A TECHNICAL PUBLICATION OF ASSE'S ENGINEERING PRACTICE SPECIALTY

ByDesign

AMERICAN SOCIETY OF SAFETY ENGINEERS www.asse.org

Ship Fire Safety Design

By Marjorie Murtagh Cooke

Editor's Note: *This article deals specifically with international shipboard fire protection requirements for large passenger ships. Domestic regulations for passenger vessels and international requirements for small passenger ships (i.e., ships carrying no more than 36 passengers) are not addressed.*

Thousands of passenger ships operate worldwide. They are built and operated to comply with applicable fire safety standards and as such, they carry certificates issued by national inspectors verifying compliance. But does a certificate of compliance mean that a passenger ship is firesafe? It should, but it will depend on the knowledge and experience of a critical group of people associated with creating a ship's fire safety environment.

Shipboard fire protection rules were developed to create a safety system that relies on the fire safety knowledge of the designer, builder, owner, operator, crew, national administration and the inspectors responsible for enforcing the requirements. Each must understand the safety system for it to be successful. If any one of them does not properly fulfill his/her role, the ship can experience accidents, sometimes with serious or fatal results.

To evaluate a ship's fire safety, it is necessary to know when and where it was built; what standards were in effect at that time; whether the ship's design, owner, flag or class society has changed during its lifetime; how well-versed the inspectors are in marine fire safety; and how well-trained the crew is in responding to a shipboard fire emergency.

Standards

When and where a ship is built are directly related to which standards apply. If a ship is built in the U.S. and intends to operate between U.S. ports, it must comply with the domestic safety regulations promulgated by the U.S. Coast Guard contained in the Code of Federal Regulations (CFR). If a ship is built to operate internationally, whether here or under the flag of a foreign administration, it must, at a minimum, comply with the safety requirements of the International Convention for Safety of Life at Sea (SOLAS).

The first SOLAS Convention took place in 1912 following the loss of the *Titanic,* when the differing safety standards of the world's maritime administrations came under scrutiny. At the SOLAS Convention of 1914, the world maritime community agreed to specify some minimum safety standards for ships. World War I interfered with its ratification and the requirements were carried over to the Convention of 1929.

Since that time, three more conventions were held in 1948, 1960 and 1974, which are still in effect today. Each convention is a standalone document that remains in effect and applies to ships built on or after specified dates (keel laying date), unless agreement is reached to retroactively apply certain requirements to all ships.

In the case of fire protection, ships that undergo any repairs, alterations or modifications must also comply with specific requirements. Member states (administrations) prepare the conventions, which must be ratified by a majority of the member states representing at least half of worldwide shipping before they come into effect.

For example, SOLAS 74 was finalized in 1974, but it did not come into effect until May 1980. This lengthy ratification method could not keep pace with changing technology advances and SOLAS 74 included a simpler method to approve amendments to the convention.

continued on page 9

2007 ■ Vol. 7, No. 2

Featured Articles

Ship Fire Safety Design

continued from page 1

In the 32 years since SOLAS 74 was created, it has been amended more than 35 times (SOLAS 74, as amended). Each set of amendments also contains application dates (i.e., dates they enter into force.) and may apply to new or existing ships.

Some times, the member states will agree to supplementary recommended resolutions or guidelines that may apply to some or all ships. To determine the requirements that apply to any ship, one must know the date the keel was laid, the date(s) and plans of any modifications as well as copies of each convention, its amendments and any additional documents (e.g., codes, resolutions guidelines) associated with them. Knowing what standards apply is a good start; however, using the conventions and their amendments as a "cookbook" is not appropriate. Shipboard fire protection requires an understanding of the safety system it is intended to provide. Lessons learned from more than a century of shipboard fires correlate an absence of that understanding with a higher potential for disaster.

Standards Development

Modern shipboard fire protection can trace it roots to June 15, 1904, when the U.S. passenger vessel, *General Slocum,* burned out of control on New York City's East River, ultimately causing the death of about 1,000 passengers and two crewmembers. The investigating commission described the wooden vessel as "a mere tinder box of the greatest possible inflammability" with the entire disaster taking less than 20 minutes. They called for a reduction of this fire hazard on all passenger ships of the day by changing materials, fireproof bulkheads, hatches, etc.

By 1922, National Fire Protection Association's (NFPA) marine fire safety section had developed and adopted basic fire safety regulations for the construction and maintenance of ships. Then on the morning of Sept. 8, 1934, the S*S Morro Castle* burned off the coast of New Jersey and nearly 140 people lost their lives. At the time, the ship had some fire barriers, but fire doors had several inches of overhead clearance, including highly combustible finishes that permitted fire to easily spread from one compartment to the next. The bulkheads themselves were combustible, as were all the furnishings, and both readily fueled the fire. The large loss of life prompted public outcry.

Congressional hearings resulted in increased research funding for a better method of shipboard fire construction. NFPA performed a series of tests aboard a test ship and the results produced a method they dubbed "fireproof." The method was based on the development of noncombustible fire boundaries to separate each space and to contain the fire to the space of origin until the ship's crew could extinguish it.

Combustibles were also restricted to limit the fire load and some boundaries were required to be able to prevent the passage of smoke and fire for a fixed period of time. The U.S. would ultimately codify this new construction method and require all new U.S. ships to be constructed this way.

However, the international community had different views. The U.K. preferred heat-activated sprinklers to detect and suppress the fire in the space of origin and France preferred to reduce the spread of fire by immediately alerting the ship's officers to the presence of a fire. Rapid knowledge via fire detectors was their preferred method.

None could convince the other of their method's superior benefits, so in 1948, the SOLAS Convention was ratified with three methods of acceptable fire safety construction. Method I, requiring "incombustible"(non-combustible) construction; Method II, which required the installation of sprinklers; and Method III, which also placed some restrictions on combustibles and required the addition of fire detectors.

The convention creating the International Maritime Organization (IMO) [which was originally called the InterGovernmental Maritime Consultative Organization (IMCO] was adopted in Geneva in 1948 and IMO first met in 1959. A specialized agency of the UN headquartered in London, IMO took over the responsibility of serving as the depository of all international maritime treaties. It is under IMO's auspices that member states convene in sessions which mirror the procedures in place at the UN to discuss maritime issues.

At the first IMO Convention in 1960, member countries updated (certain passenger ship fire protection requirements were applied to cargo ships) the 1948 SOLAS Convention, but the three fire construction methods for passenger ships remained.

In the 1960s, a series of fires aboard international passenger ships highlighted the inadequacies of the previous conventions. Two such fires were particularly referenced. On Dec. 22, 1963, the *TSMS Lakonia* experienced a fatal fire only days after passing its safety inspection. Fire alarms sounded but too softly to be heard by most passengers. The fire spread so rapidly that by the time they realized there was an emergency, it was too late. The fire eventually took the lives of 128 people. The board of inquiry maintained that the *Lakonia* never should have passed safety inspections before sailing.

Just 2 years later on Nov. 13, 1965, the passenger ship *Yarmouth Castle* had a fire with a loss of 90 lives. Although sprinklers were installed in most areas, the ship's largely wooden superstructure and the wooden interiors together with the chimney effect of a main stairway were the main cause of the fire's rapid spread.

As a result, many passenger ship fire safety changes were incorporated into the 1974 SOLAS Convention (requirements for cargo ships, including tankers, were also updated), which came into force in 1980 and is still in force today, as amended. The changes allowed for only two construction methods: SOLAS 74 required all new passenger ships to be built of noncombustible materials and to have either a fixed fire sprinkler system or a fixed fire detection system installed.

A new chapter devoted strictly to fire safety provided the following principles:

•division of the ship into main and vertical zones by thermal and structural boundaries;

•separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries;

•restricted use of combustible materials;

•detection of any fire in the zone of origin;

•containment and extinction of any fire in the space of origin;

•protection of the means of escape or of access for firefighting purposes;

•ready availability of fire-extinguishing appliances;

•minimization of the possibility of ignition of flammable cargo vapor.

These would serve as the basis for all fire safety regulations.

On April 7, 1990, a fire started aboard the Bahamian passenger ship *Scandinavian Star*. The international inquiry determined that within a few minutes of ignition,

continued on page 10

continued from page 9

flames and toxic fumes spread rapidly through the cabin sections on several decks and within 1 hour, 158 were dead.

Fire protection and evacuation were once again at the forefront of discussion at IMO. The inquiry into the *Scandinavian Star* disaster had also highlighted a weakness of the conventions. A large number of the regulations permitted broad interpretation of the requirements. The term "to the satisfaction of the Administration" and similar phrases appeared more than 200 times in the sections addressing fire protection alone. Since what an administration finds "satisfactory" may vary from country to country, "lenient" interpretations could reduce fire safety.

In December 1992, IMO adopted a significant set of fire safety amendments, applicable to both new and existing passenger ships. The retroactive amendments consolidated all of the prior methods and included noncombustible construction as well as the installation of both automatic sprinkler and smoke detection systems.

They also set a date for upgrading fire safety bulkheads to noncombustible materials (regardless of the keel laying date of the ship), improved methods for assisting escape and centralized remote closing of fire doors and the shutdown of ventilation. A major revision of the fire protection regulations was needed to simplify their use and to minimize their ambiguity.

In December 2000, IMO adopted a completely revised SOLAS chapter on fire protection that entered into force on July 1, 2002. The new structure focuses on the "fire scenario process" starting with prevention, detection and suppression through to means of escape. A new International Fire Safety Systems Code dealing with the technical details of the regulations was developed. An entirely new part that deals exclusively with the human element such as training, drills and maintenance was created. A new part that sets out a methodology for approving alternative (or novel) designs and arrangements was also added.

On March 23, 2006, the *Star Princess,* a modern Bahamian cruise ship experienced a fatal fire that destroyed or damaged almost 300 passenger cabins on five decks. One passenger died as a result of smoke inhalation and 13 others were treated for the effects of the smoke. None appear to have been alerted by the audible alarms fitted to the smoke and heat detectors fitted in each stateroom and in the corridors.

The U.K.'s MAIB concluded that there were no regulatory violations, although no restrictions had been placed on the combustibles used to outfit and separate external stateroom balconies. The balconies' polycarbonate partitions, polyurethane deck tiles and plastic furniture were highly combustible and produced large quantities of thick black smoke when burned. Toxic smoke filled staterooms and corridors, thereby hindering escape and rescue of passengers from the affected areas.

In December 2006, new amendments were adopted to strengthen the fire protection arrangements in relation to cabin balconies on passenger vessels. The amendments are aimed at ensuring that existing regulations are also applied to cabin balconies on new passenger ships.

For existing passenger ships, relevant provisions require that furniture on cabin balconies is of restricted fire risk unless fixed water-spraying systems, fixed fire detection and fire alarm systems are fitted and those partitions separating balconies be constructed of noncombustible materials, similar to the provisions for new passenger ships. The amendments are expected to enter into force on July 1, 2008.

Shipboard vs. Land Standards

Land-based fire safety requirements have evolved over time in a similar fashion as those for ships (i.e., fatal fires have provided painful lessons and prompted revisions of standards). The fires with high fatalities are well known (e.g., Triangle Shirtwaist Factory, Coconut Grove Nightclub) and are associated with a lack of safe egress for large numbers of people.

Achieving safe egress from a burning building has been a dominant factor in the development of these standards. Originally called the Building Exits Code, now known as the Life Safety Code, NFPA 101 is the U.S. national land-based fire safety standard for buildings and other structures. It applies to both new and existing structures. State and local jurisdictions may adopt all or part of the code as regulations that are then enforced by the appropriate inspector or jurisdictional official.

The Life Safety Code recognizes the need for differing system approaches to fire protection and escape depending on the type of building occupancy, such as assemblies (restaurants, nightclubs, ballrooms, gymnasiums, cafeterias, conference and meeting rooms); hotels (sleeping rooms); mercantile (shops, including those containing clothing, jewelry, beauty, health and fitness supplies, luggage, books and stationery, electrical and electronic equipment, toys); businesses (offices); educational (classrooms, daycare); healthcare (medical spaces); storage, libraries, warehouses; indoor storage; materials handling equipment and industrial occupancies (power plants and laundries).

The numbers and types of people (children or adults, ambulatory or not, familiar with the surroundings or not, etc.) and activities (e.g., sleeping, working, relaxing) are factors that affect the design considerations for fire safety. Each type

FIGURE 1 Shipboard vs. Land Standards

	High-Rise Building	Passenger Ship
Standards	NFPA 101, as adopted by the local jurisdiction	SOLAS for all ships on international voyages
Applicable to new and/or existing	If adopted, NFPA 101 applies to both new and existing	Based on keel laying date and specific applicability of amendments
Construction material	Concrete and steel	Steel
Time-Rated Fire Barriers	0, 20 min, 30 min, 45 min, 1 hr, 1 and 1/2 hr, 3 hr and 4 hr ratings	0, 30 min and 1 hr ratings
Occupancies	**May contain:** Assembly areas with and without fixed seating; Residential (hotels, dormitories), Business (offices, restaurants), Mercantile (shops, classed by type and concentration of merchandise), Educational (classrooms, daycare), Healthcare (medical facility), Industrial (general, special purpose, high hazard) or Storage (low hazard, ordinary hazard, high hazard) areas.	**Likely contains all:** Assembly areas with and without fixed seating; Residential (hotels, dormitories), Business (offices, restaurants), Mercantile (shops, classed by type and concentration of merchandise), Educational (classrooms, daycare), Healthcare, Industrial (general, special purpose, high hazard) and Storage (low hazard, ordinary hazard, high hazard) areas
Determination of occupancy load in public spaces	Determined by dividing the net area of the space by the area in m² (sq ft) projected for each person (varies by occupancy; ranges from 0.65 to >10m²)	Determined by either the number of seats or by assigning 2m² of gross deck area per person (based upon area for person wearing a life vest.
Means of egress/escape	Generally horizontal via protected corridors to stairwell downward to exit to street	Generally horizontal via protected corridors to stairway upward (or downward) to area of assembly prior to controlled passage to embarkation area and boarding of lifeboats/liferafts
Installed active systems	Automatic fire detection, alarm and sprinkler systems	Automatic fire detection, alarm and sprinkler systems
Firefighting personnel	Local jurisdiction professional fire fighters familiar with building	Ship's professional officers and crew trained in fighting fires and familiar with ship

of occupancy is discussed in detail by chapter in the code and each has unique aspects that affect its fire safety, including the number of people allowed to occupy a space, possible sources of ignition, types and concentration of combustibles, fire detection and alarm needs, fire suppression needs, smoke control requirements and barrier protection. Multiple occupancies within a single building are expected to comply with each of the appropriate requirements and to consider employing the most stringent to all.

The Life Safety Code is also the basis for marine fire protection. Confinement of fires to the space of origin is common to both buildings and ships even though they may use different fire barriers and different ratings. Ships must account for their steel structures that in time will transfer heat beyond the space of origin. With applied insulation, the most highly rated barrier on a ship is expected to prevent the passage of fire and smoke for 1 hour, while shoreside ratings may provide 3 to 4 hours of containment.

On both ships and in buildings, fire rarely spreads because of heat transfer through a fire barrier. In both situations, it is more likely that the integrity of a fire barrier will be jeopardized by a door left open or some other opening, such as a cable or pipe penetration, improperly filled with fire stop material, which permits the flames to spread beyond the space of origin.

High-rise buildings are sometimes compared to passenger ships due to their mixed occupancies and evacuation challenges; however, there are some obvious differences. Figure 1 provides some examples. High-rises may be used for accommodation spaces (hotel rooms, residences, health care and/or daycare facilities), shops (mercantile occupancies), offices, storerooms, restaurants, atriums, convention facilities, ballrooms, lounges, libraries, gaming facilities, movie houses, entertainment centers, laundries and similar facilities.

Ships are unique, not just for their design, but for their operating environment, which makes them self-contained floating cities. In addition to all spaces mentioned for high-rise buildings, ships include what would normally be provided by municipal services (e.g., electrical generation, water production, sewage treatment plants, garbage collection and storage facilities, fuel supply stations and fuel storage facilities) as well as a main power plant for propulsion and auxiliary services, and a command-and-control station to maintain navigation, external and internal communications, centralized alarm systems, etc.

Ships also provide their own fire departments—the ship's officers and crew who are intimately familiar with the ship. Although ships are provided with evacuation systems and outfitted with lifesaving appliances to permit passengers to escape a burning ship, the concept of going "over the side" is one of last resort. The perils of evacuating large numbers of people at sea are many. Although it has been successfully done, it is not the primary choice for any member of the maritime community. The preference is for the ship to serve as its own lifeboat.

There are no fire departments down the street or in the next town to support a four- or five-alarm fire. "Defend in place" and areas of safe refuge take on particular importance at sea. Evacuation, if it is employed as a last resort, is expected to be conducted in stages. Places of assembly (muster stations) are designated for large numbers of passengers to remain in an area of safe refuge while firefighting is conducted and accounting for passengers by name is performed.

Areas of safe refuge are considered to be those outside of a main vertical zone (MVZ). These are created by 1-hour fire barriers that extend from the keel up and, thus, limit the extent of the ship that should be at risk to fire at any one time. Other considerations include orientation of the stairways (oriented fore and aft on a ship to provide maximum stability for those using them), escape on ships is generally up rather than down, which reduces the speed at which large numbers of people will move and space must be allowed for persons wearing life vests to transit corridors and doorways.

Fire safety standards for land-based systems and shipboard fire safety systems are comparable. One standard is not superior; rather they each are part of a safety system that accounts for differences in construction materials, designs, functions and their operating environment. It is the knowledge and understanding of each safety system that is most important.

Standards Enforcement

According to IMO, it is now responsible for nearly 50 international conventions and agreements and numerous protocols and amendments. IMO has no powers to enforce conventions. That responsibility lies with the member governments. Once accepted, each convention requires member governments to take the necessary steps required by the convention.

Flag states are responsible for ensuring that ships under their flag comply with its requirements. This may require a national law to be enacted or revised, or it may require the establishment of new national organizations to provide and train, or otherwise arrange for, inspectors to enforce the standards. SOLAS requires the maritime administration of the flag state to be responsible for inspections and surveys, which may be performed by either officers of the administration or entrusted to recognized institutions, such as classification societies.

Inspectors must be conversant in the regulations and standards to be imposed. They must also be given the right tools to do so. Unless they are given time and opportunity to review the history of the ship prior to boarding, it is unlikely they will be able to evaluate the system while "on the run." In the case of the *Scandinavian Star,* there had been changes to several decks during the life of the ship that were not known to the inspectors until after the fire. Ships' plans, both initial and current, must be readily available and knowledge of fire protection is essential. New guidelines for organizations, which delegated the responsibility of surveying and inspecting ships, were adopted in November 1993 and became mandatory in 1996.

SOLAS requires passenger ships to be surveyed before they are put into service and then at least once every 12 months and otherwise if the occasion arises (e.g., after repairs or accidents). The surveys must include a complete inspection of the ship's structure, machinery and equipment.

Upon satisfactory completion (i.e., the ship complies with all necessary requirements), a Safety Certificate for Passenger Ships is issued as a confirmation of this. Certificates for passenger ships are not to be issued for more than 12 months, but dispensation may be granted in some situations. If a dispensation from any provisions of the regulations has been granted, a separate certificate of dispensation should be issued.

The certificates are evidence that the

continued on page 12

Ship Fire Safety Design

continued from page 11

authorities have found the condition of the ship to be in compliance with the regulations. Certificates must be carried onboard the ship to show that it has been inspected and has met the required standards. These certificates are normally accepted as proof by authorities from other states that the vessel concerned has reached the required standard, but in some cases, further action may be taken.

Under the terms of the conventions, control provisions also allow member governments to inspect ships of other member states if there are clear grounds for believing that the ship and its equipment do not substantially comply with the requirements of the convention. This procedure, port state control, refers to verification of the safety condition of a ship by the administration of any port in which the ship operates.

Port state control inspections are normally limited to checking certificates and documents. But if certificates are not valid or if there are clear grounds for believing that the condition of the ship, its equipment or its crew does not substantially meet the requirements of a relevant instrument, a more detailed inspection may be carried out.

Another regulation makes it possible for port state control officers inspecting foreign ships to check operational requirements "when there are clear grounds for believing that the master or crew are not familiar with essential shipboard procedures relating to the safety of ships." This provides an additional safety net; however, it should not be misconstrued as another complete review of the safety condition of the ship or its crew by another administration.

In the U.S., the control verification of passenger ships operating from U.S. ports falls within the purview of the U.S. Coast Guard. Since almost all large cruise ships operating from U.S. ports are foreign flagships, the Coast Guard has an extensive port state control program in effect. There are limits, not just within the convention, but also those imposed by time and resources that limit the ability of the Coast Guard to inspect every aspect of ship safety. As a result, they are responsible for verification, not for inspection.

Conclusion

Modern ships carry as many as 6,000 people and ships of larger capacity are on the drawing boards. It is likely that new designs and options for passenger ships will continue to be popular and future ships will be designed using performance-based criteria rather than traditional prescriptive regulations. The prescriptive regulations have been viewed as restrictions rather than a safety goal.

Land applications of performance-based standards have prompted their use for marine applications. System modeling has increased in sophistication and can be expected to be applied to ship systems as they develop.

Some designers have already proposed new schemes based upon the latitude offered by the new regulations. This is a natural extension of cruising and new fire protection regulations endeavor to permit more latitude in design as long as an equivalent level of safety is provided. This is not an impossible feat; rather it is an engineering challenge. Equivalent safety can be properly evaluated when the safety of the system is understood. Key to its success will be the inclusion of fire safety experts in the process.

Shipboard fire safety has not been, nor will it ever be, the purview of the amateur. Lessons learned from the history of shipboard fires are an important aspect of fire safety and a certificate is not a guarantee. ■

References

International Maritime Organization. (1974). International Convention for Safety of Life at Sea (as amended) London: Author.

Marine Accident Investigation Branch. (2006). Report on the investigation of the fire onboard *Star Princess* off Jamaica on March 23, 2006 (Report No. 28/2006). Southampton, U.K.: Author.

National Fire Protection Association. *National fire protection handbook.* Quincy, MA: Author.

National Transportation Safety Board. (1996). *Marine accident report: Fire on board the Panamanian passenger ship* Universe Explorer *in the Lynn Canal near Juneau, AK, July 27, 1996* (NTSB/MAR-98/02). Washington, DC: Author.

Norwegian Official Reports. (1991). The *Scandinavian Star* disaster of April 7, 1990: Report of the committee appointed by royal decrees of April, 20 and May 4, 1990. Oslo, Norway: Author.

U.S. Coast Guard. (1966). The Marine Board of Investigation convened to investigate the fire on board the Panamanian *SS Yarmouth Castle* on Nov. 13, 1965, and subsequent sinking with loss of life. Washington, DC: Author.

U.S. Commission of Investigation. (1904, Oct. 4). Report upon the disaster of the steamer *General Slocum.* Washington, DC: Author.

Vassalos, D. (2006, Oct.). Passenger ship safety: Containing the risk. *Marine Technology and SNAME News, 43*(4), 203-212.

Marjorie Murtagh Cooke is a senior maritime expert with Robson Forensic Inc. She is the former director, Office of Marine Safety, for the National Transportation Safety Board and the former chair of the Subcommittee on Fire Protection for the International Maritime Organization.

Practice Specialty Fees to Increase

The Council on Practices and Standards (CoPS) would like to inform you that effective January 2008, the cost to join a practice specialty will increase from $15 to $20 (per practice specialty).

In the nearly 14 years since the last price increase, ASSE and CoPS have worked hard to keep practice specialty membership fees affordable, even during several postage rate hikes and increasing printing and publication costs. The minor $5 increase will be used to address rising printing and postage costs as well as the additional labor and personnel needed to publish each of the 13 different technical publications and to provide our current high-caliber products and services. It will also position the practice specialties for future growth and improvement.

Thanks to practice specialty members' article contributions, we are pleased to see that the technical publications have increased in quality and page length. Most of the technical publications now average between 16 and 24 pages of content, compared to the average length of four to six pages in 1995. And, since it is CoPS mission to give practice specialty members only the best product possible, the small change in price will allow us to continue to offer you the superior resources you depend on and deserve. We appreciate your support and understanding.