend and a good way to improve the overall fire safety. Risk assessment provides a method of determining unbiased comparisons from which to make decisions for the handling of the hazards being examined (Ross, 1994). It is used during the design stage and repeated and refined during the commissioning and operating stages of a ship's life. The results of risk assessment may help the designers to ensure that the design process addresses all unacceptable risks, and reduces the frequency or probability of those risks to acceptable level. This could be a further study of this dissertation.

(END)

References

Cahill, R. A. (1990). Disasters at sea: Titanic to Exxon Valdez. London: Random Century Ltd.

Casualty Statistics 1998. London: Institute of London Underwriters.

Coote, J. (1985). Total loss. London: Adlard Coles Ltd.

Cowley, J. (1994). Fire casualties and their regulatory repercussions. In Institute of Marine Engineers Conference Proceedings on Fire Safety on Ships – Developments into the 21st Century (pp. 7-34). London: Institute of Marine Engineers.

Finney, A. W. (1985). Design of fire-detection and alarm systems –current trends and state of the art. Conference on ship fires in the 1980s (pp. 23-26). London: Marine Management (Holdings) Ltd.

Galbraith, P. (1999, Jan.). IFE Journal. Oil tankers: fire safety by design. Retrieved March 1, 2000 from the Internet: http://www.fire.org.uk/marine/papers/tankers.htm

International Convention for the Safety of Life at Sea, Consolidated Edition, London, International Maritime Organization, (1997).

Lygate, J. F. (Eds.). (1998). Rushbrook's Fire Aboard (3rd ed.). Glasgow, Scotland: Brown, Son & Ferguson, Ltd.

Manum, I. A. (1994). Keynote address. In Institute of Marine Engineers Conference Proceedings on Fire Safety on Ships – Developments into the 21st Century (pp. 5-6). London: Institute of Marine Engineers.

Matthewson, B., & Beck, W. G. (1994). The concept of safety by design - a field surveyor's viewpoint. In Institute of Marine Engineers Conference Proceedings on Fire Safety on Ships – Developments into the 21st Century (pp. 83-94). London: Institute of Marine Engineers.

Mawhinney, J. R. (1994). Water mist fire suppression systems for marine applications: a case study. In Institute of Marine Engineers Conference Proceedings on Fire

Safety on Ships – Developments into the 21st Century (pp. 119-130). London: Institute of Marine Engineers.

Mckay, R. S. (1994). Fine water spray fire suppression alternative to halon 1301 in machinery spaces – machinery space risk analysis. In Institute of Marine Engineers Conference Proceedings on Fire Safety on Ships – Developments into the 21st Century (pp. 131-137). London: Institute of Marine Engineers.

Mendiola, S. & Achutegui, J. J. (1999, Jan.). IFE Journal. Fire ranks second in Maritime casualties. Retrieved March 1, 2000 from the Internet: http://www.fire.org.uk/marine/papers/marinecasn.htm

MSC/Circ.668 (1994). Annex: Guidelines for the approval of equivalent water-based fire-extinguishing systems as referred to in SOLAS 74 for machinery spaces and cargo pump-rooms. London, International Maritime Organization.

Noble, I. G. (1985). Structural fire protection of cargo ships and guidance on the requirements of merchant shipping (fire protection) regulations 1984. In Conference on ship fires in the 1980s (pp. 11-18). London: Marine Management (Holdings) Ltd.

Robinson, A. (1999, Jan.). IFE Journal. The Scandinavian Star incident: a case study. Retrieved March 1, 2000 from the Internet: http://www.fire.org.uk/marine/papers/scanstar.htm

Ross, J. S. (1994). The management of safety – the role of safety cases and risk assessment. In Institute of Marine Engineers Conference Proceedings on Fire Safety on Ships – Developments into the 21st Century (pp. 225-230). London: Institute of Marine Engineers.

Rules and Regulations for the Classification and Construction of Sea-Going Ships, Beijing, China Classification Society, (1991).

Stavitskiy, M. G., Vostryakov, V. I., Kortunov, M. F., Martynenko, V. I., & Sidoryuk, V. M. (1983). Fire Fighting Aboard Ships. Houston: Gulf Publishing Company.

Wighus, R. (1991). Extinguishment of enclosed gas fires with water spray. In Proceedings of the third international symposium on fire safety science. Edinburgh, Scotland: University of Edinburgh.

Appendix A

Some of the Regulations in SOLAS II-2 referred in this dissertation

Regulation 3 - Definitions (part)

For the purpose of this chapter, unless expressly provided otherwise:

1 Non-combustible material is a material which neither burns nor gives off flammable vapours in sufficient quantity for self-ignition when heated to approximately 750°C, this being determined to the satisfaction of the Administration by an established test procedure. Any other material is a combustible material.

2 A standard fire test is one in which specimens of the relevant bulkheads or decks are exposed in a test furnace to temperatures corresponding approximately to the standard time-temperature curve. The specimen shall have an exposed surface of not less than 4.65 m^2 and height (or length of deck) of 2.44 m, resembling as closely as possible the intended construction and including where appropriate at least one joint. The standard time-temperature curve is defined by a smooth curve drawn through the following temperature points measured above the initial furnace temperature:

at the end of the first 5 min	556°C
at the end of the first 10 min	659°C
at the end of the first 15 min	718°C
at the end of the first 30 min	821°C
at the end of the first 60 min	925°C

3 "A" class divisions are those divisions formed by bulkheads and decks which comply with the following:

.1 they shall be constructed of steel or other equivalent material;

.2 they shall be suitably stiffened;

.3 they shall be so constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour standard fire test;

.4 they shall be insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 139°C above the original temperature, nor will the temperature, at any one point, including any joint, rise more than 180°C above the original temperature, within the time listed below:

class "A-60"	60 min
class "A-30"	30 min
class "A-15"	15 min
class "A-0"	0 min

.5 the Administration may require a test of a prototype bulkhead or deck to ensure that it meets the above requirements for integrity and temperature rise.4

4 "B" class divisions are those divisions formed by bulkheads, decks, ceiling or linings which comply with the following:

.1 they shall be so constructed as to be capable of preventing the passage of flame to the end of the first half hour of the standard fire test;

.2 they shall have an insulation value such that the average temperature of the unexposed side will not rise more than 139°C above the original temperature, nor will the temperature at any one point, including any joint, rise more than 225°C above the original temperature, within the time listed below:

class "B-15"	15 min
class "B-0"	0 min

.3 they shall be constructed of approved non-combustible materials and all materials entering into the construction and erection of "B" class divisions shall be non-combustible, with the exception that combustible veneers may be permitted provided they meet other requirements of this chapter;
.4 the Administration may require a test of a prototype division to ensure that it meets the above requirements for integrity and temperature rise.

5 "C" class divisions are divisions constructed of approved non-combustible materials. They need meet neither requirements relative to the passage of smoke and flame nor limitations relative to the temperature rise. Combustible veneers are permitted provided they meet other requirements of this chapter.

6 Continuous "B" class ceilings or linings are those "B" class ceilings or linings which terminate only at an "A" or "B" class division.

7 Steel or other equivalent material. Where the words steel or other equivalent material occur, equivalent material means any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the applicable exposure to the standard fire test (e.g. aluminium alloy with appropriate insulation).

8 Low flame spread means that the surface thus described will adequately restrict the spread of flame, this being determined to the satisfaction of the Administration by an established test procedure.

9 Main vertical zones are those sections into which the hull, superstructure, and deckhouses are divided by "A" class divisions, the mean length of which on any deck does not in general exceed 40 m.

……

Regulation 10 - Fixed pressure water-spraying fire-extinguishing systems in machinery spaces

1 Any required fixed pressure water-spraying fire-extinguishing system in machinery spaces shall be provided with spraying nozzles of an approved type.

2 The number and arrangement of the nozzles shall be to the satisfaction of the Administration and shall be such as to ensure an effective average distribution of water of at least 5 l/m^2 per minute in the spaces to be protected. Where increased application rates are considered necessary, these shall be to the satisfaction of the Administration. Nozzles shall be fitted above bilges, tank tops and other areas over which oil fuel is liable to spread and also above other specific fire hazards in the machinery spaces.

3 The system may be divided into sections, the distribution valves of which shall be operated from easily accessible positions outside the spaces to be protected and will not be readily cut off by a fire in the protected space.

4 The system shall be kept charged at the necessary pressure and the pump supplying the water for the system shall be put automatically into action by a pressure drop in the system.

5 The pump shall be capable of simultaneously supplying at the necessary pressure all sections of the system in any one compartment to be protected. The pump and its controls

shall be installed outside the space or spaces to be protected. It shall not be possible for a fire in the space or spaces protected by the water-spraying system to put the system out of action.

6 The pump may be driven by independent internal combustion machinery but, if it is dependent upon power being supplied from the emergency generator fitted in compliance with the provisions of regulation II-1/44 or regulation II-1/45, as appropriate, that generator shall be so arranged as to start automatically in case of main power failure so that power for the pump required by paragraph 5 is immediately available. When the pump is driven by independent internal combustion machinery it shall be so situated that a fire in the protected space will not affect the air supply to the machinery.

7 Precautions shall be taken to prevent the nozzles from becoming clogged by impurities in the water or corrosion of piping, nozzles, valves and pump.

Regulation 26 - Fire integrity of bulkheads and decks in ships carrying more than 36 passengers

(Paragraphs 2.2(7) and 2.2(13) of this regulation apply to ships constructed on or after 1 February 1992)

1 In addition to complying with the specific provisions for fire integrity of bulkheads and decks mentioned elsewhere in this part, the minimum fire integrity of all bulkheads and decks shall be as prescribed in tables 1 to 2. Where, due to any particular structural arrangements in the ship, difficulty is experienced in determining from the tables the minimum fire integrity value of any divisions, such values shall be determined to the satisfaction of the Administration.

2 The following requirements shall govern application of the tables:
.1 Table 1 shall apply to bulkheads not bounding either main vertical zones or horizontal zones. Table 2 shall apply to decks not forming steps in main vertical zones nor bounding horizontal zones.

.2 For determining the appropriate fire integrity standards to be applied to boundaries between adjacent spaces, such spaces are classified according to their fire risk as shown in categories (1) to (14) below. Where the contents and use of a space are such that there is a doubt as to its classification for the purpose of this regulation, it shall be treated as a space within the relevant category having the most stringent boundary requirements. The title of each category is intended to be typical rather than restrictive. The number in parentheses preceding each category refers to the applicable column or row in the tables.

(1) Control stations Spaces containing emergency sources of power and lighting.
Wheelhouse and chartroom.
Spaces containing the ship's radio equipment.
Fire-extinguishing rooms, fire control rooms and fire-recording stations.
Control room for propulsion machinery when located outside the propulsion machinery space.
Spaces containing centralized fire alarm equipment.
Spaces containing centralized emergency public address system stations and equipment.

(2) Stairways Interior stairways, lifts and escalators (other than those wholly contained within the machinery spaces) for passengers and crew and enclosures thereto.
In this connection a stairway which is enclosed at only one level shall be regarded as part of the space from which it is not separated by a fire door.

(3) Corridors Passenger and crew corridors.

(4) Evacuation stations and external escape routes Survival craft stowage area.

Open deck spaces and enclosed promenades forming lifeboat and liferaft embarkation and lowering stations.

Muster station, internal and external.

The ship's side to the waterline in the lightest seagoing condition, superstructure and deckhouse side situated below and adjacent to the liferaft's and evacuation slide's embarkation areas.

(5) Open deck spaces Open deck spaces and enclosed promenades clear of lifeboat and liferaft embarkation and lowering stations.

Air spaces (the space outside superstructures and deckhouses).

(6) Accommodation spaces of minor fire risk Cabins containing furniture and furnishings of restricted fire risk.

Offices and dispensaries containing furniture and furnishings of restricted fire risk.

Public spaces containing furniture and furnishings of restricted fire risk and having a deck area of less than 50 m2.

(7) Accommodation spaces of moderate fire risk Spaces as in category (6) above but containing furniture and furnishings of other than restricted fire risk.

Public spaces containing furniture and furnishings of restricted fire risk and having a deck area of 50 m 2 or more.

Isolated lockers and small store-rooms in accommodation spaces having areas less than 4 m 2 (in which flammable liquids are not stowed).

Sale shops.

Motion picture projection and film stowage rooms.

Diet kitchens (containing no open flame).

Cleaning gear lockers (in which flammable liquids are not stowed).

Laboratories (in which flammable liquids are not stowed).

Pharmacies.

Small drying rooms (having a deck area of 4 m 2 or less).

Specie rooms.

Operating rooms

(8) Accommodation spaces of greater fire risk Public spaces containing furniture and furnishings of other than restricted fire risk and having a deck area of 50 m 2 or more.

Barber shops and beauty parlours.

(9) Sanitary and similar spaces Communal sanitary facilities, showers, baths, water closets, etc.

Small laundry rooms.

Indoor swimming pool area.

Isolated pantries containing no cooking appliances in accommodation spaces.

Private sanitary facilities shall be considered a portion of the space in which they are located.

(10) Tanks, voids and auxiliary machinery spaces having little or no fire risk Water tanks forming part of the ship's structure.

Voids and cofferdams.

Auxiliary machinery spaces which do not contain machinery having a pressure lubrication system and where storage of combustibles is prohibited, such as: ventilation and air-conditioning rooms; windlass room; steering gear room; stabilizer equipment room; electrical propulsion motor room; rooms containing section switchboards and

purely electrical equipment other than oil-filled electrical transformers (above 10 kVA); shaft alleys and pipe tunnels; spaces for pumps and refrigeration machinery (not handling or using flammable liquids).

Closed trunks serving the spaces listed above.

Other closed trunks such as pipe and cable trunks.

(11) Auxiliary machinery spaces, cargo spaces, cargo and other oil tanks and other similar spaces of moderate fire risk Cargo oil tanks.

Cargo holds, trunkways and hatchways.

Refrigerated chambers.

Oil fuel tanks (where installed in a separate space with no machinery).

Shaft alleys and pipe tunnels allowing storage of combustibles.

Auxiliary machinery spaces as in category (10) which contain machinery having a pressure lubrication system or where storage of combustibles is permitted.

Oil fuel filling stations.

Spaces containing oil-filled electrical transformers (above 10 kVA).

Spaces containing turbine and reciprocating steam engine driven auxiliary generators and small internal combustion engines of power output up to 110 kW driving generators, sprinkler, drencher or fire pumps, bilge pumps, etc.

Closed trunks serving the spaces listed above.

(12) Machinery spaces and main galleys Main propulsion machinery rooms (other than electric propulsion motor rooms) and boiler rooms.

Auxiliary machinery spaces other than those in categories (10) and (11) which contain internal combustion machinery or other oil-burning, heating or pumping units.

Main galleys and annexes.

Trunks and casings to the spaces listed above.

(13) Store-rooms, workshops, pantries, etc.

Main pantries not annexed to galleys.

Main laundry.

Large drying rooms (having a deck area of more than 4 m2).

Miscellaneous stores.

Mail and baggage rooms.

Garbage rooms.

Workshops (not part of machinery spaces, galleys, etc.).

Lockers and store-rooms having areas greater than 4 m2, other than those spaces that have provisions for the storage of flammable liquids.

(14) Other spaces in which flammable liquids are stowed Lamp rooms.

Paint rooms.

Store-rooms containing flammable liquids (including dyes, medicines, etc.).

Laboratories (in which flammable liquids are stowed).

.3 Where a single value is shown for the fire integrity of a boundary between two spaces, that value shall apply in all cases.

.4 In determining the applicable fire integrity standard of a boundary between two spaces within a main vertical zone or horizontal zone which is not protected by an automatic sprinkler system complying with regulation 12 or between such zones neither of which is so protected, the higher of the two values given in the table shall apply.

.5 Where a sprinklered zone and a non sprinklered zone meet within accomodation and service spaces, the higher of the two values given in the tables shall apply to the division between the zones.

.6 Notwithstanding the provisions of regulation 25 there are no special requirements for material or integrity of boundaries where only a dash appears in the tables.

.7 The Administration shall determine in respect of category (5) spaces whether the insulation values in table 1 shall apply to ends of deckhouses and superstructures, and whether the insulation values in table 2 shall apply to weather decks. In no case shall the requirements of category (5) of table 1 and 2 necessitate enclosure of spaces which in the opinion of the Administration need not be enclosed.

3 Continuous "B" class ceilings or linings, in association with the relevant decks or bulkheads, may be accepted as contributing wholly or in part, to the required insulation and integrity of a division.

4 In approving structural fire protection details, the Administration shall have regard to the risk of heat transmission at intersections and terminal points of required thermal barriers.

Appendix B

Fire Ranks Second in Maritime Casualties

by S. Mendiola & J.J. Achútegui, and M.A. De la Rosa

A survey of total loss accidents in merchant shipping over a period of 25 years shows that these can be arranged in the following order: stranding, fire, water-leaks, gales and collision; other accidents are also taken into consideration. The analysis considers ships over 500grt of different flags, plying any route of navigation and trade. Initially, a sample of 500 merchant ships - of different types and tonnage - and under 15 different flags is analysed to determine age and type of ship, and the causes of loss. On a second analysis, the same 15 flags are considered, but now over a wider range on a sample totaling 1,500 merchant ships. The results of both analyses are compared. It is shown that fire together with explosion amounts to 25% of maritime casualty returns -in the total loss lists- while stranding and fire take more than 50% of the toll.

1. Introduction

Maritime accidents fall into one of the following groups due to several circumstances: those caused by weather conditions, such as gales, reduced visibility [1], ice, etc; or those due to pilot navigation error, narrow [2] and/or congested [3] waters, collision with unknown objects, ship lying at anchor or moored at buoys with strong currents, manoevering at close quarters or with limited space and adverse conditions in port. Cargo related accidents occur through the carriage of dangerous goods, cargo on deck, heavy cargo, or cases relevant to the ship's seaworthiness. Failure in the steering system [4], main engine, different devices, war, terrorism, piracy, collision and misinterpretation in communications at sea, etc [5, 6] can all lead to accident.

Accidents by collision [7] have decreased significantly where a maritime traffic management service or, at least, a Traffic Separation Scheme (TSS) has been implemented. Currently a worldwide maritime traffic management system is being contemplated [8].

The SOLAS (Safety of life at sea) convention rules the safety of navigation in sea trade [9] in shipbuilding and fire-resistant bulkheads, life-saving appliances and facilities, radio communications, grain in bulk and dangerous goods transportation. These international provisions make it compulsory for sea-time training on board merchant vessels, and for fire and abandon-ship drills.

Fire aboard merchant ships is serious, sometimes leading to total loss of the ship and/or her cargo, to gross damage, and to loss of life. In the past, when merchant vessels were built out of wood and propulsion was achieved by wind action on the sails, lighting was achieved by means of oil or paraffin lanterns; tragic fires happened far too often, due mainly to the ship's rolling and the subsequent falling and breaking of the lanterns. In this day and age, flame lights are not allowed on board, or are prohibited by their inefficiency and danger. Nevertheless, fire still poses a high risk for several other reasons.

The stranding of merchant vessels [10] can result in fire and explosions [11] particularly when large tankers engaged in the crude oil trade are involved. Such was the case with the 'Torrey Canyon' in 1967 [12], when a series of explosions and fires after her stranding in the Scilly Isles (Seven Stones, Polard Rock) caused an all-time record in sea pollution. Probably petroleum products, shipped in bulk, present the highest risk, when errors occur [13], but we have other substances such as coal, a number of ores [14], feeding stuff, fertilizers, fish meal [15], etc.

which are apparently harmless - when one is not acquainted with case histories - but which are liable to produce a spontaneous combustion.

Accident investigations [16] show that fire leads to serious consequences not only in carriage of dangerous goods, but also poses a risk to other goods which otherwise would not be dangerous and would not create a hazard during sea passage - such as sugar, walnuts, cotton, and the like which can readily be stowed with no apparent fire risk. This kind of cargo burns easily and canbecome a risk if neighbouring hot work or a faulty mains line causes fire to break out in the cargo hold. Extinguishing this fire will prove difficult once it has gained a hold and it will spread quickly if there is sufficient oxygen.

This work analysed various maritime accidents during a 25-year period and, with samples of 500 ships or more, it was found that stranding and fire aboard taken together, amounted to 50 percent of the constructive total losses.

2. Method and Results

The method followed in this research on maritime casualties has consisted of analysing total losses of merchant ships, under different flags, which gross tonnage of 500grt or over, throughout 25 years. Data for accidents were taken from "Modern Shipping Disasters" [17], which lists disasters alphabetically by vessel's name. To obtain useful or reliable results for a given flag, it is necessary to consider a group of 100 ships for each flag. To quantify, causes, ages, and class-type under different flags, a sample 500 ships [18] is needed. Firstly a total of 500 merchant ship losses under 15 flags was analysed, to establish ship's age when lost and the trade she was on (class or type of goods transported). The number of ships, and total gross tonnage per flag was recorded, and this data is presented in Table 1. The reasons for these accidents have been analysed and quantified in Table 2 both as numbers and as a percentage of the total.

Whilst a sample of 500 accidents is sufficient to establish causes, it is not a large enough sample to discriminate behaviour between different flags. In the next two tables, Tables 3 & 4, the same particulars have been analysed, but the number of ships has been increased to a total of 1,500.

2.1 Age estimation In the analysis of '15 flags - 500 ships' (Table 1), the losses have been separated into four periods of a ship's active service - first 0-5 years, second 6-12 years, third 13-20 years, and fourth ages overrunning 21 years. In Table 1, the sum of the losses in the first two periods, 38+72, amount to 110 ships, meaning 22% of the 500 ships analysed. The losses in the third and fourth periods, 185+205=390 ships, make 78% of the total analysed. The first particular to consider is that losses in ships over 13 years do outnumber the others, and are 3.5 times more frequent than in new and middle-aged ships; but it is also true, that the over-ageing of the world shipping, in the 25 years under survey, is a trend to consider. The 205 vessels in the table, aged over 21 years, amount to 41% of the 500 ships and 15 flags of the sample, and only Japan looms as a younger fleet.

2.2 Trade Regarding ships classified by trade, those carrying general cargo (break-bulk) are the majority, making a total of 333 units, meaning 66.6% of the total; dry-bulkers come to 51 ships with 10.2%; tankers number 55 with 11%; and the rest of ships make a total 61 units, coming to 12.2% of the 500 analysed. Total gross tonnage amounts to 3,941,360 which divided by the 500 ships, comes to a mean of 7,883grt per ship.

2.3 Cause Table 2 shows 15 flags and 500 merchant ships, entering the nine most frequent circumstances in maritime accidents, resulting in total losses confirmed by ships' classification societies. The results of the table places "stranding" as the leading maritime casualty - in fine weather, reason unspecified - followed by stranding in heavy weather, a total of 146 being entered with 29.2% of the 500 ships involved in accidents. Ranking second is "fire"; fire in the engine room is the most common cause, with 61 cases forming 55% of the total caused by fire. Total accidents by fire amount to 111 ships and represent 22.2% of the total. Third cause of total loss is attached to "water-leaks" with 72 cases and 14.4% of the total. Fourth are "gales" affecting 70 ships and a share of 14%. Fifth place is held by "collisions" with 48 cases and a 9.6% share.

The remainder of the total losses having a lesser frequency impact in this table stand in the following order: explosions, faults in cargo, war, and striking unknown floating objects.

2.4 Ship losses In Table 3 the same 15 flags are analysed, increasing the number of merchant ships - in total loss casualties - , to 1,500 of 500grt and over, the results being entered by age, class of ship and gross tonnage. In the first nine flags with 100 or more ships, ages are analysed separately, the type of ships involved in the casualties, the mean per flag and the total mean. For the analysis and quantifying of ships the same four periods of Table 1 are maintained.

In considering the first two periods - new and middle-aged ships on one hand, and the two second periods - too long in service and old ships - on the other, if the ratio of the former over the latter is greater than unity, the flag of that merchant fleet can be assumed to be as of new construction. For a valid comparison, there needs to be 100 or more ships per flag in making the estimation.

Japan has a ratio greater than 2 [(39+50) / (31+7) = 2.342] Greece has the lowest ratio, [16/134 = 0.119], indicating the oldest fleet; Cyprus [19/131 = 0.145] turns out to be the second oldest flag; following this line Panama with 0.154; Philippines 0.174; Italy 0.244; UK 0.250; Liberia 0.363; and Spain 0.887.

The whole 15 flags show a mean ratio for the 1,500 ships of (140+251) / (483 + 626) = 0.352. From the total of ships in casualty 9.3% are under 6 years and 41.7% are over 21 years old.

These results do not mean that ships had a casualty for being very old, but rather that the world fleet in the 25 years under survey is quite old, neither doesn't mean that Japan's casualties occur mainly in her new ships, but rather that her fleet is new.

As in Table 1, two letters have been entered at the head of the columns, for readily identifying class of ship, GC = general cargo, BC = bulkcarrier (dry-bulkers), etc. Total contribution of GC ships is 1,034 units, a share of 69% of the total. Next column is for dry-bulkers with 121 ships with a 8.1% share, followed by tankers on trades of crude oil or oil products, with 193 tankers and 12.9%. The rest of ships (all columns to the right) entered in the same line (G total) amount to 152 ships, with 10% of the total. The mean of the gross tonnage of the first four columns with 150 ships per flag is highest for Liberia with 3,524,820 grt/150 = 23,499grt. This figure, representing less GC ships and several in BC and TA ships for a same number of ships, means a higher tonnage average. On the contrary, Panama, with a higher number of GC ships and few BC and TA ships, has the lowest tonnage average of the four analysed with 874,780/150=5,832grt. Total mean (15 flags) amount to 12,472,710 / 1,500 = 8,315grt.

Comparing Table 1 and 3, the total tonnage average per ship is only of 8,315-7,883=432grt. Ages in each table keep a similar ratio, and only column 13-20 years shows a difference as high as 4.8%. Regarding types of ships, the highest difference between tables does not surpass 2.4%.

In Table 4 we have arranged the accidents of the 15 flags in 10 columns, for allocating 1,500 ships per flag and their casualties under their corresponding entries and headings. "Stranding" is still the first reason for accidents totalling 455 cases and representing 30.3% of the total.

"Fire" ranks second involving 304 ships with 20.3% of the losses; fire in the engine room has the highest rate in this category, with 165 accidents. Third is "water-leaks", with 202 total losses, 13.4% of the total. The accident in the fourth place is "gales" with 157 ships and 10.5%. In fifth place comes "collisions" with 149 ships and 9.9%. Finally, the remaining five case reasons come to 233 total losses with 15.6%.

Analysing individually, the first nine flags in this table with 100 or over ships in casualty per flag, Greece and Spain come into the highest rate in their total losses because of "fire aboard". On the contrary, Japan is the country with the lowest rate of losses by fire, with only five cases out of the 127 total losses, the most important accidents on record being "collisions".

3. Conclusions

On analysing total loss accidents for 15 flags with sample sizes of 500 and 1,500 ships of over 500grt, over a period of 25 years, the first leading circumstances of maritime casualties in the merchant fleet for both sample sizes were in the following order: stranding; fire; water-leaks; gales; and collisions. Other five accident causes were entered, but had little impact. In the reckoning of ships in both models, fire was the second most frequent circumstance in the accidents and, together with stranding, represent more than the 50% of maritime casualty returns and, if we include explosions in the column of fire, these latter items (explosion + fire) would add up to 25% of casualties. On considering flags one by one with over 100 ships, Greece and Spain are the flags where the highest number of accidents by fire is to be found, while Japan is the lowest. In this latter flag "collision" is the leading accident eventually ending in a casualty.