MARITIME STRATEGIC EVALUATION FOR ISRAEL 2021/22

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Hazards of Transport of Dangerous Goods in Ships

Aleksander Gerson

Maritime transport constitutes 80 percent of the total global transport of commodities (approximately 11.5 billion tons annually). Due to their significant advantage in size ("economies of scale") over any other mode of transport (whether air- or land-based), ships can transport goods economically and cheaply all over the world. The State of Israel, the Mediterranean Sea's eastern-most country and a "geo-political island," is uniquely dependent on maritime transport for import and export, comprising up to 99 percent of Israeli international trade. Even though bulk seaborne merchandise (liquid or dry), such as ore, grain, crude oil, and all petrochemical products constitute the largest portion of global trade, this article focuses on transport of Dangerous Goods (DG) in container ships, an area in which the most significant increase in vessel size has occurred (approximately sixteen-fold over the past fifty to sixty years), including the volume of goods transported and DG carried.

There is a clear financial incentive for ship owners and operators to transport increasing quantities of containers carrying DG. Carrying this out safely requires in-depth knowledge of the risks involved for any hazardous substance (manufacturing, packaging, loading, and locating on board), and careful consideration of the interface between DGs and the ship and its crew. Carrying DG aboard ships currently involves very sophisticated computations and planning in order to minimize risks to security, safety, and contamination of the marine environment. The world regulator (International Maritime Organization, IMO) and shipping company owners have not yet adapted their policies and procedures sufficiently to keep up with the impact and consequences of the dramatic changes in container ship size.

This article discusses the global changes and trends in transportation of DG in containers in increasingly large ships (mega-ships), their inherent problems, the Israeli perspective, and whether the State of Israel is prepared for the future in this respect.

Background

Container vessels of the 1960s carrying 1,500 TEU (Twenty-foot Equivalent Unit) containers were considered large ships and would typically each carry several to a few dozen containers of hazardous materials. That size is now dwarfed by current container ships carrying 24,000 containers (Ultra Large Container Ships, ULCS), which is the current norm and constitutes a sixteen-fold increase over the past fifty to sixty years. As the cost of transporting a container with DG is relatively high, increasing the quantity of DG containers offers obvious economic benefits for ship owners. The larger the vessels, the greater the quantities of DG they carry, often several hundred such containers per vessel. The downside of this trend is an increase in risks (security, safety, and contamination of the marine environment).

The need for international regulation of transport of DG at sea was already recognized in the 1929 Safety of Life at Sea (SOLAS) Convention, which recommended

formulating internationally recognized standards. Classification of DG and initial regulations regarding their carriage ensued and were approved by the 1948 SOLAS Committee. The Committee also decided to continue to develop further international conventions, codes, and regulations.

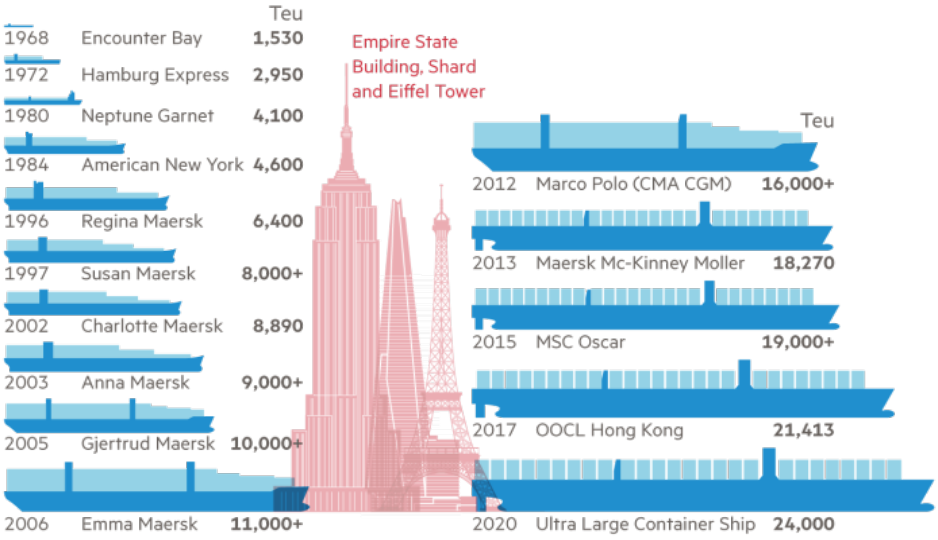

Figure 1: The growth of container ships in the past fifty years[1]

The major achievements in this field are enshrined in the following Conventions:

- SOLAS Chapter VII – Carriage of DG
- SOLAS Chapter II-2 – Construction – fire protection, fire detection, and fire extinction
- International Maritime Dangerous Goods Code (IMDG Code)[2]
- State of Israel legislation – (Ports Regulations 1982), Chapter 16a

Of 250 million containers transporting goods around the world every year, approximately 25 million (10 percent) contain DG of many different types. Hundreds of millions of tons of DG are transported in liquid or dry bulk. These include toxic and corrosive chemicals, substances that release combustible and noxious gases in contact with water or are susceptible to spontaneous combustion, fuels of various kinds, liquified or compressed gases, such as LNG (Liquefied Natural Gas) and LPG (Liquefied Petroleum Gas).

1 "Too big to sail? The debate over huge container ships". *Financial Times*, March 28, 2021.

2 https://imo.org: IMDG Code 40-20.

Preparing DG for transportation, starting at the manufacturer's plant, packaging, loading, transporting them in often unpredictable and rapidly changing and extreme weather conditions—these require highly trained and skilled personnel both ashore and at sea. The IMO has issued multiple regulations and codes to minimize the dangers of transporting DG, alongside regulations issued by other relevant important international bodies such as Lloyds, American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV), Germanische Lloyds (GL), International Association of Independent Tanker Owners (INTERTANCO), The Society of International Gas Tankers (SIGITTO), International Chamber of Shipping (ICS). However, in case of a serious incident occurring at sea involving DG, ships' crews have very limited means at their disposal for tackling such an event.

Case 1 – The burning and foundering of the X-*Press Pearl* with its total cargo of 1,500 containers in May 2021 (fortunately the ship was close to the Sri Lanka shore and the crew was rescued prior to the explosion and spread of the fire) caused not only economic damage but also serious environmental damage in the relatively shallow coastal waters of Sri Lanka, the extent of which has not yet been determined. Although formal results of the inquiry have not yet been published, apparently a leak from a container with nitrous acid caused the huge fire (the mechanism has still not been clarified). The CEO of X-Press Carriers has stated that in view of the total loss and foundering of the vessel itself, the inquiry is likely to take a long time. Due to the extreme temperature, most of the fuels and oils were burned or evaporated, therefore contamination of the sea with fuel and oil was largely limited, a relatively "fortunate" result of the incident. This event raised public awareness (at least locally) to the dangers to life and the environment caused by transport of DG.

Figure 2: The burning and sinking of X-*Press Pearl*, May 2021

Case 2 – In February 2021, Israel suffered an event of contamination of the shore from the release or leak of approximately 1,000 tons of crude oil. However, this damage is incomparable in its significance to the possibility of a marine accident involving a mega container ship (these ships can carry 8,000–6,000 tons of fuel on board) in the vicinity of Israel's shores. Soon, such ships will be arriving regularly at the Haifa and Ashdod ports.

A recent meeting of marine insurance firms that convened in London due to the concerning number of fires on large container ships[3] in the last five years highlighted a possible correlation between the incidence of fires and the substantial number of mis-declarations (aimed at saving shippers' expenses) of containers' contents.[4]

Identification of an oil stain at sea is relatively simple, however contamination with dangerous chemicals, some of which are extremely noxious, may be invisible, difficult to identify, and almost impossible to decontaminate.

Is the State of Israel ready to effectively supervise its marine waters and ports?

Dangerous Goods (DG) are classified into nine categories

1. Explosives (Class 1) 
2. Gases (2.1 Flammable; 2.2 Non-flammable or toxic; 2.3 Toxic) 
3. Flammable Liquids (Class 3) 
4. Solids (4.1 Flammable; 4.2 Liable to spontaneous combustion; Emit flammable gases in contact with water) 
5. Oxidizing Substances (5.1 Oxidizing agent; 5.2 Organic peroxides) 
6. Toxic and Infectious Substances (6.1 Toxic; 6.2 Infectious) 
7. Radioactive (Class 7) 
8. Corrosives (Class 8; Acids and Bases) 
9. Other (Class 9)  and Marine Pollutants 

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3 Insurance Marine News, "Marine Insurance London: Fires on containerships – solutions still elusive", *International Union of Marine Insurance (IUMI)*, December 9, 2020.

4 Mike Wackett, "Zim develops early detection software for cargo misdeclarations", theloadstar, August 17, 2020; Mike Wackett, "The need for change: container shipping is an 'accident waiting to happen'", theloadstar, November 8, 2021.

An additional list of High Consequence DG (HCDG) includes those with potential for misuse in a terrorist event and may result in serious consequences such as mass casualties and mass destruction, particularly for Class 7 (Radioactive), "mass socio-economic disruption" (IMDG Code Vol I -1.3.4.1.2).

Case 3 – Explosion on board the ammunitions ship SS *Mont Blanc* in the port of Halifax, Nova Scotia, Canada, in 1917 destroyed the port and half of the city and caused 2,000 casualties. If a catastrophe of similar proportions was considered unlikely today, the proof of the contrary was provided by an explosion in the port of Beirut in 2020 when 3,000 tons of ammonium nitrate (a fertilizer) exploded, destroying the Beirut port, and caused 218 fatalities and 7,000 injured.

Figure 3: Explosions of DG at Halifax port (1917) and Beirut port (2020)

Table 1:

Types of HCDG		
The following United Nations (UN) numbers are considered HCDG. UN Numbers are a globally recognised way of labelling dangerous goods[5]		
UN Number	Proper shipping names	Class division
3375	Ammonium nitrate emulsion or suspension or gel, intermediate for blasting explosives	5.1
3139	Oxidising liquid, N.O.S.	5.1
1942	Ammonium nitrate with not more than 0.2% total combustible material, including any organic substance calculated as carbon, to the exclusion of another added substance	5.1

The table above lists a few examples of HCDG carried in ships that require special precautions and care during storage, loading, and discharging. Ammonium nitrate poses three main risks:

5 https://imo.org: IMDG Code 40–20. Chapter 1.10.3.1.

- **Decomposition** – Ammonium nitrate melts at 170°C, and above 210°C it decomposes and releases a toxic gas
- **Fire** – Ammonium nitrate, whether solid or liquid, is an oxidizing agent, which can release oxygen to "fuel" burning, even in an oxygen-poor environment
- **Explosion** – In the presence of fire, ammonium nitrate can melt and behave like liquid, which in a confined space may explode, causing a huge shock wave and a cloud of toxic gas capable of spreading thousands of meters around the explosion site. It should never be stored alongside organic substances, fuels, oils, and especially heat sources.[6]

HCDG substances can appear under all classification categories (1–8), depending on their quantity and/or danger category.

Some shipping companies refuse to transport high risk substances such as radioactive materials, substances with wide flammability ranges (very low Flash point, minus 30°C), such as Carbon Disulphide (UN1131), which can auto-ignite at just 100°C.

or substances that have a potential for spontaneous chemical reaction above a certain temperature (SADT – Self Accelerating Decomposition Temperature), such as Class 5.2 organic peroxides.

The above are transported in reefer containers that, in addition to the electrical motor connected to ship's main power supply, are equipped with an autonomous diesel motor. They are also equipped with an audio-visual alarm and a GPS transponder that will send an alarm if the temperature rises above the safety limit.

Most ports also limit transit of explosives and radioactive substances. If permitted, these are transported in limited quantities and need to be managed by specialists. Some ports also limit transport of other kinds of DG, such as especially flammable liquids with a wide flammability range and low SADT Class 4.2 substances, some of

6 https://imo.org: IMDG Code 40-20. Chapter. 1.10.3.1

which may be classified as explosives, for example, nitroglycerin diluted in alcohol (UN 0144).

Case 4 – A ZIM-line ship loaded a container classified as Class 5.1 temperature sensitive in China (Calcium Hypochlorite, UN 1748). This substance is used for sanitizing swimming pools and, on the face of it, is not an especially dangerous substance. The shipper did not report the container's content as required, and it was loaded in a hold adjacent to the engine room bulkhead, which radiates heat from adjacent machinery. After several days at sea, the container exploded and a fire started and spread inside the hold. Fortunately, the ship's crew were alerted, stopped all ventilation to the hold, and released all CO_2 bottles available on board. This stopped the spread of the fire but did not extinguish it. The ship had arrived, in the meantime, at Port Suez (Egypt) and notified the authorities of the incident. In the absence of any remaining CO_2 bottles on board, the ship was not permitted to traverse the Suez Canal, it was detained for a few days until all CO_2 bottles were refilled ashore and returned to the ship and the fire fully extinguished. This case demonstrates the importance of crew alertness and readiness for immediate response, but also the utmost importance of accurate declaration by the shipper regarding the contents of the container. In this case, the ship was saved by the actions of the crew in blocking the spread of the fire.

Following this incident, the ZIM company discontinued their connection with the exporter/shipper of the container. Conclusions following from the event were embedded in the company's regulations for transport of DG (and this type of chemical in particular) and in the safety policy of the company (SMS).

Loading DG Containers on Ships

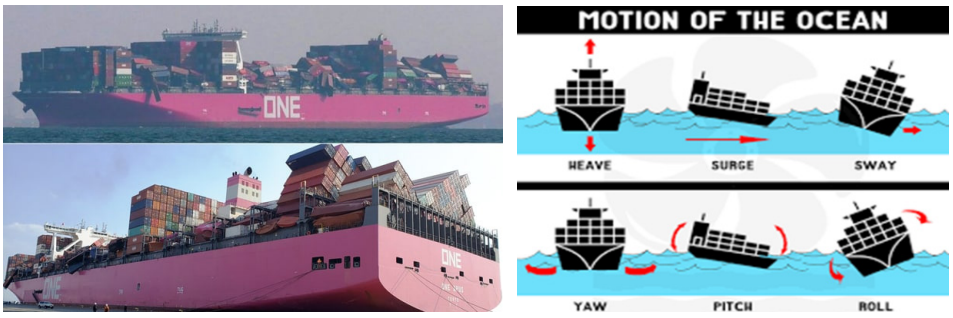

Figure 4: Motion of the ocean (left) and possible results (right)

The international code for transporting DG at sea (IMDG Code) sets out strict and obligatory measures to prevent or minimize risk in case of accident (e.g., collision), structural damage to the vessel, grounding, container collapse due to exceptionally rough sea (parametric rolling), or any other urgent occurrence (especially fire).

IMDG Code requires the following measures (among others):

- Submission of a Shipper's Declaration detailing the industrial/commercial name of the substance, UN Number, packing certificate (signed by a certified packer), classification of the substance and any sub-classification if relevant (main/ primary risk and secondary risk), ship's plan and precise location for loading the container and net weight of the dangerous substance.
- Certificate of cleaning containers or washing empty iso-tanks that previously contained dangerous substances. In the absence of such a certificate, the container is considered to contain a dangerous substance.
- Category of packing, instructions for emergency procedures in case of any structural damage to the container's integrity, including contact numbers of the shipper/manufacturer 24/7 in case of urgent need for further advice. The ship is required to carry a Document of Compliance (DoC) detailing which cargoes the ship is certified to carry in each of its cargo holds.
- Loading plan approved by the Israeli Ministry of Transport, detailing horizontal and (vertical) tier separations. Tier separation requirements are very strict for flammable liquids (Class 3) or corrosive liquids (Class 8), due to the concern of possible leak; in some cases, the most stringent "4" (see below) separation is required, where even separation by a continuous steel deck is insufficient, and a significant additional horizontal distance is required.
  - "away from" – minimum 3 meters distance between containers
  - "separated from" – minimum 6 meters distance between containers
  - "separated by a complete compartment or hold from" (on deck, minimum 24 meters apart)
  - "separated longitudinally by an intervening complete compartment or hold from" (horizontally)
- Liquid cargoes or noxious gases are required to be distanced from accommodation and engine room ventilation systems.
- If the ship is carrying flammable or noxious liquids in the holds, it is obliged to have a dedicated system for pumping hold bilges, which is separate from the ship's engine room where all other pumping arrangements are located (SOLAS II-2/19).

- The ship must be fitted with a central CO_2 fire extinguishing system for releasing the gas into the engine room or any single hold. Certain chemicals require specific fire extinguishing media, for example, Lithium (UN 1415), which needs to be delivered on board prior to loading that specific cargo.
- If the ship is loading Class 1 explosives, loading is carried out under direct supervision of a Ministry of Transport Inspector. Prior to loading, the container is examined for structural integrity, and it should have regular periodic testing of its integrity (ACEP). Once the cargo is secured in the container and a certified electrician carries out an Electrical Continuity–Megger Test, an appropriate certificate is then issued.
- Flammable materials are loaded into a hold only after ensuring disconnection of the electrical supply to the hold by physically removing fuses from the main electrical board.
- If oxidizing substances (5.1) are loaded in bulk, the ship needs to prove its ability to maintain residual stability in the event of flooding of two holds with water (CO_2 is ineffective in extinguishing a fire cause by oxidizing substances); loading is carried out under supervision of a Ministry of Transport Inspector.
- Highly flammable cargoes (IMDG Code 7.2.7.1.3) cannot be loaded onto a ship carrying Class 1 explosives. These flammable cargoes and other substances susceptible to spontaneous temperature-dependent reaction are subject to a minimal separation from crew accommodation and/or heat or source of possible ignition. Reefer containers come under the category of a potential source of ignition.

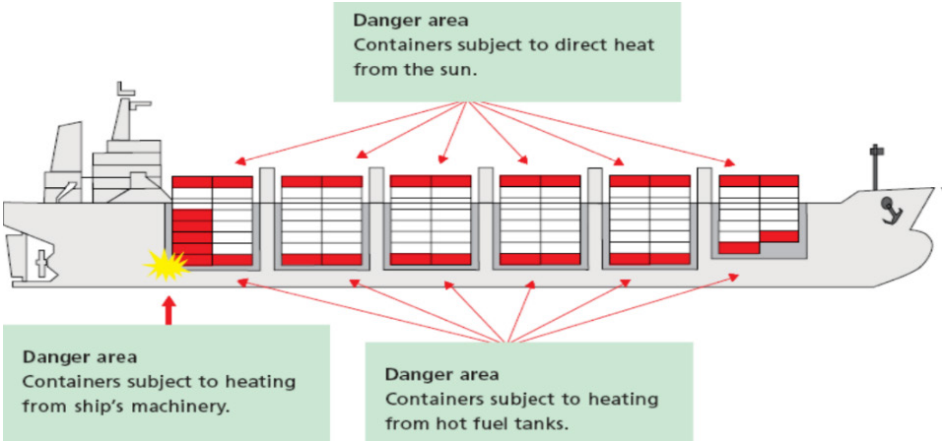

Figure 5: Areas on a ship that could be affected by high temperatures[7]

7 https://www.ukpandi.com

Due to strict separation requirements below deck, loading planners prefer loading containers with DG on the deck (Class 1 containers and flammable substances with susceptibility to spontaneous combustion in particular). Certain substances can only be loaded on the deck and in proximity to the ship's side, where in case of emergency they can be pushed overboard (at least in theory, as container ships have no lifting appliances) or can be isolated more easily in case of explosion or fire.

Loading Above or Below Deck

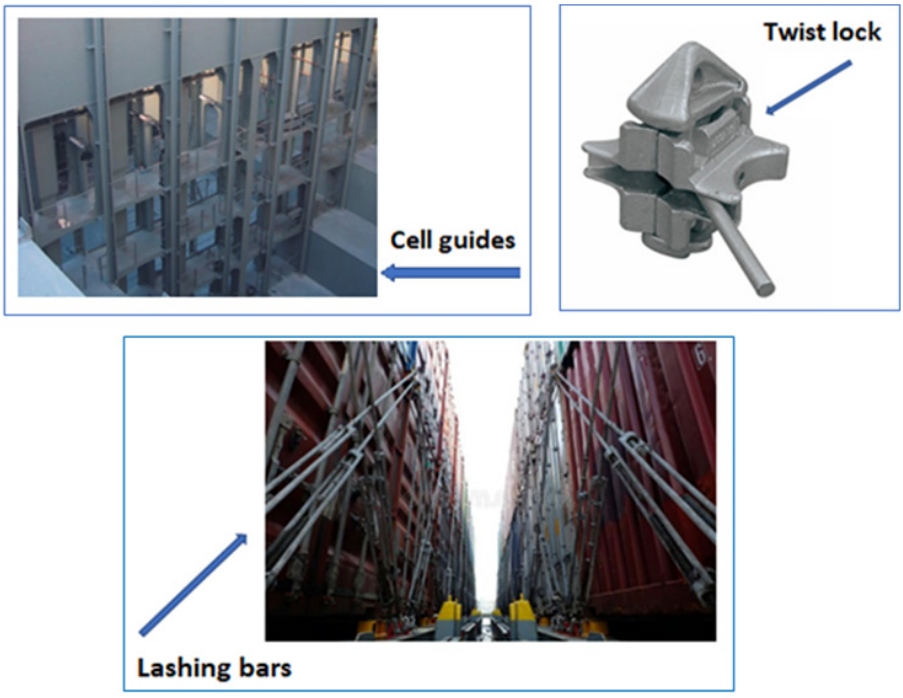

Figure 6: Various tying means to secure containers

There are advantages and disadvantages for loading above or below deck. As already mentioned, segregation rules (Chapter 7.2 of IMDG Code: General segregation provisions)[8] on deck are less stringent and access to containers (at least the lower tiers) is easier. However:

- Lashing bars on deck that connect to the ship's hull can usually reach up only to the fourth tier of containers on deck. Above this height containers are only secured to one another by twist locks at their four corners.

8 The International Maritime Dangerous Goods (IMDG) Code.

- When the sea is very rough, work on deck can be hazardous, especially accessing containers stacked high, in case some fault is suspected.
- In case of strong rolling, container ships are under some circumstances susceptible to parametric rolling and container lashing may fail. If containers containing DG collapse, there is danger of contact between substances that can cause a severe chemical reaction, resulting in potential catastrophe, such as fire or loss of the entire vessel.
- Containers stored inside a ship's hold under deck are stacked within Cell Guides and are therefore more secure in the face of waves and heavy spray in rough weather including all ship's movements at sea. However, transport underdeck may be more costly and segregation more stringent.

When Is Large Too Large and What Can Be Done?

There are many aspects to the problems of transporting dangerous goods containers and particularly in mega-ships. Numerous accidents were caused by collapse of a container stack onto the deck; however, the causes are not always clear. Probable factors may be intrinsic factors of the container, lashing, overloading, sub-optimal spread of weight, incorrect prediction of the ship's movements in rough sea and inadequate lashing calculations.

The current methodology for calculating the forces relies on an assumption of three to five tiers of containers. However, with growth of container ships, these calculations have become overly complex. By the time the ship's software, if at all capable, can calculate all the loading parameters, the ship will have left port and making any adjustment becomes impossible.

Ship operators continue to consult the *Cargo Securing Manual,* which is calculated for ships of Panamax size (maximal ship size that can traverse the Panama Canal), however, this is no longer sufficient for much larger ships with multiple tiers of containers on deck.[9]

Case 5 – While writing this article, news arrived of a fire on board the ZIM *Kingston* with a loss of 109 containers, which fell into the sea opposite the Canadian shore. Apparently, the ship encountered severe weather, which caused collapse of part of the container lashings, some containers contained Xanthates, which ignited.

9 Louise Vogdrup-Schmidt, "Lloyd's Register: 24,000 teu ships on the way". *shippingwatch*, October 16, 2014.

Figure 7: Collapsed containers due to severe rolling

Figure 8: Damage and burn due to collapse of containers, ZIM Kingston, October 2021[10]

Hazards from xanthates include, but are not limited to:

- production of toxic or flammable decomposition products (carbon disulphide* (CS2) and potentially alcohol vapors)
- spontaneous combustion that creates toxic combustion products (sulphur dioxide, carbon monoxide, and carbon dioxide)
- low order explosions from ignition of decomposition products
- acute harm if ingested or significant amounts absorbed through the skin
- acute irritation if inhaled or absorbed on skin surface.

This severe event demonstrates the hazards related to transport of DG at sea and the susceptibility of container ships to violent and sometimes unpredictable rolling. Spraying water directly into the containers was impossible in this case, as the chemical causing the fire releases a flammable gas when it comes into contact with water. Getting the fire under control took seven days. Pollution of the marine environment occurred, as some containers and debris were washed ashore. If it were not for the proximity to the Canadian shore and immediate assistance from the well-equipped Canadian Coast Guard, this accident could have had dire consequences. The Canadian authorities (CTSB) intend to investigate all of the aspects related to the accident, including the captain's decision not to seek shelter despite all warnings of an imminent storm. Danaos, the operators of the Malta-flagged vessel, have so far declined any comment.

[10] Mike Schuler, "ZIM Kingston Cargo Fire Stabilized and Ship Held Overnight, Canadian Coast Guard Says", *gCaptain*, October 25, 2021.

Robust and Smart Containers

Case 6 – The collision between the container ship *Ever Decent* and the passenger ship *Norwegian Dream* in 1999 in the English Channel triggered a change in the SOLAS Convention. The force of the collision caused containers to detach and land on the prow of the passenger ship; fire broke out in containers containing paints on board the *Ever Decent*. The *Ever Decent* was severely damaged by the collision and the fire and had to be towed to the nearest port.

Figure 9: Damage from collision of container ship *Ever Decent* and passenger ship Norwegian Dream in 1999

Following this incident, since 2016 a water-mist lance is obligatory as part of the fire-fighting equipment on ships. This can penetrate the side of the container, a simple but effective means of combatting fire in a container when every second makes a difference. It has been suggested that in the future each container will be equipped with a fire-extinguishing system, which will be connected to the ship's central fire-fighting system, somewhat similar to the inert gas system in place in every modern tanker. The industry also considers using austenitic steel in container construction.

Figure 10: Water-Mist Lance, capable of penetrating the container's side

Despite all the regulatory improvements, false declarations made by dishonest shippers still constitute a significant problem. Another problem is the tendency of ship operators to ignore the need to recover containers that have dropped into the sea and are considered pollutants according to Annex 5 of MARPOL. Obligatory fitting of containers with a transponder will facilitate their identification and location if they fall into the sea, especially those that contain hazardous, noxious, or polluting substances might help to solve this issue.

Hazards of Transport of Dangerous Goods Containers at Sea and Size of Container Ships — "Communicating Vessels"

As mentioned, economic pressures and the wish to minimize the voyage duration even in stormy weather, are triggers for building ships of ever-increasing size with considerable costs. Delays in arriving at a loading or discharging port within the designated timeframe of a ship that costs 100,000 USD per day to operate will inevitably trigger insurance claims by shippers and recipients when the continuity of the logistic chain is disrupted. Commercial pressures from owners or charterers in turn will be delegated to ships' command.

ISM Code-MSC Resolution MSC.275(85), related to safety management code for ships, states that it is up to the ship's operator to "assess all identified risks to its ships, personnel and the environment and establish appropriate safeguards."

IMO states that masters and deck officers serving on Ultra-Large Container Ships (ULCSs) are required to undergo training in parametric and synchronous rolling, which constitutes a danger to the ship and the cargo (IMO MSC Circ. 1228, 2007), as part of the regulations regarding safety of navigation in unusual weather circumstances.

Recent publications and the numerous adverse incidents involving DG in recent years indicate that the world regulator (IMO) and shipping company owners have not yet updated their approach to consider the dramatic changes in container ship size and the updated training requirements. The recent blockage of the Suez Canal by the ULCS *Ever Given* (March 2021) has highlighted this issue. Even though there was no involvement of DG in this incident, it should serve as a wake-up call to the shipping community as to the extent at which a serious incident in ships of this dimension can be complex and trigger wide-reaching consequences, especially in bottleneck areas such as the Suez Canal.

A large-scale incident involving DG with potential loss of lives and environmental pollution should be pre-empted, especially in ecologically vulnerable areas. A

coastal state such as the State of Israel, with heavy marine traffic occurring not far from its shores (to and from the Far East through the Suez Canal), should prepare for the eventuality of an extreme incident with mass casualties and large-scale marine pollution. It is imperative for the State of Israel to introduce a consolidated plan for tackling potential large-scale incidents involving marine pollution and/or loss of life. This should be achieved in collaboration with neighboring countries and as soon as possible.

Acronyms and Abbreviations

Classification Society – A non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures.

Class (IMDG) – Classification of Dangerous Goods in accordance with the Code (1–9)

CTSB – Canadian Transportation Safety Board

Flammable Range – The explosive flammable range of a combustible gas or vapor is the range between the lower exposure limit (LEL) and the upper exposure limit (UEL) for that particular gas or vapor

Flash Point – The fire point is the lowest temperature at which the vapours keep burning after the ignition source is removed

IACS – International Association of Classification Societies e.g. American Bureau of Shipping. Lloyds Register, ClassNK, Det Norske Veritas, Germanische Lloyds, Registro Italiano Navale etc.

IBC Code – The International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk

IGC Code – International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

ICS – International Chamber of Shipping

INTERTANKO – International Association of Independent Tankers Owners

ISM Code – International Management Code for the Safe Operation of Ships and for Pollution Prevention

LC/LD 50 – LD50 (median lethal dose) for acute oral or dermal toxicity, LC50 for acute toxicity on inhalation

MARPOL – The International Convention for Prevention of Marine Pollution from Ships

MSC – Maritime Safety Committee

MEPC – Maritime Environmental Protection Committee

NGOs – Non-Governmental Organizations (see Classification Societies)

SIGTTO – The Society of International Gas Tanker and Terminal Operators

SMS – Safety Management System (ISM Code)

SOLAS – The International Convention for the Safety of Life at Sea

TEU – Twenty foot equivalent

ULCS – Ultra Large Container Ship

UN number – (United Nations number) is a four-digit number that identifies hazardous materials, and articles (such as explosives, flammable liquids, oxidizers, toxic liquids, etc.)