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WORK PROGRAMME

Analysis of current safety regulations concerning fire-fighting on board containerships

Submitted by IUMI

SUMMARY

Executive summary:	This document is related to document MSC 102/21/7 and provides further information for the assessment of the need to review the regulations in SOLAS chapter II-2 for the avoidance of damage to containerships and containerized cargoes stowed under deck and on deck of container ships
Strategic direction, if applicable:	6
Output:	Not applicable
Action to be taken:	Paragraph 4
Related documents:	SOLAS chapter II-2, as amended; FP 54/15, FP 54/INF.2 and MSC 102/21/7

Introduction

1 In document MSC 102/21/7 (Bahamas et al.), the co-sponsors propose a new output on the need for amendments to SOLAS chapter II-2 regulations regarding enhanced provisions for early fire detection and effective control of fires in containerized cargoes stowed on deck and under deck of containerships.

2 The growing number of containership fires and the increased exposure of marine insurers to cover losses arising due to such fires, has led IUMI to review the current regulations regarding fire-fighting on board containerships, with a view to potential improvement. The focus is on fires in the cargo area on deck and below deck. Fires in the engine room, service spaces and accommodation are not included in the analysis.

3 A copy of this analysis, commissioned by the IUMI member GDV (German Insurance Association), is set out in the annex for the information of the Committee.

Action requested of the Committee

4 The Committee is invited to note this information when considering the proposal contained in document MSC 102/21/7.

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ANNEX

ANALYSIS OF CURRENT SAFETY REGULATIONS CONCERNING FIREFIGHTING ONBOARD OF CONTAINERSHIPS

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1 Introduction

Time and again serious fire incidents on container vessels are reported; often involving fatalities of crew or followed by a constructive total loss of the vessel. Even though statistics available might not have recorded all incidents, it is evident that the number of serious fire incidents is increasing.

Catastrophic examples of the past are, e.g., **Hanjin Pennsylvania** (4,000 TEU, fire on 11 November 2002, two fatalities, constructive total loss) the **Hyundai Fortune** (5,551 TEU, fire on 21 March 2006), **MSC Flaminia** (6,732 TEU, fire on 14 July 2012, three fatalities and two seriously injured, constructive total loss), and recently the **MAERSK Honam** (15,262 TEU, fire on 6 March 2018, five fatalities) and the **Yantian Express** (7,510 TEU, fire on 3 January 2019).

The International Union of Marine Insurance (IUMI) describes the subject-matter in the position paper "Firefighting systems on-board container vessels" [7] as follows:

> "Every ineffective attempt to put out such a major fire increases the damage to the cargo, the vessel and the environment. Moreover, the crew is in great danger when a fire breaks out on board: crew members face considerable risks when fighting such fires with the equipment currently legally required because, as well as the heat of the fire, they may also be exposed to explosions or detonations. Some, as was most recently the case on the **MSC Flaminia**, are unable to extinguish or contain the fire and ultimately pay with their lives."

The above-mentioned cases of fire on board all occurred on the open sea where it can take several days until external assistance arrives. Hence, the crew has to fight the fire with the available equipment and resources on their own. In the case of the **MSC Flaminia** it had taken weeks until the fire was under control, respectively all combustible material had burned away.

In order to enhance the effectiveness of fire fighting, Germany prepared a Formal Safety Assessment (FSA) related to "the issue of fire safety for on-deck containers" [4] in 2009. This FSA was considered in the International Maritime Organization's (IMO) Sub-Committee on Fire Protection (FP) at its 54th session and finally brought the Maritime Safety Committee (MSC) at its 92th session to issue an amendment to Chapter II-2/10 of the International Convention for the Safety of Life at Sea (SOLAS) in 2014. These amendments of SOLAS Chapter II-2/10 apply to new ships keel-laid on or after 1 January 2016, "requiring the carriage of two or four (depending on the ship's size) mobile water monitors as well as a water mist lance, which may be used to penetrate the wall of a burning container in order to flood it with water, both in connection with an upgraded capacity of the fire main line" [9].

In January 2019, the working group VIII of the "57. Deutscher Verkehrsgerichtstag" (German Council on Jurisdiction in Traffic) in Goslar highlighted the topic "Firefighting on ocean-going vessels – a global challenge". The working group's recommendations [10], *i.a.*, comprise:

.1 Advance the international firefighting standards and request the German Federal Government to campaign for new technical requirements at the IMO;

.2 a holistic approach consists of automatic fire alarm systems for the fast detection of incipient fires on and below deck, and the furnishing of technical capability for the automated use of water as extinguishing agent, and revision of regulations covering the establishment of fire compartments;

.3 the use of technologies to combat fires without the need for crew members to work in the danger zone is supported;

.4 it is essential to constantly adapt the training of crews to reflect technical requirements, including regular practical training on board and ashore; and

.5 the carrier's obligation to declare the cargo correctly should be monitored by the relevant authorities; flag- and port state controls have to pay more attention to fire protection.

Taking the above into consideration, this study will analyse the current regulations regarding firefighting on board of container vessels with a view to potential for improvement. The focus is on fire in the cargo area on deck and below deck. This excludes fire in the engine room, service spaces and accommodation.

1.1 Related documents

FP 54/INF.2	International Maritime Organization (IMO): Sub-Committee on Fire Protection, Review of Fire Protection Requirements for on-deck Cargo Areas, FSA – Container fire on deck, Details of the Formal Safety Assessment, Submitted by Germany, 11 December 2009
MSC.365(93)	International Maritime Organization (IMO): Resolution (adopted on 22 May 2014), Amendments to the International Convention for the Safety of Life at Sea, 1974, as amended; London, 22 May 2014
MSC-MEPC.2/Circ.12/Rev.2	International Maritime Organization (IMO): Revised Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process, London, 09 April 2018
SOLAS 2014	International Maritime Organization (IMO): International Convention for the Safety of Life at Sea, 1974, as amended; Consolidated Edition 2014. London, 2014

FSS-Code 2015 International Maritime Organization (IMO): FSS-Code – International Code for Fire Safety Systems, Edition 2015. London, 2015

2 Firefighting conditions on containerships

The increase in size of containerships over the past two decades is significant. In 2000, the Post-Panamax containerships had a capacity of less than 7,000 TEU. The average ship size had a length of 290 m and a breadth of 40 m [13].

In 2005, **MSC Pamela** was the first containership with a capacity of 9,178 TEU and a breadth of 45 m. 18 rows of containers could be stowed on deck [13].

In the following year 2006 the first 13,000 TEU containership was designed with a capacity of 21 container rows on deck and 19 container rows below deck. The ship's length was about 382 m [13].

In 2013, the Maersk **Triple-E-Class** with 18,100 TEU was the next generation of containerships; nowadays containership designs reach up to 24,000 TEU. These ships have a length of 430 m and a breadth of 62 m [13].

On 1 January 2018 the world container fleet comprised 5,152 ships, thereof 913 ships with a capacity of more than 8,000 TEU. 162 ships of more than 10,000 TEU were in the order books for 2018 [14].

2.1 Characteristics of containerships

The design of containerships is optimised to carry as many containers as possible within the given dimensions. Designs are mainly restricted by draught (port entrance) and breadth (reach of gantry cranes) only. As a consequence, there is only a minimum space between the container bays on deck. This space, apart from incorporating a transverse bulkhead under deck and cross beam on deck as indispensable structural members, contains the lashing bridges for the securing of the cargo and the access hatches to the cargo holds.

Due to this optimised design there is very restricted accessibility with fire hoses between the container bays. Only the lower tiers of the huge towers of deck cargo are within easy reach for the crew.

Below deck the containers are stacked into cell guides designed for the dimensions of a forty foot (FEU) or two twenty foot (TEU) containers. Thus, access to a cargo hold fully stowed with containers is generally extremely limited. The lateral distance between container rows is a couple of centimetres on average. This is the same for the longitudinal distance of containers to bulkheads fore and aft.

Major trading routes for the mega carriers are Inner Asia (e.g. Singapore – China), Asia – Europe, Asia – North America and Europe – North America, restricted to ports which possess the infrastructure necessary to handle such large vessels. A large containership is on average manned with about 20 crew members.

2.2 Fire-fighting equipment according to SOLAS Chapter II-2

The International Convention for the Safety of Life at Sea (SOLAS) governs the minimum safety standards for the construction, technical equipment and operation of ships. In Chapter II-2 regulations for fire protection, fire detection and fire extinction are set out.

It has to be born in mind that these regulations date back from the time of general cargo vessels when ships were substantially smaller in size, not as restricted and specialised in construction, and manned with considerably larger crews than today.

Compared to a smaller general cargo vessel the detection and the localisation of a fire on a containership are delayed due to its size in the first place but also by further impediments.

The container itself is constructed to protect the cargo inside. This containment function is upheld when a fire breaks out. Thus, it is not possible for the crew to reach the source of the fire. Due to the high thermal conductivity of the steel structure of the container the spread of the fire accelerates which may lead to the collapse of the container stack and even the hatch cover.

The international regulations for fire protection systems and firefighting had not kept pace with the rapid development of containerships until 2014 when the SOLAS convention was eventually amended.

Resolution MSC.365(93) stipulates the following amendment to SOLAS regulation 10 (fire-fighting) with a new paragraph 1.2 [2] which is binding for ships constructed on or after 1 January 2016:

> "1.2 For open-top container holds and on deck container stowage areas on ships designed to carry containers on or above the weather deck, constructed on or after 1 January 2016, fire protection arrangements shall be provided for the purpose of containing a fire in the space or area of origin and cooling adjacent areas to prevent fire spread and structural damage."

The further amendments to the SOLAS Convention in 2014 are described in more detail in chapter 2.2.8.

Fire detection and fire alarm system

Regulation 7 (detection and alarm), paragraph 2.2 of SOLAS requires for each vessel a fixed fire detection and fire alarm system [1]:

> "A fixed fire detection and fire alarm system and a sample extraction smoke detection system required in this regulation and other regulations in this part shall be of an approved type and comply with the Fire Safety Systems Code."

Very common in dry cargo vessels are combined fume extraction systems and CO_2 extinguishing systems for the cargo holds. The air in the cargo holds is constantly extracted via the CO_2 piping system and checked for smoke particles by smoke detectors in the CO_2 room. In the CO_2 room as well as on the bridge and in the engine control room a smoke detection panel shows in which cargo hold the smoke has developed. The vessel’s command can release the CO_2 remotely-controlled into the respective cargo hold for extinguishing or at least smothering the fire. The principle of CO_2 is the dilution of oxygen below approx. 14 per cent; it does not have a notable cooling effect on a fire.

Detectors for flames or heat in cargo holds are not frequently installed as they are not commonly not required for dry cargo vessels by SOLAS.

Fire-extinguishing arrangements in cargo spaces

In regulation 10 (firefighting) of SOLAS, paragraph 7.1.3, the guidelines for fixed gas fire-extinguishing systems for general cargo are described as follows [1]:

> "Except for ro-ro and vehicle spaces, cargo spaces on cargo ships of 2,000 gross tonnage and upwards shall be protected by a fixed carbon dioxide or inert gas fire-extinguishing system complying with the provisions of the Fire Safety Systems Code, or by a fire-extinguishing system which gives equivalent protection."

As per Fire Safety Systems Code (FSS-Code), chapter 5, paragraph 2.2.1.1 the available quantity of CO_2 on board shall be sufficient to flood a minimum of 30% of the largest cargo hold to damp down the fire [12]. This rule indicates that the CO_2 quantity on board is limited. Once all CO_2 is released into a cargo hold, the extinguishing agent is depleted.

Water supply systems

The sea water extinguishing system is the most crucial firefighting system on board as the extinguishing agent sea water is available indefinitely.

Regulation 10 (firefighting) of SOLAS, paragraphs 2 – 2.1.1 require for each vessel a water supply system [1]:

> "Ships shall be provided with fire pumps, fire mains, hydrants and hoses complying with the applicable requirements of this regulation."

> "Materials readily rendered ineffective by heat shall not be used for fire mains and hydrants unless adequately protected. The pipes and hydrants shall be so placed that the fire hoses may be easily coupled to them. The arrangement of pipes and hydrants shall be such as to avoid the possibility of freezing. Suitable drainage provisions shall be provided for fire main piping. Isolation valves shall be installed for all open deck fire main branches used for purposes other than fire fighting. In ships where deck cargo may be carried, the positions of the hydrants shall be such that they are always readily accessible, and the pipes shall be arranged as far as practicable to avoid risk of damage by such cargo."

The following paragraph 2.1.2.2 refers to the ready availability of water supply in cargo ships as follows [1]:

> "with a periodically unattended machinery space or when only one person is required on watch, there shall be immediate water delivery from the fire main system at a suitable pressure, either by remote starting of one of the main fire pumps with remote starting from the navigation bridge and fire control station, if any, or permanent pressurization of the fire main system by one of the main fire pumps, except that the Administration may waive this requirement for cargo ships of less than 1,600 gross tonnage if the fire pump starting arrangement in the machinery space is in an easily accessible position."

The number and position of hydrants are defined in paragraph 2.1.5.1 [1]:

> "The number and position of hydrants shall be such that at least two jets of water not emanating from the same hydrant, one of which shall be from a single length of hose, may reach any part of the ship normally accessible to the passengers or crew while the ship is being navigated and any part of any cargo space when empty, any ro-ro space or any vehicle space, in which latter case the two jets shall reach any part of the space, each from a single length of hose. Furthermore, such hydrants shall be positioned near the accesses to the protected spaces."

The minimum pressure to be maintained at all hydrants is 0.27 N/mm^2 for cargo ships of 6,000 gross tonnage or more, and 0.25 N/mm^2 for cargo ships of less than 6,000 gross tonnage. In addition, "the maximum pressure at any hydrant shall not exceed that at which the effective control of a fire hose can be demonstrated." [1, paragraph 2.1.6].

International shore connection

Regulation 10 (firefighting) of SOLAS, paragraph 2.1.7 specifies the international shore connection [1]:

> "2.1.7.1 Ships of 500 gross tonnage and upwards shall be provided with at least one international shore connection complying with the Fire Safety Systems Code.
>
> 2.1.7.2 Facilities shall be available enabling such a connection to be used on either side of the ship."

The international shore connection, mounted on the port and starboard side of the ship in the deck house area, is of paramount importance for external assistance in ports. The fire brigade can connect a fire hose to the standardised shore connection and feed the vessel’s sea water extinguishing system with water for firefighting.

Fire pumps

The standards for fire pumps are defined in regulation 10 (firefighting) of SOLAS, paragraph 2.2 and following [1]. Thus, cargo ships of 1,000 gross tonnage and upwards shall be provided with at least two independently driven fire pumps [1, paragraph 2.2.2] to operate the water supply system.

The capacity of each fire pump is defined in paragraph 2.2.4.2 [1]:

> "Each of the required fire pumps (…) shall have a capacity not less than 80% of the total required capacity divided by the minimum number of required fire pumps, but in any case not less than 25 m3/h, and each such pump shall in any event be capable of delivering at least two required jets of water. These fire pumps shall be capable of supplying the fire main system under the required conditions. Where more pumps than the minimum of required pumps are installed, such additional pumps shall have a capacity of at least 25 m3/h and shall be capable of delivering at least the two jets of water required in paragraph 2.1.5.1."

Fire hoses and nozzles

In regulation 10 (firefighting) of SOLAS, paragraph 2.3.1.1., i.a., the length of fire hoses is defined [1]. Hence, fire hoses on deck shall have at least a length of 10 m but not more than 20 m. On ships with a maximum breadth over 30 m, fire hoses shall have a maximum length of 25 m.

Paragraph 2.3.2.3.1 specifies the regulations for cargo ships as follows [1]:

> "of 1,000 gross tonnage and upwards, the number of fire hoses to be provided shall be one for each 30 m length of the ship and one spare, but in no case less than five in all. This number does not include any hoses required in any engine-room or boiler room. The Administration may increase the number of hoses required so as to ensure that hoses in sufficient number are available and accessible at all times, having regard to the type of ship and the nature of trade in which the ship is employed. Ships carrying dangerous goods in accordance with regulation 19 shall be provided with three hoses and nozzles, in addition to those required above;"

Fire-fighter's outfits

Standards regarding the fire-fighter's outfits are stipulated in regulation 10 (firefighting) of SOLAS, paragraph 10.2. and following. Thus, "ships shall carry at least two fire-fighter's outfits" [1, paragraph 10.2.1]. The Administration, however, "may require additional sets of personal equipment and breathing apparatus, having due regard to the size and type of the ship" [1, paragraph 10.2.4].

Amendments to the SOLAS Convention in 2014

The amendments of SOLAS Chapter II-2/10 which apply to new ships keel-laid on or after 1 January 2016 and require the carriage of mobile water monitors as well as a water mist lance, read as follows [2]:

> "The following new paragraph is added after paragraph 7.2:
>
> "7.3 Firefighting for ships constructed on or after 1 January 2016 designed to carry containers on or above the weather deck
>
> 7.3.1 Ships shall carry, in addition to the equipment and arrangements required by paragraphs 1 and 2, at least one water mist lance.
>
> 7.3.1.1 The water mist lance shall consist of a tube with a piercing nozzle which is capable of penetrating a container wall and producing water mist inside a confined space (container, etc.) when connected to the fire main.
>
> 7.3.2 Ships designed to carry five or more tiers of containers on or above the weather deck shall carry, in addition to the requirements of paragraph 7.3.1, mobile water monitors as follows:
>
> > .1 ships with breadth less than 30 m: at least two mobile water monitors; or
> >
> > .2 ships with breadth of 30 m or more: at least four mobile water monitors.
>
> 7.3.2.1 The mobile water monitors, all necessary hoses, fittings and required fixing hardware shall be kept ready for use in a location outside the cargo space area not likely to be cut off in the event of a fire in the cargo spaces.
>
> 7.3.2.2 A sufficient number of fire hydrants shall be provided such that:
>
> > .1 all provided mobile water monitors can be operated simultaneously for creating effective water barriers forward and aft of each container bay;
> >
> > .2 the two jets of water required by paragraph 2.1.5.1 can be supplied at the pressure required by paragraph 2.1.6; and
> >
> > .3 each of the required mobile water monitors can be supplied by separate hydrants at the pressure necessary to reach the top tier of containers on deck.
>
> 7.3.2.3 The mobile water monitors may be supplied by the fire main, provided the capacity of fire pumps and fire main diameter are adequate to simultaneously operate the mobile water monitors and two jets of water from fire hoses at the required pressure values. If carrying dangerous goods, the capacity of fire pumps and fire main diameter shall also comply with regulation 19.3.1.5, as far as applicable to on-deck cargo areas.

7.3.2.4 The operational performance of each mobile water monitor shall be tested during initial survey on board the ship to the satisfaction of the Administration. The test shall verify that:

.1 the mobile water monitor can be securely fixed to the ship structure ensuring safe and effective operation; and

.2 the mobile water monitor jet reaches the top tier of containers with all required monitors and water jets from fire hoses operated simultaneously."

Reportedly, the mobile water monitor jet has reached the eighth tier of containers during test runs, i.e. a vertical height of about 20.8 m. However, it has not been reported whether the tests were carried out under laboratory conditions without the impact of wind and the sea, and whether also containers stowed in the eighth tier in the centre rows of a bay could be reached sufficiently with the mobile water monitor jets.

2.3 Outlook on SOLAS Chapter II-2

Summarising the above measures of firefighting according to SOLAS Chapter II-2, it is evident that the regulations do not keep up with the significant increase of size of containerships.

However, with the amendments to the SOLAS Convention in 2014, a first step has been made for a positive impact on firefighting on board of new containerships. Though, these amendments (mobile water monitors and a water mist lance) were the minimum consensus reached at the IMO, the improvement of fire safety on board of containerships needs to progress in order to match the increased size of container vessels and to address the urgent need to respond to these developments.

3 Identification of hazards

Hazard is defined as "a potential to threaten human life, health, property or the environment" [3]. The hazard identification (HAZID) ranges over the following issues related to firefighting on container vessels:

Sources of ignition

Every fire begins with an ignition source. These sources can be various, and in context with container shipping the subsequent sources of ignition have been identified:

- **Smoking** of dock workers and **mechanical sparks** from cargo handling as occurring in traditional cargo work are less likely due to the packing of containers under more favourable conditions in a clearly arranged work area with dedicated personnel.
- **Welding and cutting works** for the repair of cell guides in port are a typical ignition source for containerships. The risk of ignition is reduced, however, due to the metal surface of containers, compared to traditional packages in general cargo ships.
- **Spontaneous combustion** due to chemical or biological reactions in containers are more likely than with traditional stowage aboard ships due to the lack of ventilation and hence, low heat dissipation at an early stage of heat development. Moreover, containers subjected to radiation from sunshine tend to heat up considerably with internal temperatures that may accelerate or even trigger spontaneous combustion.

- **Incorrect or missing declaration of hazardous materials** and consequently, wrong stowage and separation within containers may lead to **spontaneous combustion** or **explosion**.
- Proper packing/stuffing of containers continues to be a matter of concern, despite the issuing of the Code of Practice for Packing of Cargo Transport Units (CTU-Code) with the risk of **breaking of packages**, leakage of critical contents and subsequent **exothermal reaction**.

Fire detection

An early detection of the fire increases the feasibility of effective and speedy firefighting. The following points have been identified in this context:

- Early signs of a fire are **smell, visible smoke and heat** which are strongly reduced due to the confinement within the container walls. Traditional smoke detectors in cargo holds fail in the early stage of a fire. Detection by smell is reportedly more effective, provided there is a favourable wind direction to the ship's bridge or accommodation.
- Alarm by **smoke detectors** indicates that a fire under deck has already penetrated the container wall with the fire rapidly spreading to other containers.
- **Detection by heat**, i.e., radiation or visible paint blisters, is impeded if the fire starts remotely in the bulk of containers under deck. Further impediments are the ship’s size, heat dissipation through the steel structure of the containers, and restricted number of persons aboard who could smell, see or feel the signs of fire. Crew members of containerships frequently take the passage way under deck to reach the forward service spaces, particularly in harsh weather. This may delay early fire detection.

Fire localisation

As for fire detection, an instant localisation of the fire is of paramount importance for effective and prompt firefighting.

- The localisation in deck stow is generally concurrent with detection but likely to be impeded due to the ship’s size.
- The purpose of localisation under deck is the direct attack of the fire with sea water, but localisation under deck is difficult or even impossible due to massive smoke and heat. This situation is similar to traditional general cargo transport.
- The indirect localisation of the fire, i.e., in which tier and row, from adjacent cargo holds is extremely difficult due to the inaccessibility of the bulkheads to the hold with the fire.

Fire control and extinguishing

Regarding fire control and extinguishing the following difficulties have been identified for containerships:

The conventional flooding of a cargo hold with CO_2 fails largely because the fire will spread by the high thermal conductivity of the container structure made of steel to other containers, which contain their share of oxygen for supporting the fire in them. This is comparable to the traditional scenario of a fire in a cargo of pressed cotton bales which contain their amount of oxygen within the tube like cotton fibres and hence, the fire cannot effectively be controlled by CO_2 but progresses further.

- Delayed detection and delayed localisation in holds prevent early effective cooling measures of the fire with abundant water which is the only means of controlling and finally extinguishing it.
- Activating the application of abundant sea water is impeded by the ship's size, the height of container stacks on deck, width of bays on deck and under deck, the distance of access ports, restricted number of crew, and limited number and capacity of fire pumps.
- External support is necessary due to the resulting extent of the fire, but often late at the location and impeded by weather and sea conditions and distance.

3.1 Typical scenarios

There are three typical scenarios resulting from the above hazard identification which will be described further:

1. Basic scenario of a burning container vessel at sea,
2. specific scenario of a container vessel burning after collision,
3. specific scenario of a container vessel burning with dangerous goods involved.

3.1.1 Scenario 1: Basic scenario of a burning container vessel at sea

In this basic scenario with a burning container at sea there are multiple threats to human health or life such as burns by the heat of the fire, inhalation of smoke or physical injuries caused by explosion. During firefighting or evacuation of the vessel there is the additional risk of physical injury by falling, squeezing and the like.

The threat to property (cargo inside the containers and the container itself) through fire and heat is obvious. Additionally, there are risks related to the firefighting measures, e.g., by soaking the cargo with sea water.

Moreover, fire poses a severe risk to the ship as such. Damages to the ship in the area of the fire may result in the loss of structural integrity, e.g., when hatch covers collapse or glowing out of longitudinal main girders and side shell with subsequent loss of structural hull strength. Besides, there can be a risk through the firefighting measures when cargo holds are flooded with sea water, resulting in a reduced stability and the risk of capsizing.

Hazards to the environment are contaminated sea water after being used for firefighting and the spill of hazardous cargo. In case of a total loss of the vessel there is also the risk of bunker oil being spilled.

Example for scenario 1: Fire on deck, forecastle area

The following example for scenario 1 is described in [5] and based on a 5,100 TEU container ship, length 294 m, breadth 32.2 m, draft 13.5 m, and the ship manned with 21 crew. As [5] is in German language, an official translation for this scenario was commissioned.

In this and the following example for the basic scenario there were no hazardous substances considered. Moreover, the point of time of the fire was not defined and effects of adverse weather conditions were neglected.

In this scenario a container on the forecastle in bay 10, row 02, tier 03 had caught fire. The fire was detected by the officer of the watch on the bridge due to heavy smoke emissions. After informing the vessel's Master the general alarm was activated and the crew was mustered. At this point of time about 10 minutes had passed since the detection of the fire.

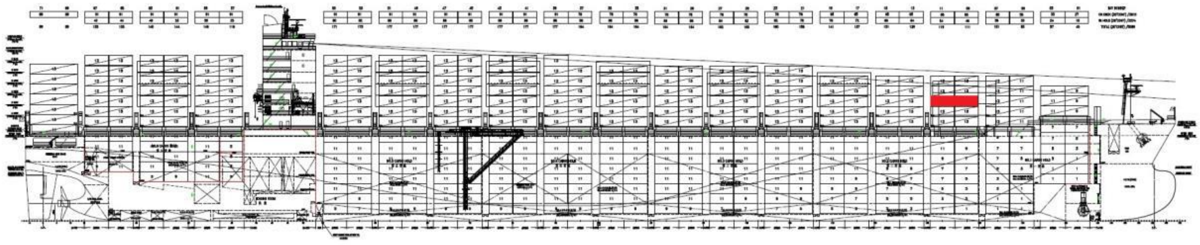

Figure 1: Side view of the example vessel with the burning container on deck [5]

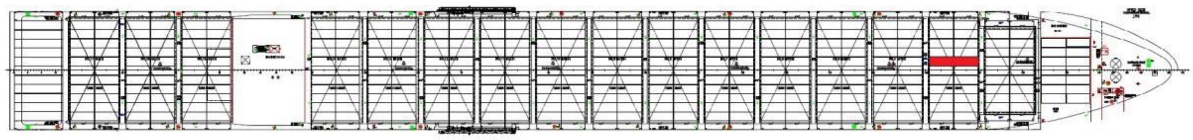

Figure 2: Top view of the example vessel with the burning container on deck [5]

After the completeness of the crew was ascertained, two fire squads were equipped with personal protection and breathing apparatuses. This took another 10 minutes.

The squad leader decided to cool the burning and adjacent containers on the forward and aft side of the bay with sea water. The two squads needed about 1.5 minutes for the 180 m from the accommodation to the operational area at bay 10.

Forward and aft of bay 10 hoses with a length of 25 m were connected to the fire hydrants (marked red in figure 3). A further fire hose was taken from another fire hose box because at the operational area there was no fire hose box installed (marked purple in figure 3). Another 5 minutes had passed until the fire line was charged and the cooling of the containers began; so overall more than 27 minutes had passed since the general alarm had been activated.

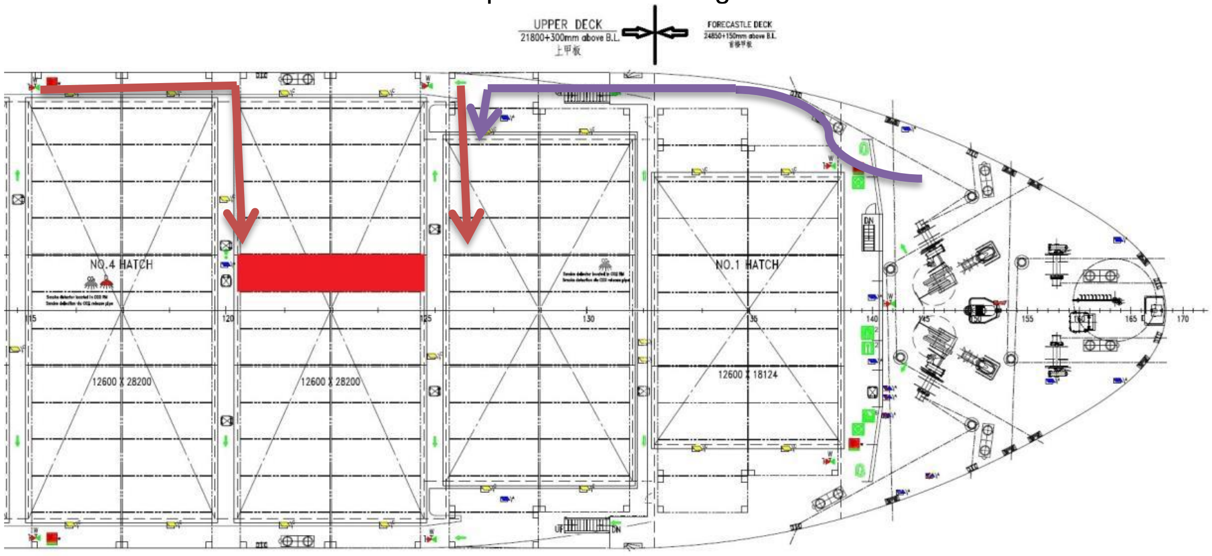

Figure 3: Top view of the upper deck of the example vessel with the burning container on deck [5]
Hoses used for firefighting are marked red, respectively purple

Further possible measures to be taken by the crew in this situation were:

1. Installation of the mobile water monitors, respectively further fire hoses being fixed by wires or ropes, at the forward and aft of the container bay for additional cooling by sea water, and to prevent the possible collapse of the container stack.
2. Fitting of additional fire hoses for cooling of the hatch covers by sea water, and for the adjacent container bays.

For the above measures four crew members with firefighters' outfits and breathing apparatus would be permanently on scene and acting in the zone of dangerous smoke gas. The other crew members of the fire squads were busy providing the necessary firefighting equipment and to relieve the crew with the breathing apparatus for a rest period. This status could, however, not be upheld for a sustained period as the crew needed recovery time. Also, the equipment needed to be maintained after use, *e.g.*, the bottles of the breathing apparatuses had to be re-filled.

In the above scenario the following measures could not be taken by the crew:

1. Firefighting of the burning container, *e.g.*, with the water mist lance, as tier 03 was not accessible. The lashing bridge at bay 10 only reached to tier 02. The use of a ladder was considered being too dangerous for the crew due to the heat of the burning container and the risk of falling during escape.
2. Deployment of additional fire squads since there were neither further breathing apparatuses available nor crew members.

Example for scenario 1: Fire in cargo hold

The following example for scenario 1 is also described in [5] and based on the same sample vessel. For the description of this scenario an official translation of [5] was carried out.

In this scenario a container on the forecastle in bay 26, row 01, tier 06 in cargo hold no. 3 had caught fire. The fire was detected by the combined fume extraction and CO_2 extinguishing system with an alarm on the bridge. In order to exclude a false alarm, the watchman equipped with a handheld VHF radio set was sent for control to cargo hold no. 3. For the distance of about 150 m from the bridge to cargo hold no. 3 the watchman needed 2 minutes. Via VHF he reported to the bridge smoke escaping from the ventilation flaps of cargo hold no. 3. After informing the vessel's Master of the situation the general alarm was activated and the crew was mustered. Mustering and informing the crew took approx. 10 minutes.

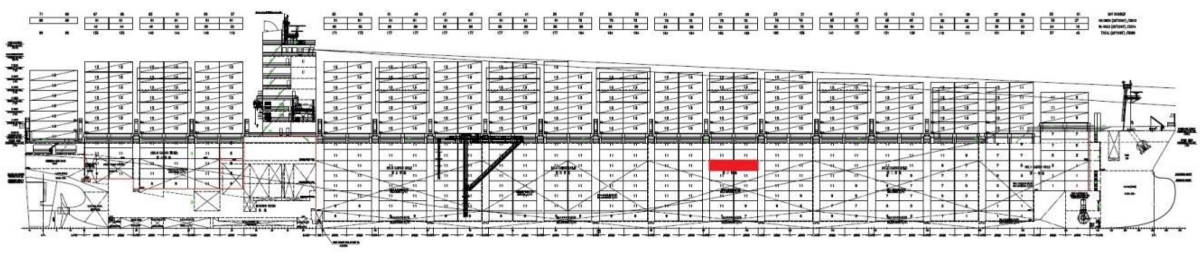

Figure 4: Side view of the sample vessel with the burning container in the cargo hold [5]

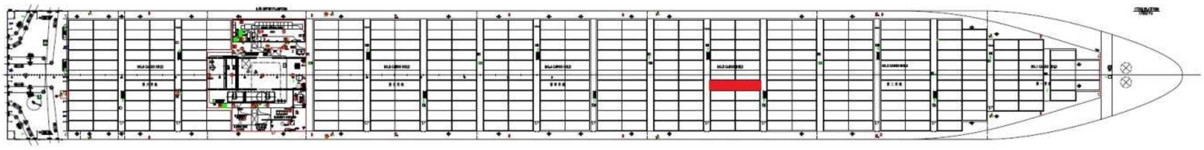

Figure 5: Top view of the sample vessel with the burning container in the cargo hold [5]

The squad leader decided to flood the cargo hold no. 3 with CO_2. On the bridge all cargo hold fans were deactivated; the cargo hold ventilation flaps had to be closed by hand. For this task two fire squads were equipped with personal protection and breathing apparatuses. This took another 10 minutes.

The two fire squads were approaching on the port and starboard side to cargo hold no. 3 for closing all 14 ventilation flaps. They needed another 15 minutes for the closing of all ventilation flaps and the way back to the muster station at the accommodation.

After a second mustering of the crew the cargo hold no. 3 was flooded with CO_2. At this point of time 35 minutes had passed since the detection of the fire.

Further possible measures to be taken by the crew in this situation were:

1. Fitting of fire hoses for cooling of the hatch covers and the vessel's structure by sea water.
2. The ventilation flaps of cargo hold no. 3 could be punctured by cutting tools in order to spray sea water by fire hoses into the cargo hold as a provisional sprinkler system. However, this measure would be time consuming and the crew had to work in the danger zone.

For these measures fire hoses and nozzles from all the upper deck area had to be used since there was not sufficient firefighting equipment in the vicinity of cargo hold no. 3.

In the above scenario the following measures could not be taken by the crew:

1. Entering the cargo hold for firefighting of the burning container directly. Searching for the burning container in the cargo hold filled with smoke is a very risky operation for the crew and has to be avoided. Moreover, the space between the top of the containers stacked in the cargo hold and the underside of the hatch cover is narrow; the crew could only proceed there crawling, especially when high cube containers are loaded.
2. Release further CO_2 into the cargo hold as the extinguishing agent is spent.

3.1.2 Scenario 2: Specific scenario of a container vessel burning after collision

Compared to the basic scenario 1, in this specific scenario of a container vessel burning after a collision, there are further hazards to human health or life such as injuries caused by the impact of the collision.

Additional risks to the ship as such are structural failures caused by the impact of the collision and a potential loss of stability due to flooded compartments. An outage of technical equipment, *e.g.*, the main fire pump, can significantly reduce the possible measures for firefighting. If the vessel is not under command after the collision, there is also the risk of grounding in shallow waters.

An additional hazard to the environment is the possibility that burning containers could fall overboard as a consequence of the collision.

In this scenario the firefighting of the burning containers is impeded due to the additional risks to the ship and a confusing situation after the collision. Due to the consequences of the collision, the crew available for firefighting measures might be reduced, with the fire squads not fully manned.

Example for scenario 2: "EVER LEVEL" – Collision on the Elbe River

The following example for a specific scenario of a container vessel burning after a collision is described in [15].

On 25 November 1983 the containership "EVER LEVEL" collided on the Elbe River with the general cargo ship "ITAPAGÉ". The bow of "ITAPAGÉ" hit the starboard side of "EVER LEVEL", then scratching along the ship's side of the "EVER LEVEL" on a length of about 30 m until the movement of "ITAPAGÉ" was stopped at the accommodation.

Due to the attrition of both vessels high thermal energy was released with the consequence that containers loaded with fireworks immediately caught fire. The fire flashed over to the accommodation, burning containers fell overboard, and "EVER LEVEL" developed a list.

On "EVER LEVEL" there were two fatalities and 19 persons injured; no casualties were reported on "ITAPAGÉ".

Three firefighting boats and ten tug boats were involved in the firefighting. On 1 December 1983 the fire was under control and "EVER LEVEL" could be transferred to the Port of Brunsbüttel where the local fire brigade and the plant fire brigade of Bayer AG finally extinguished the fire.

Figure 6: "EVER LEVEL" burning after the collision with "ITAPAGÉ" [15]

On 3 December 1983 "EVER LEVEL" moved under own power and with tug assistance to Hamburg to discharge the containers. Afterwards she was repaired at Blohm & Voss Shipyard in Hamburg.

Itapagé returned to Hamburg after the collision; the locating and salvage of the containers lost overboard took several weeks.

3.1.3 Scenario 3: Specific scenario with dangerous goods involved

In comparison to the basic scenario 1, in this specific scenario of a burning container vessel the presence and involvement of dangerous goods generates additional hazards to human health or life such as the inhalation of toxic smoke or injuries caused by an explosion or the contact with contaminated sea water.

An explosion also causes an additional risk to the ship as structural members may collapse leading to a loss of the structural integrity.

In this scenario the firefighting of the burning containers can unexpectedly aggravate due to an explosion or a sudden emission of toxic smoke.

Example for scenario 3: "DG HARMONY" – Explosion of calcium hypochlorite

The following example for a specific scenario of a container vessel burning with dangerous goods involved is described in [16]:

> "On 9 November 1998 the "DG HARMONY" was en route from Miami/United States off the coast of Brazil when about 07.20 hrs the vessel shuddered. Within moments, dense smoke covered the ship. The master of the vessel (…) rushed to the bridge. After checking the wind, he turned the ship starboard. The wind cleared the smoke from the deck, and he saw flames coming from cargo hold 3.
>
> The chief officer, who had the watch, had already sounded a general alarm and alerted the crew to assemble. The smoke detection system indicated that there was smoke in hold 3 and the engine room. The crew began fighting the fire, wearing fire suits and using hoses and pumps. The crew continued to fight the fire until late afternoon, when the captain ordered most of the crew to abandon ship. A lifeboat was launched at 6 p.m., carrying away fourteen crew members and leaving only the captain and handful of others behind.
>
> The captain and the others who remained aboard the "DG HARMONY" continued to fight the fire and operate the vessel. They finally abandoned ship at 2 a.m., after yet another explosion, when the captain decided that it was no longer safe to remain on board. The vessel had been on fire for more than eighteen hours, and portions of her deck and side shell plating had turned red and white hot. The captain collected the vessel's log books and charts, and he and the remaining crew members evacuated, transferring via a lifeboat (…) to a container ship that had been standing by.
>
> The "DG HARMONY" continued to burn for three weeks. Most of its cargo was destroyed or damaged. The vessel itself was declared a constructive total loss and eventually scrapped."

Figure 7: "DG HARMONY" burning after the explosion of calcium hypochlorite [Source: Maik Ebel, www.bv1800.tk]

It was found that the fire had started at bay 26, the forward part of hold no. 3, where ten containers of calcium hypochlorite were stowed. One 22-ton hatch cover had been blown off by the force of the explosion.

To fight the fire the crew used all three fire pumps at maximum capacity, all fire hydrants and all available fire hoses, even further fire hoses from the engine room were taken. After about an hour of firefighting, the adjacent heavy fuel oil tank in cargo hold no. 3 breached and the fire spread onto the deck.

Before the second explosion, the captain and the remaining crew members "took all the remaining fire hoses and nozzles and fixed them to railings and other extensions with the pumps running, intending to create a water curtain to protect the super-structure and the engine area." [16]

There were no fatalities or severe injuries reported in this accident.

3.2 Ranking of accident scenarios

The above accident scenarios are assessed below and prioritised by risk level. Risk is defined as follows [3]:

Risk = Probability/Frequency x Consequence

The risk index (RI) is established by adding the probability/frequency and consequence indices [3].

The following table, scaled for a maritime safety issue, gives an overview of the severity index (SI) [3]:

Table 1: Severity Index [3]

Severity Index (SI)				
SI	**Severity**	**Effects on Human Safety**	**Effects on Ship**	**S (Equivalent fatalities)**
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

The following table shows an indication of the frequency index (FI) [3]:

Table 2: Frequency Index [3]

Frequency Index (FI)			
FI	**Frequency**	**Definition**	**F (per ship year)**
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e., likely to occur a few times during the ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1,000 ships, i.e., likely to occur in the total life of several similar ships	10^{-3}
1	Extremely remote	Likely to occur once in a lifetime (20 years) of a world fleet of 5,000 ships.	10^{-5}

The following table shows the risk matrix based on the tables 1 and 2 by adding the probability/frequency and consequence indices [3]:

Table 3: Risk Index [3]

Risk Index (RI)					
		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonable probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

The severity index for cargo-related fires on containerships is defined as follows, based on the extent of the fire:

Table 4: Severity index for cargo-related fires on containerships

Severity Index (SI)		
SI	**Severity**	**Definition**
1	Minor	Minor fire, local ship damage
2	Significant	Medium fire, non-severe ship damage
3	Severe	Major fire, severe damage to the ship
4	Catastrophic	Major fire, total loss of the ship

Data base

In "Analyse von Bränden und Löscheinsätzen auf Vollcontainerschiffen im Zeitraum 2000 – 2015" [5] ("Analysis of fires and firefighting on board container ships from 2000 to 2015") a total of 56 cases of cargo-related fires on containerships were analysed, providing the basis for the risk analysis.

According to the DNV GL "Container Ship Update" [9] in this period 143 fires were reported; thereof 56 cargo-related fires. Thus, both sources came to a similar data base by using different methods.

With the data from [5], the three accident scenarios are prioritised by risk level:

Scenario 1: Basic scenario of a burning container vessel at sea

A total of 44 cases of the data base are attributed to the basic scenario. This scenario is rated with a frequency of FI = 3, remote, and with a severity of SI = 4, as the cases include a total loss, resulting in a risk index of RI = 7.

Scenario 2: Specific scenario of a container vessel burning after a collision

In the data base there is not any case with a collision as root cause for a burning container. This scenario is rated with a frequency of FI = 1, extremely remote, and with a severity of SI = 3, resulting in a risk index of RI = 4.

Scenario 3: Specific scenario of a container vessel burning with dangerous goods involved

The data base shows 12 incidents with dangerous goods involved. This scenario is rated with a frequency of FI = 3, remote, and with a severity of SI = 4, as the incidents include a total loss, resulting in a risk index of RI = 7.

Consequently, scenario 1, the basic scenario of a burning container vessel at sea, and scenario 3, the specific scenario of a container vessel burning with dangerous goods involved, are the accident scenarios with the highest risk indices RI = 7.

4. Risk analysis

The above ranking of incident scenarios shows that the two scenarios with the risk indices RI = 7, the basic scenario of a burning container vessel at sea and the specific scenario of a container vessel burning with dangerous goods involved, are characterised by a high severity index.

The data base [5] revealed that 76 per cent of the cargo-related fires on containerships were major fires, 15 per cent medium fires and only 9 per cent minor fires. Moreover, 85 per cent of the fires could only be extinguished with external help.

According to the data base [5], the average time to extinguish a major fire was 105.8 hours; equivalent to approx. 4.4 days. This figure excludes the major fires of **Hanjin Pennsylvania**, **Hyundai Fortune** and **MSC Flaminia**. When including these three major fire incidents, the average time to extinguish a major fire extends to 241.2 hours; equivalent to approx. 10 days.

The data base [5] further states that on average 35 containers are damaged by a cargo-related fire. With the three major fires of **Hanjin Pennsylvania**, **Hyundai Fortune** and **MSC Flaminia** included, the average damage of a fire amounts to170 containers.

Finally, 20 per cent of the fires analysed in the data base [5] led to fatalities or injuries; with a total of six fatalities and eleven persons injured.

From the above it can be summarised that any cargo-related fire on a containership has a great potential for a major fire with a high severity index. Consequently, measures to reduce the severity of fires to a level that is tolerable have to be identified.

In principle, the severity of cargo-related fires can be reduced by improvement of the two following key points:

1. measures to improve an early detection and localisation of the fire, and

2. measures to prevent the fire from spreading to adjacent sections (fire compartments).

4.1 Measures to improve an early detection and localisation of the fire

In [8] "A contribution to the discussion" by the German Insurance Association GDV several technical measures to improve an early detection and localisation of a fire are described. These technical measures were adopted by the IUMI in the position paper "Firefighting systems on board container vessels" [7]. In both papers infrared cameras on deck and thermal sensors under deck are recommended for an earlier detection and localisation of incipient fires [7]:

> "(…) the detection of a fire on deck is left to chance. SOLAS does not stipulate that fire detectors must be fitted on deck. A fire is only discovered if a perceptible amount of smoke is produced, the fire results in noises that drown out the ordinary noises of the ship, or if flame is discernible at night.
>
> To detect fires as early as possible, infrared cameras, thermal sensors or similar systems that detect any substantive warming of a container shall be considered for use. On deck it would be expedient to use infrared cameras which are mounted on the fire compartment boundary structures and are mechanically protected. There are no structural elements suitable for thermal sensors or similar systems on deck. However, the vessel's structure below deck offers good possibilities for deploying thermal sensors or similar systems."

This approach is to be supported as any practical solution for an earlier detection and localisation of incipient fires is an improvement of the current situation.

4.2 Measures to prevent the fire from spreading to adjacent sections (fire compartments)

The GDV [8] and the IUMI position paper [7] have referred to the topic of fire spreading and offer detailed proposals for a possible solution to subdividing a ship into fire compartments [7]:

> "In contrast to a general cargo vessel, fire spreading to the deck load on a container vessel will have even more catastrophic consequences. With the exception of the superstructures, there are no natural fire compartments on deck. Due to a lack of suitable equipment, it is practically impossible to cool the deck by using water. If the fire spreads, the crew who is trying to cool the deck and the hatches will be in immediate danger."
>
> "Firefighting operations on container vessels are designed to avoid that the fire spreads further. Accordingly, the operations shall ensure that the container/s which have initially caught fire **burn out in a controlled manner** in such and the fire does not spread further.
>
> This approach is still correct and reasonable but however, in view of the rapid pace of development towards ever larger ships, more sophisticated technical solutions are required. It is impracticable to monitor each container separately and provide it with its own fire-detection and firefighting means. Even if it would be technically possible, economic considerations would make such a solution not viable.
>
> To enable the controlled burning of a limited number of containers without losing sight of what is economically feasible, **separating a ship into fire compartments** offers an effective and efficient solution. It would be expedient to utilize the existing division of

the ship below deck (hatches) for establishing fire compartments. A fire compartment can range over one or more hatches. Vertically, the fire compartments are demarcated by the hatch covers and the deck. Below deck, the fire compartments could be demarcated by the bulkheads and the hull. By additionally cooling the ship's structure, the effectiveness of the fire compartment below deck is ensured. With fires below deck, the aim is to maintain the stability of the vessel's hull including the deck and the hatch covers, and to prevent the fire spreading to the deck and to the adjacent neighbouring holds. On deck, the lashing structures to secure the container using rods and turnbuckles in the higher levels (5-7) could be used and extended for vertically separating the fire compartments. By providing additional sprinklers on the lashing structures, the fire is prevented from spreading to other fire compartments; monitors enable the fire to be attacked in a targeted way."

For fire compartments below deck, GDV and IUMI recommend to install a water-based firefighting system in addition to the CO_2-system [7]:

"This system should be suitable for cooling the vessel's structure including the hold walls, the bulkheads, the tank deck, the hatch covers, the deck and the cargo. This additional cooling shall prevent the negative thermal influence of the fire on the structure of the vessel and thus avoid the fire spreading to other fire compartments.

The **water supply** should have ample capacity in order to be able to supply at least three fire compartments simultaneously."

4.3 Measures to protect the technical and command centre of the vessel

For the fire compartments on deck, GDV and IUMI propose water curtains and monitors on the boundary structures as follows [7]:

"a) The **boundary structures** of the fire compartments on deck must be positioned vertically in a way that they align with the water-cooled bulkheads below deck. Otherwise if a fire breaks out below deck and spreads to the deck, there would be a risk of it affecting two fire compartments on deck.

b) The boundary structures are to be constructed in a way that they are able to accommodate a **water-based firefighting system**. This must ensure that deck cargo up to the maximum height and width can be cooled with water curtains, including the fore and aft sides of the fire compartment.

c) The **water supply** for a fire compartment must be designed in a way that their firefighting systems, including the monitors on the boundary structures, are able to cool the structural elements of the fire compartment boundary sufficiently on both sides."

This proposal of subdividing the ship into fire compartments protected by a water-based firefighting system is a promising approach to hamper the spreading of a fire and is technically feasible with little efforts for new builds.

The GDV and IUMI position papers identify the accommodation as a separate fire compartment, *i.a.*, for the protection of the crew. Moreover, a separate water curtain is considered for the lifesaving equipment [7]:

"a) All the ship's superstructures must be protected fore and aft against the effects of flames and heat by effective water curtains. The superstructures form a fire compartment boundary and provide a **refuge for the crew**. They also house the technical equipment for operating both the ship and the firefighting systems. In order to be able to attack or cool fires from a safe distance with large quantities of water, monitors must be installed on the fore and aft sides of the superstructures as on all the other fire compartment boundary structures.

b) **Lifesaving equipment** such as lifeboats and life rafts must also be protected by their own water curtains that can be activated on demand."

This approach by GDV and IUMI for subdividing the ship into fire compartments by the use of abundant sea water has the capability to reduce the risks for the crew, the ship, the cargo and the environment by a cargo-related fire.

5 Conclusions and summary

According to the data base [5], there are, on average, about four cargo-related fire accidents on containerships per year. Most of these fires were major fires which could only be extinguished with external help. Additionally, the fires analysed in the data base [5] led to six fatalities and 11 injured crew members.

Summarizing the results of the data base [5], it can be stated that any cargo-related fire on a containership has a great potential to develop into a major fire with catastrophic consequences.

As measures to reduce the severity of cargo-related fires on containerships, an early detection and localization of the fire, as well as, the prevention of the fire from spreading to adjacent sections have been identified.

With the amendments to the SOLAS Convention in 2014, a first step to mitigate the risks for crew, ship and cargo caused by a fire on a containership has been taken. However, with the increasing number of serious fire incidents and a further growing of size and complexity of modern containerships, there is a compelling need to advance firefighting measures.

The GDV paper "A contribution to the discussion" [8] and the IUMI position paper "Firefighting systems on-board container vessels" [7] have referred to these topics and offer detailed proposals for possible solutions:

- infrared cameras on deck and thermal sensors under deck for an earlier detection and localisation of incipient fires,
- fire compartments divided by water curtains,
- permanently fixed monitors being fed by abundant sea water.

Such measures present an economically and technically feasible solution with little efforts for new builds.

The measures described in the GDV and IUMI position papers "would not only protect live and health of the crew, but also protect the vessel, the cargo and the environment. In the event of a fire, separation into fire compartments plus additional firefighting systems would enable the crew to more effectively attack and suppress fires." [7].

Bearing in mind the above facts, "the debate on how to improve firefighting systems on-board vessels further with regard to fire protection, fire detection and fire extinction" [7] must progress.

6. List of Abbreviations

CO_2	Carbon Dioxide
CTU-Code	Code of Practice for Packing of Cargo Transport Units
DNV GL	Det Norske Veritas Germanischer Lloyd
FEU	Fourty Foot Equivalent Unit
FI	Frequency Index
FP	Sub-Committee on Fire Protection
FSA	Formal Safety Assessment
FSS-Code	Fire Safety Systems Code
GDV	Gesamtverband der Deutschen Versicherungswirtschaft e.V.
HAZID	Hazard Identification
IMO	International Maritime Organization
IUMI	International Union of Marine Insurance e.V.
m	Metre
m^3/h	Cubic metre per hour
MSC	Maritime Safety Committee
N/mm^2	Newton per square millimetre
RI	Risk Index
SI	Severity Index
SOLAS	International Convention for the Safety of Life at Sea
TEU	Twenty Foot Equivalent Unit
VHF	Very high frequency

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