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Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea

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ABSTRACT

The release of packaged or containerized dangerous goods during transport can have serious consequences on board a ship. This study was focused on identifying factors contributing to these types of releases and on investigating the contribution of dangerous goods accidents to overall container ship accident rates. Records of dangerous goods releases from a US and a UK database for an 11-year period covering 1998–2008 were analyzed to identify and categorize main contributing factors. The majority of releases, estimated as 97% of the US events and 94% of the UK events, did not follow another primary accident type such as a collision. Faults that occurred during activities such as preparation of the goods for transport, packaging, stuffing containers, and loading the ship were main factors contributing to the release of the dangerous goods on board the ship. For container ship casualties occurring worldwide during the same period, 1998–2008, accidents involving packaged dangerous goods were estimated to account for 15% of all fatalities. Self-ignition or ignition of incorrectly declared dangerous goods was identified as a contributing factor for the fatal accidents. Ensuring that dangerous goods are correctly prepared and documented for marine transport is thus very important for preventing releases and improving on board safety.

1. Introduction

There have been serious accidents involving the sea transport of containerized dangerous goods in recent years, including a fire that resulted in a fatality and the loss of the *Sea Elegance* container ship in 2003, the explosion and fire on the *Hyundai Fortune* in 2006, and the explosion and fire on the *Zim Haifa* in 2007. Dangerous goods are transported on a regular basis in cargo transport units and include many widely used commodities. Burgess (2006) states that on many shipping routes, dangerous goods are carried in about 10% of containers. Munich Re Group (2002) reports that container vessels can sometimes carry as much as 10–40% hazardous cargo.

Mawson (2003) states that the safe transport of dangerous goods is one of the most serious challenges to container shipping. The ship operator receives containers that are closed and sealed, and thus cannot confirm with certainty that the contents are properly stowed, secured, and prepared for transport. Even the nature of the contents themselves cannot be confirmed with certainty. Non-compliance with the relevant International Maritime Organization (IMO) codes and guidelines for cargo transport units carrying dangerous goods is not infrequent. Results of inspection programs carried out in 2008 showed that on average 34% of inspected units were noted to have deficiencies, for the 11 countries reporting (IMO Sub-Committee on Dangerous Goods, Solid Cargoes, and Containers, 2009).

There can be many participants involved in the packaging and transport of dangerous goods before they are loaded onto a ship, including supplier, road or rail carrier, freight consolidator, and stevedore. The safety of the marine transport operation depends on the reliable and conscientious performance of these participants. Wang and Foinikis (2001), in their formal safety assessment of container ships, observed that shore error accounts for a high percentage of all major loss incidents. Darbra and Casal's (2004) study of major accidents involving hazardous materials at port facilities found impact to be a predominant cause, including ship/land, ship/ship, and land vehicle collisions. This observation was based on data for accidents that occurred during transport, processing and storage of hazardous substances. A study specifically focused on releases of containerized dangerous goods during sea transport was not found in the literature.

The overall goals of this study were to investigate the contribution of dangerous goods releases to overall container ship accident rates and to assess the contributing factors to releases with respect to where along the transport chain they originate. Objectives were as follows:

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– To identify and categorize main contributing factors leading to release of packaged dangerous goods on ships, estimate the distribution of each category, and compare the distribution of contributing factors for different data sets, through an analysis of empirical data on accidents and incidents.
– To estimate the contribution of dangerous goods releases to total fatality rates resulting from container ship accidents.

1.1. Definitions

For this study, definitions of key terms used are as follows:

'Accident' is an unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage (IMO, 2002a).

'Incident' is "an unintended event that can lead to an undesirable outcome such as an accident" (Ventikos and Psaraftis, 2004).

'Dangerous goods' mean the substances, materials and articles covered by the International Maritime Dangerous Goods (IMDG) Code (IMO, 2008).

'Ship casualty' is an event where there has been ship loss or damage.

2. Methods and data sources

Information on dangerous goods releases and accidents involving dangerous goods during marine transport was obtained from national databases and international information sources. The two national databases used were the US Department of Transportation's Pipeline and Hazardous Materials Safety Administration's (PHMSA) Hazardous Materials Incident Reporting System (HMIRS) database and the UK's Marine Accident Investigation Branch (MAIB) accident database. The majority of dangerous goods occurrences in these national databases were lower consequence incidents from a human and ship damage perspective. There were no fatalities resulting from release of packaged dangerous goods on ships reported in either of the national databases, and injuries resulted from a minority of the occurrences. To include a larger set of dangerous goods accidents with serious consequences in the study, information on worldwide accidents and incidents was compiled. There was no comprehensive source for worldwide incidents so a range of sources was consulted. Lower consequence incidents, i.e. those not resulting in fatalities or significant ship damage, or requiring emergency response services, were generally not included in the worldwide list of dangerous goods occurrences, and the information available for each incident was generally not as consistent as that available through the national databases, but it was useful for providing information on the more rare serious accidents.

Sources consulted for information on container ship accidents occurring internationally included Ren's (2009) list of fire/explosion accidents originating in container cargo areas as derived from Lloyd's Maritime Information Unit (LMIU) database, the IMO's Global Integrated Shipping Information System (GISIS) Marine Casualties and Incidents Module (2010), an IMO summary of incidents involving hazardous and noxious substances (IMO Technical Group of the MEPC on OPRC-HNS, 2008), Burgess (2006) and Compton (2006).

More detailed information on the types of dangerous goods occurrences included in the study and descriptions of the HMIRS and MAIB databases are provided in the following sub-sections.

2.1. Inclusion criteria

Dangerous goods accidents and incidents included in the study were those where there had been a release on board a commercial ship during transport of packaged dangerous goods, i.e. goods transported in cargo transport units. Bulk transport release occurrences were not included. Events involving loss of containers overboard without release were also not included.

For the national databases, HMIRS and MAIB, records for an 11-year period covering 1998–2008 were analyzed. Information on worldwide fatal accidents on container ships covered the same period. A group of serious dangerous goods releases occurring on a worldwide basis on container ships for the period 2006–2007 was also included.

2.2. HMIRS database

The HMIRS database includes records of hazardous materials (dangerous goods) releases, "threats to release", and "undeclared shipments of dangerous goods with no release" that occur during transport of dangerous goods in the US. The HMIRS is a public database that was accessed on-line for this study (http://www.phmsa.dot.gov/hazmat/library/data-stats/incidents). The data is self-reported by carriers of dangerous goods who are required by federal regulation to file a report (Battelle Memorial Institute, 2009). All transport modes are included and any unintentional release of a hazardous material during transport is considered a reportable incident. Information reported includes transport mode, transport phase, incident location, information on the hazardous material involved (UN Number, name of the product, class, etc.), information on the release, failure cause, and consequences (including fatalities, injuries, evacuation requirements, etc.). Full details of the information reported are available in (Catapult Technology Ltd., 2005).

All reports in the water transport mode for the period 1998–2008 were reviewed to identify cases where dangerous goods had been released during en-route transport. Incidents that occurred during unloading of the contents of a container at a port facility ("in transit storage") or during loading of a container (for example puncturing a drum when loading it into the container with a fork lift) were excluded. Occurrences on barges or military vessels were also excluded. In total 95 applicable events were identified for this period. Fig. 1 shows the number of applicable reports per year.

The "cause of failure" field was reviewed for each report to assign a category of initial contributing factors based on transport activities, as discussed in Section 3.3. In some cases the cause category was not specific enough with respect to where along the transport chain the fault may have occurred – examples of these categories include "human error", "inadequate procedures" or "inadequate training". When the cause of failure was not specific or the entry was missing, as was the case for 23% of the reports, then the information in the "description of events" and "recommendations/actions taken" free texts fields was used to categorize

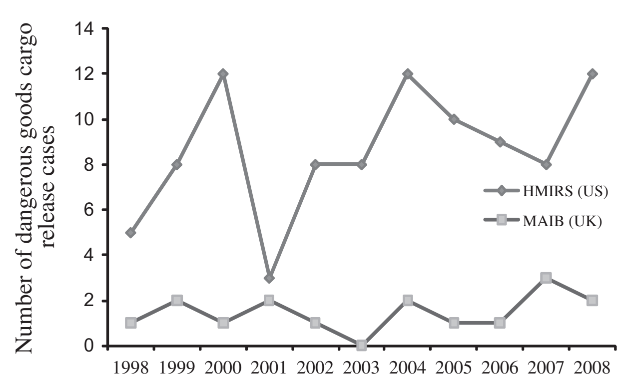

Fig. 1. Number of dangerous goods cargo releases on board vessels reported in the HMIRS and MAIB data sets for the 11-year period 1998–2008.

the reports. For 83 of the 95 identified reports there was sufficient information to designate a contributing factor.

2.3. MAIB database

The Marine Accident Investigation Branch (MAIB) accident database includes all reportable marine accidents that have occurred within UK territorial waters as well as accidents involving UK vessels worldwide. Case information from the MAIB database was provided in response to a request. Information on causes and contributing factors was obtained from designated failure causes and review of narratives for each record. For this database, an accident is considered to be "an undesired event that results in personal injury, damage or loss" (MAIB, 2009a). Occurrences where there has been "an escape of any harmful substance or agent" if the occurrence "might have caused serious injury or damage to the health of any person" is included in the definition of a reportable accident (MAIB, 2009b). The MAIB provided case information from their database for all accidents and incidents where there had been an escape of harmful substance, as well as for other accident types where dangerous goods were noted to be involved.

The data was reviewed to identify relevant cases involving release of packaged dangerous goods during transport. For the period 1998–2008 there were 16 relevant cases identified, as shown in Fig. 1. The narrative field of each record was reviewed to identify contributing factors for each case. For two cases it was not possible to determine an approximate cause or contributing factors.

3. Results

3.1. Dangerous goods releases as a primary and initiating accident type

For 97% of the HMIRS events and 94% of the MAIB events reported for the period 1998–2008, faults that occurred during activities such as preparation of the goods for transport, packaging, stuffing containers, and loading the ship were main factors contributing to the release of the dangerous goods on board the ship. Damage caused by storms and extreme ship motions were identified for the remaining few events. Fig. 2 illustrates the basic categories of faults that were committed prior to ship departure and that were identified as contributing factors.

The basic categories of faults have been shown in a simplified fault tree presentation as contributing to a "top event" of the release of dangerous goods. Consequences following from this event would vary depending on the type, quantity, and circumstances of the dangerous goods release and could be modeled with event tree analysis for specific goods types. Examples of consequences described in the databases include evacuations, injuries, ship delays, cargo damage, and clean-up costs. Releases resulting in fires and explosions have lead to fatalities in a few cases, as discussed in Section 3.3.

The main failure cause identified for each relevant dangerous goods release incident reported in the HMIRS database could be assigned to one of the following general fault categories:

- Container/packaging deficiencies and filling errors: This includes faults such as loose closures or components, defective components or devices, open valves, valves freezing, corrosion, etc. Errors during package filling, including overfilling tanks and receptacles, are also included here. These originate at the point in the transport chain where the dangerous goods are put into the package.
- Poor securing, bracing, and blocking, and preparation of the cargo transport unit: This includes faults such as inadequate blocking and bracing, placing too much weight on lower packages, loose or protruding nails in the container, and loading packages the wrong way up. These faults are introduced at the point in the transport chain where goods are loaded into containers and cargo transport units.
- Loading/unloading at the port: Examples of these faults include drops and making contact with other containers or with ship or port structures during loading and unloading, resulting in damage and release.

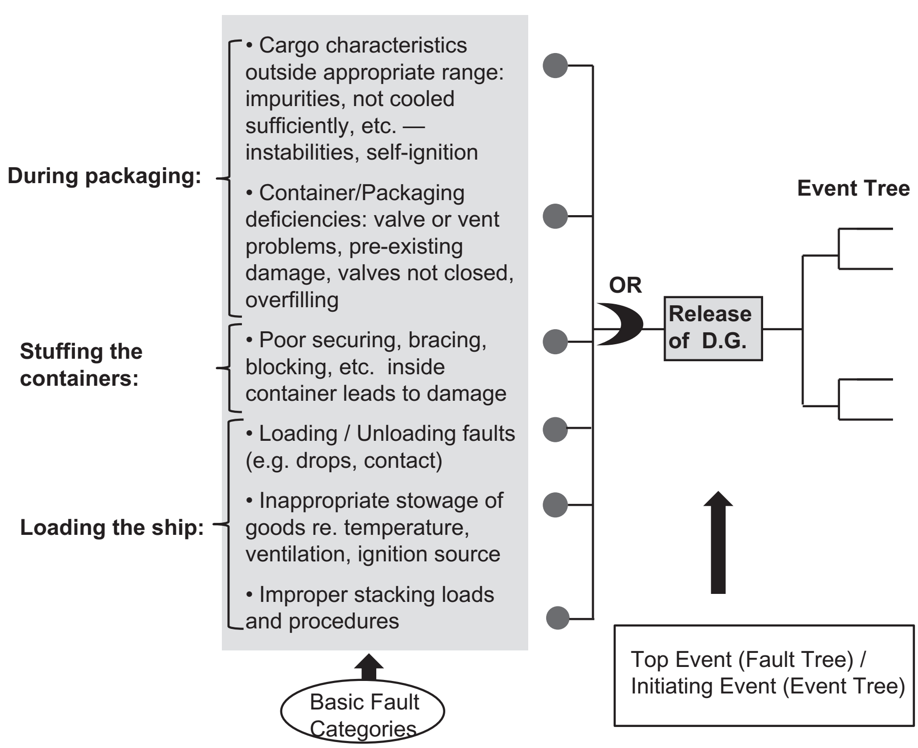

Fig. 2. Basic fault categories for accidents/incidents where release of dangerous goods is the primary event in an accident.

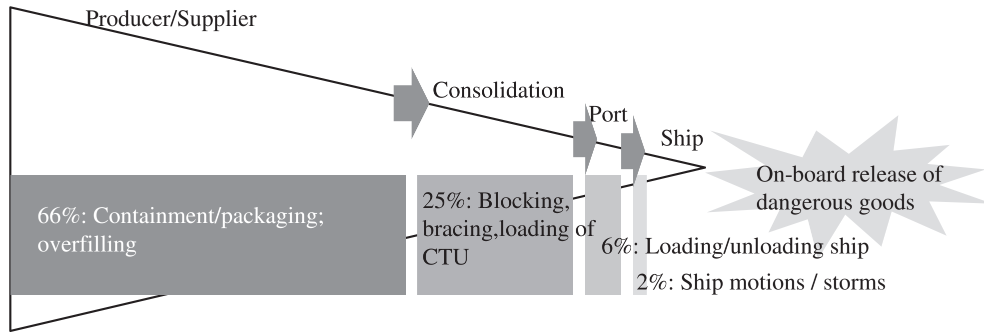

Fig. 3. Distribution of generalized causes contributing to release of dangerous goods in HMIRS water transport mode incidents, $n = 83$, 1998–2008.

There were also a small percentage of incidents where heavy weather and extreme ship motions resulted in releases. Fig. 3 shows the distribution of dangerous goods releases according to basic fault categories.

An estimated 91% of the contributing faults were introduced prior to the dangerous goods being loaded onto the ship. Containment and packaging problems represent the largest category of contributing factors, followed by problems introduced when loading the cargo transport unit. Only 2% of releases were attributed to excessive ship motions and storms.

Faults introduced early in the transport chain also represented the majority of contributing factors to dangerous goods releases identified in the MAIB cases for the period 1998–2008, as shown in the first column of Fig. 4. The two categories containment/packaging and poor securing of cargo inside the cargo transport unit (CTU) were contributing factors in 57% of the cases. Cargo self-ignition was identified in three cases, all of which involved metal filings and waste products. One release resulted from damage sustained during a storm. In addition there were two cases involving dangerous goods during this period that did not involve a release but were serious enough to warrant investigations by MAIB. Both involved exceedance of container stack loads, resulting in damage to containers holding dangerous goods (MAIB, 2002, 2007).

The distribution of main factors contributing to serious dangerous goods releases for a group of worldwide incidents on container ships for the 2-year period 2006–2007 is shown in the bar in the right of Fig. 4. These incidents are listed in Table 1. The list was derived from sources including an IMO summary of incidents involving hazardous and noxious substances (IMO Technical Group of the MEPC on OPRC-HNS, 2008) and a summary of major fire and explosion incidents on container vessels developed as part of a formal safety assessment of container fires on deck (IMO Sub-committee on Fire Protection, 2009). Incidents involving the release of packaged dangerous goods on container ships were identified from these sources and additional reference material (shown in Table 1) was consulted for information on factors potentially contributing to releases. Problems with containment and packaging, including packaging that was not gas-tight, a rusty metal drum, and a slow-leaking tank, were a contributing factor in 50% of the releases. Cargo self-ignition due to warm temperatures was identified for 30% of the releases, and in the case of the *Zim Haifa* this involved calcium hypochlorite that had not been correctly declared by the shipper. Thus it could be considered that for at least 70% of the serious release incidents listed in Table 1 the contributing factors originated prior to the dangerous goods being loaded on board the ship.

3.2. Dangerous goods releases resulting from other ship accident types

Dangerous goods release can also occur after another initial ship accident type if this has resulted in conditions leading to packaging damage. Other ship accident types include collision, contact,

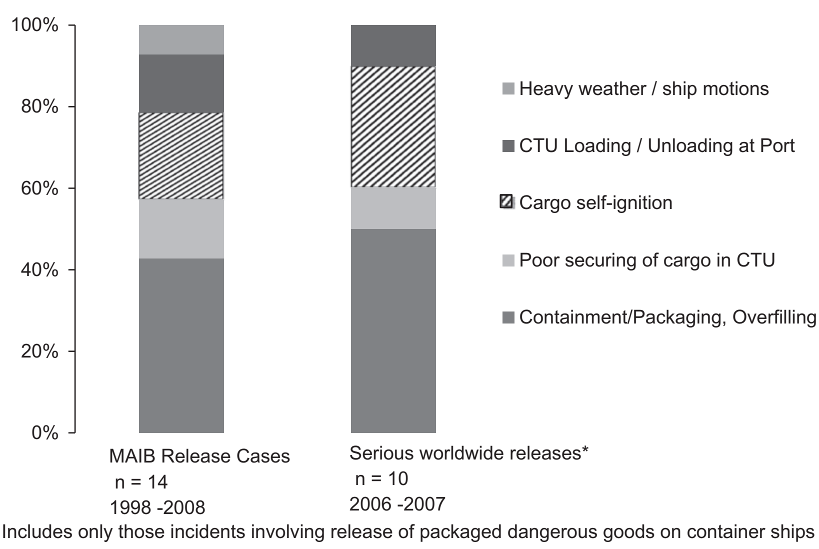

Fig. 4. Distribution of potential factors contributing to dangerous goods releases reported in MAIB for the period 1998–2008 (11-year period) and major releases/fires on container ships involving dangerous goods (from 2006 to 2007 (2-year period)).

Table 1
Worldwide serious incidents involving release of containerised IMDG dangerous goods on board container ships 2006–2007.

Ship name	Year of incident	Incident type	Factors considered to contribute to DG release	Reference
Kota Pahlawan	2006	Vapor release	Packaging of solid xanthates not gas-tight as required by regulations	Australian Transport Safety Bureau (2007)
Horizon Producer	2006	Release of toxic fumes, resulting in 15 injuries	Undeclared Class 9 pesticide, rusty hole in drum	HMIRS (2009)
Hanjin London	2006	Release of harmful vapor resulting in 8 injuries	Reaction of titanium tetrachloride with humidity in tank container	BSU (2007)
Bermuda Islander	2006	Spill of sulfuric acid	Damage to a drum due to slippage from pallet	IMO Technical Group of the MEPC on OPRC-HNS (2008)
Star Fuji	2006	Small release of chloroacetic acid	Slow leak in tank	US Coast Guard (2006)
MOL Renaissance	2006	Fire	Not reported	Burgess (2006)
Hyundai Fortune	2006	Fire/explosion, 1 injury to crew member	Natural ignition of fireworks due to ambient temperatures and improper stowage alleged as contributing factors	GISIS (2010)
APL Chile	2007	Leak of ethylenediamine from damaged drum	Damage to drums in container	Alaska RRT (2007)
CMA-CGM Fidelio	2007	Small explosions in container holding pesticides	Safety officers stated that hot weather probably caused the incident	IMO Technical Group of the MEPC (2008)
Zim Haifa	2007	Fire/explosion	Undeclared calcium hypochlorite, stowage location too warm	Stuart (2007)
OOCL Keelung	2007	Spill resulted in 6 injuries	Faulty twistlock thought to have jarred valve of container of methyl methacrylate during unloading	IMO Technical Group of the MEPC on OPRC-HNS (2008)

grounding, hull damage, extreme ship motions, or fire initiated in other cargo or another ship area, as shown in Fig. 5.

Accidents that produce extreme ship motions and forces, such as collision and contact, may result in damaged containers or packaging, as depicted in the simplified event sequence. Water ingress to a hold as a result of ship damage suffered during an accident or as a result of extreme wave forces may also damage packaging or the water may react with the dangerous goods. Fire in other cargo types or other areas of the ship such as the engine room may spread to dangerous goods cargo.

For the HMIRS and MAIB databases, release of dangerous goods as a secondary event was found for only a few cases. All of these involved heavy weather which resulted in severe ship motions that were a main contributor to the release of dangerous goods. Two releases, representing 2% of all incidents, were noted in the HMIRS database for the period 1998–2008 to have resulted from the initiating event of extreme ship motions. For the MAIB, there was one event related to extreme ship motions during the same period.

A search of IMO sources and other literature identified a few cases of dangerous goods releases following other primary accident types, and provided concrete examples to develop the simplified event sequence shown in Fig. 5. The collision between the container ship *Ever Decent* and the passenger ship *Norwegian Dream* in 1999 is an example where the impact led to fire which involved dangerous goods (IMO Legal Committee, 2002). The break up and sinking of the MSC Carla in 1997 due to hull damage raised issues due to the loss of containers holding radioactive material (Lyman, 1999). Overall there were many more examples found

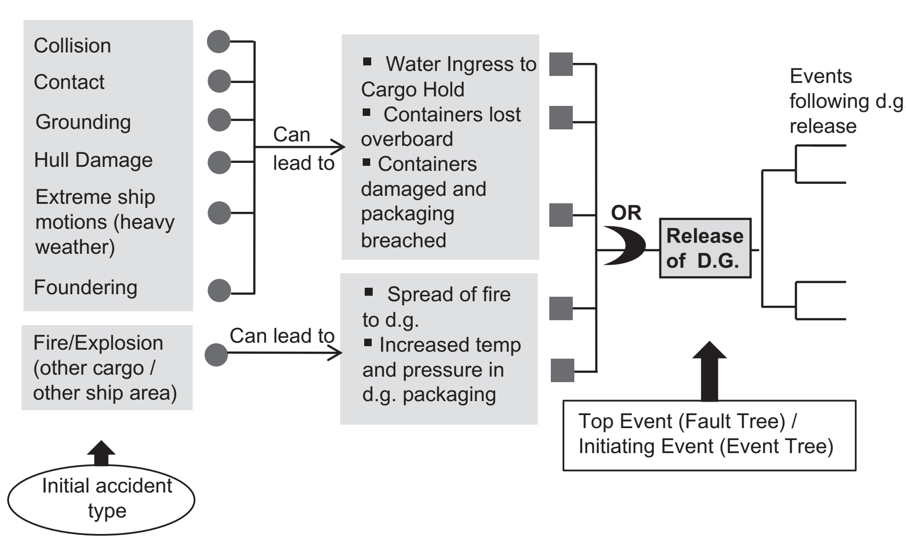

Fig. 5. Simplified event sequence where dangerous goods release follows another primary accident type.

Table 2
Fatal dangerous goods fire/explosion casualties on container ships, 1998–2008.

Vessel name	Accident year	Number of dead or missing
Sea-Land Mariner	1998	2
Hanjin Pennsylvania	2002	2
Sea Elegance	2003	1
Total		5

where dangerous goods release had initiated the accident, as described in Section 3.1.

3.3. Contribution of dangerous goods to fatal accidents on container vessels

Three fatal accidents on container ships were identified where dangerous goods were considered to be a contributing factor, for the period 1998–2008. These were part of a group of 11 container ship accident events resulting in fatalities (dead or missing) that were identified for the period from IMO databases and lists of serious and very serious casualties (IMO, 1999, 2001, 2002b, 2004, 2005; GISIS, 2010). The fatalities occurred as a result of ship casualties categorized as collision, grounding, fire/explosion, hull failure, and machinery damage. Fatalities resulting from occupational accidents (e.g. slips, falls, etc.) were not included as part of this study.

The three fatal accidents where dangerous goods were involved represent 27% of the 11 ship casualties with fatalities identified for all container ship casualty categories. All of the accidents where dangerous goods were a factor were categorized as fire and explosion casualties and are listed in Table 2.

Table 2 shows that in total five fatalities resulted from dangerous goods fire/explosion accidents on container ships identified for the period 1998–2008. Using a container ship fleet at risk estimate of 35,750 (calculated from world fleet statistics (Lloyd's Register-Fairplay, 2004, 2009)) for the period 1998–2008 as a denominator, frequency of fatalities resulting from accidents involving dangerous goods is estimated to be:

$$\text{Frequency (dangerous goods accident fatalities)} = 1.4 \times 10^{-4} \text{ per ship year}$$

Fatality frequency per ship year for all casualty categories for the period 1998–2008, where there were 34 dead and missing during 11 accidents, was estimated to be:

$$\text{Frequency (all container ship casualty fatalities)} = 9.5 \times 10^{-4} \text{ per ship year}$$

Thus 15% of fatalities from container ship casualties during this period were a result of accidents involving dangerous goods.

Activities connected with documentation and preparation of the packaged dangerous goods for transport were identified as contributing factors for each of the three accidents shown in Table 2. The fire and explosion on the *Sea-Land Mariner* resulted from the ignition of flammable vapors from expandable polymeric beads which had not been properly declared or placarded (Maritime Administrator, Republic of the Marshall Islands, 1999). The explosion and fire on the *Sea Elegance* container ship in 2003 was caused by undeclared calcium hypochlorite which had been stowed adjacent to a fuel oil tank and engine bulkhead (South African Maritime Safety Authority, 2004). For the *Hanjin Pennsylvania*, Cohen (2006), citing an Organisation for Economic Cooperation and Development report (2004), states that "the cause was found to be improperly packed, improperly loaded, and improperly documented fireworks and calcium hypochlorite (a bleaching agent used in swimming pools) in containers." Kelman (2008) also stated that although resolving the exact cause is difficult, it is believed that a cargo of undeclared calcium hypochlorite was the cause of the *Hanjin Pennsylvania* explosion and fire. Thus activities connected with documentation and preparation of goods for transport by the shipper were identified in all three cases.

4. Discussion

For the four sets of shipboard dangerous goods occurrences analyzed, all showed a similar tendency where the majority had main contributing factors that originated prior to the goods being loaded onto the ship. Problems with packaging and containment and with loading of goods into cargo transport units were the most common types of factors contributing to the releases in the HMIRS dataset, which contained a higher percentage of less serious events (only 4% resulted in injuries). These factors were also cited for the MAIB cases and the group of worldwide serious dangerous goods releases on container ships, but self-ignition of cargo was also a contributing factor in a number of cases. These two data sources had a higher percentage of reported incidents with injuries – 19% for the MAIB cases and 36% for the worldwide group. For the four fatal accidents identified from worldwide ship casualty information, ignition of cargo following mis-declaration of the dangerous goods and resulting inappropriate stowage was identified as the major factor. Thus ignition of cargo was seen to occur more frequently in the serious accidents. The importance of activities in the supply and transport chain prior to the ship transport segment is apparent for all types of occurrences, both minor and serious. Focus on correct declaration, condition of packaging (closures, valves, filling levels), and blocking and bracing in cargo transport units should reduce the number and severity of dangerous goods releases during sea transport.

5. Limitations

Differences in the level of severity of occurrences and the reporting thresholds for each dataset may have contributed to some of the differences in distributions of contributing factors, and uncertainties and limitations in the data sets should also be noted. Information on serious releases of packaged dangerous goods is not available in a consistent form for all worldwide incidents as there is no international database that specifically collects information on these types of events. The world ship casualty databases lack information on causes in many cases and supplementary data must be used. There is therefore uncertainty about whether all relevant incidents have been included and contributing factors identified. Serious dangerous goods accidents do not have a high frequency, however, so it was considered worthwhile to include these in the study even with the uncertainties. The national HMIRS database had the largest group of occurrences but only a few where injuries had been reported and none with fatalities. Inclusion of occurrences from both national and international sources ensured that a larger group of occurrences with a broader range of severities was part of the analysis.

6. Conclusions

Accidents involving packaged dangerous goods were estimated to account for 15% of all fatalities resulting from container ship casualties during the period 1998–2008. During this period there were three fatal accidents involving dangerous goods, representing 27% of the 11 container ship casualty accidents which reported fatalities. These accidents were categorized as fire and explosion.

Self-ignition or ignition of incorrectly declared dangerous goods was identified as a contributing factor for each.

An analysis of dangerous goods release incidents in the water transport mode reported in the HMIRS database for the 11-year period 1998 to 2008 estimated that 66% of failure causes could be categorized as deficiencies with packaging and containment, such as loose closures, corrosion, malfunctioning valves, overfilling, etc. A further 25% were caused by failures occurring during loading of cargo transport units, including inadequate blocking or bracing. These two types of failures were introduced prior to loading the goods on a ship and together were associated with 91% of all releases. For dangerous goods releases reported in the MAIB database for 1998–2008, they were contributing factors in 57% of the cases. These findings point to the importance for marine safety of ensuring that dangerous goods are correctly prepared and documented for transport, and the influence of these activities on shipboard dangerous goods releases.

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