INTERNATIONAL MARITIME ORGANIZATION

IMO

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MARITIME SAFETY COMMITTEE
87th session
Agenda item 18

MSC 87/INF.2
24 September 2009
ENGLISH ONLY

FORMAL SAFETY ASSESSMENT

FSA – dangerous goods transport with open-top containerships

Submitted by Denmark

SUMMARY

Executive summary:	This document is related to document MSC 87/18/1 entitled "FSA – dangerous goods transport with open-top containerships" and contains further details of FSA study
Strategic direction:	12.1
High-level action:	12.1.1
Planned output:	12.1.1.1
Action to be taken:	Paragraph 2
Related document:	MSC 87/18/1

Introduction

1 As referred to in document MSC 87/18/1 submitted by Denmark, a high-level FSA application on dangerous goods transport with open-top containerships has been performed. The report providing further details on this study is contained in the annex to this document.

Action requested of the Committee

2 The Committee is invited to note the information provided in this document, in relation to its consideration of document MSC 87/18/1.

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ANNEX

FORMAL SAFETY ASSESSMENT OF DANGEROUS GOODS TRANSPORT WITH OPEN-TOP CONTAINERSHIPS

Contents

1 Introduction

This annex presents a high-level Formal Safety Assessment (FSA) of the transport of dangerous goods (DG) with open-top containerships.

Dangerous goods comprise 5 % to 10 % of all transported cargo, depending on the route. The transport of packaged dangerous goods and the outfitting of vessels are governed by International Maritime Dangerous Goods (IMDG) Code [17] and SOLAS II-2/19 [16]. Whereas the IMDG Code is updated regularly to reflect current dangerous goods, SOLAS II-2/19 has remained unchanged for about 22 years. The IMDG Code still requires stowing of several dangerous goods on deck. Especially in case of open-top (hatch-less) containerships, current regulations greatly reduce the flexibility of cargo transport. For these types of ships no cargo that requires on-deck-stowage can be transported in hatch-less cargo holds. For that reason all open-top vessels are also equipped with closed holds, mostly in the front and in the back.
Due to commercial interest in the transport of dangerous goods it was considered worthwhile to investigate whether the intention of the regulations could be met by refined designs or operations of open-top containerships. For this purpose, in this work it is investigated whether the transport of dangerous goods that are currently classified "on-deck stowage only" in the IMDG Code could be accomplished in the open holds of open-top containerships (i.e. a potential future operation) with at least the same level of safety as the currently accepted solution. The current accepted solution is the transport of such goods on the open deck. This work takes a risk-based approach following the FSA guidelines to answering this question and to provide justification for possible modernization of regulations pertaining to carriage of dangerous goods on open-top containerships.

The formal safety assessment was carried out according to the "Guidelines for formal safety assessment (FSA) for use in IMO rule making process" [18]. These guidelines were revised and updated at the Maritime Safety Committee's (MSC) 83rd session [19]. The purpose of this guideline is to introduce a process which provides objective indicators for the rule making process.

Since the time the FSA methodology was introduced by IMO, a number of FSA studies have been executed. At present, five FSAs that were performed within the SAFEDOR project were submitted to IMO. These FSAs systematically investigate the risk for generic ship types LNG carriers [24] containerships [23] crude oil tankers [25], cruise ships [26], and RoPax ships [27].
In these studies the cost-effectiveness measures "gross cost of averting a fatality" (GCAF) and "net costs of averting a fatality" (NCAF) were applied for decision making. In this present work these criteria are considered only of secondary importance. Instead, the risk acceptance criterion that was applied in this FSA is whether by introduction of suitable risk control options a level of safety can be reached that is at least as good as the currently accepted solution, i.e. transport of dangerous goods classed "on-deck stowage only" on the open deck. The acceptance criterion was assessed in two respects, which in the following will be called "variant 1" and "variant 2":

- variant 1: A risk control option is suitable to achieve a level of safety of the proposed solution that can be considered equivalent to the level of safety of the accepted solution, for all dangerous goods classes that are in focus of this work.
- variant 2: A risk control option is suitable to achieve a level of safety of the proposed solution that can be considered equivalent to the level of safety of the accepted solution, for a selection of the dangerous goods classes that are in focus of this work.

If in the course of this FSA risk control options were identified that satisfies the acceptance criterion for all (in case of variant 1) or a selection of (in case of variant 2) "on-deck stowage only" dangerous goods classes in focus of this work, a decision may be considered to permit the stowage of goods of these classes in open holds.

The FSA process (see Figure 1) consists of five steps which constitute a risk assessment[1] process, followed by a reporting task.

Step 1 (Hazard Identification, HazID, see section 4 of this Annex) of this analysis relates to the identification and prioritization of the most important scenarios of dangerous goods transport. A review of the current regulations and classifications for the transport of Dangerous Goods (DG), such as SOLAS and the IMDG Code, was conducted. Hazards imposed by substances classified in the IMDG Code serve as a basis for the analysis. DG incident statistics, container trade statistics and incident reports have been studied in order to restrict the analysis to a suitable focus.

The purpose of Step 2 (Risk Analysis, see section 5) is a detailed investigation into the causes and consequences of the scenarios that were identified in Step 1. The risk level associated with dangerous goods transport is assessed, and one of the main objectives of the risk analysis is to identify high risk areas where further attention can be focused, e.g. by proposing new risk control options (RCOs).
Various methods have been employed in order to investigate the causes and consequences of the scenarios selected for further study. Risk models are established for carriage of dangerous goods requiring on-deck stowage in the open-top holds of open-top containerships. The overall risk model is for a novel use of an existing ship type. Additionally, risk models were also developed for the carriage of dangerous goods on deck on conventional containerships, as described in the IMDG. Thus, it is possible to compare the safety levels between the current situation and the carriage of goods within open-top holds.

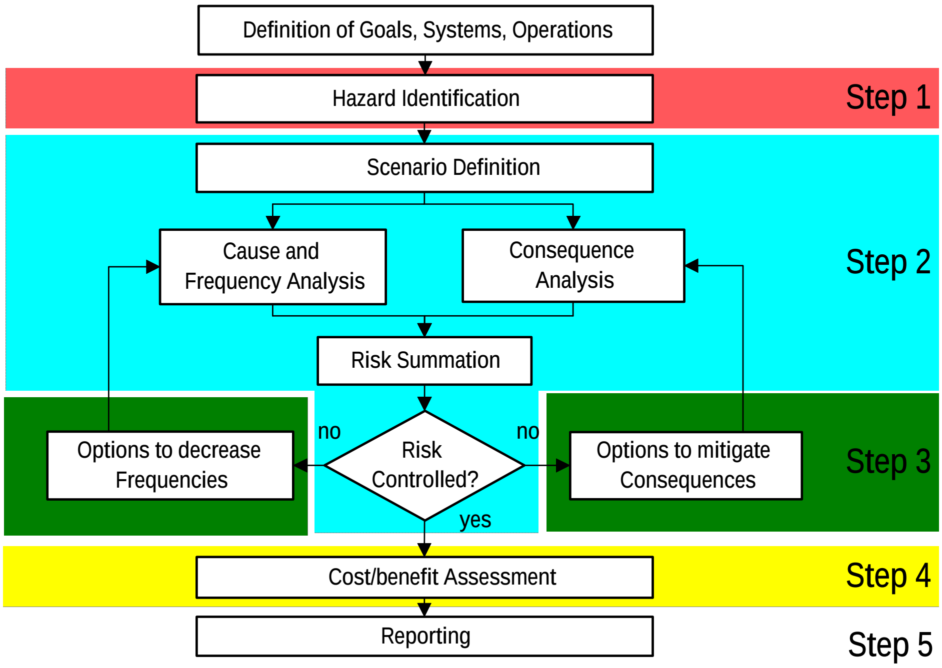

Figure 1: Flow chart of the Formal Safety Assessment process based on MSC/Circ. 1023 (2002, annotations in italics added)

In the third step (see section 6) different risk control options (RCOs) are identified to control the major risks identified in the previous tasks of this sub-project.
The RCOs are then assessed through cost-benefit analysis (step 4, see section 7) using the standard IMO procedures and criteria for cost effectiveness. An RCO is a means of controlling the level of risk that is

[1] For a more extensive introduction to risk assessment in the Maritime industry, see [33].

associated with a hazard. The level of risk for a hazard can be reduced by either reducing the frequency of occurrence or the consequence of the hazard, or both. Only cost effective RCOs will be recommended, i.e. RCOs for which the gross cost of averting a fatality (GCAF) is below 3 million US$, i.e. the cost effectiveness criterion given in [19], Table 2 of Appendix 7.
In the final step 5 this work concludes by formulating a list of recommendations with respect to the implementation of identified risk control options, see section 8.

The present work was limited to embrace potential loss of life and property damage. For this purpose, only the associated risk to health and life of the crew of the studied ship are considered; property risk in terms of ships' structure and possible loss of payload is considered only in scenarios that involve possible human life loss. The likelihood of exposure to security risks is considered out of the scope of the present work since it is related to other safety issues. Occupational hazards with the potential of injuring, or in special circumstances even causing the death of individual crew members are also not within the focus of this risk analysis.

Appendices to this Annex include lists of participants of the HazID and RCO evaluation sessions, the set of risk models that were used for the quantitative risk assessment, and a complete list of identified RCOs.

2 Background information

In this preparatory step the current regulations for the sea transport of packaged dangerous goods are reviewed and analysed. Furthermore, ships and ship systems that are in focus of the analysis are presented. Trade and incident data is reviewed for the purpose of defining the focus of the analysis.

In the HazID session itself the current regulations are only considered to a minor extent. This is due to the fact that scenarios in focus examine the transport of "on deck only" dangerous goods in open-top cargo holds, which is prohibited under current regulations. For the purpose of this analysis it is assumed that all cargo can be transported in the open-top cargo area; and hazards related to such hypothetical scenarios are identified.

2.1 Open-top containerships

2.1.1 General description

"Open-top" or "hatch-less" containerships are designed in such a way that one or more of the cargo holds are not fitted with a hatch cover, i.e. these holds are completely open. Vessels of this type first appeared around the beginning of the 1990s. The intention of introducing open hatches was to make cargo handling more economic. Almost all of the open-top vessels currently in service, about 120, are of "Feeder-Max" size (500-1000 TEU). However, there are a few "Handysize" (1000-2000 TEU) and "Sub-Panamax" (2000-3000 TEU) ships. In a typical design these vessels have no hatch covers, usually except for holds 1 and 2, which are equipped with hatch covers to allow the carriage of DG.

2.1.2 Comparison of selected cargo hold features

In the subsequent paragraphs selected main design requirements and features of open-top design and conventional containership design are discussed with respect to the transport of dangerous goods. The features described include: cargo access, ventilation, bilge pumps, fire detection and fire extinguishing and electrical installations. Design features that are applicable to both ship types are distinguished from design features that are exclusive to each ship type.

2.1.2.1 Cargo access

Design aspects that are applicable to both containership types:
On both ship types cargo holds are accessible for the crew through lashing bridges and inclined ladders at both ends of a container bay. These structures can be entered from the main deck and from alleyways next to the hold. Supervision of particular on-deck containers is possible; however, it is not possible to open the doors of a container.

Design aspects that are specific to conventional containerships:
Hatch covers are closed during voyage. Hence, only containers stowed on deck can be watched from deck.

Design aspects that are specific to open-top containerships:
No hatch covers are installed. Hence, a limited view on containers stowed in holds is possible from deck. However, on open-top containerships access to cargo during voyage is also restricted to use of lashing bridges.

2.1.2.2 Ventilation

Design aspects that are applicable to both containership types:
Ventilation is installed as required by SOLAS II-2/19 with respect to the transport of dangerous goods.

Design aspects that are specific to conventional containerships:
SOLAS II-2/19 requires that "*[a]dequate power ventilation shall be provided in enclosed cargo spaces. The arrangement is such as to provide for at least six air changes per hour in the cargo space, based on an empty cargo space, and for removal of vapours from the upper or lower parts of the cargo space, as appropriate.*" For dangerous goods classes 4 and 5.1 this requirement is not applicable to closed freight containers. For container cargo spaces for classes 2, 3, 6.1 and 8 when carried in closed freight containers, the ventilation rate may be reduced to not less than two air changes. This can be achieved either by mechanical extraction of exhaust air in combination with natural supply air, or by mechanical supply of air in combination with natural exhaust air. *"The fans shall be such as to avoid the possibility of ignition of flammable gas/air mixtures. [...] Natural ventilation is provided in enclosed cargo spaces intended for the carriage of solid dangerous goods in bulk, where there is no provision for mechanical ventilation."*

Design aspects that are specific to open-top containerships:
Ventilation of the open-top cargo area is provided by natural ventilation via the open-top holds and mechanical ventilation. Due to the open structure, gases and vapours lighter than air can disappear. This process can be accelerated by the use of forced ventilation. Forced ventilation is also required to remove gases and vapours that are heavier than air. For open-top containerships the requirements on ventilation set by SOLAS II-2/19 are interpreted in MSC/Circ.1120 [31]:
"Power ventilation should be required only for the lower part of the cargo hold for which purpose ducting is required. The ventilation capacity should be at least two air changes per hour, based on the empty hold volume below weather deck."
With approximately 80 % of the volume of a hold filled with containers up to ten air changes per hour can be reached.

2.1.2.3 Bilge Pumps

Design aspects that are applicable to both containership types:

General requirements on the bilge system for ships carrying dangerous goods are set in regulation SOLAS II-2/19:

"3.5.1 Where it is intended to carry flammable or toxic liquids in enclosed cargo spaces, the bilge pumping system shall be designed to protect against inadvertent pumping of such liquids through machinery space piping or pumps. Where large quantities of such liquids are carried, consideration shall be given to the provision of additional means of draining those cargo spaces.

3.5.2 If the bilge drainage system is additional to the system served by pumps in the machinery space, the capacity of the system shall be not less than 10 m^3/h per cargo space served. If the additional system is common, the capacity need not exceed 25 m^3/h. The additional bilge system need not be arranged with redundancy.

3.5.3 Whenever flammable or toxic liquids are carried, the bilge line into the machinery space shall be isolated either by fitting a blank flange or by a closed lockable valve.

3.5.4 Enclosed spaces outside machinery spaces containing bilge pumps serving cargo spaces intended for carriage of flammable or toxic liquids shall be fitted with separate mechanical ventilation giving at least six air changes per hour. If the space has access from another enclosed space, the door shall be self-closing.

3.5.5 If bilge drainage of cargo spaces is arranged by gravity drainage, the drainage shall be either led directly overboard or to a closed drain tank located outside the machinery spaces. The tank shall be provided with a vent pipe to a safe location on the open deck. Drainage from a cargo space into bilge wells in a lower space is only permitted if that space satisfies the same requirements as the cargo space above."

Design aspects that are specific to conventional containerships:

No additional requirements are in focus of this FSA.

Design aspects that are specific to open-top containerships:

Specific further requirements on bilge pumps installed on open-top containerships are specified in MSC/Circ. 608/Rev.1:

"8.1 The bilge pumping system should have a required capacity to pump

> *1 the maximum hourly rate of green water shipped in seagoing conditions as established by the comprehensive model testing specified*
> *2 an amount equal to rainfall of 100 mm/hour regardless of the installation of rain covers*
> *3 the amount of shipped green water measured during the seakeeping model tests for the dead ship condition in beam seas multiplied by safety factor 2*
> *4 four-thirds of the amount of water required for fire-fighting purposes in the largest hold*
> *5 an amount equal to the capacity required for ships with closed cargo holds*

whichever is the greater

8.2 The pumping of hold bilges should be possible by at least three bilge pumps.

8.3 At least one of these pumps should have a capacity of not less than the required capacity as defined in 8.1 and should be dedicated to bilge and ballast service only. It should be located in such a way that it will not be affected by a fire or other casualty to the space containing the pumps required in 8.4 below or the space containing the main source of power and should be supplied from the emergency switchboard required by regulation 11-1/43 of SOLAS 1974 as amended.

8.4 The combined output of at least two further pumps should not be less than the required capacity as defined in 8.1. These pumps should be supplied from the main source of electrical power required by regulation 11-1/41 of SOLAS 1974 as amended or any other source of power independent of the emergency switchboard required by regulation 11-1/43 of SOLAS 1974 as amended.

8.5 The bilge pumping system including the piping system should incorporate sufficient redundancy features so that the system will be fully operational and capable of dewatering the hold spaces at the required capacity in the event of failure of any one system component. […]

8.7 All open cargo holds should be fitted with high bilge level alarms. The alarms should annunciate in the machinery spaces and the manned control location and be independent of bilge pump controls.

8.8 If the loss of suction prevents the proper functioning of the bilge system special measures to prevent this should be considered as for instance the installation of level indicators.
8.9 Open cargo hold drain wells should be designed to ensure unobstructed discharge of water and easy access for cleaning under all conditions. […]"

2.1.2.4 Fire Detection

Design aspects that are applicable to both containership types:
General requirements on the fire detection system for ships carrying dangerous goods are set in regulation SOLAS II-2/19.3.3, stating that *"cargo spaces shall be fitted with either a fixed fire detection and fire alarm system or a sample extraction smoke detection system complying with the requirements of the Fire Safety Systems Code"* (FSS Code). Cargo holds for the transport of dangerous goods are always equipped with fire detection systems. The most common system is a sample smoke extraction and alarm system.

Design aspects that are specific to conventional containerships:
No additional requirements are in focus of this FSA. Typically, on conventional containerships a CO_2 fire fighting system is installed and a sample extraction smoke detection system operates through the piping of this fire fighting system.

Design aspects that are specific to open-top containerships:
DSC 1/INF.4 states that *"sample extraction smoke detection system activated by smoke or ionisation is particularly effective for the application in open-top holds."* This fire detection system *"shall be designed and arranged to take account of the specific hold and container configuration and ventilation arrangement."* (MSC/Circ. 608/Rev.1).
Furthermore, it can be argued that on open-top containerships fires may be detected visually by bridge watch, as smoke dissipating from the cargo hold can be detected at early stages of the fire.

2.1.2.5 Electrical Installations

Design aspects that are applicable to both containership types:
In SOLAS II-2/19.3.2 it is stated that *"electrical equipment and wiring shall not be fitted in enclosed cargo spaces or vehicle spaces unless it is essential for operational purposes in the opinion of the Administration. However, if electrical equipment is fitted in such spaces, it shall be of a certified safe type*[2] *for use in the dangerous environments to which it may be exposed unless it is possible to completely isolate the electrical system (e.g. by removal of links in the system, other than fuses). Cable penetrations of the decks and bulkheads shall be sealed against the passage of gas or vapour. Through runs of cables and cables within the cargo spaces shall be protected against damage from impact. Any other equipment which may constitute a source of ignition of flammable vapour shall not be permitted."*

Design aspects that are specific to conventional containerships:
No additional requirements are in focus of this FSA.

Design aspects that are specific to open-top containerships:
No additional requirements are in focus of this FSA.

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[2] Reference is made to the recommendations of the International Electrotechnical Commission, in particular, IEC Publication 60092 Electrical installations in ships.

2.1.2.6 Fire Extinguishing

Design aspects that are applicable to both containership types:

General requirements on water-based fire extinguishing systems with respect to the transport of dangerous goods are specified in SOLAS II-2/19.3.1

"3.1.1 Arrangements shall be made to ensure immediate availability of a supply of water from the fire main at the required pressure either by permanent pressurization or by suitably placed remote arrangements for the fire pumps.

3.1.2 The quantity of water delivered shall be capable of supplying four nozzles of a size and at pressures as specified in regulation 10.2, capable of being trained on any part of the cargo space when empty. This amount of water may be applied by equivalent means to the satisfaction of the Administration.

3.1.3 Means shall be provided for effectively cooling the designated underdeck cargo space by at least 5 l/min per square metre of the horizontal area of cargo spaces, either by a fixed arrangement of spraying nozzles or by flooding the cargo space with water. Hoses may be used for this purpose in small cargo spaces and in small areas of larger cargo spaces at the discretion of the Administration. [...]

3.1.4 Provision to flood a designated under-deck cargo space with suitable specified media may be substituted for the requirements in paragraph 3.1.3.

3.1.5 The total required capacity of the water supply shall satisfy paragraphs 3.1.2 and 3.1.3, if applicable, simultaneously calculated for the largest designated cargo space. The capacity requirements of paragraph 3.1.2 shall be met by the total capacity of the main fire pump(s), not including the capacity of the emergency fire pump, if fitted. If a drencher system is used to satisfy paragraph 3.1.3, the drencher pump shall also be taken into account in this total capacity calculation. [...]"

On-deck fire-fighting equipment includes fire pumps and hoses, hydrants, as well as portable fire extinguishers.

Furthermore, MSC/Circ.1120 states that a *"fixed high expansion foam system, complying with the FSS Code, chapter 6, section 2.2, is acceptable, except if cargoes dangerously react with water (see IMDG Code)."*

Design aspects that are specific to conventional containerships:

On conventional containerships for closed cargo spaces a CO_2 fire fighting system is most commonly used.

Design aspects that are specific to open-top containerships:

For open holds CO_2 fire fighting systems are not feasible; hence water-based systems are in place. The following requirements on these systems that are specific to open-top containerships are specified in MSC/Circ. 608/Rev.1:

"9.1 The fire protection system for open-top container holds shall be based on the philosophy of containing the fire in the bay of origin and to cool adjacent areas to prevent structural damage.

9.2 Open-top container holds shall be protected by a fixed water spray system. The system shall be capable of spraying water into the cargo hold from deck level downward. The system shall be designed and arranged to take account of the specific hold and container configuration. [...]

9.3 The water spray system should be able to effectively contain a fire in the container bay of origin. The spray system shall be subdivided with each subdivision to consist of a ring-line at deck level in an open cargo hold around a container bay.

9.4 The water spray system shall be capable of spraying the outer vertical boundaries of each container bay in an open cargo hold and of cooling the adjacent structure. The uniform application density should be not less than 1.1 litres/min/m^2. At least one dedicated fire extinguishing pump for the hold water spray system with a capacity to serve all container bays in any one open-top container hold simultaneously shall be provided. The pump(s) shall be installed outside the open-top area. The availability of water to the water spray system shall be at least 50 per cent of the total capacity with adequate spray patterns in the open-top container hold and with any one dedicated pump inoperable. For the case of a single *dedicated water spray pump this may be accomplished by an interconnection to an alternative source of water. The extinguishing system shall be supplemented by hose supply from the weather deck."*

These requirements are extended by interpretations in MSC/Circ.1120:
"Water supplies for open-top container spaces in ships
1 The water spray system required in paragraphs 9.2, 9.3 and 9.4 of MSC/Circ.608/Rev.1 […] will also satisfy the requirement for dangerous goods.
2 The amount of water required for fire-fighting purposes in the largest hold should allow simultaneous use of the water spray system plus four jets of water from hose nozzles."

2.2 Carriage of packaged dangerous goods

2.2.1 The IMDG code

The objective of the International Maritime Dangerous Goods (IMDG) Code [17] is to enhance the safe transport of dangerous goods while facilitating the free unrestricted movement of such goods. It is intended for use not only by the mariner but also by all those involved in industries and services connected with shipping. The IMDG Code specifies requirements on terminology, packaging, labelling, markings, stowage, segregation, handling, and emergency response. The code is updated and maintained by the IMO every two years.
Dangerous goods are categorised into 15 classes according to the predominant type of hazard they represent:

Class 1: Explosives
Class 2.1: Flammable gases
Class 2.2: Non-flammable, non-toxic gases
Class 2.3: Toxic gases
Class 3: Flammable Liquids
Class 4.1: Flammable solids, self-reactive substances and desensitized explosives
Class 4.2: Substances liable to spontaneous combustion
Class 4.3: substances which, in contact with water, emit flammable gases
Class 5.1: Oxidizing Substances
Class 5.2: Organic Peroxides
Class 6.1: Toxic Substances
Class 6.2: Infectious Substances
Class 7: Radioactive substances
Class 8: Corrosive substances
Class 9: Miscellaneous substances

2.2.2 Stowage of dangerous goods

Stowage requirements for every hazardous substance are defined in chapter 7.1 of the IMDG Code. Of main interest in this HazID are those substances that require stowage on deck. In the IMDG Code dangerous goods are assigned stowage categories; categories 01 to 15 are defined for goods of class 1, and categories A through E are defined for goods of classes 2 through 9. On cargo ships stowage on deck is prescribed for those class 1 substances that are stowage category 14 and for those substances of class 2 to class 9 which are stowage category C or D.

On-deck stowage of certain substances is required for several reasons. These can be grouped into three categories:

- Applicability of preventive measures that mitigate the frequency of an accident;

- Applicability and impact of emergency procedures / countermeasures that mitigate the severity of an unwanted incident;
- Ship design considerations that have an effect on severity (natural exhaust, likelihood of structural damage).

According to IMDG Code § 7.1.1.8 stowage on deck has been generally prescribed in cases where

- Constant supervision is required
- Accessibility is particularly required
- There is a substantial risk of formation of explosive gas mixtures, development of highly toxic vapours, or unobserved corrosion of the ship

However, the IMDG Code states that "in the view of the high protective advantages, stowage under deck has been recommended wherever possible, except that, for certain articles of class 1 whose principal hazard is the production of smoke or toxic fumes, stowage on deck has been recommended".

In general, on-deck only cargoes are associated with greater risks [12], whereas the type of risk may also apply to under deck cargoes.

General considerations that impose on-deck stowage:

- Atmosphere on deck is beneficial for vapour exhaust. Applies to flammable and fire enhancing vapours in case of an explosion or fire, toxic vapours to prevent poisoning or suffocation.
- Incidents, such as smoke or leaking containers can be better observed when stowed on deck.
- Corrosive substances could be washed away/overboard with copious amounts of water. Under deck damage to the ship structure may be caused if cargo is transported under deck.

Hazards that suggest cargo stowage on-deck only (Brief summary of hazards specified in the IMDG-Code):

Class 2: Gases

Poisonous, corrosive, and flammable gases should be restricted to on-deck only stowage due to the greater risk of explosion, poisoning or suffocation. Gases, especially those being heavier than air, could accumulate inside a cargo hold.

Refrigerated gases are kept liquefied at very low temperatures. These gases should be restricted to on-deck only stowage due to a greater risk associated with leakages, which may lead to frostbite, and with increasing pressure when temperature rises (supervision, accessibility required).

Class 2.1: Flammable Gases
Many of these flammable gases require a refrigerated transport. In general, required supervision and a higher risk of explosion suggests on-deck only stowage.

Class 2.2: Non-flammable, non-toxic gases
Gases of this class require either a refrigerated transport or have an oxidizing effect, thus, imposing greater risk in case of fire.

Class 2.3: Toxic Gases
Almost all of these gases require on-deck stowage only due to a risk of intoxication or suffocation.

Class 3: Flammable Liquids

Danger of combustion is typically caused by vapours of the substance. In individual cases, cargo imposes greater risk due to fire, explosion or flashback. Gases, especially those with low flashpoint, have a very low boiling temperature and should be kept as cool as possible. A secondary risk label (6.1) indicates a higher risk due to inhalation of toxic vapours (isocyanates).

Class 4: Flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases

Class 4.1: Flammable solids, self-reactive substances and desensitized explosives

Cargo imposes greater risk of explosion. Substances might generate explosive gases when decomposing, thus, should be stored as cool as possible.

Class 4.2: substances liable to spontaneous combustion

Pyrophoric substances may ignite spontaneously in air or carbon dioxide. There is no possibility to extinguish such fires in cargo hold and adjacent containers are difficult to cool. Substances might also evolve toxic fumes when involved in a fire and form an explosive mixture with air (celluloid).

Class 4.3: substances which, in contact with water, emit flammable gases

Substances impose a higher risk of explosion or toxic vapours. Substances that react violently with water usually evolve hydrogen gas.

Class 5: Oxidizing substances and organic peroxides

Class 5.1: oxidizing substances

Oxidizing and explosive effect of these substances (permanganates, hypochlorites) imposes strong reaction in case of fires. These substances must be separated from flammable substances.

Class 5.2: organic peroxides

Stowage on deck is required due to thermal instability and extended fire risk.

Class 6: Toxic and infectious substances

Substances present a severe risk associated with inhalation or irritation. Risk associated with imminent corrosion could be determined for some substances.

Class 8: Corrosive substances

Stowage on deck is required due to increased risk of unobserved corrosion of the ship and toxic or irritating vapours. Liquid mineral acids and other substances present a serious inhalation hazard.

2.2.3 Emergency procedures

Emergency procedures apply in case of accidents and help control or mitigate consequences. These actions are applicable for two main categories of incidents, spillages and fires.

The general recommendation is to wash spillages overboard with copious quantities of water. If a dangerous reaction with water is expected this should be done from as far away as practicable. The general rule is that the safety of the crew always has priority over pollution of the sea.

Water is the main fire fighting medium at sea. However, for some substances being highly reactive with water dry chemical extinguishing is recommended. These extinguishing media are available onboard in only very low quantities; hence, the only alternative is to use copious quantities of water having a cooling effect. A general recommendation for the handling of dangerous goods in case of fire is to jettison them overboard when there is a likelihood of their involvement in a fire. However, this may be impractical, depending on where exactly the container is located.

Class 2: Gases

General: The emergency team must avoid contact with liquefied gases. Very low temperatures around leakages of liquefied gases can pose additional hazards.

2.1 Flammable gases:
Spillage: Let gas dissipate, for large quantities of liquefied gas use water jet from as far as possible to accelerate evaporation.
Fire: Create water spray, cool nearby cargo with copious quantities of water or jettison cargo involved in fire, do not try to extinguish gas flame.

2.2 Non-flammable, non-toxic gases:
Spillage: Let gas dissipate, for large quantities of liquefied gas use water jet from as far as possible to accelerate evaporation.
Fire: Use copious quantities of water.

2.3 Toxic gases:
Spillage: Let gas dissipate, for large quantities of liquefied gas use water jet from as far as possible to accelerate evaporation.
Fire: Create water spray, cool nearby cargo with copious quantities of water or jettison cargo involved in fire, do not try to extinguish gas flame.

Class 3: Flammable Liquids

Vaporized flammable liquids:
Spillage: Wash overboard with copious quantities of water, do not use direct water jet.
Fire: Create water spray and cool burning transport, cool nearby cargo with copious quantities of water or jettison cargo involved in fire.

Toxic and corrosive flammable liquids:
Spillage: Wash overboard with copious quantities of water, do not use direct water jet. Use water spray to drive vapours away.
Fire: Create water spray and cool burning transport, cool nearby cargo with copious quantities of water or jettison cargo involved in fire.

Flammable liquids not soluble in water:
Spillage: Restrict leakage, try to absorb, collect or enclose spillage. If not possible, wash overboard with copious quantities of water.
Fire: Create water spray and cool burning transport, cool nearby cargo with copious quantities of water or jettison cargo involved in fire.

Class 4: Flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases

4.1 Flammable solids, self-reactive substances and desensitized explosives
Spillage: Wash overboard with copious quantities of water, collect if possible (not self-reactive), if molten smother with dry inert material.
Fire: Create water spray and cool burning transport, cool nearby cargo with copious quantities of water or jettison cargo involved in fire.

4.2 Substances liable to spontaneous combustion (water-reactive)
Spillage: Avoid getting water in or on cargo transport units, dispose overboard immediately
Fire: Do not use water or foam, smother with dry inert material or let fire burn. If not practicable, cool nearby cargo with copious quantities of water. Try to avoid water get into the container.

4.3 Substances which, in contact with water, emit flammable gases
Spillage: Keep dry and dispose overboard or wash overboard with copious quantities of water
Fire: Do not use water or foam, smother with dry inert material or let fire burn. If not practicable, cool nearby cargo with copious quantities of water. Try to avoid water get into the container. Remove receptacles likely to be involved in a fire.

Class 5: Oxidizing substances and organic peroxides
5.1 Oxidizing substances
Spillage: Wash overboard with copious quantities of water.
Fire: Create water spray and cool burning transport, cool nearby cargo with copious quantities of water.

5.2 Organic Peroxides
Spillage: Wash overboard with copious quantities of water. Collect damaged or leaking receptacles and dispose overboard.
Fire: Cool burning transport units and nearby cargo exposed to the fire with copious quantities of water. After extinguishing keep water spraying for several hours.

Class 6: Toxic and infectious substances
6.1 Toxic substances
Spillage: Wash overboard with copious quantities of water. Do not direct water jet straight onto the spillage.
6.2 Infectious substances
Spillage: Wash overboard with copious quantities of water. Do not direct water jet straight onto the spillage.

Class 8: Corrosive substances
Corrosive substances
Spillage: Wash overboard with copious quantities of water. Do not direct water jet straight onto the spillage.

2.2.4 Cargo handling

Depending on the route, of all cargo that is transported in containers between 5 % and 10 % are declared DG. Undeclared DG are not factored in, but estimations go up to 30 % of the declared DG [8]. That means, with about 100 million containers being transported per year up to 10 million contain DG and up to 3 million contain undeclared DG. Transport insurers expect that the portion of packaged DG will even increase in the future.

For the cargo covered by the regulations of the IMDG Code a review of DG statistics [7] of the Hamburg port has been conducted. The Hamburg port is one of the second biggests port in Europe with approximately 9 million containers handled per year (2006). Furthermore Hamburg is regarded as the feeder centre for the Baltic Sea. Thus, data from this port can be seen as fairly representative for Europe.

Statistics from the years 2002 to 2006, shown in Figure 2, indicate that the most transported packaged DG are those of class 3 – flammable liquids, followed by class 8 –corrosive substances. Classes 9, 5.1 and 6.1 are also transported in major quantities.

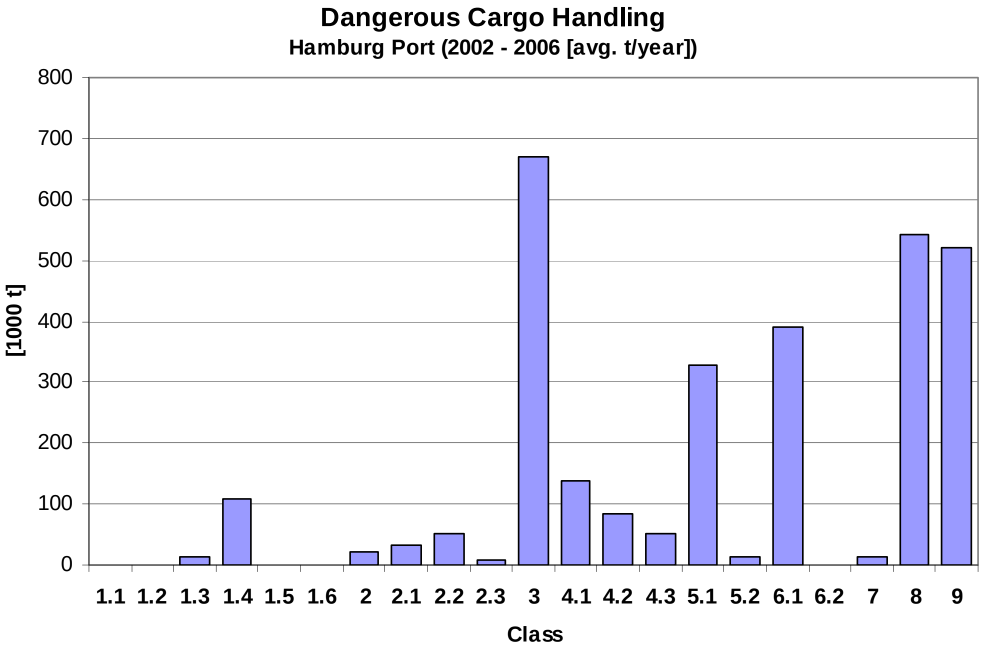


Figure 2: Hamburg Port Statistics: Handling of packaged dangerous goods

Based on a container safety study [9], conducted by IMO between 1996 and 2000, 30 % of all inspected containers (approx. 20,000) had defects. In 29 % of those cases the container itself (structure) showed defects, 20 % were marked inadequately, 15 % had problems with the documentation, 15 % were badly stowed or showed poor cargo securing and in 14 % of the cases the labelling was wrong or insufficient.

2.3 Dangerous goods incidents

Extensive studies of DG incidents have been made by the Lund University, Sweden [35]. In this work, two US-American databases have been analyzed in detail; one database of the U.S. National Response Center (NRC) and the Hazardous Materials Information System (HMIS). According to those databases, almost 35 % of all documented incidents involve class 8 substances and more than 25 % involve substances of class 3 (see Figure 3). When compared with the port statistics these classes also reflect the largest portions in DG transport. A large number of incidents do not necessarily mean that the substances involved are associated with a higher risk. In order to determine the risk the consequences of an incident have to be known, but quantifications of such consequences are only rarely available.

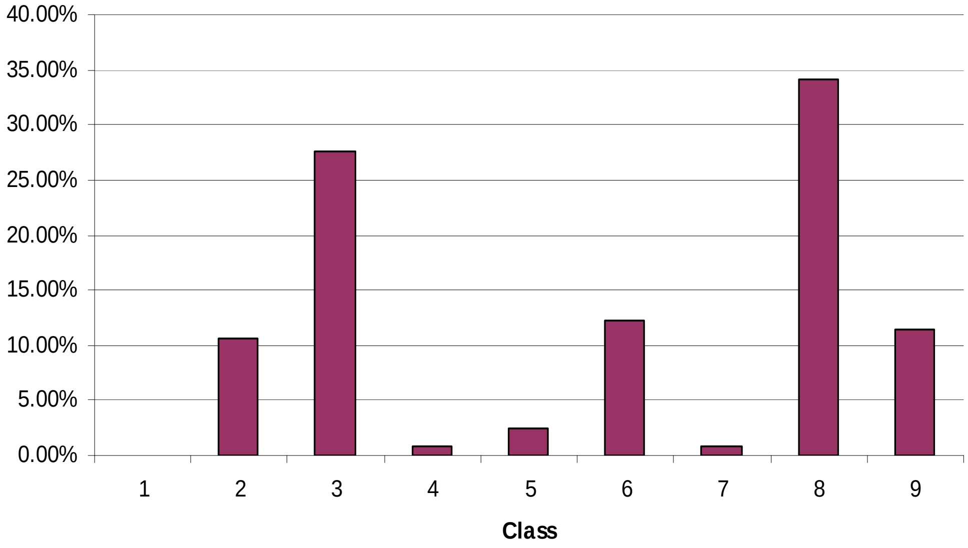


Figure 3: Distribution of dangerous goods classes involved in sea transport incidents; based on DG-vessel incidents, 1993-2004 [35].

The incident type has also been extracted from the databases, as shown in Figure 4.

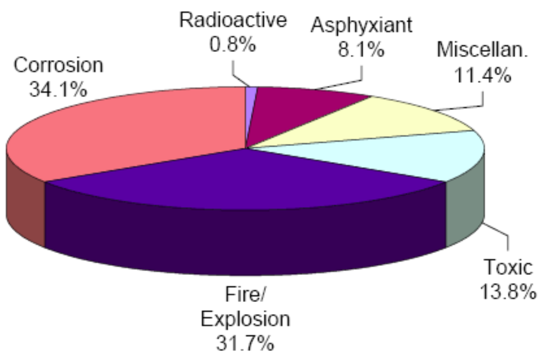


Figure 4: Distribution of incident types based on DG-vessel incidents, 1993-2004 [35].

In order to find out whether certain classes of substances show a disproportionate share of the incidents and thus give hint for the focus of further analysis, port statistics and hazard incident databases have been compared. From this comparison it can be concluded that, based on the their share in incidents (Figure 3) in relation to their share in transport (Figure 2), especially class 2, class 3 and class 8 seem to be more likely to be involved in an incident than other classes. In contrast, involvement of classes 1, 4 and 5 seem to be less likely.

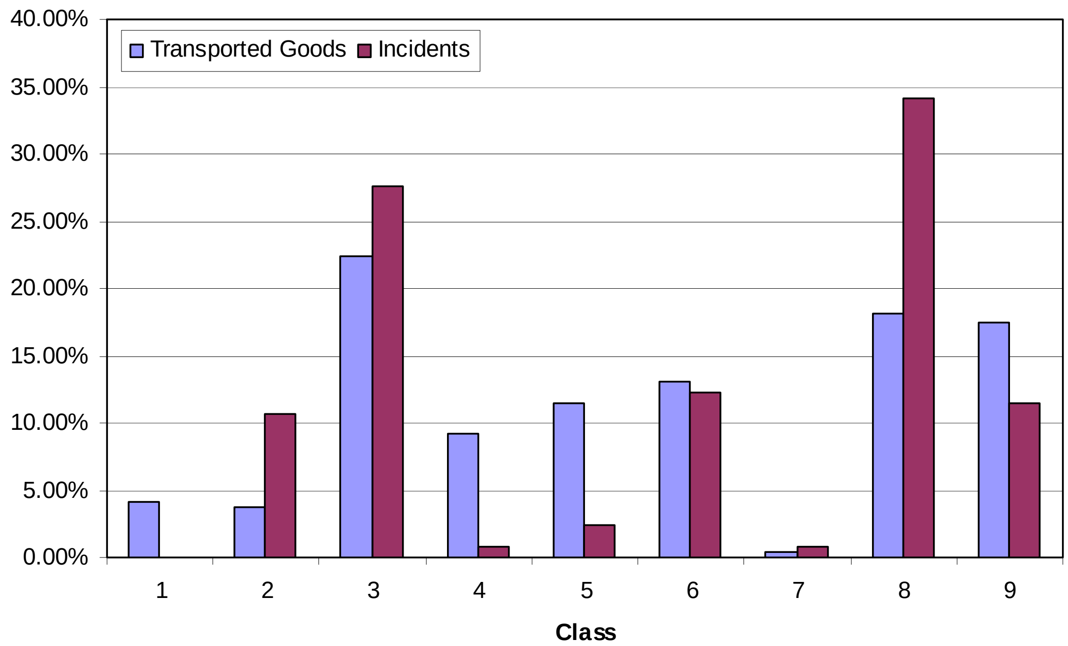


Figure 5: Class-based comparison: Share of different classes in sea transport and their involvement in DG-incidents

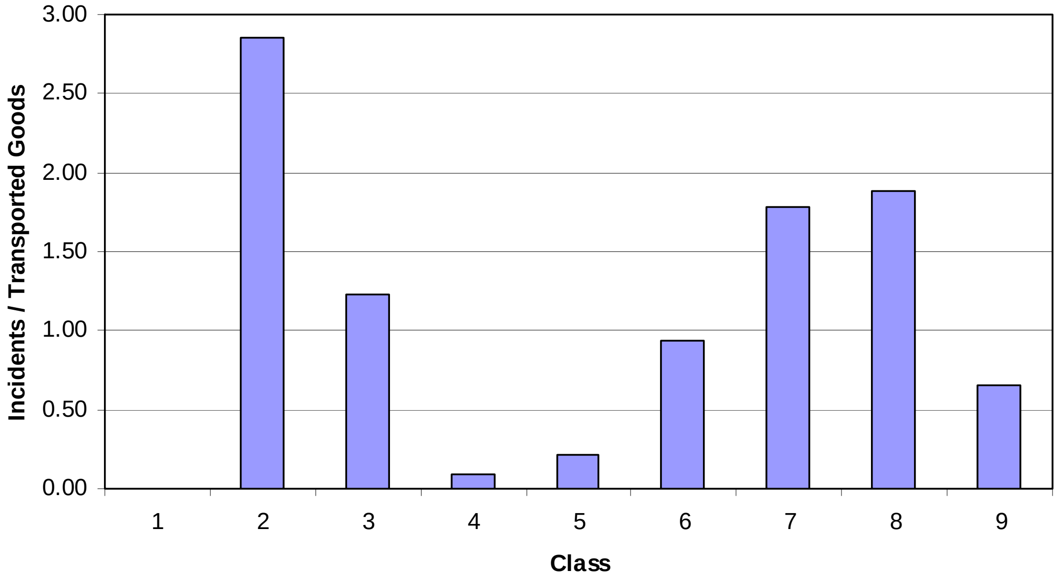


Figure 6: Proportional share of incidents of a certain DG class

Almost all of the known serious DG accidents are associated with fire and explosion. Possible reasons are manifold, including the production of the particular substance (impurification), poor packaging, improper labelling, handling, stowing, cargo securing etc. In most cases external factors are also involved, so that cumulative occurrence leads to an accident [4]. Table 1 shows an overview of major DG-accidents that occurred during 1998 - 2006.

Table 1: Major DG accidents 1998 - 2006

Name	Year	Accident/Type	Human Loss	Property damage
DG Harmony	1998	Fire	2 fatalities	>US$ 20,000,000
Sealand Mariner	1998	Explosion, Fire		
Aconagua	1998	Explosion, Fire		>US$ 15,000,000
Ever Decent	1999	Fire after collision		
CMA Djakarta	1999	Explosion, Fire		>US$ 25,000,000
Hanjin Bremen	2000	Fire		
Sloman Traveller	2001	Fire		
Hanjin Pennsylvania	2002	Fire, Explosion	2 fatalities	> US$ 100,000,000
Sea Elegance	2003	Fire	1 fatality	
LT Utile	2003	Fire		
MOL Renaissance	2006	Fire		
Hyundai Fortune	2006	Fire		Approx. US$ 300,000,000

Not only injuries, fatalities or damages to the ship itself should be considered. The property damage that is caused by loss of cargo is also significant and in many cases exceeds the damage to the vessel.
A realistic quantification of cargo values can neither be achieved based on volume nor on weight. Furthermore, the number of empty containers being transported is very difficult to determine since shipping industry treats this information very confidential. Nevertheless, a global value is required, especially for calculation of insurance rates. (Re)-insurers calculated a weight based value of US$ 1,795 per ton in 2004 [34]. Considering an average weight of 10 t for a 20 ft container and 18 t for a 40 ft container as well as a safety margin of 10 % the average value will be US$ 20,000 and US$ 36,500 respectively for a single container. In the Container-Vessel-FSA (MSC 83/INF.8, [23]) a value of US$ 20,000 has been used for a 20 ft container. For certain trans-pacific routes and routes between Europe and the United States average values of US$ 100,000 per container can be reached [34]. Here, the number of certificates issued by Germanischer Lloyd for the specific container types was analysed, in order to obtain an approximation of the relation between transported 20 ft and 40 ft containers. From Figure 7 it can be derived that about half of the containers are 20 ft and half are 40 ft which would result in an average cost per container of about US$ 30,000. Not included in this calculation are reefers and containers for special purposes, as well as empty containers.

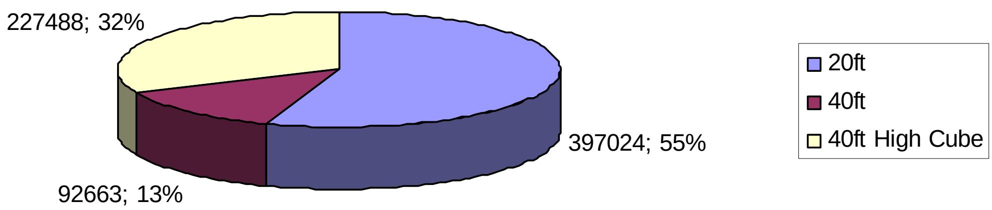


Figure 7: Containers certified by GL in 2005 and 2006 (Jan-Nov)

3 Approach and methodology

The analysis reported in this Annex consists of a hazard identification phase, which is informed by an analysis of incident statistics, a ranking of hazards, and a quantitative risk assessment of the highest-ranked hazards. These phases are described in the subsequent sections.

3.1 Casualty databases

Casualty databases are potentially important tools for gauging the safety and the environmental performance of the industry. They can be used to study and analyse the historic accident scenarios and to find the vulnerable operational or design problems. They can also be used to guide the regulatory process so that the regulations that are being produced may be focused so as to address the weakest links in the safety and environmental prevention chain. A further use of casualty data is to alert to areas of design, operation and training which may be in need of additional attention or of a new approach.

There are many casualty databases, most well-known the Lloyds Register Fairplay (LRFP) and Lloyds Maritime Intelligent Unit (LMIU) which are and will be the largest international ships' accident database for the foreseeable future. Unfortunately, the marine incident/accident databases, which have evolved over the years, were not designed with the application of a possible risk assessment in mind, and therefore suffer from a number of serious limitations which make their usage in risk assessment and engineering projects quite problematic. A critical review of such databases can be found in [39].

There is currently no international registry of dangerous goods transport incidents. Historical casualty data from LMIU do not include data on dangerous goods release, although the involvement of dangerous goods in a casualty may be mentioned in the "précis" section of a casualty record. There are many releases of dangerous goods that do not result in a ship casualty, but that may result in a crew fatality. For this reason, dangerous goods transport incident data for the 15-year period from 1993 to 2007 was obtained from the United States Office of Hazardous Materials Safety website for analysis. This data, which was collected through the Hazardous Materials Information System (HMIS), included all incidents where there is a release or threat of release of dangerous goods. The data was considered to be the most comprehensive record of dangerous goods incidents available. It is a national database, but the volume of dangerous goods transported to, from, and within the United States was considered to be sufficiently large to constitute a representative sample.

3.2 Hazard identification: Process-FMEA

For the hazard identification Failure Mode and Effects Analysis (FMEA) was applied. The analysis was performed in Hamburg on November 14th/15th 2007, and it involved the participants listed in Annex A.1. FMEA is a method that examines potential failures in products or processes. It may be used to evaluate risk management priorities for mitigating known threat-vulnerabilities. FMEA helps select remedial actions that reduce cumulative impacts of life-cycle risks from a system failure. This method illustrates connections between causes and consequences in a standard format.

The basic process is to take a description of the steps and tasks to be performed by a system, and list the consequences if a task fails. Then the FMEA participants evaluate the consequences with respect to two criteria, frequency and severity. Predefined scales for frequency and severity estimations were used in the course of the FMEA to ensure that experts base their judgements on the same basis. These scales are based on recommendations of [19]. For the assessment of the severity class, descriptions were given for safety implications and property-related implications. With respect to consequences, it should be noted that SOLAS is concerned predominantly with safety-related aspects. The ranges of the frequency and severity indexes that were applied in this work are as follows:

- Frequency index, F $\in$ {1..8}
- Severity index, S $\in$ {1..6}

From these indices the risk index RI is calculated by addition:

$$RI = F + S$$

The risk index is used to prioritize all potential failures with the ultimate aim to decide upon actions leading to reduce the risk, usually by reducing severity and / or improving controls for detecting the failure.

In the analysis at hand a relational third rating scale (the "Open-Top-Index") was introduced (Table 2). This scale is used to assess the consequences of an incident on an open-top containership in relation to a conventional containership, i.e. a ship with hatch covers. It is important to note that this index does not affect the Risk-Index (RI). The combination of the Severity-, Frequency- and the Open-Top-Index (SI, FI, and OI, respectively) is useful in order to determine scenarios that are particularly critical for the open-top design. These scenarios can be identified by calculating the "Risk Priority Number":

$$RPN = SI * FI * OI$$

The RPN overweighs those hazards which are more critical for the open-top designs compared to those being equal or less critical. Please note that the RPN has no direct relation to the risk. It is only applied for the ranking of the hazards.

Table 2: Open-Top Index (OI)

OI	Description
1	superior to conventional design
2	equal to conventional design
3	inferior to conventional design

3.3 Risk assessment

Following the hazard identification, the quantitative risk assessment was carried out. This assessment was performed for specific classes or sub-classes (divisions) of dangerous goods (see section 2.2.1), rather than particular substances.

The overall approach was to model the outcome of the release of a specific dangerous goods class using event trees. Inputs to the modelling included comments and judgements obtained in the HazID workshop, as well as data and information from incident and accident reports. Ship casualty data from the Lloyd's Maritime Intelligence Unit's (LMIU) casualty database, which was used in other SAFEDOR FSAs, could not be used. This database does not generally include information on whether dangerous goods were involved in an incident, although the involvement may be mentioned in the "Precis" field of the database. Even if the "Precis" field includes mention of the goods involved in the fire, a generic term such as "chemicals" may be used, rather than specification of the dangerous goods class or UN Number. Data on dangerous goods accidents and incidents was obtained from the United States Office of Hazmat Safety's Hazardous Materials Information System (HMIS). This database includes information on all dangerous goods releases or “threats to release” that occur during transport of dangerous goods in the US. A more detailed discussion of this is provided in section 1.

3.3.1 General approach

The general methodology that was applied during risk assessment consists of the linking the fault tree with the event tree analysis in order to represent a full accident scenario. A scenario of accident is a sequence of events starting with a perturbation from the normal course of events. This initial perturbation is called “basic event”. This perturbation will trigger a response from the vessel systems and/or crew in an effort to bring the vessel back to a normal state. These responses constitute the “pivotal events” in the accident sequences. While most of the pivotal events will serve to protect the vessel or mitigate the consequences, a few events may actually exacerbate the sequence. Finally, each sequence will end with a certain level of damage (from no damage to total vessel loss, for example). These consequences are called “end states”. The combination of the fault tree and event tree techniques can be symbolised as a bow tie. The scenario of accident is then represented as a complete path from the initiating event to the end event [30]. The risk assessment methodology is illustrated in Figure 8.

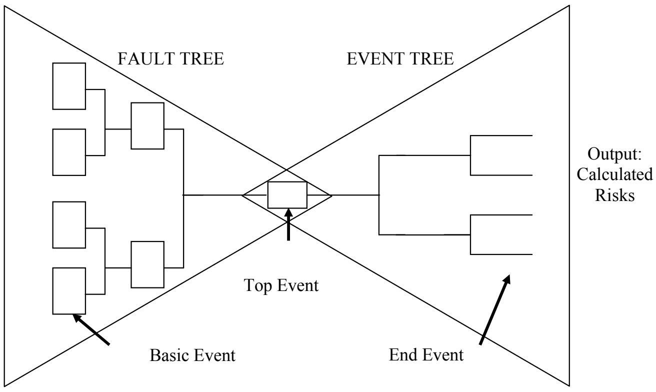


Figure 8: Risk assessment methodology

3.3.2 High level cause identification – Fault Tree Analysis

High level causes of dangerous goods releases were discussed qualitatively. The HazID expert workshop identified some “root causes” for release of dangerous goods or initiation of a dangerous goods incident. Causes were considered to be either “internal”, such as poor quality packaging, poor stowage procedures, or inappropriate handling procedures; or “external” such as excessive ship motions, collision, or fire from other sources on the ship (engine room, other cargo, etc.). High level causes were also identified during review of incidents reports and accident cases.

3.3.3 Evaluation of possible outcomes – Event Tree Analysis

Event trees were constructed for those dangerous goods classes or sub-classes that were identified during the HazID to have a risk index (RI) of 7 or higher. Event trees were constructed for both, carriage of dangerous goods in the hold of an open-top containership and on deck of a conventional containership of the same size. MS-Excel spreadsheets were used for calculations and graphical presentation of each of the trees. Initial input frequencies for a dangerous goods release were derived from data in the US HMIS. Quantitative probability data for branches along the trees were derived from various sources including HMIS data, literature references, from engineering judgement, and in some cases based on simplified assumptions. Quantitative background data and assumptions are described in this report for each of the classes modelled, to give full transparency to all calculation results presented. Probabilities were calculated for each accident sequence. The severity of the outcome of each sequence with respect to consequences for human safety were quantitatively described by assigning an expected number of fatalities for each branch or group of scenario sequences.

The total frequency figures and total expected number of fatalities were combined to derive key safety figures such as PLL (Potential Loss of Life) and individual risk per ship year for each dangerous goods class or sub-class considered.

3.3.4 Risk summation

The Potential Loss of Life (PLL) and individual risk per ship year was summed for all dangerous goods classes considered to get an indication of the risk from carriage of dangerous goods in the hold of open-top containerships and on deck of a conventional containership of similar characteristics. Fatalities due to fire were separated from those due to other causes such as toxicity, asphyxiation, etc. Fatalities from fire were broadly compared against those fire fatalities estimated for containerships in [23].

3.4 Definition of boundaries of this work

3.4.1 System description

The hazard assessment in this task is focused by consideration of a reference vessel. A so called Feeder-Max container carrier with a capacity of approximately 900 TEU has been chosen since it reflects to a large extent the market of open-top containerships. A typical vessel of this type is shown in Figure 9. Features of such vessels are described in section 2.1.

The principal dimensions of the reference vessel are as follows:

LOA:	149 m
LBP:	139 m
Breadth, moulded:	22.5 m
Depth, 1st Deck:	11.3 m
Depth, Forecastle deck:	14 m
Design Draught:	8.5 m
Scantling Draught:	8.7 m
Deadweight (Scant. Draught):	13,700 TDW
Design Speed:	18.2 knots

The vessel is a "gearless" ship, i.e. it does not have its own loading gear on board. The ship meets the requirements of SOLAS II-2/19, for carriage of dangerous goods.

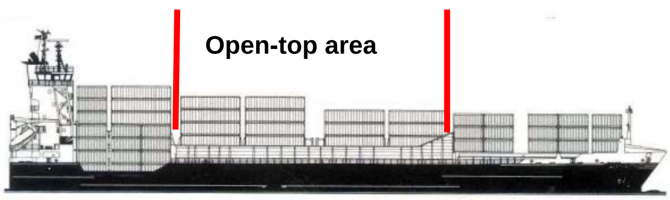


Figure 9: 900 TEU Containership

This ship type was developed in the middle of the 1990s to meet the need for bringing containerized cargo also to small container ports which could not be served by the larger vessels in such an efficient way. With regard to their principal dimensions and equipment, these ships differ only negligibly, even if advancement over 1000 TEU and the trend to more connections for reefer containers are noticeable. However, risk increases with the number of containers being transported.

3.4.2 Operations

In order to structure the analysis, the following processes were considered for the FMEA.

- Operations in restricted waters and open sea transport
- Loading/unloading

It should be noted that documented DG-incidents with vessels occur during the voyage or en route phase [35].

3.4.3 Boundaries of risk assessment

This high level risk assessment is focussed on a limited number of dangerous goods classes and sub-classes (i.e. particularly classes 1, 2.1, 2.2, 2.3, 3, 4.1, 4.2, 5.1, 6.1, and 8) and the hazards they represent. These classes, sub-classes and hazards were selected as a result of the hazard identification.
The incident statistics used are for only one region (United States) and cover a fifteen-year period from 1993 to 2007. The containership calls at United States ports were about 8 % of the containership calls at world ports for the years 2003 to 2005 (see data and discussion in Section 5.1 of this report). Thus the incident data considered represents a sample of approximately 8 % of all containership activity. Data from US waters, however, may not be representative for ships trading in other areas. The Hazardous Materials Information System is considered to be one of the best sources of information on dangerous goods transport incidents, because transporters of dangerous goods are required by law to report any incidents where there has been a spill or threat of spill, even if there are minimal consequences. Thus there is no bias towards larger release events, which can occur when the data is only collected by incident response agencies.

Changes have taken place over the 15-year period covered by the statistics, including changes to dangerous goods transport regulations and improvements to ship equipment and dangerous goods transport procedures. The effects of these changes could not be analysed in detail, but could contribute to a lower release rate than that used for the initiating events in the event trees.

The assessment is focussed on carriage of dangerous goods requiring on-deck stowage in the open holds of open-top containerships – a situation that is currently not permitted under existing regulations. However, all frequencies that are derived from historical data, are for carriage as currently permitted under the IMDG. The risk analysis is focused on the “en route” phase of transport. Risks associated with loading and unloading activities were not analysed. This was also the case for the containership risk analysis [23] and formal safety assessment carried out within the SAFEDOR project.

4 Hazard identification (HazID) and accident scenarios

4.1 Structure of the FMEA

Failure Modes and Effects Analysis (FMEA) was applied for the hazard identification. As discussed in section 3.4.2, the following processes have been considered for the FMEA.

- Operations in restricted waters and open sea transport
- Loading/unloading

Most of the documented DG-incidents with vessels occur during the voyage or en route phase [35]. Furthermore, a strict distinction between transport and loading operations with respect to dangerous goods incidents seems unfavourably. Experts agreed that design differences between open-top and conventional vessels mostly affect the outcomes of an incident when the vessel is in operation.

For the FMEA a structure was chosen (Table 3) that is based on the classes and sub-divisions of the IMDG Code. The hazard identification followed the substances of these classes and their associated hazards.

4.2 Root causes

Dangerous goods incidents can be caused by several “root causes”, i.e. causes at the beginning of a chain of events that may lead to an accident. Root causes include the basic events that lead to a leakage of the packaging, fire, explosion etc. These root causes have not been considered here in detail because a rating of the frequency of each root cause associated with a certain consequence was not feasible. For many of the incidents that are documented or that are known from expert’s personal experience root causes are even unknown. For that reason experts agreed that the chain of events leading to an incident should start with either internal or external root causes with no further differentiation.

Internal root causes are causes emanating from the DG-container itself, including those involving non-DG:

- Production (impurification)
- Bad stowage
- Inadequate packaging
- Improper segregation
- Bad labelling (→ improper stowage)
- Damage of packaging due to handling

External root causes involve events from outside the DG-container:

- Sea sloshing / green water
- Heavy weather
- Fire
- Overheating due to bad stowage
- Grounding
- Collision
- Parametric roll
- Vibrations

Table 3: FMEA Structure

Class 1 – explosives		
	division 1.1 and 1.2: mass explosives and projectiles	
	division 1.3 and 1.4: minor blast, minor projection hazard	
	division 1.5 and 1.6 (no relevance)	
Class 2 – gases		
	2.1 flammable gases	
	2.2 non-flammable, non-toxic gases	
	2.3 toxic gases	
Class 3 - flammable liquids		
	packing group I (boiling point < 35°C)	
	packing group II (flash point <23°C)	
	packing group III (flash point between 23°C and 61°C)	
	liquid desensitized explosives	
Class 4 - flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases		
	4.1 flammable solids, self-reactive substances and solid desensitized explosives	
		flammable solids
		self-reactive solids
		solid desensitized explosives
	4.2 substances liable to spontaneous combustion	
		packing group I (pyrophoric solids)
		packing group II and III (combustible substances)
	4.3 substances which, in contact with water, emit flammable gases	
Class 5 - oxidizing substances and organic peroxides		
	5.1 oxidizing substances	
		solid substances
		liquid substances
	5.2 organic peroxides	
Class 6 - toxic and infectious substances		
	6.1 toxic substances	
		toxic by inhalation
		toxic by dermal or oral contact
	6.2 infectious substances	
Class 7 - radioactive material		
Class 8 - corrosive substances		
Class 9 - miscellaneous dangerous substances and articles		
	substances evolving flammable vapours	
	marine pollutants	
	lithium Batteries	
	fumigated units	

4.3 HazID evaluation

For the purpose of the FSA, a high-level analysis was performed. Hazards were identified with respect to safety (effect on human life) and property (effect on ship and cargo). Environmental damage is hard to assess for dangerous goods substances, however, it has also been considered associated with property damage.

During the HazID in total 59 hazards were identified with risk indices ranging from 3 to 9. A hazard was considered to be serious if the risk index (RI) was 7 or higher. The highest risk indices are distributed as follows:

- RI = 7: 6 hazards,
- RI = 8: 2 hazards
- RI = 9: 3 hazards

A comparison of the hazard judgements for conventional transport versus the open-top transport showed that in 13 cases, both options were judged to have the same level of risk. In 22 cases the risk index for conventional transport was higher that for open-top transport. In 24 cases the risk index for open-top transport was higher than for conventional transport.

The highest-ranked scenarios (based on their risk index) are compiled in Table 4. It can be observed that the highest-risk hazards relate to (sub-) classes 1, 2.1, 2.2, 2.3, 3, 4.1, 4.2, 5.1, 6.1, and 8 only.

Table 4: Scenarios with the highest Risk Index (RI)

RI	Substance/Class involved	Failure
9	2.2 non-flammable, non-toxic gases	gas leakage
9	2.3 toxic gases	gas leakage
9	4.3 substances which, in contact with water, emit flammable gases	exposure of material to water and / or humidity (packaging failure, green water shipped in seagoing conditions or rainfall, rupture of container)
8	2.1 flammable gases	gas leakage
8	2.2 non-flammable, non-toxic gases, subsidiary risk 5.1 (oxidizing substance)	gas leakage
7	3 flammable liquids, packing group II	leakage
7	4.2 substances liable to spontaneous combustion – packing group I	spontaneous ignition by itself after rupture of packaging/containment
7	5.1 oxidizing substances	leakage from damaged packaging (self-decomposition is possible, but is limited to special substances)
7	6.1 toxic substances, toxic by inhalation	leakage of packaging
7	8 corrosive substances	leakage of liquids
7	1.3/1.4 explosives (minor blast, minor projection hazard, fire hazard)	ignition

4.4 Comparison with conventional containership design

In 1995 a study was conducted by HSE on safety requirements for the safe transport of dangerous goods on containerships [12]. Requirements for both, the conventional and open-top stowage should be measured by the same standards. For this reason, open-top vessels have been evaluated and compared with conventional containerships. The study concluded that the open-top design is superior in almost all categories listed in Table 5. Experts involved in the HazID of this FSA did not support all ratings made in the study. In general they confirmed that fire fighting on open-top vessels is more efficient, due to the support of water spray systems inside the hold and the beneficial level from which extinguishing equipment can be applied (low stowage height with respect to deck-level). However, for large fires and explosions structural damages to the ship structure may be more likely.

Accidents that are associated with the accumulation of gases being heavier than air and leakage of liquids pose a higher threat.

Table 5: Comparison of containerships by selected features [12]

	Conventional on deck container positions (reference)	**Open-top container positions**	
		Design features	**Expert Rating (HazID)**
Access	reference	[lashing bridges], open hold	O
Supervision	reference	[lashing bridges], open hold	O-
Explosive Gas Mixtures	reference	Mechanical ventilation	-
Toxic Vapours	reference	Mechanical ventilation	-
Fire detection and fire protection	reference	Smoke detection system, sprinkler system, supplemental fire hoses, flooding of hold	+
Container securing	reference	Cell guides in and above hold	+
Container jettisoning	n.a.	n.a.	n.a.
Unobserved corrosion	reference	Detection, Sprinkler system, bilge/stripping system, damage stability	-
+ better ; +O better or equal; O equal; O- equal or worse; - worse			

5 Risk Assessment

5.1 Incident data analysis

Dangerous goods transport incident data for the 15-year period from 1993 to 2007 was obtained from the United States Office of Hazardous Materials Safety website for analysis. This data, collected through the Hazardous Materials Information System (HMIS), was considered to be the most comprehensive record of dangerous goods incidents available. Data from the HMIS included all incidents where there is a release or threat of release of dangerous goods.

In the United States, all "releases" or "threat of release" of dangerous goods (referred to as "hazardous materials") during transport must be reported for inclusion in the HMIS. Carriers of dangerous goods by road, rail, water, or air are required to report any unintentional release. Extensive information is reported for each event, including transport mode, transport phase, UN Number of the dangerous goods involved, name of the product, class, and consequences (including fatalities, injuries, evacuation requirements, etc.). Comments of the incident reporter are also included in a "remarks" field. Full details of the information reported are available in [2]. For this work, incident reports for 1993 to 2007 were assessed. During this 15-year period, approximately 16,000 incidents per year on average were reported to the system. The number of incidents of a dangerous goods release or threat of release reported for the water transport mode over this period is only about 11 per year (see Figure 10).

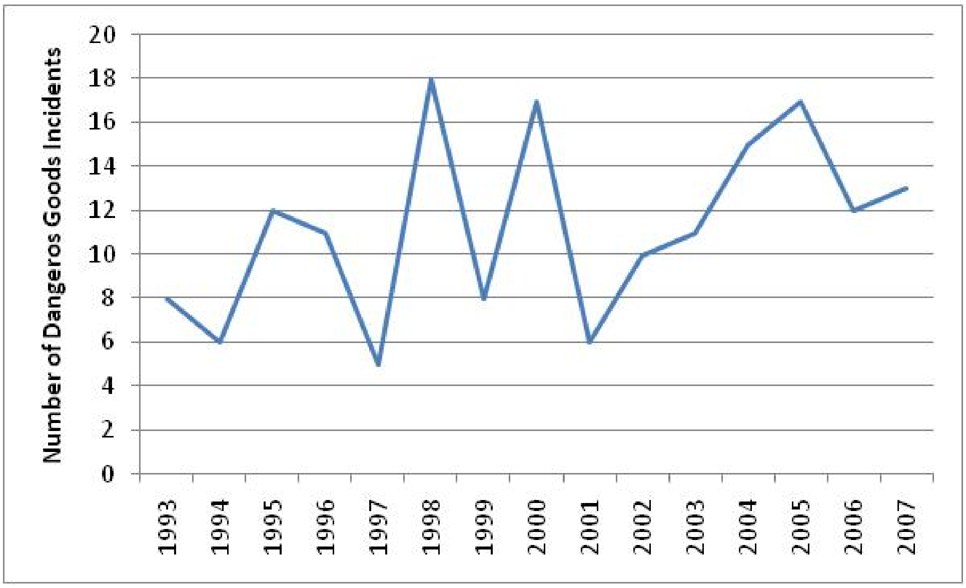


Figure 10: Dangerous Goods Transport Incidents (Release or Threat of Release) for the Water Transport Mode reported to the Hazardous Materials Information System (HMIS)

Figure 10 includes incidents that have occurred during loading, unloading, at temporary storage/terminal, or while the dangerous goods are en route. It also includes incidents for both ship and barge transport. If only dangerous goods in containers that are "en route" by ship are considered, the average is about seven incidents per year. Ship type was not provided in the database, although many of the incident comments include a mention of containers. All incidents occurring on barges and military vessels were excluded from the analysis. For 2005 to 2007, incidents reported for the water mode also include a significant number of cases where undeclared dangerous goods were reported, but there was no release or threat of release. These were not included in Figure 10 or Figure 11, and were not included in the estimates of release rates per ship year.

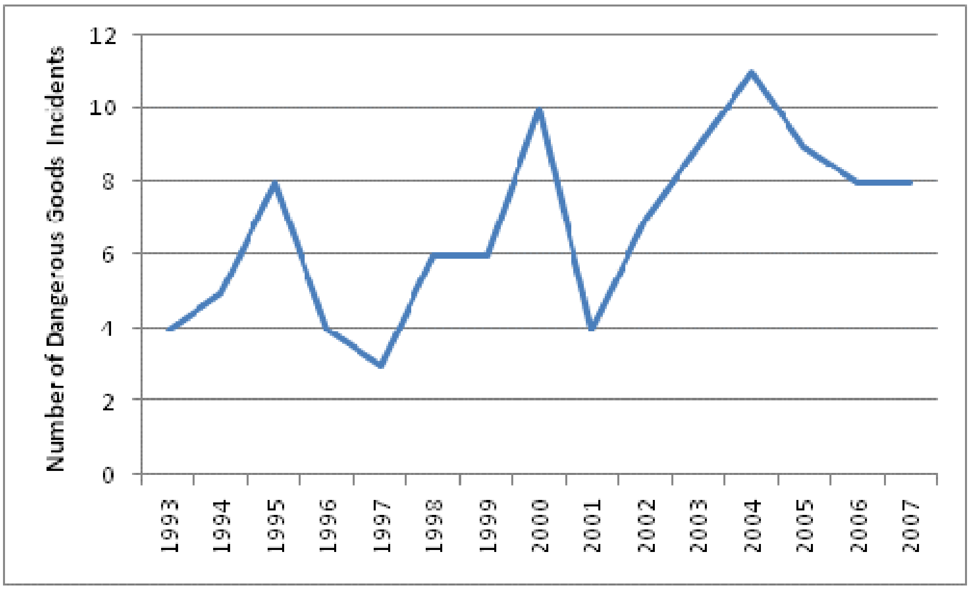


Figure 11: Dangerous goods incidents per year recorded in the HMIS database for "en route" containers in the water transport mode, 1993 - 2007

Dangerous goods incidents by dangerous goods class for the period 1993 to 2007 are shown in Figure 12 and Figure 13.

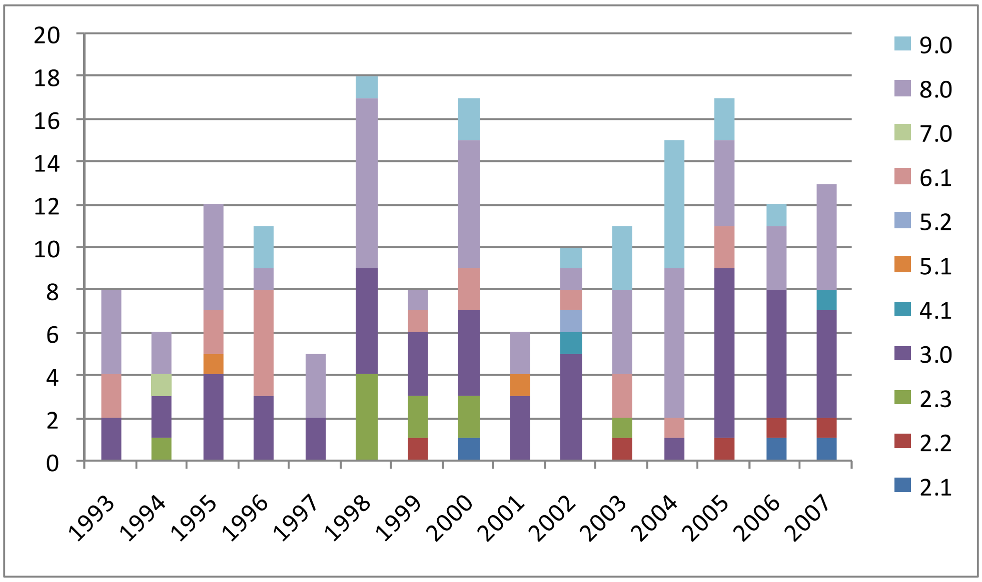


Figure 12: Dangerous goods incidents per year by class for the water transport mode (all transport phases), as recorded in the HMIS data base

Figure 12 shows all water transport mode incidents, including those that occurred during all transport phases – loading, unloading, temporary storage (at the terminal), and while the goods were en route.

Figure 13 shows just those incidents that involved release of dangerous goods while they were en route by ship.

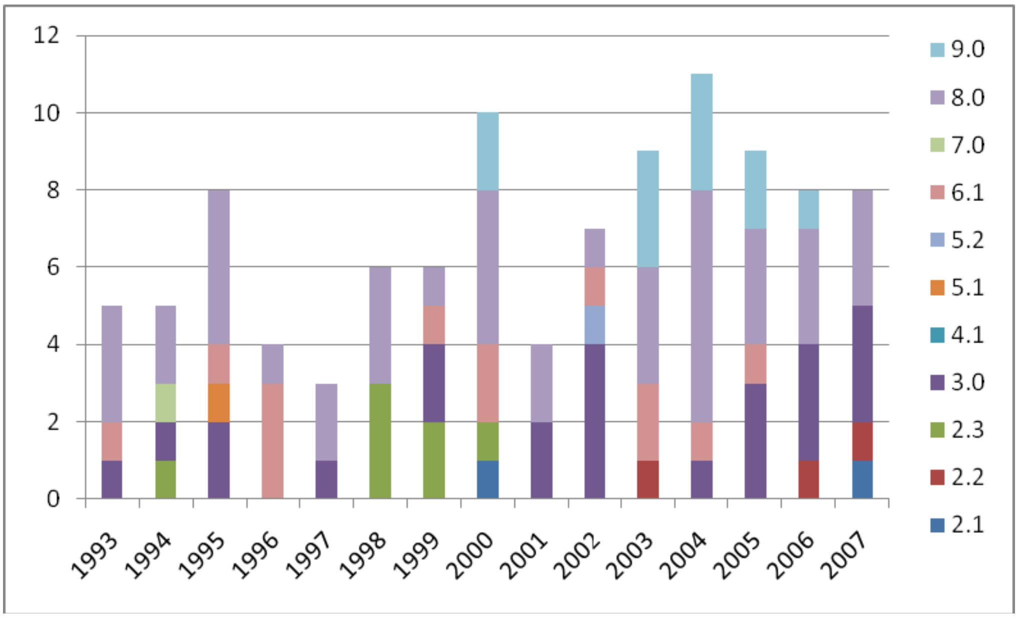


Figure 13: Dangerous goods incidents per year by class for the water transport mode ("en route" transport phase only), as recorded in the HMIS data base

The largest number of incidents were recorded for class 8 (41 incidents), class 3 (23 incidents), and class 6.1 (13 incidents). Class 3 (flammable liquids) and class 8 (corrosive substances) are the most frequently transported classes of dangerous goods.

5.1.1 Release rate frequency analysis

Dangerous goods are by definition substances that can cause damage or harm to humans, the environment, or infrastructure if released from their packaging. Thus, "release" was considered to be the most appropriate initiating event in the event trees for the classes of dangerous goods ranked highest in the hazard identification process. The HazID in section 4 identified "leakage", "packaging rupture", or exposure of material to water and/or humidity after packaging failure or rupture as the failure mode in scenarios that could result in fatalities or injuries.

The HMIS data was used as the basis to estimate a frequency for number of release incidents per dangerous goods class per ship year. Incident reports and written remarks for each dangerous goods release incident that occurred during the water transport mode were reviewed. Those that were obviously not containership incidents (occurring on barges or military vessels) or that did not occur during the en route transport phase (for example loading incidents caused by fork-lift operators, cranes dropping containers, etc.) were not included when calculating the release rate. There is the possibility that some of the incidents included were for containers on general purpose ships and not pure containerships, however, it is felt that this results in a conservative estimate of release frequencies. There was a total of 103 incidents reported to the HMIS over the 15-year period from 1993 to 2007, as shown in Table 2. An average number of incidents per year was estimated for each class using this data (see Table 6). These averages were used to estimate a frequency of incidents per class per ship year as follows:

$$\text{Incidents per ship year} = \frac{\text{avg. number of incidents per year}}{\text{avg. container vessel calls/yr. * avg. calls/container ship}}$$

where:

- *Avg. number of incidents per year* is from HMIS data for 1993 -2007 (US Incidents)
- *Avg. containerships calls per year* was estimated from US port call data for 1999 to 2006, to be 17,774 calls for all US ports (see Table 7)
- *Avg. calls/ containership* is estimated to be 84, using world containership port calls and world merchant fleet estimates for the period 2003 to 2006 (see Table 8).

For the years 2003, 2004, and 2005, containership calls at US ports were about 8 % of the containership calls at world ports. Thus the incident data considered is for a sample of approximately 8 % of all containership activity. The average size of vessels calling at US ports, however, is larger than the majority of open-top containerships, and this could be considered a limitation of the estimates. The HMIS data includes both Atlantic and Pacific ports, including containership calls at ports in Hawaii.

It should be noted that for many dangerous goods classes and sub-classes there were very few relevant incidents over the 15-year period considered. Only one incident was reported for classes 5.1 and 5.2, and there were no relevant incidents for class 4. This means that the incident frequencies for these classes would change significantly if even one more or one less incident was reported, and the certainty is low. Only class 6.1, class 8 and class 3 have a significant number of incidents to give confidence in the estimated release rate. The estimated release rates for other classes were still used, however, in the risk models, as it was the best data available for estimation purposes. It was felt that comparisons between different classes and ship types were still valuable, even though the certainty in the absolute value for classes with few incidents is low.

Table 6: Dangerous Goods Release Incidents by Class for En Route Ship Transport 1993 - 2007

Class	Total Incidents 1993 - 2007	Average per year (based on 1993 -2007)	Average Number of Incidents per ship year
2.1	2	0.133	0.00063
2.2	3	0.200	0.00095
2.3	7	0.466	0.00221
3	23	1.533	0.00726
4.1	0	0	0
4.2	0	0	0
4.3	0	0	0
5.1	1	0.067	0.00032
5.2	1	0.067	0.00032
6.1	13	0.867	0.00410
6.2	0	0	0
7	1	0.067	0.00032
8	41	2.733	0.01294
9	11	0.733	0.00347
All Classes	**103**	6.87	0.0325

Table 7: Containership Calls at US Ports 1999 – 2006 (data from [45] and [50])

	1999	2000	2001	2002	2003	2004	2005	2006	Avg.
Containership Calls	16,625	17,410	17,076	17,138	17,287	18,279	18,542	19,591	17,774
Avg. Containership Size per call (DWT)	36,586	37,784	39,656	42,158	43,168	43,610	44,593	46,598	41,769
Average TEU per Vessel per call	2,550	2,652	2,801	3,020	3,144	3,234	3,313	3,445	3,020

Table 8: Containership Calls at World Ports

	2003	2004	2005
Containership Calls at World Ports[1]	211,530	219,374	227,459
Average DWT per call[1]	32,462	33,248	33,985
Average TEU per call[1]	2,300	2,410	2,476
Number of containerships, world merchant fleet[2]	2,441	2,594	2,837
Average Number of Calls per Vessel (estimated)	87	85	80
Notes: [1] Data from [49]; [2] Data from [51]			

The same dangerous goods release incident frequency was used for both conventional containerships and open-top containerships. It was not possible to determine type of containership for the specific incidents reported in the HMIS. All incident reports were reviewed and the causes for the release incidents noted in the HMIS database were not considered to be dependent on vessel type. Many were related to packing faults, human errors with respect to filling containers and closing valves, securing within containers, and shifting of containers during heavy weather. Most of these causes originate on the land side of the transport chain, prior to loading on to the ship.

5.1.2 Estimate and comparison of average number of incidents per ship year

Table 6 shows an average number of 0.0325 dangerous goods incidents per ship year, for all ships combined. A containership operator involved in the project reports that approximately 2 dangerous goods incidents occur per year for a fleet of 44 containerships (of which 5 are open-top). Most of these incidents involved leakage of liquid. Two incidents per year for a fleet of 44 vessels yields an average of 0.045 incidents per ship per year, which is reasonably close to the estimate of 0.0325 incidents per year obtained as described above. It was therefore considered reasonable to use the estimates of incidents per ship year as shown in Table 6 for most classes. In the case of classes 4.2 and 4.3, where there were no incidents reported and the estimated frequency was zero, a higher frequency was assumed, as described in sections 6.6 and 6.7 of this report.

5.2 Common assumptions

In the risk modelling process and quantification of the event trees, some common assumptions were made to represent the generic containership. Some of the assumptions were as follows:

Number of crew and safety of life. The reference open-top vessel requires 12 to 15 crew members for safe manning. A total crew of 15 was used for the risk models. It is assumed that 3 shifts of crews are used in rotation throughout the year. Accident scenarios with single or multiple fatalities 1, 2, 3, 5, and 10 were included as outcomes in the event trees.

Risk models were constructed for each of the dangerous goods classes identified in the HazID as having a risk index of 7 or greater (see section 4.2 for the full list). Separate event tree models were constructed for both open-top containerships and conventional containerships. The same initiating event frequency was used for both conventional and open-top ships, and the same model structure was used for both, to allow comparisons. It was considered an important part of the analysis to be able to compare the relative risk of dangerous goods carried "on deck" on a conventional containership with carriage in an open-top hold of an open-top containership.

5.3 Risk models

5.3.1 Risk model – Class 2.1: Flammable Gases

Class 2.1, flammable gases, were assigned a risk index of 8 during the HazID FMEA session. There are 18 Class 2.1 gases which require on-deck stowage according to the IMDG Code [17]. Many of these are transported as refrigerated liquids. Consequences of a flammable gas release are explosion and fire, if there is an ignition source.

5.3.1.1 Sample accident cases and possible causes

There are only two incidents listed in the HMIS database for Class 2.1 during the 15 year period from 1993 to 2007. A summary of these is as follows:

- A tank containing petroleum gases, liquefied (Propane, UN 1075) broke loose in heavy weather and was damaged. There was no ignition, and the propane was pumped from the tank when the vessel arrived in port.
- A container loaded with lighters (UN 1057) from China was tested upon arrival at port and found to have a small quantity of flammable gas. The container was ventilated and packages were inspected. There was no evidence of damage to any of the packaging.

Possible causes for release of gas were also discussed during the HazID workshop and both internal (related to the specific gas receptacle) and external causes were identified for release of gas during transport. A simplified fault tree presentation of high level causes leading to release of a gas during transport is shown in Figure 14. This is also applicable to Class 2.2 and 2.3 gases.

5.3.1.2 Event tree model

The event tree for Class 2.1, flammable gases, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

<u>Probability of Initiating Event: Release of Class 2.1, Flammable Gas</u>: There were 2 events recorded in the Hazardous Materials Incident Report System (HMIRS) database during the period 1993 to 2007. The estimated probability of release is 0.00063 releases per ship year, as shown in Table 6.

<u>Crew is aware of a release before consequences occur</u>: It was assumed that crew would be aware of a release before consequences occurred in 60 % of the cases for goods stowed in the hold of an open-top containership. Releases of refrigerated gases may be quite apparent, but slow releases in non-accident situations (such as what has occurred with lighters packed in a container) would be difficult to detect. In cases with highly flammable gases, ignition may occur very shortly after a release. Where the release has been the result of a high-energy event such as collapse of a container stack ignition may also occur quickly. For on-deck stowage on a conventional containership, it was assumed that 70 % of the time a release would be detected.

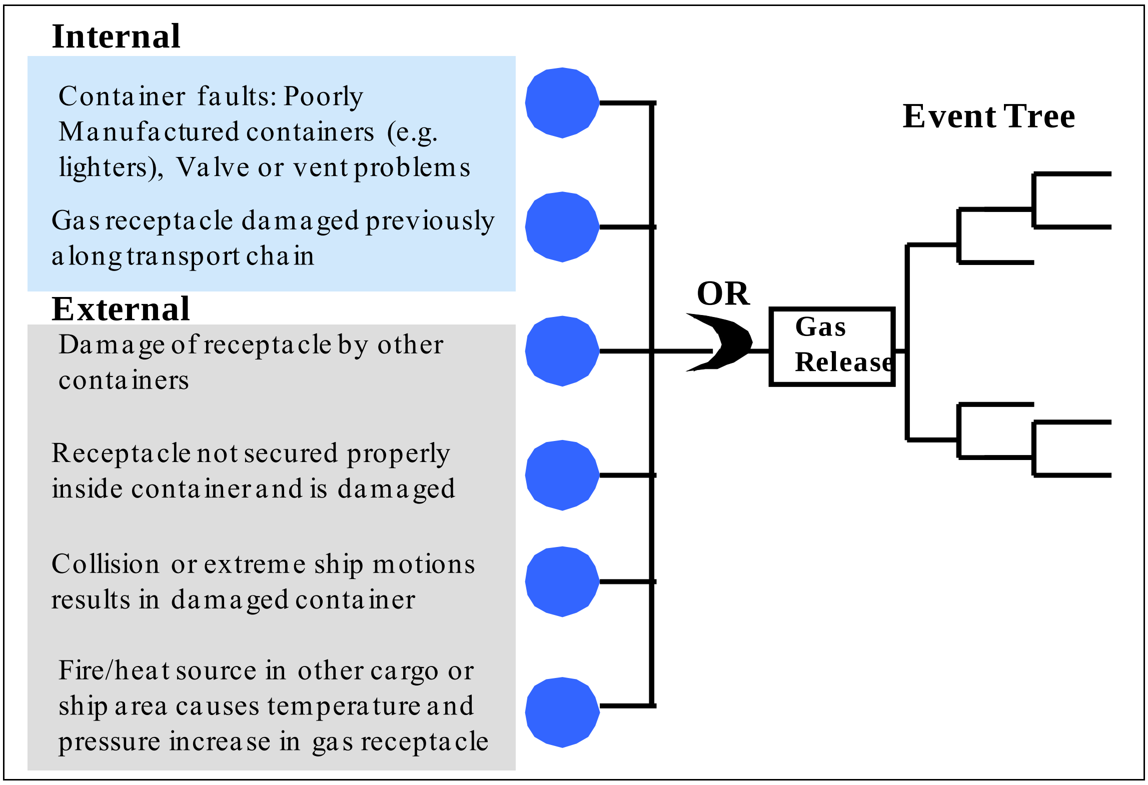


Figure 14: High level causes for release of gas.

Ignition occurs: For a fire to start after gas is released, there must be an ignition source. This could be a flame from a cigarette or welding activities, impact between hard metal to metal surfaces from hand tools such as hammers or from an object being dropped, lightening, or even from static electricity. Hydrogen, for example, is easily ignited with low-ignition energy, including static electricity. There can be immediate ignition from the incident causing the release (an impact event can result in sparks or a spontaneous release such as a rupture event may generate heat), or it can be a delayed ignition where a gas cloud drifts to an ignition source. Gas releases are generally more likely to be ignited than liquid releases due to the higher flash point of gases [1]. (Max 15 % for blowout occurring, from [1]). There is no standard probability used for probability of ignition given a release – it depends on a number of factors including rate of release and source of appropriate ignition source. Given that the event tree model is generic for all gases in Class 2.1, and intrinsically safe (non-sparking) electrical equipment is used on ships, an ignition probability of 10 % was used for cases where crew was not aware of a release. For cases where crew is aware of a release before any consequences occur, a probability of 5 % was used. The same probabilities were used for this branch for both conventional and open-top containerships.

Fire fighting measures are effective: Flammable gas fires are difficult to extinguish. It is assumed that for open-top containerships fire fighting measures would be easier for those containers that are at or below deck level, as there is a sprinkler system around the top of the hold and the potential to flood each hold. Therefore it was assumed that there was a 30 % chance of successful fire fighting for an open-top ship and a 10 % chance for on-deck stowage on a conventional ship.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: The SAFEDOR Cargo Safety – Qualitative Design Review report [40] stated that 32 % of reported fire/explosion reports occurred in port areas, 57 % occurred at sea, and 12 % were reported as "unknown". It was assumed that for most accidents in port areas that fire fighting assistance would be available quickly. A small percentage of fires at sea may also obtain assistance (the Sea-Land Mariner was assisted by the USS Wasp). The reference open-top vessel that was used in this work is not a large containership used for trans-oceanic voyages. For the event tree analysis it was assumed that in 50 % of the cases timely fire-fighting assistance can be obtained.

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged. The high probability was assumed because even in cases with severe fire and explosions, such as the Hanjin Pennsylvania, the vessel was eventually brought in to a port, although in this case it was declared a constructive loss.

Timely evacuation and rescue of crew possible: As for the question above, it was assumed that in most cases this would be possible. For all of the 26 fire/explosion in cargo area of containership accidents in the LMIU database investigated for the SAFEDOR containership risk analysis, the crew was rescued. However, it is conceivable that in some situations out at sea or in severe weather, or where fire has spread to the accommodation area, that not all crew may be rescued. With dangerous goods on board the fires are likely to progress more quickly, there is the potential for explosions, and crew may also be affected by toxic gases and smoke. It was assumed that timely rescue would be possible in 98 % of the cases.

5.3.2 Risk model – Class 2.2: non-flammable, non-toxic gases (no subsidiary risk)

Class 2.2, non-flammable non-toxic gases, requiring open deck stowage, were considered in two groups during the HazID work carried out in Task 4.8.1. The first group included those substances which had no subsidiary risk, and the second included substances which have a subsidiary risk of 5.1 (oxidizer).

The group of substances in Class 2.2 which did not have a subsidiary risk received a risk index rating (RI) of 9 and were considered together in one risk model. They included the following substances:

- Nitrogen, refrigerated liquid (UN 1977)
- Trifluoromethane, refrigerated liquid (UN 3136)
- Gas, refrigerated liquid, N.O.S. (UN 3311)

A *"refrigerated liquefied gas"* is defined by the IMDG as "a gas which when packaged for transport is made partially liquid because of its low temperature". Refrigerated gases are transported in insulated tank containers that do not have a refrigerator unit (no reefer containers are used). The tank containers used for refrigerated liquefied gases are vacuum insulated portable tanks. The gases are transported at very low temperatures to keep them in a partially liquid state – for liquid nitrogen the boiling point is -196°C, and trifluoromethane has a boiling point of -82°C. The pressure inside the container is almost the same as atmospheric pressure at the time that the container is filled with the liquid gas. During transport the cryogenic liquid warms up a bit and when a certain pressure is reached gas leaves the container through a relief valve. Because of this periodic release (venting) of gas on-deck stowage is required.

Potential effects of a release of Class 2.2 gases include personnel injuries or deaths due to suffocation because the gas replaces oxygen, and structural damage from the cryogenic liquid. Low temperatures can result in embrittlement and cracking of steel structures. There is also the potential for frostbite and serious skin burns if there is skin contact with the cryogenic fluid. Refrigerated liquid gases vaporise to very large volumes of cold gas (1 litre of liquid nitrogen yields 700 litres of gaseous nitrogen [5]). Although nitrogen is slightly lighter than air when at the same temperature, when the gas is colder it is heavier.

5.3.2.1 Sample accident cases and potential causes

The US HMIS data for 1993 – 2007 includes three relevant incidents with release of Class 2.2 gases. Two of them were related to venting. In one case the cold vapour caused the valve to freeze in the open position for a number of hours. It eventually re-seated by itself. The other case was also related to excessive venting (oxygen refrigerated liquid (UN 1073)). There were no injuries or consequences to the vessel in either case. The third case involved the loss of a container overboard during rough weather. Two of the incidents were for Class 2.2 gases with a subsidiary risk of 5.1, and the other was for a Class 2.2 gas with no subsidiary risk.

Causes noted in the HMIS database include normal venting from the tank and problems with the valve freezing in the open position. Other conceivable causes include overfilling of the tank, damage to the valve during loading or due to contact with other containers if there is shifting during rough seas. The internal and external causes identified during the HazID and shown in Figure 14 also apply to Class 2.2 gases.

5.3.2.2 Event tree model

The event tree for Class 2.2, non-flammable, non-toxic gases, with no subsidiary risk, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

Probability of Initiating Event: Release of Class 2.2, non-flammable, non-toxic gases: There were 3 events recorded for Class 2.2 in the HMIS database during the period 1993 to 2007. The estimated probability of release for Class 2.2 is 0.00095 releases per ship year, as shown in Table 6. This was divided between Class 2.2 with no subsidiary risk and Class 2.2 with a subsidiary risk of 5.1. As only one release was for those with no subsidiary risk, it was assigned an initial probability of 0.00032. Class 2.2, subsidiary risk 5.1 was assigned a probability of release of 0.00063.

Release is apparent to crew: It was assumed that 80 % of the time a release of refrigerated liquid gas would be apparent to the crew of a conventional containership. The same probability was assumed for open-top containerships. Because the gases are refrigerated, they will form a “fog” when released, due to condensation of water vapour in the air. Leakage from control valves, pipes, etc. should result in visible frost formation. Release of gas from a safety relief valve is often accompanied by a lot of noise. It was considered that about 80 % of the time the release of cryogenic liquid or of vapour would be apparent to the crew. When there is foggy, rainy, or cold weather, or where there is already significant frost build-up occurring on the ship, leakage or release of gas may not be apparent right away. A release would also not be apparent right away if it was quite small.

Release can be controlled: It is assumed that in most cases it is not possible for crew to contain the release of gas. For the few incidents that are noted in the HMIS database, there was no attempt made to control or check the venting of gas from the container. It was assumed that there would be a slightly higher probability of attempting to control the leak if the container was located on deck of a conventional containership, rather than below deck. A probability of 0.05 for controlling the release was assumed for conventional containerships, and 0.03 for open-top containerships.

Gas dissipates from hold (ventilation is effective): This branch statement is only applicable for gases carried in the hold of an open-top containership. For a slow rate of release, the ventilation system on the ship may be able to keep up and maintain a safe atmosphere in the hold. For a faster release, the air change may not be sufficient, especially given the potential size of the expanded gas cloud. This, however, wouldn’t be as much of a danger if the crew is aware of the risks and stays out of the hold until the area has been well ventilated. There is also the potential for the gas to enter other holds if the release is large, if the gas is cold and heavier than air, and if the container is at or above deck level. It was assumed that there was a 50 % probability of gas dissipating from the hold of an open-top containership when the crew is aware of the release and can start the ventilation system. A 20 % probability was assumed for cases where the crew is not aware of the release.

Gas temperatures/properties/release rates are such that structure is not damaged?: There were no cases in the HMIS database of structural damage resulting from the release of a refrigerated liquid gas. There is, however, the potential for the release of a cryogenic liquid to result in localised damage. The following probabilities were assumed for the open-top containership model:

- Where gas release is apparent to the crew, and the gas is effectively ventilated from the hold, a 10 % probability of damage was assumed
- Where gas release is apparent to the crew and the gas cannot be ventilated (due to size of release, limitations in ventilation), a 30 % probability of damage was assumed
- Where the release is not apparent (likely a smaller leak), and the gas dissipates from the hold, a 5 % probability of damage was assumed
- Where the release is not apparent and dissipation does not occur, a 20 % probability of damage was assumed.

For conventional containerships, it was assumed that there was a 10 % probability of damage for larger releases (those apparent to the crew), and a 5 % probability of damage for smaller releases that the crew was not aware of.

The following branch statements are only applicable for the event tree for the open-top containership:

Crew members stay out of hold when gas is at a dangerous level: When crew members are aware of the gas release, it was assumed that they would stay out of the hold or take appropriate precautions 97 % of the time. It is not common for crew members to enter the hold of an open-top containership during a voyage in any case. For cases where crew members are not aware of a gas release, it was assumed that they would stay out of the hold 95 % of the time.

Other crew members/rescuers use Self-Contained Breathing Apparatus (SCBA) during a rescue attempt: There are a number of documented accident cases where crew members or rescuers attempt to come to the aid of a fallen worker in an oxygen-poor atmosphere in a hold or confined space and also become accident victims. It was assumed that this also had the potential to happen in the hold of an open-top containership. For the case where the crew is aware of the gas release, it was assumed that this had a 5 % probability of occurring. For cases where the crew is not aware of the release, a 10 % probability was used.

5.3.3 Risk model – Class 2.2: non-flammable, non-toxic gases (subsidiary risk 5.1 (oxidizing substance))

Class 2.2, non-flammable non-toxic gases, requiring open deck stowage, that have a subsidiary risk of 5.1 (oxidizer) received a risk index rating of 8 in the HazID FMEA workshop. There are six gases in this category, as follows:

- Air, refrigerated liquid (UN 1003)
- Oxygen, refrigerated liquid (UN 1073)
- Nitrogen trifluoride (UN 2451)
- Compressed Gas, Oxidizing, N.O.S. (UN 3311)
- Liquefied Gas, Oxidizing, N.O.S. (UN 3157)
- Gas, refrigerated Liquid, Oxidizing, N.O.S. (UN 3156)

5.3.3.1 Sample accident cases and potential causes

There were three relevant incidents with release of Class 2.2 gases recorded in the US HMIS database for 1993 to 2007. Two of them were related to venting, as described in Section 6.2.1. There were no injuries or consequences to the vessel in either case. The third case involved the loss of a container overboard during rough weather. Two of the incidents were for Class 2.2 gases with a subsidiary risk of 5.1, and the other was for a Class 2.2 gas with no subsidiary risk.

Causes noted in the HMIS database include normal venting from the tank and problems with the valve freezing in the open position. Other conceivable causes include overfilling of the tank, damage to the valve during loading or due to contact with other containers if there is shifting during rough seas. The internal and external causes identified during the HazID and shown in Figure 14 also apply to Class 2.2 gases.

5.3.3.2 Event tree model

The event tree for Class 2.2, non-flammable, non-toxic gases, with subsidiary risk 5.1 (oxidizer), is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

<u>Probability of Initiating Event: Release of Class 2.2, non-flammable, non-toxic gases</u>: There were 3 events recorded for Class 2.2 in the HMIS database during the period 1993 to 2007. The estimated probability of release for Class 2.2 is 0.00095 releases per ship year, as shown in Table 6. This was divided between Class 2.2 with no subsidiary risk and Class 2.2 with a subsidiary risk of 5.1. As only one release was for those with no subsidiary risk, it was assigned an initial probability of 0.00032. Class 2.2, subsidiary risk 5.1 was assigned a probability of release of 0.00063, based on two releases.

<u>Release is apparent to crew</u>: It was assumed that 80 % of the time a release of refrigerated liquid gas would be apparent to the crew, as per the reasoning described in Section 6.2.2. The same probability was assumed for both conventional and open-top containerships.

<u>Release can be controlled</u>: It is assumed that in most cases it is not possible for crew to contain the release of gas. A probability of 0.05 for controlling the leak was assumed for conventional containerships, and 0.03 for open-top containerships. It was assumed that there would be a slightly higher probability of controlling a release with on-deck stowage because the tank would be more accessible.

<u>Ignition occurs</u>: It was assumed that there is higher probability of ignition if the release is not apparent to the crew. If it is apparent, they will stay away from the area and ensure that there are no possible sources of ignition and fuel. However, there is still a chance that it could occur due to reaction with oil, grease, etc. Oxidizers increase the intensity and risk for a fire, but are not flammable substances. For stowage in open-top container holds in cases where the crew is assumed to be aware of the release, it was assumed that there is a 0.05 probability that ignition and fire will occur. If they are not aware, it is assumed the probability will increase to 0.10. For on-deck stowage on conventional containerships, it was assumed that the probability of ignition when the crew is aware of the leak is only 0.025. This lower probability was assumed because there is less chance of gas accumulation. For cases where the crew is not aware of a leak, the probability of ignition was assumed to 0.10. Although there is less chance for gas accumulation with on-deck stowage, there is a higher chance of the presence of an ignition source due to more crew activity on deck.

For branches following after a "yes" to the ignition question:
<u>Fire is below deck in an open-top hold</u>: Approximately 70 % of the containers are stowed below deck, so a probability of 70 % was assigned. This question is relevant for effectiveness of firefighting measures. It is not applicable for goods stowed on deck of conventional containerships.

Firefighting measures are effective?: The following probabilities were assumed:

- Fire below deck in an open-top hold: 90 % chance of effectiveness, as the hold may be flooded with water.
- Fire above deck in an open-top hold: 80 % chance of effectiveness. Generally there are only three tiers above the open-top hold and the firefighting systems should be effective in most of these cases.
- Fire on deck in a conventional containership: 80 % chance of effectiveness, as the fire would initiate at deck level where the gas containers are stowed. If they were stowed higher in the stacks effectiveness would be lower.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: For the event tree analysis it was assumed that in 50 % of the cases timely firefighting assistance can be obtained (see discussion in Section 6.1.2).

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged (see discussion in Section 6.1.2).

Timely evacuation and rescue of crew possible: It was assumed that timely rescue would be possible in 98 % of the cases (see discussion in Section 6.1.2).

For branches following after a "no" to the ignition question:
The branch statements and probabilities are as for the release of a Class 2.2 gas with no subsidiary risk, as described in Section 6.2.2.

5.3.4 Risk model – Class 2.3: Toxic gases

Class 2.3, toxic gases, was rated with a Risk Index of 9 during the FMEA. There are many substances included in this class that require on-deck stowage (68 are listed in the IMDG Code [17]). Many of these have a subsidiary risk as well: Class 2.1 (flammable gas), Class 5.1 (oxidizing substance), or Class 8 (corrosive). Some are much lighter than air and some are much heavier. Some have a colour and strong odour, while others are colourless and odourless.

5.3.4.1 Sample accident cases and potential causes

There are seven relevant incidents involving Class 2.3, Toxic Gases, in the HMIS database for the period 1993 -2007. All involved ammonia anhydrous gas (UN 1005), which is a toxic and corrosive gas that is highly irritating to skin, eyes, and mucous membranes. A brief description of each incident is as follows:

- Relief valve failed on empty tank, resulting in slow release of residual gas. No injuries.
- Leak discovered at sea; crew members suited up with chemical suits but were unable to determine the cause of the leak because the gas cloud was obscuring visibility and they were unable to stop it. One crew member suffered slight freezer burns.
- No direct release but problems with faulty valve or gauge.
- Leak was identified from tank on deck - a shore based response team removed the tank from the vessel.
- Odour was noticed on the vessel while at sea. Land based response team met the vessel, re-sealed the valve, wrapped the valve and gauge, and removed the tank from vessel.

- Odour noticed while vessel was at sea. No noticeable leak was observed but the odour was strong so the area was closed off to crew for safety reasons. A hazmat team boarded the vessel at port and inspected the tank. One valve was found to be in the open position and this was considered to be the cause of the release.
- An odour was noticed to be coming from an empty tank containing residual gas while the vessel was at sea. The tank was removed by a response team at port.

As noted above, causes for release included faulty valves and valves set in the wrong position. The internal and external causes identified during the HazID and shown in Figure 14 also apply to Class 2.3 gases.

5.3.4.2 Event tree model

An event tree was constructed with branches for subsidiary flammability risk. This is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

<u>Probability of Initiating Event: Release of Class 2.3, Toxic Gases</u>: There were seven events recorded in the HMIS database during the period 1993 to 2007. The estimated probability of release is 0.0022 releases per ship year, as shown in Table 6.

<u>Release is apparent to crew prior to any crew consequences</u>: It was assumed that 70 % of the time a release of gas would be apparent to the crew of an open-top containership when the gas container is stowed in the hold. Because many of the gases are liquefied or refrigerated, they will form a “fog” when released, due to condensation of water vapour in the air. Others have a distinctive colour or odour. There are some, however, that are colourless and odourless and a slow release may not be noticed. Release of gas from a safety relief valve is often accompanied by a lot of noise. It was assumed that with a container stowed on the deck of a conventional containership, there would be a slightly higher chance of noticing the release before there were consequences, and a probability of 80 % was used.

<u>Release can be controlled</u>: It is assumed that in most cases it is not possible for crew to contain the release of gas. For the seven incidents that are noted in the HMIS database, there was only one attempt made by the crew to stop the release and this was unsuccessful. It was assumed that there would be a slightly higher chance of attempting to control the leak if the container was located on deck of a conventional containership, rather than below deck. A probability of 0.05 for controlling the leak was assumed for conventional containerships, and 0.03 for open-top containerships.

<u>Crew members exposed to gas in lethal concentrations on deck or in hold</u>: It was considered that there would be quite a low probability of this if the crew were aware of the release early. The HMIS database had no fatalities from the seven incidents registered. A probability of 0.1 % of lethal exposure was assumed if the crew was aware of the leak, and a 0.5 % probability was used if the crew is not aware of the release. For cases where the crew is not aware of the leak before human consequences occur, the leak would in most cases be very small.

<u>Gas has subsidiary class 2.1 or 5.1 and fire or explosion occurs</u>: Of 68 Class 2.3 gases requiring on-deck stowage, 23 (34 %) have a subsidiary risk of 2.1 (flammable gas) and 13 (20 %) had a subsidiary risk of Class 5.1 (oxidizing substance). Given a release, there needs to be a source of ignition (in the case of flammable gases), or an ignition source and presence of flammable materials for those substances with a subsidiary risk of an oxidizer. There would be a higher probability of fire or explosion occurring if the leak is not apparent to the crew. If it is apparent, they will stay away from the area and ensure that there are no possible sources of ignition. However, there is still a chance that ignition could occur due to reaction with oil, grease, etc. Probabilities for this branch of the tree were estimated as follows:

- Crew is aware of the leak: P = 50 % (percentage of goods with flammable or oxidizing properties) x 10 % (chance of ignition source) = 5 % overall chance of fire
- Crew is not aware of the leak: P = 50 % (percentage of goods with flammable or oxidizing properties) x 20 % (chance of ignition) = 10 % overall chance of fire

It was assumed that probabilities would be the same for an open-top or conventional ship. In the case of the open-top ship there would be less effective dissipation of gas, and with on-deck stowage there would be a higher chance of an ignition source, so it was felt that these two factors would balance and the probability of fire developing would be approximately the same for both ship types.

Firefighting measures are effective: Flammable gas fires are difficult to extinguish. Also, due to the toxic properties, crews would need to be wearing self-contained breathing apparatus which would make fire fighting more difficult. It is assumed that for open-top containerships fire fighting measures would be easier for those containers that are at or below deck level, as there is a sprinkler system around the top of the hold and the potential to flood each hold. Therefore it was assumed that there was a 30 % chance of successful firefighting for an open-top ship and a 10 % chance for on-deck stowage on a conventional ship.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: For the event tree analysis it was assumed that in 50 % of the cases timely firefighting assistance can be obtained (see discussion in Section 6.1.2).

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged (see discussion in Section 6.1.2).

Timely evacuation and rescue of crew possible: It was assumed that timely rescue would be possible in 98 % of the cases (see discussion in Section 6.1.2).

5.3.5 Risk model – Class 3: Flammable iquids

Class 3, Flammable Liquids, packing group II, received a risk index of 7 during the HazID FMEA workshop. Class 3 includes the following substances:

- flammable liquids
- liquid desensitized explosives

Class 3 substances include many fuels such as gasoline, kerosene, petrol, and diesel fuels, and in total more Class 3 substances are transported than any other class.

The IMDG Code groups Class 3 substances into three packing groups according to their flashpoint, their boiling point, and their viscosity, as follows:

Table 9: Class 3 Packing Groups (IMDG Code) [17]

Packing Group	Flashpoint in °C closed cup (c.c.)	Initial boiling point in °C
I	-	≤35
II	< 23	> 35
III	≥ 23 to ≤ 60	> 35

The flashpoint is the lowest temperature at which the vapour from a liquid can form an ignitable mixture with air. It gives an indication of the "risk of the formation of an explosive or ignitable mixture when the liquid escapes from its packaging" (IMDG Code, [17]). Thus those substances in packing group II have a higher risk of igniting upon release than those in packing group III.

5.3.5.1 Sample accident cases and potential causes

There were 23 relevant incidents involving Class 3, Flammable liquids, reported to the HMIS for the period 1993 -2007. Seventeen of these were for substances assigned to packing group I, five were assigned to packing group II, and one was assigned to packing group III.

A summary of some of the incidents recorded in the HMIS are as follows:

- Leak discovered coming from container with UN 1298 (trimethyl chlorosilane) while at sea. After unloading, the container was found to have a loose rupture disk flange. No injuries were reported.
- Resin solution (UN 1866) was found to be leaking from a tank container while the vessel was at sea. An emergency response team at port found a butterfly valve to be leaking, and cleaned a few litres of leaked product from the vessel deck.
- Overfilling caused some product to leak through dome cover of tank, due to expansion of product (1,3,5-Trimethylbenzene, UN 2325).
- Crew discovered a small leak of a few drops per hour from a container with UN 1993 (solvent). Container unloaded at next port, opened, and cleaned. No injuries.
- Acetone leak from valve that was left open.
- A slow leak of a few drips was discovered at sea and further investigated at port. One drum in the container was found to be leaking from a seam and was removed (UN 1993, flammable liquid N.O.S.).
- During discharge it was found that a container had been leaking. After opening the container one drum with a tear was found. The floor of the container was covered with liquid (UN 1993, flammable liquid N.O.S.). Clean up occurred at the port.
- Container loaded with UN 1263 (paint) was found to be leaking while the vessel was at sea. After emergency unloading at the next port of call the ship's deck and hatch cover were found to be covered with liquid. Drums within the container were found to have come loose and overturned.
- Release of diesel fuel from an air compressor inside a container. The release was discovered during unloading.
- Container found to be leaking a blue substance during unloading. It was found that inner liners of some drums had corroded and leakage had occurred. The vessel bay had to be cleaned, as did a number of containers (UN 1993, flammable liquid N.O.S.).
- Cargo tank container (UN 1919, methyl acrylate, stabilized) found to be leaking while en route. The crew used water to wash the leakage overboard during the rest of the voyage (leakage rate estimated to be one drip per minute). Container was unloaded at next port.
- Leaking fluid (UN 1866 (resin solution)) from a container discovered during unloading. Container was discharged for further investigation.
- Container was found to be leaking at sea and was opened by the crew to allow ventilation. The product was UN 1866 (Resin solution). Leaking drums were removed and clean up operations took place at port.
- Strong odour noticed to be coming from container on board a vessel. Container was opened at port and one leaking drum was found. It was stated that the drum liner may have failed or it may have been damaged during loading (UN 1993).
- A leak at a tank container discharge valve was discovered when the vessel was at sea (UN 1993). The crew contained the leak using absorbent and wrapped the valve with plastic to stop additional leaking.

- Leak discovered during unloading. Upon inspection at port a drum inside the container was found to be leaking (UN 1993).
- Leak discovered at a filler cap during an inspection. The leak had sealed itself as the leaked product was an emulsifier (UN 1993).
- Container (with UN 1123, butyl acetates) found to be leaking while vessel was at sea. Area was ventilated but further investigation and clean up could not be performed due to limited access.
- Leakage and odour was discovered at sea. Response personnel boarded the vessel to investigate the leak. Small amount of product was found to be leaking. Remediation plan put in place for when vessel berthed.
- Upon unloading, a drum was discovered to have leaked. Most of the product evaporated en route.
- One box found to be leaking (UN 1133, adhesives containing flammable liquid). A hazmat team cleaned up the spill and repackaged the product. No injuries.

A summary of the high level causes for the releases of Class 3 substances is shown in Figure 15.

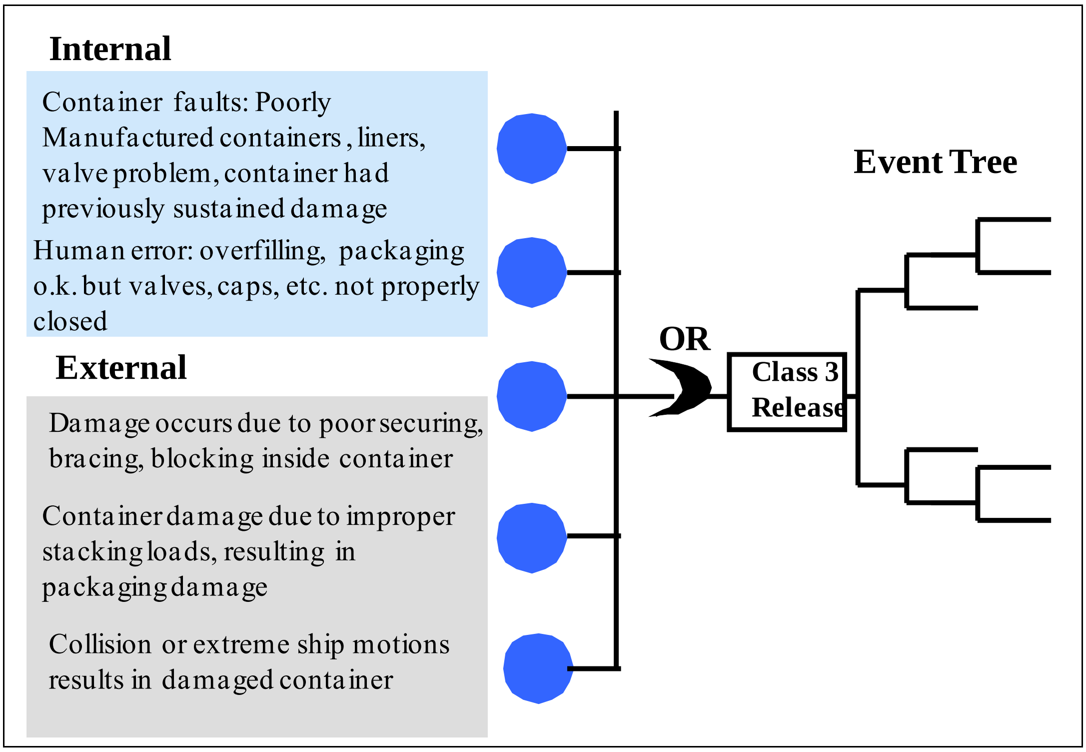


Figure 15: High level causes for release of Class 3 Flammable Liquids.

5.3.5.2 Event tree model

The event tree for Class 3, flammable liquids, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

Initiating event – probability of breach of packaging: A probability of 0.0073 Class 3 releases per ship year was estimated using data from the HMIS database, as shown in Table 6.

Release is apparent to crew prior to ignition and protective measures are taken: Twelve of the 23 incident reports noted that the leak was discovered at sea, seven noted the leak was first apparent during unloading, and for four cases it was not clear from the incident report when the leak was discovered. Leaks for containers stowed at or above deck level are more likely to be discovered during regular inspections. When leaks were discovered by the crew, actions such as flushing with water, application of absorbents, or ventilation were taken to prevent consequences. A probability of 60 % was assumed for discovery of leaks for cargo stowed on deck, and 40 % for containers stowed below deck level in open-top holds.

Ignition occurs: Ronza et al. [41] analyzed data from the US Marine Investigations Module (MINMOD) (Marine Casualty and Pollution Database) to estimate ignition and explosion probabilities of hydrocarbon spills. The MINMOD database includes data on maritime spills in general (not just dangerous goods transportation spills). The estimates of ignition, however, are based on a large number of spills and seemed to be the most applicable for estimating ignitions of flammable liquids. Ronza et al. [41] estimated an ignition probability of 0.02 for light fractions of hydrocarbons. Kerosene/jet fuel and diesel oil/gas oil were estimated to have ignition probabilities of 0.005 and 0.007. Given that these are packing group III substances with a flashpoint above 23° Celsius, it was deemed more appropriate to use the value of 0.02 (2 %) probability of ignition as estimated for "light fractions". This was used for event tree branches where crew members do not discover a spill in time to take precautionary measures. The probability of ignition occurring in cases where crew had discovered the leak was deemed to be low. None of the incidents in the HMIS dataset resulted in ignition. A 1 % chance of ignition was assumed in cases where the leak had been discovered. The same ignition probabilities were assumed for both conventional and open-top containerships.

Firefighting measures are effective (fire controlled?): Foam is the recommended firefighting agent for flammable liquids. Water application may be used to cool adjacent areas but may spread a flammable liquid and increase vapour production. Foam floats on flammable liquids and provides a seal against release of flammable vapours. Because water is not the most effective in fighting flammable liquid fires, firefighting effectiveness was estimated to be 40 % for fires in the hold of open-top containerships and 20 % for fires on deck.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: For the event tree analysis it was assumed that in 50 % of the cases timely firefighting assistance can be obtained (see discussion in Section 6.1.2).

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged (see discussion in Section 6.1.2).

Timely evacuation and rescue of crew possible: It was assumed that timely rescue would be possible in 98 % of the cases (see discussion in Section 6.1.2).

5.3.6 Risk model – Class 4.2: Substances liable to spontaneous combustion

Class 4.2, substances liable to spontaneous combustion, received a risk index of 7 during the HazID evaluation. Class 4.2 includes two groups of substances, which are defined according the IMDG Code as follows:

- "Pyrophoric substances, which are substances, including mixtures and solutions (liquid or solid), which, even in small quantities, ignite within 5 minutes of coming into contact with air. These substances are the most liable to spontaneous combustion; and
- Self-heating substances, which are substances, other than pyrophoric substances, which in contact with air without energy supply, are liable to self-heating. These substances will ignite only when in large amounts (kilograms) and after long periods of time (hours or days)."

The first group, pyrophoric substances, received a risk index of 7 during the HazID evaluation process and it is this group that is modelled by the event tree. There are 46 Class 4.2 substances that require on-deck stowage (SAFEDOR-D-4.8.1). Of these, 22 are pyrophoric substances. Many of these evolve flammable vapours when in contact with water.

5.3.6.1 Sample accident cases and potential causes

There were no incidents involving Class 4.2 substances reported in the HMIRS database for the period 1993 to 2007. There was an incident with a Class 4.2 fire on board the Kitano containership in Canadian waters in 2001. This incident involved active carbon pellets, which are self-heating substances, not pyrophoric substances (and they do not require on-deck stowage). There were no crew injuries as a result of this fire, but 15 containers suffered some degree of smoke, fire, or water damage. The vessel sustained only superficial damage to the coating on a hatch cover [44]. The possible cause of the fire is that the pellets self-ignited. They were being transported in packages that were less than 3 m^3 and thus were not declared as dangerous goods, which is in conformance with the regulations (carbon pellets of the type on the Kitano only need to be declared as Class 4.2 when transported in volumes greater than 3 m^3). For this incident, the crew fought the fire but it was not totally extinguished until the ship anchored in Halifax harbour and firefighters from a salvage company provided assistance.

5.3.6.2 Event tree model

The event tree for Class 4.2, substances liable to spontaneous combustion, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

Initiating Event Probability: There were no events recorded in the HMIS for this class for the period 1993 to 2007. It was, however, still considered a possibility to have an incident with Class 4.2 dangerous goods. As a conservative estimate, an incident probability of 0.00015 per ship year was used. This is equivalent to half of the frequency observed for Class 5.1 and 5.2 in the HMIS database (there was one incident during the 15-year period for each of these sub-classes). Class 4.2 pyrophoric substances require a high level of packaging (packing group I) and it is considered very unlikely that there would be a package failure and release.

Material Ignites: There is probably a 99 % chance that the substance would ignite, as the substances in this class ignite within 5 minutes after coming in contact with air. It is not considered likely that the crew could prevent an ignition, even if they were immediately aware of the release. The same probability was assumed for both on-deck stowage and stowage within an open-top containership hold.

Firefighting measures effective: For an open-top ship firefighting may be more effective in some cases as it is possible to flood the hold. For those substances that evolve flammable gases when in contact with water, however, an open-top hold may be a disadvantage if there is water that has accumulated in the hold. It was considered that in most cases, it is extremely difficult to extinguish fires with these types of substances, so the probability of effective firefighting measures was assumed to be 5 % for both conventional and open-top containerships.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: For the event tree analysis it was assumed that in 50 % of the cases timely firefighting assistance can be obtained (see discussion in Section 6.1.2).

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged (see discussion in Section 6.1.2).

Timely evacuation and rescue of crew possible: It was assumed that timely rescue would be possible in 98 % of the cases (see discussion in Section 6.1.2).

5.3.7 Risk model – Class 4.3: Substances which, in contact with water, emit flammable gases

Class 4.3, substances which, in contact with water, emit flammable gases, received a risk index of 9 during the HazID evaluation. There are 27 substances in this class which require on-deck stowage.

5.3.7.1 Sample accident cases and potential causes

There were no incidents involving release of Class 4.3 substances reported in the HMIRS database for the period 1993 - 2007. A recent case of the release and ignition of Class 4.3 substances occurred in January 2005 on the RoRo ship MS Schieborg. It was reported that the fire began when a trailer carrying calcium carbide overturned during heavy weather after a huge wave swept over the bow. The calcium carbide came in contact with water, reacted, and caught fire. The crew could not control the fire and were forced to abandon ship. All crew were rescued. Consequences included crew injuries, cargo damage, and vessel damage [10]. The vessel was eventually taken under tow and the fire extinguished after a number of days.

5.3.7.2 Event tree model

The event tree for Class 4.3, substances which, in contact with water, emit flammable gases, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

Initial probability: There were no events recorded in the HMIRS database for this class (similar to Class 4.2), during the period 1993 - 2007. However, as described above, there has been a recent incident with Class 4.3 goods on a RoRo ship, and it is considered possible that an incident could occur on a containership. As a conservative estimate, an incident probability of 0.00015 per ship year was used, the same estimate used for release of a 4.2 dangerous good.

Ignition occurs: The probability of Class 4.3 substances coming in contact with water after release would be quite high both on a conventional containership and an open-top containership. It was assumed that the probability would be slighter higher for substances carried in the hold of an open-top ship. A 95 % probability of ignition was assumed for an open-top vessel and a 90 % probability for on-deck stowage.

Firefighting measures effective: It was mentioned during the HazID expert workshop that there is no way to fight fires involving Class 4.3 using existing firefighting equipment on ships. Recommended emergency procedures for Class 4.3 call for the use of dry inert material for firefighting, or letting the fire burn. Water or foam should not be used for these fires. A firefighting effectiveness probability of 1 % was assumed for both on-deck stowage and stowage within the hold of an open-top containership. It was considered that fires involving small amounts of the goods could potentially be controlled on board a ship, as there are small amounts of dry chemical extinguishers.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: For the event tree analysis it was assumed that in 50 % of the cases timely firefighting assistance can be obtained (see discussion in Section 6.1.2).

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged (see discussion in Section 6.1.2).

Timely evacuation and rescue of crew possible: It was assumed that timely rescue would be possible in 98 % of the cases (see discussion in Section 6.1.2).

5.3.8 Risk Model – Class 5.1: Oxidizing substances

Class 5.1, oxidizing substances, received a risk index of 7 during the HazID evaluation. There are 27 substances in this class which require on-deck stowage. According to the IMDG Code, Class 5.1 can be described as substances which, “in certain circumstances directly or indirectly evolve oxygen. For this reason, oxidizing substances increase the risk and intensity of fire in combustible material with which they come into contact.”

5.3.8.1 Sample accident cases and potential causes

Calcium hypochlorite, a Class 5.1 substance, is considered to be particularly dangerous and has been identified as the cause of some very large accidents, as follows:

- DG Harmony fire in 1998, which resulted in the constructive loss of the vessel and loss of almost all cargo. The crew was forced to abandon ship. The calcium hypochlorite was being carried in accordance with the IMDG regulations at the time: they have since been amended. The fire was caused by a rise in temperature during the voyage and it was determined that the product should be carried at a lower temperature.
- CMA Djakarta fire and explosion in 1999 that resulted in extensive damage to the ship and its cargo. The crew was forced to abandon the vessel.

Calcium hypochlorite is suspected by some to be the cause of the fire on the Hanjin Pennsylvania, although this has not been formally confirmed. This accident resulted in the deaths of 2 crew members, extensive damage to the vessel and destruction of about 50 % of the containers by fire and explosion [52]. Calcium hypochlorite was also suspected to be part of the cause of the fire on the Sea Elegance, a refrigerated modular containership. This accident (fire) resulted in the loss of life of one crew member and the total loss of the ship and its cargo.

The International Group of P & I Clubs lobbied for changes to the IMDG Code to require stricter handling and carriage procedures for calcium hypochlorite. When they felt that the IMO regulations did not incorporate all of their key recommendations, they recommended additional restrictions [43].

The HMIS has one incident report on record for Class 5.1 during the period from 1993 to 2007 (this is only for US waters). A leak of hydrogen peroxide was discovered after the container was unloaded. Clean up operations occurred on land. The causes for the leak were determined to be an opened discharge valve in a security flange, overloaded tank, and loose bolts in the manhole.

5.3.8.2 Event tree model

The event tree constructed for Class 5.1, shown in Appendix A.4, portrays a series of events beginning with breach of packaging and release of substance. For some substances, such as calcium hypochlorite, decomposition can occur within the package itself, resulting in temperature rise and further decomposition. The end result can be explosion and fire. This is what occurred during the DG Harmony incident. The expert group within the HazID workshop identified leakage from damaged packaging as the primary case to consider, so that is what was modelled in the event tree for Class 5.1. Probabilities estimated for each branch of the event tree are as follows:

Initiating event – probability of breach of packaging: A probability of 0.000316 per ship year was estimated using data from the HMIS database, as shown in Table 6.

Fire with or without explosion occurs: Information on probability for a fire or explosion given a release was not found, so a probability of 50 % was used for both on-deck stowage and stowage in the hold of an open-top containership.

Fire fighting measures effective: Experts in the HazID workshop stated that fire fighting on an open-top containership would be superior for these types of substances, as water is an effective medium and the container hold can be flooded. An 80 % probability of effectiveness was assumed for open-top containerships and a 30 % effectiveness was assumed for conventional containerships when goods are stowed on deck.

For the following branches, the same values were assumed for both conventional vessels and open-top vessels:

Firefighting assistance from other vessels or land possible to control the situation: For the event tree analysis it was assumed that in 50 % of the cases timely firefighting assistance can be obtained (see discussion in Section 6.1.2).

Fire extinguishing / vessel towing possible: It was assumed that in most cases (95 %) the fire would eventually be brought under control and the vessel towed and salvaged (see discussion in Section 6.1.2).

Timely evacuation and rescue of crew possible: It was assumed that timely rescue would be possible in 98 % of the cases (see discussion in Section 6.1.2).

5.3.9 Risk Model – Class 6.1: Toxic substances, toxic by inhalation

Class 6.1 toxic substances, toxic by inhalation, received a risk index of 7 during the HazID evaluation. Class 6.1 consists of substances that are toxic by inhalation, by dermal contact, or if swallowed. There are 108 substances in this class which require on-deck stowage, all of which are toxic or highly toxic by inhalation. A few may react with water or steam and evolve a toxic gas. Some evolve toxic vapours that are heavier than air.

5.3.9.1 Sample accident cases and potential causes

There are 13 incidents recorded in the HMIS for the period 1993 -2007 for en route water transport of Class 6.1 substances. A brief description of each is as follows:

- Leakage noted to be coming from one container while vessel was at sea. Leakage stopped after one day, and leaked material had been washed overboard. Upon arrival at port, the container was unloaded and opened and a ruptured, empty drum was found (UN 1897 tetrachloroethylene).

- Container was noted to be leaking while the vessel was at sea. The crew took steps to prevent spread of the leaked material. Upon arrival, hazmat response team found that a crate had shifted and pushed against a drum, and a nail from the crate punctured the drum (UN 2810, poisonous liquids NOS).
- Leakage observed at sea from two containers containing drums of cresols (UN 2076). Crew used respirators while investigating and placing bucket under one leak. Further investigation and clean up was done at port.
- Spill discovered after container had been unloaded at harbour. The container flooring had been contaminated (Phenetides (UN 2311)).
- Spill discovered after container had been removed from the ship. Leakage had occurred from a few drums – one had been overfilled and was leaking from a cap, others were leaking from seams. Material had not spilled on to the ground (and none had likely spilled onto the ship).
- Spill discovered at sea. A drum of UN 2078 (Toulene Isocyanate) was found to be leaking (puncture). The vessel returned to port for clean up procedures.
- A release of chloral anhydrous inhibit occurred (no details of leak provided).
- A tank containing UN 2281 (Hexamethylenediisocyanate) was found to be leaking at a discharge valve. Container discharged at next port for repairs. No damage to vessel, personnel, or port property.
- A small leak was discovered by the crew while en route from South Africa to New York. About 15 litres of UN 1143 (Crotonaldehyde, stabilized) leaked from a tank. The cause was suspected to be overfilling. It was suspected that the cargo expanded when the ship moved into warmer areas. The product was released from a relief valve and dripped on to the deck. The crew contained the spill until the vessel reached anchorage and a hazmat team assessed the situation.
- Crew noticed odour in the vicinity of five containers loaded with UN 3018 (Organophosphorus pest. liq.). All containers had to be unloaded and searched to find the damaged packages. Most of the spilled material had been absorbed by other materials within the container.
- A tank loaded with dichloromethane (UN 1593) was noticed to be venting by the crew (noise alerted the crew). The venting continued for 10 hours and the spill was managed by a response team at port.
- Leak of toxic solid, inorganic, N.O.S. (UN 3288). No other details.

Three of the thirteen incidents involved dangerous goods that require on-deck stowage. There were no injuries or deaths associated with any of the incidents.

5.3.9.2 Event tree model

The event tree for Class 6.1, toxic substances, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement.

<u>Initiating Event</u>: An initial release frequency of 0.0041 was estimated for the release of 6.1 toxic substances using HMIS data, as shown in Table 6. This was based on 13 incidents. Only three of these incidents involved goods that require on-deck stowage. A probability of release of just those goods that require on-deck stowage was estimated as follows:
P (on deck class 6.1) = 0.0041 x 3/13 = 0.000947

<u>Release is apparent to the crew</u>: It was assumed that the release would be apparent 60 % of the time for substances stowed on deck in a conventional containership, and 30 % of the time for goods stowed in the hold of an open-top containership.

<u>Release can be controlled</u>: Some of the incidents described in the HMIS involved leakage from drums inside sealed containers. These leakages were not discovered until after the container had been unloaded.

For 3 of the 10 releases discovered at sea, the crew was able to control the leak without sustaining injuries. It was estimated that a release could be controlled 30 % of the time on a conventional containership, and 10 % of the time if the container was in the hold of an open-top containership.

Crew members exposed to toxic fumes for a time and concentration combination that could cause fatality: None of the 13 incidents in the HMIRS database resulted in a fatality, so it was assumed that the probability of exposure sufficient to result in a fatality would be quite low. A probability of 0.1 % was assumed for cases where the crew was aware of the release. For cases where they are not (the leaks would be likely be small if they are not aware), a probability of 0.2 % was assumed.

5.3.10 Risk Model – Class 8: Corrosive substances

Class 8 is the designation for corrosive substances, which means "substances which, by chemical action, will cause severe damage when in contact with living tissue or, in the case of leakage, will materially damage, or even destroy, other goods or the means of transport" (IMDG Code). There are about 71 Class 8 substances that require on-deck stowage listed in the IMDG Code, [17]. Some of these have a subsidiary risk such as Class 3, Class 4.2, Class 4.3, Class 5.1 and Class 6.1. Some of the substances are highly corrosive to metals in the presence of water and some evolve toxic gases when in a fire. Because of the large number of substances and the range of subsidiary risks, a fairly generic high level event tree model was constructed for Class 8.

5.3.10.1 Sample accident cases and potential causes

The US HMIS includes 41 relevant incidents with release of Class 8 while the vessel was en route, during the 15 year period from 1993 to 2007. There were more incidents for this class than for any other during the period. A summary of the main causes provided for the releases is as follows:

- drum was overhanging pallet, weight caused crease in drum and hole resulted
- loose closure on drum
- product container loaded upside down
- loose bolts at discharge valve
- improperly secured package overturns, leaks through vent closures
- pressure relief valve improperly adjusted, leaking through valve
- overfilling, leaks from tank overflow valve
- loose flange by manhole cover (human error), corrected by tightening bolts
- loose nut at discharge gasket
- loose caps on "tote" containers (350 gallon size)
- defective "O" ring valve on hazardous cargo totes (empty with residual)
- leaking from valve that was not properly tightened
- leaking from tote container where "O" ring wasn't seated in discharge valve handle
- hazardous material package punctured by sharp protrusion on container wall (loading error)
- temperature increase and vessel movement results in liquid leaks from container overflow valves
- failure of tank valve gasket
- valve on tank top inadvertently left open (human error)
- buckling of container structure and frame resulted in tear in container, damage to packaging, and release of dangerous goods (phosphoric acid)
- leaking from damaged O-ring on tank valve assembly
- improper packing of container: no buffering between stacked pallets (sodium hydroxide solid)
- improper loading, blocking and bracing caused rupture of bags of sodium hydroxide solid
- hold down bolts on tank relief valve were loose
- pails were dislodged from pallet during ocean voyages and pinched between container wall and pallets

- blocking and bracing loosened during voyage, drums overturned and were damaged
- drum punctured by nail in floor of container due to transport vibration
- drum rubbed against side of container during transport, rupture occurred
- pail punctured by bolt protruding from side of container
- inappropriate packaging used for acid (non-compliance with regulations).

There were no serious consequences for human life for any of the recorded incidents, although some resulted in substantial clean up operations and delays. There were also some releases that resulted in corrosion to the vessel.

A summary of the high level causes resulting in release of Class 8 substances is shown in Figure 16.

5.3.10.2 Event tree model

The event tree for Class 8, corrosive substances, is shown in Appendix A.4. Probabilities for each of the various branch points along the event tree were estimated based on available data or subjective assumptions, and are described below for each branch point statement:

Initiating Event: release of Class 8 substance: An initial release frequency of 0.0129 was estimated for the release of Class 8 corrosive substances using HMIS data, as shown in Table 6. This was based on the occurrence of 41 incidents over a 15-year period.

Release source is apparent to crew: Three out of 41 releases, or about 7 %, had a volume of more than 100 gallons (378 litres). Ten out of 41, approximately 25 %, had a total release volume of more than 100 litres. About 26 releases, approximately 63 %, were noted to have been discovered on the vessel. For containers stowed in the hold of an open-top containership, it was assumed that it was less likely that a leak would be discovered by the crew (as compared to on-deck stowage). Based on this, it was assumed that releases were apparent to the crew about 30 % of the time for open-top containerships, and 60 % of the time for containers stowed on deck for conventional containerships. Incident report descriptions in the HMIS database show cases with relatively large releases where it was still difficult to identify the source of the release and only after containers were unloaded was the specific container identified.

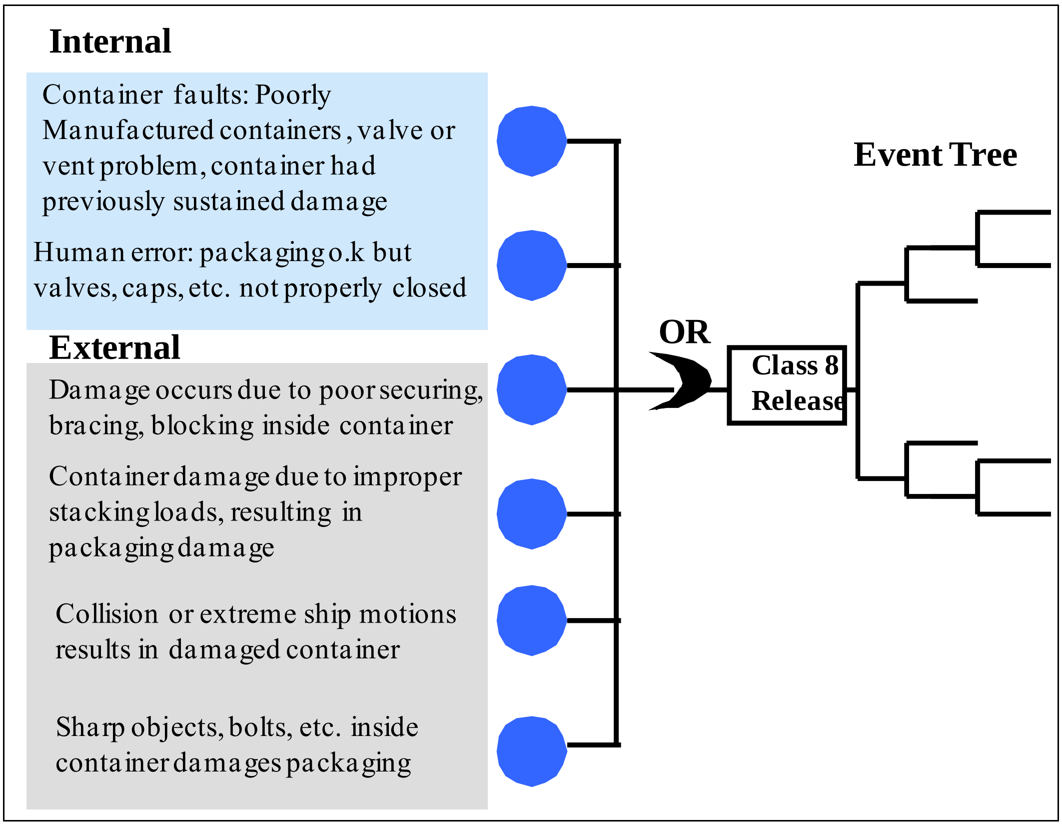


Figure 16: High level causes for release of Class 8 Corrosive Substances.

<u>Release can be controlled/contained</u>: The 41 incident reports in the HMIS report include 13 cases (30 %) where actions were described to be taken at sea by the crew to control and confine the leak. Therefore a probability of 30 % was used in the event tree for conventional containerships, and a probability of 20 % was assumed for leaks in the hold of an open-top containership, where it may be more dangerous to enter due to vapours and fumes. The most common measure of control noted in the HMIS reports was application of absorbent materials and booms to the spill area, and roping off the area to ensure the safety of the crew. There were no injuries reported to result from crew actions to contain the spill. For most cases, final clean-up was completed while in port using contractors and emergency response teams. One of the more serious incidents, a release of monochloroacetic acid that was giving off a fog-like vapour, required a number of emergency response teams using self-contained breathing apparatus and working in half-hour shifts to unload the containers and investigate the spill. It took four days to unload the affected containers and decontaminate the area.

<u>Crew member has contact with materials that is sufficient to cause fatalities</u>: Both contact time and material properties must be such that a fatality can occur. There are no fatalities recorded in the HMIS database from release of Class 8 materials on board ships. Given that some of the materials give off very corrosive vapours when evaporating or could release toxic gas if involved in a fire, there is a potential for fatalities to occur as the result of a Class 8 material release. It was assumed that there was a 0.1 % chance for a crew member to have enough contact with a Class 8 material to result in a fatality. In a relative context, there is likely a greater chance that crew will have some contact with spilled material if it is on deck, but the likelihood of serious contact is probably higher in the hold of an open-top containership. It was felt that these two differences were comparable and therefore the same probability was used for both transport conditions.

5.4 *Risk Summation*

5.4.1 Human safety – PLL and individual risk (crew members)

Risk figures estimated from the risk model described in previous sections are summarised in tables 6 and 7. The potential loss of life (PLL) figures were calculated by summing the probability of each final event multiplied by the expected number of fatalities for each event. Expected number of fatalities for each scenario is shown in the rightmost column of the event trees (shown in Appendix A.4). The PLL figures are an estimate of the expected average number of fatalities per ship year for each of the analysed dangerous goods release scenarios.

From the point of view of an individual crew member, the expected probability per year to be killed by a specific dangerous goods release scenario is expressed by the individual risk figures. The individual risk figures are derived from the PLL figures taking into account the total number of crew members on board. The individual risks tabulated above are based on an assumed crew of 15 and a work organisation where three shifts of crew alternate to operate the ship continuously.

Table 10 summarises the risks for carrying goods requiring on-deck stowage in the holds of open-top containerships (possible future operational scenario). Table 11 summarises the risks for carrying the dangerous goods on deck on conventional containerships (the current situation).

Table 10: Summary of PLL and individual risk for crew members for carrying dangerous goods requiring on-deck stowage in the holds of open-top containerships

	From Fire		From toxicity, etc.		Total	
Dangerous Goods Class	PLL Crew Per Ship Yr	Individual Risk Crew	PLL Crew Per Ship Yr	Individual Risk Crew	PLL Crew Per Ship Yr	Individual Risk Crew
Class 2.1	3.23E-05	7.17E-07	0.00E+00	0.00E+00	3.23E-05	7.17E-07
Class 2.2, no subs. risk	0.00E+00	0.00E+00	6.63E-06	1.47E-07	6.63E-06	1.47E-07
Class 2.2, subs. risk 5.1	2.48E-06	5.50E-08	1.23E-05	2.74E-07	1.48E-05	3.29E-07
Class 2.3	1.01E-04	2.24E-06	3.32E-06	7.37E-08	1.04E-04	2.31E-06
Class 3	9.67E-05	2.15E-06			9.67E-05	2.15E-06
Class 4.2	7.24E-05	1.61E-06			7.24E-05	1.61E-06
Class 4.3	7.24E-05	1.61E-06			7.24E-05	1.61E-06
Class 5.1	3.47E-07	7.71E-09			3.47E-07	7.71E-09
Class 6.1			1.58E-06	3.51E-08	1.58E-06	3.51E-08
Class 8			1.21E-05	2.69E-07	1.21E-05	2.69E-07
Total	3.77E-04	8.38E-06	3.60E-05	8.00E-07	4.13E-04	9.18E-06

The total PLL from all causes for open-top containerships carrying on-deck stowage dangerous goods in open holds is 4.13 E-04. This includes fire, asphyxiation, and exposure to toxic substances. The total individual risk to a crew member is 9.18 E-06. The total PLL from all causes for dangerous goods carried on deck for conventional containerships is 3.82 E-04, which is only slightly lower, but not significantly different. The total individual risk to a crew member is 8.49 E-06. The PLL for both ship types is dominated by scenarios which result in fatalities from fire. PLL for crew by asphyxiation and exposure to toxic substances was estimated to be twice as high for stowage in open-top container positions as compared to on-deck stowage. Both ability to detect a gas release and dispersion of gas were considered to be better with on-deck stowage. Operational measures such as required ventilation and monitoring for gases prior to entering a hold could reduce the risk for stowage in the open-top hold positions.

Class 2.3, toxic gases, had the highest PLL for both on-deck stowage and stowage in the hold of an open-top containership. Class 3, flammable liquids, had the next highest PLL for both stowage cases, followed by Class 4.2, substances liable to spontaneous combustion, and Class 4.3, substances which, in contact with water, emit flammable gases. During the HazID workshop, the scenarios that received the highest risk index were for release of the following: Class 2.2, non-toxic non-flammable gases; Class 2.3, toxic gases; and Class 4.3, substances which, in contact with water, emit flammable gases. For the risk analysis, however, Class 2.2 (no subsidiary risk) had a relatively low estimated PLL estimated for both stowage cases. The average number of incidents estimated per year for this class was very low, and thus the estimated PLL was also low.

Table 11: Summary of PLL and individual risk for crew members for dangerous goods carried on deck of conventional containerships

	From Fire		From toxicity, etc.		Total	
Dangerous Goods Class	PLL Crew Per Ship Yr	Individual Risk Crew	PLL Crew Per Ship Yr	Individual Risk Crew	PLL Crew Per Ship Yr	Individual Risk Crew
Class 2.1	2.94E-05	6.52E-07	0.00E+00	0.00E+00	2.94E-05	6.52E-07
Class 2.2, no subs. risk	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Class 2.2, subs. risk 5.1	2.55E-06	5.67E-08	0.00E+00	0.00E+00	2.55E-06	5.67E-08
Class 2.3	1.17E-04	2.61E-06	2.24E-06	4.97E-08	1.20E-04	2.66E-06
Class 3	7.65E-05	1.70E-06			7.65E-05	1.70E-06
Class 4.2	7.24E-05	1.61E-06			7.24E-05	1.61E-06
Class 4.3	6.86E-05	1.52E-06			6.86E-05	1.52E-06
Class 5.1	1.22E-06	2.70E-08			1.22E-06	2.70E-08
Class 6.1			1.16E-06	2.57E-08	1.16E-06	2.57E-08
Class 8			1.06E-05	2.35E-07	1.06E-05	2.35E-07
Total	3.68E-04	8.18E-06	1.40E-05	3.10E-07	3.82E-04	8.49E-06

5.4.2 Comparison of fire PLL for crew

Open-top containerships are considered to have superior fire detection and fire protection systems, according to Hengst and Molenaar [12] and as agreed by experts at the HazID workshop.
The risk models, however, showed a slightly higher PLL by fire for open-top ships. Table 8 shows the PLL from fire for both ship types.

Open-top containerships had a slightly higher PLL from fire for Class 3. They had a much lower PLL for Class 5.1. For other classes and sub classes investigated, both open-top and conventional containership carriage on deck had PLL for fire that was the same or close to the same. For Class 3, it was considered to be more difficult to discover a leak for goods carried in the hold of an open-top containership, and fire fighting for Class 3 flammable liquids should be carried out using foams rather than water. Thus, the fire fighting advantages associated with open-top vessels would not be helpful for this class unless foam fire fighting agents could be used. It was considered that Class 5.1 fires would be easier to control in an open-top ship where the hold could be flooded. Class 4.3 showed a slightly higher PLL for carriage in an open-top hold. Class 4.3 substances emit flammable vapours on contact with water, so it was considered that there was a higher probability of ignition for goods carried in an open-top hold.

Table 12:. Comparison of PLL (for crew members) resulting from carriage of goods requiring on-deck stowage in the holds of open-top containerships vs. on-deck stowage on conventional containerships

Dangerous Goods Class	PLL From Fire (PLL crew per ship year)	
	Open-top container ship	Conventional container ship
Class 2.1	3.23E-05	2.94E-05
Class 2.2, no subsidiary risk	0.00E+00	0.00E+00
Class 2.2, subsidiary risk 5.1	2.48E-06	2.55E-06
Class 2.3	1.01E-04	1.17E-04
Class 3	9.67E-05	7.65E-05
Class 4.2	7.24E-05	7.24E-05
Class 4.3	7.24E-05	6.86E-05
Class 5.1	3.47E-07	1.22E-06
Class 6.1		
Class 8		
Total	3.77E-04	3.68E-04

Note: Class 3, highlighted blue, shows a moderate difference in PLL for the two types of containerships. Class 5.1, highlighted yellow, has a much lower PLL for the open-top containership.

5.4.3 Risk models in context of full containership FSA

The PLL for a containership was estimated in SAFEDOR task 4.4.2 to be 9.00 E-03 [23]. The "collision", "grounding", and "fire/explosion" scenarios were dominant for this ship type. Fire and explosion was identified as the initial cause of 6.5 % of incidents in the LMIU database involving containerships (UCC) during the sampling period of 1993 to 2004 [23]. The potential number of lives lost per ship year as a result of fires on a conventional containership, shown per ship area, was estimated to be as follows [23]:

Table 13: PLL per ship year by fire origin location

Fire Origin Location	PLL per ship year
Cargo area (all goods types)	3.89 E-04
Machinery Spaces	6.98 E-04
"Other" Spaces, including explosions	4.10 E-04
Total	**1.50 E-03**

The fire origin location "cargo area" includes all types of cargo fires, whereas the estimates for this report are only for dangerous goods, and specifically only for those classes requiring on-deck stowage, and are as follows:

Table 14: PLL (fire) from dangerous goods carriage on deck and in open-top hold

Dangerous Goods Stowage Location	PLL (fire) from dangerous goods carriage
Open-top Containership: stowage in hold	3.77 E-04
Conventional Containership: on-deck stowage	3.68 E-04

Given that the estimates are only for dangerous goods cargos, which have been estimated previously to be responsible for approximately one third of all fires [23], they will result in an overall increase for the PLL of containerships. If the new estimate of PLLs for fire from dangerous goods cargo are included with the other fire PLLs, the total PLL for fire (all sources) will increase to approximately 1.74 E-03 (from 1.50 E-03). However, given that "collision" and "grounding" scenarios are also dominant, the increase in the PLL from fire will not result in a significant increase in the PLL for containerships (including all LMIU categories).

Individual Risk

The maximum tolerable risk for a crew member is recommended to be $P=10^{-3}$ by Skjong et al. [42] and by IMO [19], originally based on the maximum tolerable risk for workers suggested by the UK's HSE in [13]. The boundary for "negligible" individual risk is suggested by [42] to be 10^{-6}. The estimates obtained within the current work are given in Table 15.

Table 15: Individual risk from dangerous goods carriage on deck and in open-top hold

Dangerous goods stowage location	Individual Risk from carriage of dangerous goods
Open-top Containership: stowage in hold	9.18 E-06
Conventional Containership: on-deck stowage	8.49 E-06

The individual risk for a crew member on a containership (from all scenarios) was estimated to be 2.25 E-04 [23]. Adding the individual risks from carriage of dangerous goods shown above will not substantially change this total individual risk.

FN Curves

FN curves were plotted for both dangerous goods carriage options, and shown together with the curves for the all scenarios for a conventional containership (shown in Figure 17).

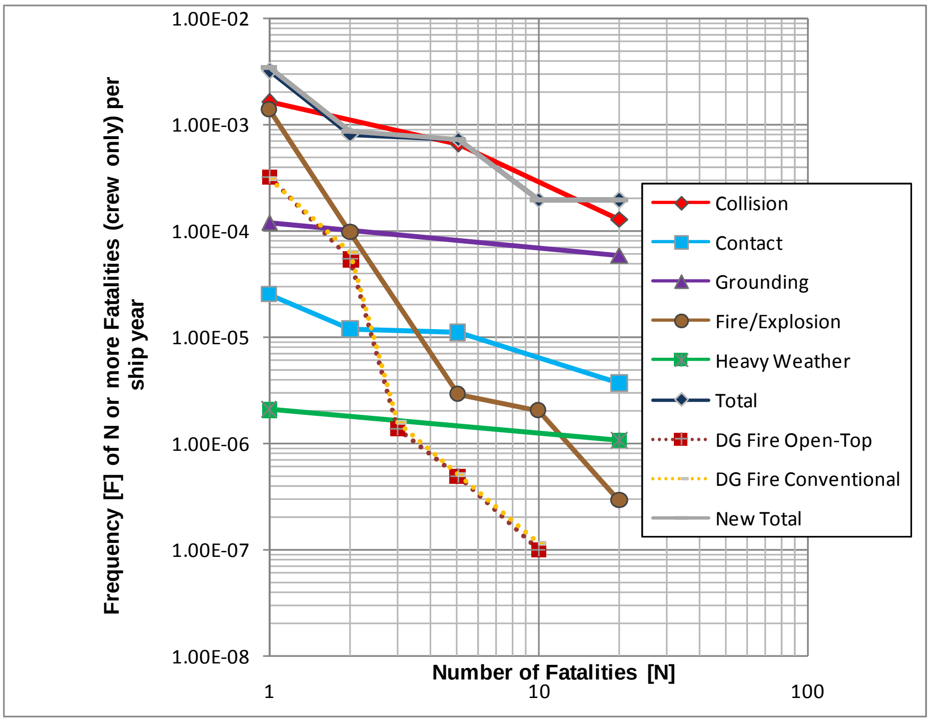


Figure 17: FN curves from scenarios from FSA for containerships [23], with FN curves from dangerous goods carriage on open-top and conventional containerships shown for comparison

The FN curve for carriage of dangerous goods in the hold of an open-top containership is very close to that for carriage of dangerous goods on deck of a conventional containership. The average of these two curves was taken and added to the total curve for comparison, as shown in Figure 18. This is a conservative comparison as the total curve from the containership FSA already includes some dangerous goods fire fatalities.

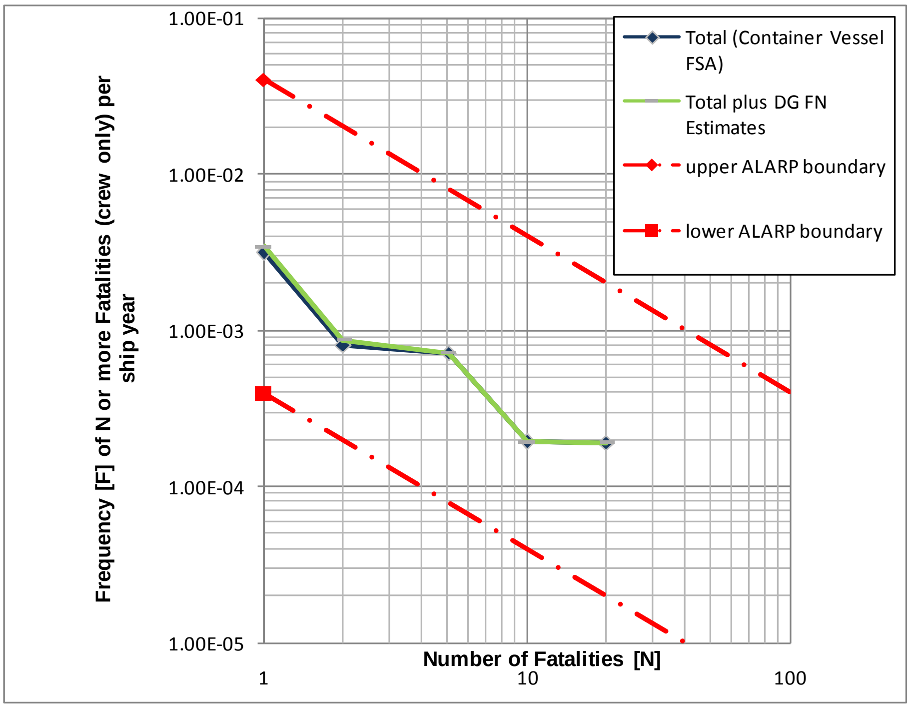


Figure 18: Total FN curve from all scenarios from FSA for containerships [23], shown together with a "new" total FN curve with average FN curve from dangerous goods carriage added. Proposed acceptance criteria for societal risk as estimated in [23] are also shown.

The addition of dangerous goods FN estimates does not significantly change the total FN curve for a containership. The dashed lines in Figure 18 show the acceptance criteria for societal risk for crew on a containership. This was estimated as described in [23], using the approach presented in MSC 72/16. This approach determines societal risk acceptance criteria for crew on a particular vessel type based on the respective economic value of shipping. For the curves shown above, an average daily charter rate of $23,500 was used for a 2,500 TEU vessel, with an economic value of a typical containership estimated to be $8.5 million per year. This was derived as described in [23].

5.4.4 Uncertainties

There are a number of uncertainties associated with this overview level model of carriage of dangerous goods on containerships, as follows:

- Estimates of initiating event probabilities (dangerous goods release) were based on relatively few incidents. Only three of the classes modelled – class 6.1, class 8, and class 3 – had enough incidents to give confidence in the estimation of release rate.
- Models were developed for classes and divisions of dangerous goods, rather than individual goods. Although this was necessary as it was not possible in this work to model each individual dangerous good, it requires a number of simplifications and generalisations for the event trees. There is a wide range with respect to possible behaviours and effects of each good which cannot be shown in a generic model.

- The data used to estimate initiating event frequencies did not include details on the ships involved, so a breakdown by ship size, age, etc. could not be performed. Most of the initial causes did not seem to be related to ship characteristics, but it would have provided more certainty if ship details had been available.

5.5 Conclusions of risk analysis

Event tree models for risk of carriage of dangerous goods requiring on-deck stowage were constructed for both transport in the open-top holds of open-top containerships and for on-deck stowage on conventional containerships. This allowed a comparison of safety levels between the current situation (on-deck stowage) and a possible future situation (the carriage of goods within open-top holds) to be performed. Event trees and comparisons were carried out for those dangerous goods classes or sub-classes that were identified during the HazID to have a risk index (RI) of 7 or higher.

Event tree models were used to estimate fatalities and probable loss of life (PLL) from carriage of dangerous goods. The PLL for both dangerous goods carriage situations was found to be quite close – the total PLL from all causes for dangerous goods carried on deck for conventional containerships was estimated to be 3.82 E-04, compared to 4.13 E-04 for open-top containerships carrying dangerous goods classified "on-deck stowage only" in open holds. The PLL for both ship types is dominated by scenarios which result in fatalities from fire. PLL for crew by asphyxiation and exposure to toxic substances was estimated to be twice as high for stowage in open-top container positions as compared to on-deck stowage.

Open-top containerships had a slightly higher PLL from fire for Class 3. They had a much lower PLL for Class 5.1. For other classes and divisions investigated, both open-top and conventional containership carriage on deck had PLL for fire that was the same or close to the same.

The FN curve for carriage of dangerous goods in the hold of an open-top containership is very close to that for carriage of dangerous goods on deck of a conventional containership. If these curves are combined with the FN curves for other containership scenarios resulting in fatalities (such as collision, grounding, etc.), the total FN curve for a containership does not change significantly.

6 Risk Control Options

The purpose of the "Identification and analysis of risk control measures and options" phase of the FSA is to propose effective and practical RCOs, comprising the following stages:

1. Focus on high risk areas requiring control;
2. Identify potential risk control measures and RCOs;
3. Evaluate the effectiveness of the RCOs in reducing risk by re-evaluating Step 2 of the FSA; and
4. Group RCOs into practical regulatory options.

The objective of this work is to address points 1 through 3. Initially, the output of the risk assessment phase (section 5) is filtered, so that the effort is focused on the areas with the highest risk contribution. The main aspects of this assessment are to review the risk levels, by considering the frequency of occurrence together with the severity of the outcomes. Accidents with an unacceptable risk level get the primary focus.
Structured review techniques are typically used to identify new RCOs for risks that are not sufficiently controlled by existing measures. These techniques may encourage the development of appropriate measures and include risk attributes and causal chains. Risk attributes relate to how a measure might control a risk, and causal chains relate to where, in the sequence between the initiating event(s) and the final outcome, risk control can best be introduced. In general RCOs should be aimed at one or more of the following:

1. Reducing the frequency of failures through improvements in design, procedures, organizational polices, training, etc;
2. Alleviating the circumstances in which failures may occur;
3. Mitigating the effect of failures, in order to prevent accidents; and
4. Mitigating the consequences of accidents.

The output from this step comprises:

1. A range of RCOs which are to be assessed for their effectiveness in reducing risk;
2. A list of entities affected by the identified RCOs (crew, passengers, third parties);
3. The interdependencies between the identified RCOs.

6.1 Identification and screening

6.1.1 General

Experts agreed that, with respect to the identified hazard groups, the stowage of dangerous goods containers on the open deck of conventional containership generally differs from the stowage in cargo hold of open-top containership in the following respects:

1. On deck a constant supply of fresh air is available, gases that may leak from containers are removed after some period of time.
2. In case of a fire in a container stowed on deck, heat and smoke are removed by natural circulation, whereas in case of stowage in cargo hold an accumulation of heat and smoke is likely.
3. For containers that are stowed on deck leaking substances can be more readily
    a. detected and
    b. washed over board
4. Ignition sources on deck are limited to sparks caused by mechanical movements and external sources (such as lightning).

It is also noteworthy that – assuming the same density of packing – experts agreed that the accessibility of a source of a leak or an origin of fire for a container that is located inside a stack will be very similar for open deck stowage and stowage in open cargo holds.

Consequently, control options address aspects that relate to the design of the vessel and its equipment, ship operations and the wider transport chain:

- equipment installed in cargo hold (ventilation, as well as detection of substances)
- personal protection of crew members (air supply and suitable protection suits)
- procedures for stowage and handling of DG containers
- packaging of dangerous goods

6.1.2 Expert session

An expert session aiming at the identification of risk control options was held at GL premises in Hamburg on 8 and 9 October 2008; participating experts are listed in Appendix A.2.
In an initial brain storming session, RCOs were discussed (see Appendix A.3) for each of the high-risk hazards which were identified in the hazard identification phase of the work.

The highest-risk hazards were determined for the following DG classes:

Class 2.1	Flammable Gases
Class 2.2	Non-flammable, non-toxic gases (no subsidiary risk)
Class 2.2	Non-flammable, non-toxic gases (subsidiary risk 5.1 (oxidizing substance))
Class 2.3	Toxic Gases
Class 3	Flammable Liquids
Class 4.2	Substances Liable to Spontaneous Combustion
Class 4.3	Substances which, in contact with water, emit flammable gases
Class 5.1	Oxidizing Substances
Class 6.1	Toxic substances, toxic by inhalation
Class 8	Corrosive Substances

Hazards associated with these DG classes were analysed in more detail in the quantitative risk analysis. By following this approach, inherently RCOs were discussed for the highest-ranking hazards within each DG class.

Due to the large range of chemical properties of the DG substances that are considered here, none of the identified RCOs is suitable to address all types of hazards that may originate from these goods. Notwithstanding, RCOs that were identified by the expert group can address one or more of the following groups of hazards:

- Gas leakage
- Leakage of liquid
- Leakage of corrosive substances
- Leakage of other substances (i.e. neither gas, liquid, nor corrosive substances)
- Exposure of Class 4.3 goods to water and/or humidity
- Spontaneous ignition by itself after rupture of packaging / containment
- Fire / Ignition
- Explosion

In the following sections, a discussion of the highest-ranked RCO is provided. A categorisation of these RCOs and an initial priorisation based on this categorisation are provided in section 6.3.

The full list of identified RCOs for these hazard groups is given in Appendix A.3.

6.2 Descriptions

6.2.1 RCO 1 – Permanent high-volume ventilation

Flammable gases escaping from damaged packages or heat emitted from damaged cargo inside stowed containers pose a hazard to the operation of the vessel. For goods stowed on deck during transport, convection by fair wind contributes to a dilution of gases and conduction of heat. In order to achieve a similar effect for the transport inside open holds, it is proposed to provide permanent ventilation during voyage, as a means of controlling atmospheric hazards. The ventilation system should be suitable to keep the hydrocarbon level below the lower flammable limit (LFL) of transported cargo; and it should be suitable to support the natural ventilation process by removing both, vapours and gases lighter that air, as well as vapours and gases that are heavier than air. Selected requirements on the design and dimensioning of such a system are summarised in the subsequent paragraphs.

Design requirements for the ventilation system

For the transport of dangerous goods the ventilation in the cargo hold must be explosion-proof. With respect to class 8 substances, the ventilation system must be suitable to withstand corrosives.
In order to support the natural ventilation in the open cargo hold the ventilation system should be able to operate in the mode of a supply air system as well as in the mode of an exhaust air ventilation system.
For the supply air mode air supplies should be located at the bottom of the cargo hold, particularly to cover the space between containers. With respect to the exhaust air mode, for the purpose of removing vapours and gases heavier than air, it is required that extraction ducts are installed at the bulkheads with inlets located at the bottom of the cargo hold and openings on each tier.
For the cost-benefit assessment of this RCO a sample solution was assumed. In this solution eight ducts are installed on each side of the bulkheads between the cargo holds. The ducts should be placed on the edges of the container stacks, i.e. on starboard and portside outside of the gangways, as well as in between the container stack.

Dimensioning of the ventilation system

Currently, for transport of dangerous goods in enclosed cargo spaces, SOLAS II-2/19 requires the ventilation to be dimensioned to provide a volume flow rate corresponding to at least two air changes per hour; based on the empty hold volume below weather deck.
Experts proposed that the capacity of a permanent ventilation system should be dimensioned larger than the currently required minimum and that ventilation should operate permanently, in order to keep the hydrocarbon level below the lower flammable limit (LFL) of transported cargo. It was deemed more appropriate to base calculations with respect to the dimensioning of such a system to requirements set for permanently operated ventilation systems that operate in other contexts or maritime transport. As reference in this work the requirements are applied which are defined for systems that are currently installed in cargo holds designed for transport of refrigerated containers that are equipped with air-cooled condensers. In particular, requirements set for Germanischer Lloyd's class notation RCP (Refrigerated Container Stowage Positions) [8] were applied for calculations. The guidelines for this class notation state that a volume flow rate of 3.100 m^3/h per 20 ft container shall be supplied[3]. Furthermore, the number of containers served by one supply fan shall not exceed 16.
For the reference vessel that is considered in the cost-benefit assessment of this RCO the requirements on the dimensioning of the ventilation system were derived as follows:

[3] This provision is based on the requirement that a temperature of 45°C shall not be exceeded in the cargo hold under the environmental conditions that are conceivable in the relation of the vessel.

Assuming the transport of 35 reefer containers per hold (which for the reference vessel corresponds to the number of containers facing one bulkhead), this yields a requirement to provide ventilation with a volume flow rate of 108.500 m^3/h. This value corresponds to 17 air changes per hour for the largest hold. If the minimum number of supply fans was to be installed (i.e. three fans, covering 12 containers each), each fan would need to have a capacity of 36.000 m^3/h.

6.2.2 RCO 2 – Installation of flammable gas sensors in cargo holds

Flammable gases that leak into in the cargo hold as consequence of damaged packaging, e.g. class 2 substances or gases emitted by class 4.3 substances reacting with water, pose a hazard that might affect the safety of the vessel substantially. While a quick release of flammable gases may be apparent to the crew visually (for instance, class 2.1 substances, which are often transported as refrigerated liquids and create visible vapour when released), a slow release of flammable gases might go unnoticed. Based on information from recorded incidents in the quantitative analysis a 60 % probability for noticing a release was assumed (section 5).

In order to raise awareness of the crew, it is proposed to install an array of sensors to detect the presence of gases that are heavier than air, combined with a suitable notification system. It is assumed that gases lighter than air will rise from the cargo hold.

The predominant group of dangerous goods involving a potential release of gases heavier than air are class 2.1 substances. Those substances heavier than air that are classified “on-deck stowage only” in the IMDG Code include ethylamine, ethane, methyl chloride, and difluoromethane. Further substances are groups of flammable liquefied gas, flammable insecticide gas (light alkane gases, ethane, propane, butane), flammable compressed gas (may be any one of several compressed flammable gases, including light hydrocarbon gases, ethane, butane, cyclobutane, etc.; hydrogen, dimethyl ether, methylethyl ether, and gases used as refrigerants, including, ethyl chloride, fluoromethane gases)[4].
While not all of these substances are heavier than air, it can be expected that vapours from liquefied gas are initially heavier than air and spread along ground.
Class 2.1 substances lighter than air, which are classified “on-deck stowage only” in the IMDG Code include acetylene, ethylene, hydrogen, methane.
For the majority of these substances gas detectors are available. Detectors that are installed in cargo holds allow for a qualitative measurement, i.e. detection of absence and presence of these gases.
For the cost-benefit analysis a sample arrangement was considered based on a stationary, continuously operating gas warning system with eight infrared sensors per hold. It is argued by manufacturers of such systems that positioning of sensors in each corner at the bottom of the hold is sufficient, since due to ship movements substances heavier than air will be detectable in the corners.

6.2.3 RCO 3 – No stowage in lowest tier for containers which hold class 4.3. substances

In the quantitative analysis it was argued that, once released, e.g. due to damaged packaging, the probability of class 4.3 substances reacting with water would be quite high for both ship types. The main hazards evolving from such reactions are generation of flammable or explosive gases and generation of toxic atmospheres.
During the expert sessions it was discussed that the most likely sources of class 4.3 substances getting in touch with water for open-top containership is a situation where the container is stored in the lowest tier and water that is accumulated in the bottom of the cargo hold may enter the container. Given the capacity of the bilge pumps in open-top containerships, it can be expected that in general the level of water that

[4] Source: CAMEO chemicals online database of hazardous materials: http://cameochemicals.noaa.gov

accumulates in the hold does not exceed the level of the lowest tier. Hence, it is recommended to store containers holding these substances in higher tiers.

6.2.4 RCO 4 – Foam extinguishing systems

Currently, open cargo holds of open-top containerships are equipped with a water-based deluge system to control cargo fires. These systems are dimensioned to provide a sufficient amount of water for controlling fires in the largest cargo hold and for protecting the affected ship surfaces from the impact of flames and heat (see descriptions in section 1.1.1.1).

Experts participating in the RCO session agreed that these systems may not be feasible to control fires that involve dangerous goods. With respect to fire fighting in presence of such goods, a purely water-based system is not suitable, because many substances react with water or cannot be extinguished with water. Furthermore, the dense packaging of cargo complicates fire-fighting with water. For instance, when fighting fires involving hydrocarbons, water evaporates. Evaporation increases the volume of water by 1,700 times, yielding substantial steam currents which can prevent water reaching the fire source.

Hence, for the purpose of gaining additional control over the spread of fires that originate from dangerous goods containers stowed in the hold, it is proposed to install a foam extinguishing system. Such a system has to be designed to overcome a number of challenges, for instance, as the stacking of containers makes it difficult to apply foam from the top; also due to thermal effects as a consequence of a fire inside the cargo hold, the application of high-expansion foam would not be effective.
Consequently, for matter of effectiveness, a foam-based fire-fighting system shall operate automatically and flood the cargo hold from the bottom. Furthermore, experts stated that a system using alcohol-resistant low-expansion foam would be the preferable option. (Systems that may serve as a reference are currently installed on tankers as deck foam systems).

Among the experts attending the RCO session there is consensus that the installation of a foam extinguishing system has no effect on the frequency of fires, but is considered suitable to control the spread of fires and therefore has an effect on the consequences. Like existing deluge systems, in most cases a foam-based system is not suitable to extinguish a fire, because very often the fire source is expected to be inside containers, which is not reached by foam. Yet, the control of the fire by means of foam is preferred to a water-based system, since foam restricts the admission of oxygen to the fire source. Therefore, the use of a foam-based fire-fighting system can be considered to be more efficient with respect to controlling the spread of a fire within the container stack.
Yet, compared to the existing water-based deluge systems, a foam-based system is likely to have a smaller cooling effect, and by heat bridges the slow spread of fire from one container to another is possible.

Notwithstanding, as there is no precedence system, the technical feasibility of implementing such a system has yet to be demonstrated. For instance, experts estimate that due to the physical properties of the foam the time required to fill a loaded hold is expected to be between three and five hours. If the fire source is in a layer that is reached late by the foam, the fire might spread to layers above the hold where this RCO has no effect.

6.2.5 RCO 5 – Fixed air supply system in cargo hold

For the expected trading pattern of the reference vessel (feeder service, calls at ports every 1 to 3 days) the cargo hold would only be entered in extraordinary situations. Yet, experts attending the RCO session agreed that the cargo hold should not be entered to conduct fire-fighting, as generally the expertise available on board will not be sufficient to effectively fight cargo fires.

For transport of DG there is already a requirement to keep at least two self-contained breathing apparatuses (SCBAs), with two spare bottles each, on board (SOLAS II-2/10 and SOLAS II-2/19
The self-contained breathing apparatuses (SCBAs) that are carried on board generally only provide breathing air for a duration of 30 minutes (SOLAS II-2/10). Simply increasing the capacity of SCBAs is only possible to a limited extent, because the sizes of the hatches do not permit to carry large bottles of breathing air.

As it may not be excluded that the cargo hold needs to be entered for extended periods of time, it is recommended to consider the installation of a fixed air supply system.
A possible implementation of such a system that was considered during the cost-benefit assessment of this RCO consists of central breathing air compressor, a pipe system for the distribution of breathing air to the cargo holds and hose for a flexible distribution within the cargo holds. In order to provide adequate access to breathing air it would be required to install a hose wheel with a 15 m hose on each deck of the cargo hold, plus the weather deck. Breathing air can be accessed via the hose by a person wearing a breathing apparatus or hood. A system based on hoses is expected to make the use of hatches easier, compared to carrying an oxygen bottle. However, the crew needs to be trained for connecting/disconnecting from the air supply system, and needs to pay attention to the routing of the hoses. The breathing air should be supplied by a separate compressor which is exclusively dedicated to this system.

It is acknowledged that such a system might impose an additional hazard, as air from the system may leak into the cargo hold and add to a fire risk by providing a source of oxygen. Therefore appropriate mechanisms must be in place for shutting off parts of the lines remotely. For instance, it should be possible to open and close lines for each cargo hold by means of valves that are located on the weather deck and remotely from a central control location.

For full protection this measure should be combined with personal protection suits (RCO 7), since many class 2.3 substances can be absorbed via skin.

6.2.6 RCO 6 – No stowage of class 8 substances close to relevant ship structures

Class 8 substances can pose a serious threat to the ship structure. While special coatings are available and recommended for relevant ship structure, experts judged that appropriate coatings are feasible only to cargo tanks, e.g. for chemical tankers, which are not affected by potentially damaging activities, such as cargo handling (containers), cargo securing (twistlocks, turnbuckles etc. falling down), sea water etc. Secondary effects, such as toxic gases could be reduced by installation of a ventilation system (see section 7.2.1). Notwithstanding, experts unanimously agreed that stowage of these substances on the open deck is highly recommended.

6.2.7 RCO 7 – Improved personal protection

The risk control options RCO 1 and RCO 2 that are described in sections 6.2.1 and 6.2.2 address the atmosphere in the cargo hold as a whole. A challenge of these solutions is to control the atmosphere while the hazard persists, for instance a leak of substances continues. Experts considered that, under circumstances where the cargo hold must be entered and the type of contamination is known, a suitable control option would be to provide improved personal protection. Such equipment could consist of portable sensors, self-contained breathing apparatus and a protective suit. In the following discussions of risk reducing effects, costs of implementation and economic benefit, these possibilities are discussed as independent risk control measures (RCMs), since they address distinct aspects of the general hazard.

RCM 7a Equip crew with oxygen and CO_2-sensors

High concentrations of CO_2 or O_2 could be critical in cases where the crew needs to enter the cargo hold. Extended exposure of crew entering the cargo hold to oxygen levels outside a range of 19.5 % vol. to 23.5 % vol. and CO_2 levels exceeding 0.5 % vol.[5] may yield adverse effects on physical capabilities and may result in fatalities. Therefore it is proposed that portable equipment for detection of high concentrations of O_2 and CO_2 should be used to detect that a breathable atmosphere is present prior to entering spaces or descending to a lower level of the hold (O_2 and CO_2 are heavier than air).

Yet, for such a measure to be effective crew members need to be trained in the use and maintenance of such equipment. In particular, the crew needs to be aware that there may be some latency until the reading of the instruments captures the correct atmospheric conditions. As this RCM is not effective with respect to other gases, a combination of a multi-gas detector and detection tubes is recommended.

RCM 7b Provision of air supply (SCBA) for people entering the cargo hold

Using an SCBA alone to some extent would make crew members independent of the atmosphere in the cargo hold. For transport of DG there is already a requirement to carry on board at least two SCBAs with two additional bottles each (SOLAS II-2/10 and SOLAS II-2/19). However, experts agreed that the required capability for the equipment to operate for 30 minutes is not sufficient to conduct major works, such as repairs or fire fighting, given that in this time included are the durations to access and retreat from the hazard source, as well as decontamination of the suit.

Installation of on-board equipment for refilling breathing apparatuses and spare charges currently is not mandatory, so if none are carried aboard breathing equipment can only be refilled in the next harbour.

Experts suggest that provision of SCBAs with a larger capacity and installation of refilling equipment would be highly beneficial. However, the physical dimensions of the SCBAs must not prevent access to certain areas, e.g. entering hatches.

RCM 7c Provide personal protection equipment

Currently, it is required to carry at least four sets of full protective clothing on board when transporting dangerous goods. However, it should be noted that, while this clothing is required to be "resistant to chemical attack" (SOLAS II-2/19), experts pointed out that currently no single type of clothing is available that protects against all types of DG substances.

It is proposed to provide different kinds of protective suits that in total cover the range of substances. A proposed suitable combination is a set of four to six limited use suits and two heavier re-usable gas-tight suits. The gas-tight suits would be used in case of accidents that require immediate action by crew[6]. The limited use suits would be used in case of minor incidents, and by crew members assisting in use of the heavy suit.

In order to select the correct type of suit for a given hazard the crew must be able to identify what substances actually are present. Furthermore, the crew needs to be educated that different kinds of suits need to be treated in different ways (e.g. disposal of single-use suits, stowage of decontaminated reusable suits). Hence, this measure would need to be accompanied by a major training effort.

It should also be noted that when pressurised suits are used, the operation time would not be extended substantially beyond the 30 minutes that are currently required; as work in such suits is extremely exhaustive. Experience has shown that even physically well trained persons, such as professional fire fighters on land, will not be able to operate for more than 45 minutes under such conditions.

[5] These are the "safe levels" defined by [45].

[6] It should be noted that experts highly recommend carry out works that require use of heavy protective suits trained personnel in harbours, whenever possible.

6.3 Categorisation

The identified RCOs (Annex 1) were condensed and categorised by means of qualitative judgements, using the following attributes[7]:

Purpose of the RCO. Possible values are the attributes *prevention* and *mitigation*, which are defined as follows:

Preventive: A Risk Control Measure that reduces the probability of the event.

Mitigating: A Risk Control Measure that reduces the severity of the outcome of the event or subsequent events, should they occur.

Effect states whether the RCO is focused primarily on human life, environment or property.

Focus of application: Possible values are the attributes *Engineering* and *Procedural*, which are defined as follows:

Engineering: Engineering risk control involves including safety features (either built in or added on) within a design.

Procedural: Procedural risk control is where the operators are relied upon to control the risk by behaving in accordance with defined procedures.

Type of risk control: Possible values are the attributes *Passive* or *Active*, which are defined as follows:

Passive: Passive risk control is where there is no action required to deliver the Risk Control Measure.

Active: Risk control is provided by "built-in" action of safety equipment or operators.

Costs: Initial estimation of costs (per ship per year) of introducing an RCO.
Three cost classes are defined ("low", "medium", and "high") on the basis of the newbuilding costs of the reference vessel, i.e. 34,000,000 US$[8], according to the Table 16.

Table 16: Categorisation of the annual costs of the RCO

Class	**Cost Range (US$ per ship per year)**	**Relative range in relation to newbuilding costs**
Low	costs < 34,000	x < 1 %
Medium	34,000 < costs < 3,400,000	1 % < x < 10 %
High	costs > 3,400,000	x > 10 %

Human Factors: Possible values are attributes *involved* and *critical*, which are defined as follows:

Involved: Human action is required to control the risk but where failure of the human action will not in itself cause an accident or allow an accident sequence to progress

Critical: Human action is vital to control the risk either where failure of the human action will directly cause an accident or will allow an accident sequence to progress.

[7] See, Appendix 6 of IMO FSA Guidelines [19].

[8] Newbuilding costs of reference open-top vessel are 25 M EUR; at the time of writing 1.00 EUR = 1.36 US$.

6.4 Initial priorisation

Priorities of the identified RCOs are generally assigned according to the following criteria[9]:

1. Preventive measures are preferred to mitigating measures
2. Passive measures are preferred to active measures
3. Measures that involve human actions are preferred to measures that critically depend on human actions.

The resulting list of RCOs is given in Table 19. A detailed description of each RCO is presented in section 7.2.

6.5 Functional dependencies

Functional dependencies between the RCOs are indicated in Table 17. Entries denote the degree to which the technical ability of an RCO (column) to achieve a risk reduction is affected by the implementation of another RCO (row).

For instance, if high-volume ventilation was installed in the cargo hold and permanently operated (RCO 1), the potential risk reduction that could be achieved by the installation of fixed sensors for flammable gases in the cargo hold would be weakly affected – as the concentration of flammable gases would be reduced, but it is expected that the principle function of the sensors will not be affected by the higher airflow created by RCO1. On the other hand, if RCO 2 was implemented, the effectiveness of RCO 1 would not be affected – the presence of the sensors does not have an effect on functionality of the ventilation.

Table 17: Functional dependencies between selected/identified RCOs

	RCO 1	RCO 2	RCO 3	RCO 4	RCO 5	RCO 6	RCO 7
RCO 1	-	Weak	No	Weak	No	No	No
RCO 2	No	-	No	No	No	No	No
RCO 3	No	No	-	No	No	No	No
RCO 4	No	No	No	-	No	No	No
RCO 5	No	No	No	No	-	No	No
RCO 6	No	No	No	No	No	-	No
RCO 7	No	No	No	No	No	No	-

As shown in Table 17, most of the identified risk control options are independent of each other. In particular, no strong dependencies were identified.

6.6 Effects with respect to dangerous goods classes

Due to the wide range of substances and their chemical properties, none of the identified RCOs is effective for all DG classes. The relevance of each RCO with respect to a particular DG class is summarised in Table 18. The information in this table is used for the calculation of the overall risk reduction that is achieved by implementing an RCO. This calculation is performed using the risk models that were developed in section 5 of Annex I. With these models the risk-reducing effect is calculated for each DG class that is affected by an RCO.

[9] This priorisation of safety measures are commonly used, e.g. in the HSE's "*Safety Assessment Principles for Nuclear Facilities*" [11].

Table 18: Effectiveness of an RCO on DG classes.

Dangerous Goods Class	RCO 1	RCO 2	RCO 3	RCO 4	RCO 5	RCO 6	RCM 7a	RCM 7b	RCM 7c
Class 2.1	X	X		X					
Class 2.2, no subs. Risk	X				X		X	X	
Class 2.2, subs. Risk 5.1	X			X	X		X	X	
Class 2.3	X			X	X			X	X
Class 3				X					
Class 4.2				X					
Class 4.3			X	X					
Class 5.1	X			X					
Class 6.1					X			X	X
Class. 8						X			

Table 19: Identified Risk Control Options (initial ranking)

RCO	Description	Purpose	Focus	Focus of application	Type	Costs	Human Factors
		(P)revention/ (M)itigation	(L)ife / (E)nv / (P)rop	(D)esign / (O)peration	(P)assive / (A)ctive	(H)igh (M)edium (L)ow	(I)nvolved / (C)ritical
RCO 1	Permanent high volume ventilation of cargo hold	P, M	L, E, P	D, O	A	H	--
RCO 2	Installation of fixed sensors for flammable gases in cargo holds	P (M)	L, E, P	D, O	A	M	--
RCO 3	No stowage in lowest tier for containers which hold class 4.3. substances	P, M	L, E, P	O	A	L	C
RCO 4	Installation of foam extinguishing systems in cargo hold.	M	L, E, P	D	A	M to H	I
RCO 5	Provide air supply (fixed installation) for crew members entering the cargo hold	M	L	D	A	M	C
RCO 6	No stowage of class 8 substances close to relevant ship structures → stowage on open deck recommended	M	L, E, P	O	A	L	C
RCO 7	Improved personal protection[10]						
RCM 7a	Equip crew with oxygen and CO_2-sensors and train crew in appropriate use!	P, M	L	O	A	L	C
RCM 7b	Provide air supply (self-contained breathing apparatus) for people entering the cargo hold (shall be mandatory)	M	L	O	A	L	C
RCM 7c	Provide personal protection equipment (set of skin protection suits, each for a limited number of substances)	M	L	O	A	L	C

[10] In the course of the cost-benefit analysis it turned out that different risk control measures that were originally subsumed in this RCO are judged to have quite different impact on the risk reduction. Hence, in the following three risk control measures are reviewed separately: RCM 7a "equipment of crew with O_2 and CO_2 sensors", RCM 7b "provision of enhanced SCBA", and RCM 7c "provision of enhanced protective clothing".

7 Cost-Efficiency Analysis

The risk acceptance criterion that was applied in this FSA on the transport of packaged dangerous goods on open-top containerships is whether by introduction of suitable risk control options a level of safety can be reached that is equivalent to the currently accepted solution, i.e. transport on the open deck. The acceptance criterion was assessed in two respects, which in the following will be called “variant 1” and “variant 2”:

- variant 1: A risk control options is suitable to achieve a level of safety of the proposed solution that can be considered equivalent to the level of safety of the accepted solution, for all dangerous goods classes that are in focus of this work.
- variant 2: A risk control options is suitable to achieve a level of safety of the proposed solution that can be considered equivalent to the level of safety of the existing solution, for a selection of the dangerous goods classes that are in focus of this work.

For the identified risk control options (RCOs) cost proportionality is also analysed. Notwithstanding, in contrast to other FSAs, cost-effectiveness is used as an informative criterion and not as a decision criterion, e.g. to determine if the achieved risk level would be considered ALARP.

In the following sections, first the risk-reduction of each RCO is calculated. With respect to safety equivalence, focus is put particularly on the possibility of reducing the level of risk by introduction of an RCO on the open-top containership to the same or lower level of risk that was determined for the conventional containership. Additionally, in sections 7.3 and 7.4 costs and the economic benefit are determined for each RCO. For these calculations the methods described in section 7.1.1 are applied.

7.1 General

The purpose of the cost-benefit assessment (CBA) is to estimate and compare the expected risk reduction and benefits to relate them to the costs associated with the implementation of each RCO identified.

A cost efficiency assessment following the IMO procedure consists of the following stages:

1. Use the risks values from the risk assessment, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration;
2. Arrange the RCOs in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO;
3. Estimate the pertinent costs and benefits for all RCOs by reassessing the risk assuming the option under consideration is in place and comparing this risk level to the established base case;
4. Estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and
5. Rank the RCOs from a cost-efficiency perspective in order to facilitate the decision-making, e.g. to screen those options that are not cost effective or impractical. Costs should be expressed in terms of life cycle costs and may include initial setup, operating, training, inspection, certification, decommission etc. Benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, indemnity of third party liabilities, etc. and an increase in the expected operating life of ships. There are several indices used by IMO that express cost effectiveness in relation to safety of life and the environment; for the purposes of this work the Gross Cost of Averting a Fatality (GCAF) and the Net Cost of Averting a Fatality (NCAF) are used.

The definitions of GCAF and NCAF are:

$$GCAF = \frac{\Delta C}{\Delta R} \tag{7.1}$$

$$NCAF = \frac{\Delta C - \Delta B}{\Delta R} \tag{7.2}$$

Where:

$$\Delta R = T * \Delta PLL \tag{7.3}$$

ΔC is the cost of implementing the risk control option during the lifetime of a vessel.
ΔR is the risk reduction, in terms of the number of fatalities averted, due to the introduction of the risk control option during the lifetime of a vessel.
ΔB is the total economic benefit (=reduced economic risk) per ship resulting from the implementation of the risk control option during the lifetime of a vessel.
ΔPLL is reduction of the potential loss of life, due to the introduction of the risk control option during the lifetime of a vessel.
T = 25 years is the expected lifetime of the vessel.

7.1.1 Cost calculation methods that are applied in this work

Costs ΔC are calculated on the basis of Net Present Value (NPV). Costs and benefits of the RCOs are spread over the lifetime of the vessel. Costs may occur in different intervals, for instance once, annually, twice per year or 3-yearly. In order to make the costs and benefits comparable and to calculate the NCAF and GCAF, Net Present Values (NPV) were calculated for applicable RCOs according to:.

$$\begin{aligned} NPV &= A + \frac{x_1}{(1+r)} + \frac{x_2}{(1+r)^2} + \frac{x_3}{(1+r)^3} + \cdots + \frac{x_T}{(1+r)^T} \\ &= A + \sum_{t=1}^{T} \frac{x_t}{(1+r)^t} \end{aligned} \tag{2.7}$$

Where:

x_t = Cost (or benefit) of RCO for any given year
A = Amount spent initially for implementation of RCO
r = Depreciation rate (see below)

A uniform depreciation rate of 5 % has been used.

The total economic benefit ΔB is determined according to:

$$\Delta B = \left(\Delta PLS + \Delta PLC\right) * \sum_{t=1}^{T} \frac{1}{(1+r)^t} \tag{7.4}$$

Where:

ΔPLS are the reduced costs for damage or loss of ship (per ship year),
ΔPLC are the reduced costs for damage or loss of cargo (per ship year),
and *r* and *T* are defines as above.

The output from the CBA comprises:

1. Costs and benefits for each RCO identified an through-life perspective;
2. Costs and benefits for those interested entities which are the most influenced by the hazard in question; and
3. Cost effectiveness expressed in terms of chosen criteria.

For the purposes of this work, only the outputs listed in items 1 and 3 are addressed.

7.2 Risk Reduction of selected RCOs

The same reference vessel as in the previous steps of the FSA is used. Details of this vessel are provided in section 3.4.1. Vessels of this type typically operate in feeder services with frequent port calls. During such voyages the cargo hold in general is not entered by crew unless required by extraordinary circumstances. These boundary conditions have a strong effect on the judgement of the potential risk reduction.
The risk is reviewed in terms of the individual risk per crew member, and the potential loss of life (PLL), based on a crew of 15 on this vessel and three shifts of crews used in rotation throughout the year to operate the vessel continuously.

Uncertainty in expert judgements

The risk reducing effect of each risk control option was determined from expert judgements. As expert opinions deviated with respect to certain RCOs the Delphi method was used to obtain consensus. In two rounds, by means of Email exchange, experts who participated in the identification session for risk control options (cf. Appendix A.2) provided their judgements on a questionnaire on which the RCOs listed in Table 19 were described in some detail.
Responses were evaluated with respect to mean value of expected risk reductions and the standard deviations of judgements. After the first Delphi round good agreement was already reached on RCOs 1, 2, 3, and 6, but differed by up to 30 % for others, e.g. for RCO 5.
In a second Delphi round experts were asked to revisit their judgements, particularly for those RCOs where expert opinions diverted by more than 10 % in the initial round, in the light of responses that were provided by their colleagues. Results of this second round are shown in Figure 19. Experts reached a strong agreement in their judgements of the risk-reducing potential of RCO 1, RCO 2, RCO 3, RCM 7a.

At the end of the second Delphi round, expert opinions still diverged a lot with respect to RCO 4, RCO 5, RCM 7b, RCM 7c. For these it is notable that RCOs that relate to personal protection (RCO 5, RCM 7b and RCO 7c) were rated higher by the fire service personnel than by dangerous goods experts.
In the calculation of the risk reduction, mean values of expert judgements from a Delphi study are used. Due to strong deviations in expert opinions with respect to some RCOs, a sensitivity analysis is performed. In case standard deviations in expert judgements are higher than 10 %, the overall risk reduction is calculated also for minimum and maximum values.

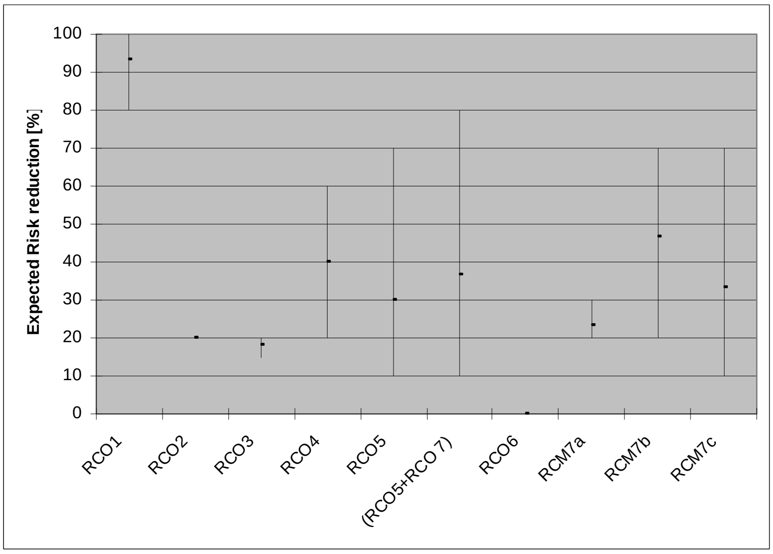


Figure 19: Results of Delphi session on risk reduction judgements.

The sensitivity of ΔR for RCOs with less expert agreement is discussed in section 7.6.1.

7.2.1 RCO 1 – Permanent high-volume ventilation

Introduction of a permanent ventilation system addresses risks with respect the hazards:

- Fire and Explosion (class 2.1, class 2.2, class 4.3, class 5.1)
- Inhalation of toxic gases (class 2.3)

Experts of the Delphi study judge that installation of permanent high-volume ventilation would yield an expected reduction of accidents related to release of flammable gases by 93 %.

Using the event tree for class 2.1 developed in section 5 of Annex I it is calculated that the introduction of permanent ventilation would reduce the individual risk to crew members from fire or explosion occurring as a consequence of combustible atmosphere by 93 %; (3E-5 lives will be saved per ship year or 7.5E-4 lives over the 25 year lifetime of the vessel) i.e. one life will be saved in 1,330 ship years.
(affected event(s) in event tree model of [2]:“release is apparent to crew”, “ignition occurs”)

By means of the event tree for class 2.2 (non-toxic gases (no subsidiary risk)) developed in section 5 of Annex I it is calculated that the introduction of permanent ventilation would reduce the individual risk to crew members of suffocation as consequence of entering a space where refrigerated liquefied gas was released by 93 %;(6E-6 lives will be saved per ship year or 1.5E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 162,000 ship years.
(affected event(s) in event tree model of [2]:“release is apparent to crew”, “release can be controlled/contained”)

By means of the event tree for class 2.2 (non-toxic gases (subsidiary risk 5.1)) developed in section 5 of Annex I it is calculated that the introduction of permanent ventilation would reduce the individual risk to crew members (as a result of either fire or suffocation as consequence of entering a space where refrigerated liquefied gas was released) by 92.6 %;(1.4E-5 lives will be saved per ship year or 3.4E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 73,000 ship years.
(affected event(s) in event tree model of [2]:“release is apparent to crew”, “release can be controlled/contained”, “ignition occurs” and “release is apparent to crew”, “release can be controlled/contained”, “no ignition occurs”, and “gas dissipates from hold”)

With respect to class 2.3 substances (toxic gases) developed in section 5 of Annex I it is calculated that the introduction of permanent ventilation would reduce the individual risk to crew members (as a result of either fire, for those gases with subsidiary fire risk, or intoxication as consequence of entering a space where toxic gas was released) by 93 %, (1E-4 lives will be saved per ship year or 2.4E-3 over the 25 year lifetime of the vessel) i.e. one life will be saved in 10,300 ship years.
(affected event(s) in event tree model of [2]:"release is apparent to crew", "release can be controlled/contained", "crew members exposed to lethal concentrations on deck or in hold", gas has subsidiary risk of class 2.1 or 5.1 and explosion/fire occurs)

With respect to class 4.3 substances this RCO is not expected to have an effect, as incidents have been recorded where ignitions occurred, even when the cargo was on open deck, and natural ventilation was good.

In summary, the calculations above yield that by the introduction of permanent ventilation 1.5E-4 lives will be saved per ship year or 3.7E-3 over the 25 year lifetime of the vessel) i.e. one life will be saved in 6,810 ship years.

On the basis of a risk reduction of 93 %, by means of calculations using the risk model of section 5 of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 2.66E-4 per ship year was determined, i.e. ΔPLL=1.47E-4 (per ship year) and ΔR = 3.68E-3.
Implementation of this RCO alone yields a PLL that is significantly lower than the PLL of 3.82E-4 which was determined for the transport on the open deck of a conventional containership (section 5 of Annex I).

This measure would neither be feasible nor necessary for the deck area of conventional containership.
Experts conclude that a residual risk will remain for both stowage positions (on deck of a conventional vessel and in open holds of an open-top vessel), as explosive atmosphere and ignition sources may also be located inside a container.
It is further recommended that, even of this RCO was implemented, when DG are transported in a cargo hold, no combined transport of reefers and DG containers inside this hold should be allowed, as reefers could be considered a potential ignition source (cf. SOLAS II-2/19).

7.2.2 RCO 2 – Installation of flammable gas sensors in cargo holds

Experts acknowledge that the installation of flammable gas sensors does not affect the frequency of the gas release. However, it is argued that this RCO can help reducing the consequences, as crew is made aware of the dangerous situation and can react correspondingly. Notwithstanding, the crew needs to be aware that by this measure the risk of a flammable atmosphere in the cargo hold being unnoticed can only be reduced but not eliminated, as not for all DG substances sensors are available and as available sensors may fail.
In summary, experts of the Delphi study judge that this measure would yield an expected reduction in accidents caused by an undetected presence of flammable gases heavier than air by 20 %.

Using the event tree for class 2.1 developed in Annex I it is calculated that the introduction of sensors for flammable gases would reduce the risk of explosions as consequence of an undetected explosive atmosphere by 13 %, (4.18E-6 lives will be saved per ship year or 1.1E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 239,000 ship years.
(affected event(s) in event tree model of Annex I, section 5: "release is apparent to crew", "ignition occurs")

On the basis of a risk reduction of 20 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 4.09E-4 was determined, i.e. ΔPLL=4.18E-6 (per ship year) and ΔR = 1.05E-3.
This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed "on deck only" on the open deck of a conventional containership (section 5 of Annex I).

7.2.3 RCO 3 – No stowage in lowest tier for containers which hold class 4.3. substances

Experts argue that beyond the situation where class 4.3 substances get in touch with water, other hazard sources are:

1. Ingress of water into a freight container would imply also the possible ingress of ambient air. Class 4.3 substances escaped from a damaged packaging would react with the air moisture.
2. Damage of packaging and reaction of goods with humidity from air.

Experts of the Delphi study judge that the proposed measure would only yield an expected reduction of the probability of accidents due to class 4.3 substances getting in touch with water by 18 %.
The reason for this low expected reduction is that these additional hazards are not addressed particularly well by this RCO.

Using the event tree for class 4.3 developed in Annex I it is calculated that the stowage of containers in higher tiers would reduce the risk of fires and explosions as a consequence of reactions of class 4.3 substances with water by 18 %, (1.3E-5 lives will be saved per ship year or 3.3E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 76,800 ship years.
(affected event(s) in event tree model of [2]:"ignition occurs")

On the basis of a risk reduction of 18 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 4.00E-4 was determined, i.e. ΔPLL=1.31E-5 (per ship year) and ΔR = 3.28E-4.
This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed "on deck only" on the open deck of a conventional containership.
Furthermore, this measure would also be feasible for deck area of conventional containership, as tier 1 above deck might get exposed to green water.

It should be noted that this discussion includes the implicit assumption that containers that are loaded with class 4.3 substances can be detected by the crew by markings on the containers and according to the loading manifest. Experience shows that in the past this has not always been the case.

7.2.4 RCO 4 – Foam extinguishing systems

Experts of the Delphi study judge that a well-maintained automatic foam extinguishing system and a crew that is well-trained in the use of such a system is expected to improve the fire fighting effectiveness on average by 40 % (but expert responses spread between 20 % and 60 % reduction).

Using the event trees for DG classes 2.1, 2.2 (with subsidiary risk of 5.1), 2.3 and 3, 4.2, 4.3 and 5.1 developed in (section 5 of Annex I) it is calculated that by the installation of a foam extinguishing system the individual risk to crew members from fire spreading will be reduced by 6 %, (2.4E-5 lives will be saved per ship year or 6.1E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 41,100 ship years.

(affected event(s) in event tree model of [2]:"fire fighting measures are effective (fire controlled)" in event trees for class 2.1, class 2.3, class 3, class 4.2, class 4.3 and class 5.1)

On the basis of a risk reduction of 40 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 3.89E-4 per ship year was determined, i.e. ΔPLL=2.43E-5 (per ship year) and ΔR = 6.08E-4.
This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed "on deck only" on the open deck of a conventional containership (Annex I).

7.2.5 RCO 5 – Fixed air supply system in cargo hold

Experts of the Delphi study judge that provision of a fixed air supply system in cargo holds would yield an expected reduction of inhalation of toxic gases/fumes accidents by 30 %. In case the crew member would also wear protective clothing (cf. RCO 7), this measure would also yield an expected reduction of accidents by 30 % (however, for this latter case this is the mean value; there is a spread of expert opinions between 10 % reduction and 70 % reduction, and a standard deviation of 28 %).

Using the event trees for class 2.2 (no subsidiary risk), class 2.2 (subsidiary risk 5.1), class 2.3, and class 6.1 developed in section 5 of Annex I it is calculated that the introduction of a fixed air supply system would reduce the risk of crew being exposed to lethal conditions by 33 %, (7.9E-6 lives will be saved per ship year or 2.0E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 127,000 ship years.
(affected events: "Crew members stay out of hold when gas is at dangerous level?" and "Other crew member/rescue worker uses SCBA or ventilates before rescue attempt?" in event tree models for class 2.2, as well as event "Crew exposed to lethal concentrations on deck or in hold" in event tree model for class 2.3)

This RCO is suggested independently of risk control options RCO 1, RCO 2, RCO3, and RCO 4.

On the basis of a risk reduction of 30 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 4.05E-4 per ship year was determined, i.e. ΔPLL = 7.88E-6 (per ship year) and ΔR = 1.97E-4.
This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed "on deck only" on the open deck of a conventional containership (cf. Annex I).

It is judged that this measure would also be feasible for the deck area of conventional containership.

7.2.6 RCO 6 – No stowage of class 8 substances close to relevant ship structures

As this RCO represents the current regulations, no improvement beyond the current standard is expected.

7.2.7 RCO 7 – Improved personal protection

RCM 7a Equip crew with oxygen and CO_2-sensors
Experts of the Delphi study judge that an expected reduction of accidents by 23 % could be achieved by implementing this measure, for those accidents resulting in exposure to unsafe levels of O_2, (either too high or too low). This reduction was applied to the risk models for Class 2.2, non-flammable, non-toxic gases, with no subsidiary risk and with subsidiary risk 5.1 (oxidizing substance). Oxygen, refrigerated liquid, UN 1073, is one of six substances in the group of Class 2.2 with subsidiary risk 5.1 that require

on-deck stowage. It was assumed that the O_2 sensors would reduce the rate of accidents involving both oxygen and the other gases in the group (which could potentially replace oxygen and act as an asphyxiant). It was assumed that crew member entries into spaces with inappropriate oxygen levels would be reduced by 23 %.

Carbon dioxide, refrigerated liquid, UN2187, may be stowed either on-deck or under deck according to current regulations. It was therefore not considered relevant to include the risk reduction associated with carbon dioxide in the risk model for Class 2.2. Solid carbon dioxide (dry ice), UN1845, belongs to Class 9 and requires on-deck stowage. No generic risk model had been developed for Class 9 due to the wide range of substances included in this class. Carbon dioxide can also be generated in spaces where there is decomposition of certain types of cargos, but this is not specifically related to carriage of dangerous goods.

Using the event trees for class 2.2, non-flammable, non-toxic gases, with no subsidiary risk and with subsidiary risk 5.1 (oxidizing substances), developed in section 5 of Annex I it is calculated that the introduction of O_2 sensors for the crew would reduce the risk of individual crew being exposed to lethal levels of oxygen (too high or too low) by 24 %, (4.58E-6 lives will be saved per ship year or 1.1E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 218,000 ship years.

(Affected event tree events are “Crew members stay out of hold when gas is at dangerous level”, and “Other crew members use SCBA or ventilates before rescue attempt”)

On the basis of a risk reduction of 23 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 4.09E-4 per ship year was determined, i.e. ΔPLL=4.58E-6 (per ship year) and ΔR = 1.15E-4.
This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed “on deck only” on the open deck of a conventional containership (cf. Annex I).

RCM 7b Provision of air supply (SCBA) for people entering the cargo hold
Participants of the Delphi study judge that this measure would yield an expected reduction of accidents by 47 %, for cases where crew members were exposed to non-breathable atmospheres and poisonous gases)(However, there is a standard deviation of 25.5 %, with judgements ranging from 20 % to 70 %).

Using the event trees for class 2.2 (both with no subsidiary risk and with subsidiary risk of class 5.1), class 2.3, and class 6.1 developed in section 5 of Annex I it is calculated that the introduction of improved air supply for crew entering the cargo hold would reduce the risk of crew being exposed to lethal conditions by 48 %, (1.2E-5 lives will be saved per ship year or 2.9E-4 over the 25 year lifetime of the vessel) i.e. one life will be saved in 87,000 ship years.

Affected event tree events for classes 2.2, are “Crew members stay out of hold when gas is at dangerous level”, and “Other crew members use SCBA or ventilates before rescue attempt”. For class 2.3 the affected event tree event is “crew members exposed to gas in lethal concentrations”, and for class 6.1 the affected event tree event is “crew members exposed to toxic material at time and concentration to cause fatalities”.

On the basis of a risk reduction of 47 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 4.02E-4 per ship year was determined, i.e. ΔPLL=1.15E-5 (per ship year) and ΔR = 2.88E-4.

This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed "on deck only" on the open deck of a conventional containership (cf. Annex I).

RCM 7c Provide personal protection equipment

Experts of the Delphi study judge that this measure would yield an expected reduction of accidents by 33 % (However, there is a standard deviation of 32.5 %, with judgements ranging from 10 % to 70 %)

Using the event trees for classes 2.3 and 6.1 developed in section 5 of Annex I it is calculated that the introduction of improved personal protection (protective suits) would reduce the risk of crew being exposed to lethal conditions by 42 %, (1.6E-6 lives will be saved per ship year or 4E-5 over the 25 year lifetime of the vessel) i.e. one life will be saved in 618,500 ship years.

Affected event tree events are for class 2.3: "crew members exposed to lethal concentrations on deck or in hold" and for class 6.1:"Crew members exposed to toxic material at time concentration to cause fatalities".

On the basis of a risk reduction of 33 %, by means of calculations using the risk model of Annex I for this RCO a reduction of the PLL from 4.13E-4 to 4.12E-4 per ship year was determined, i.e. ΔPLL=1.62E-6 (per ship year) and ΔR = 4.05E-5.

This RCO on its own does not reduce the PLL for the open-top vessel below the level of risk that was determined for the transport of dangerous goods that are classed "on deck only" on the open deck of a conventional containership (cf. Annex I).

This measure would also be feasible for the deck area of conventional containership.

7.2.8 Sensitivity analysis

The results of the calculations that are discussed above are summarised in Table 20. For these calculations fire and asphyxiation hazards were considered. By means of Table 20 the effect the implementation of each RCO would have on the PLL of the open-top containership can be compared to the PLL values for the conventional containership against the PLL values for the open-top containership with the particular RCO. As point of reference, also the PLL for the open-top vessel without any RCO is given, as calculated in section 5. It should be noted that, in compliance with the discussion in section 6.5, each RCO only has an effect on selected DG classes. PLL values that are marked in italics denote a change as a consequence of introducing a particular RCO in the open-top design with respect to a particular DG class.

The data in Table 20 are obtained from calculations based on the mean values for risk reduction as judged by the experts. The data indicates that, while several RCOs yield a reduction of the PLL value for the open-top vessel below the PLL value of the conventional vessel for particular DG classes (indicated by bold italic typesetting), only by RCO 1 the total PLL for the open-top containership could be reduced to a level below the total PLL of conventional transport.

When the calculation of PLL is performed using the maximum risk reductions that were judged by the experts also RCO 4 appears suitable to lower the PLL for the open-top transport to the order of magnitude of the PLL of conventional transport.

Table 20: Summary of PLL for crew members for carrying dangerous goods requiring on-deck stowage (values based on mean reduction)

Dangerous Goods Class	**PLL from Fire (PLL crew per ship year)[1]**										
	Conventional Container - ship (cf. Annex I)	**Open-top containership**									
		No RCO (Annex I)	**with RCO 1**	**with RCO 2**	**with RCO 3**	**with RCO 4**	**with RCO 5**	**with RCO 6**	**with RCM 7a**	**with RCM 7b**	**with RCM 7c**
Class 2.1	2.94E-05	3.23E-05	***2.26E-06***	***2.81E-05***	3.23E-05	*3.11E-05*	3.23E-05	3.23E-05	3.23E-05	3.23E-05	3.23E-05
Class 2.2, no subs. Risk	0.00E+00	6.63E-06	*4.64E-07*	6.63E-06	6.63E-06	6.63E-06	*4.55E-06*	6.63E-06	*5.03E-06*	*3.41E-06*	6.63E-06
Class 2.2, subs. Risk 5.1	2.55E-06	1.48E-05	***1.10E-06***	1.48E-05	1.48E-05	*1.36E-05*	*1.09E-05*	1.48E-05	*1.18E-05*	*8.81E-06*	1.48E-05
Class 2.3	1.20E-04	1.04E-04	***7.27E-06***	1.04E-04	1.04E-04	*8.67E-05*	***1.03E-04***	1.04E-04	1.04E-04	***1.02E-04***	***1.03E-04***
Class 3	7.65E-05	9.67E-05	9.67E-05	9.67E-05	9.67E-05	*9.42E-05*	9.67E-05	9.67E-05	9.67E-05	9.67E-05	9.67E-05
Class 4.2	7.24E-05	7.24E-05	7.24E-05	7.24E-05	7.24E-05	***7.08E-05***	7.24E-05	7.24E-05	7.24E-05	7.24E-05	7.24E-05
Class 4.3	6.68E-05	7.24E-05	7.24E-05	7.24E-05	***5.93E-05***	*7.21E-05*	7.24E-05	7.24E-05	7.24E-05	7.24E-05	7.24E-05
Class 5.1	1.22E-06	3.47E-07	***2.43E-08***	3.47E-07	3.47E-07	*1.74E-08*	3.47E-07	3.47E-07	3.47E-07	3.47E-07	3.47E-07
Class 6.1	1.16E-06	1.58E-06	1.58E-06	1.58E-06	1.58E-06	1.58E-06	***6.43E-07***	1.58E-06	1.58E-06	***8.38E-07***	***1.06E-06***
Class. 8	1.06E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05	1.21E-05
Total	**3.82E-04**	**4.13E-04**	**2.66E-04**	**4.09E-04**	**4.00E-04**	**3.89E-04**	**4.05E-04**	**4.13E-04**	**4.09E-04**	**4.02E-04**	**4.12E-04**
ΔPLL per ship year (open-top with RCS vs. open-top w/o RCO)			1.47E-04	4.19E-06	1.30E-05	2.43E-05	7.88E-06	--	4.58E-06	1.15E-05	1.62E-06
ΔR (=25 * ΔPLL)			3.68E-03	1.05E-04	3.25E-04	6.08E-04	1.97E-04	--	1.15E-04	2.88E-04	4.05E-05

[1]Values in *italics* indicate that a DG class is affected by the respective RCO; values in ***bold faced italics*** indicate that the PLL for a certain DG class that was previously higher for the open-top vessel is expected to be reduced by introduction of an RCO to a level below value of conventional vessel.

7.3 Cost of Implementing RCOs

Cost calculations based on NPV are performed for the boundary conditions defined in the introduction of section 7. It is further assumed that the vessel's operating time is 250 days per year.

Influence of oil price:

During the work on this project the price of bunker oil (IFO380) ranged between from 680 US$/tonne (July 2008) to 202 US$/tonne (December 2008)[11]. In order to obtain NPV calculations with less volatility, the average increase of the crude oil price over the last 14 years was used. For this period, an annual increase of 11.1 % can be observed, see Figure 20[12].
For the calculation of fuel cost the price of IFO380 bunker oil was used. Depending on the operating areas, MARPOL Annex VI 2008, regulations 13/14 set out requirements to increasingly use of low sulphur fuels. Presently, use of such fuels is predominantly required in SOx Emission Control Areas (SECA) and Particularly Sensitive Sea Areas (PSSAs), but a global use is anticipated for the coming decades. An increase of costs due to a switch to fuels such as Marine Diesel Oil (MDO) or Marine Gas Oil (MGO) is not considered in these calculations.

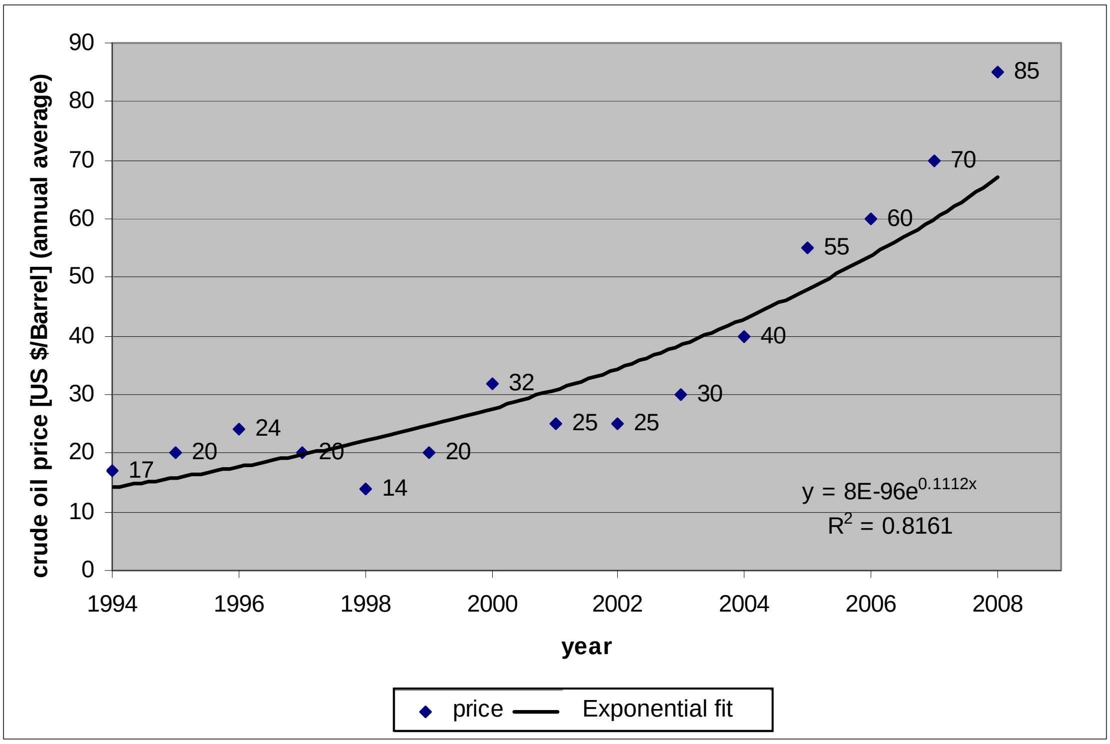


Figure 20: Development of crude oil price (1994-2008).

[11] Source: http://www.bunkerworld.com
[12] It is acknowledged that the tendency of the last 14 years will not necessarily continue in the decades to come; in fact, oil prices prior to 1994 do not fit well in the approximated curve. While from the current point of view it seems justifiable to assume an increase of 11.1 % for the matter of these calculations, it could be argued that cost-assessments for factors that include a high volatility, such as oil prices, process of raw materials or currency exchange rates, are challenging with respect to IMO decision making.

7.3.1 RCO 1 – Permanent high-volume ventilation

With respect to the design requirements outlined in section 7.2.1, installation and maintenance costs are calculated for vents and piping.
Twelve axial vents with a volume flow of 40,000 m^3/h need to be installed; four vents in each of the three cargo holds. Each unit has an initial purchase price of 11,000 US$ and causes annual maintenance costs of 400 US$, yielding a NPV of 17,000 US$ per unit, or 204,000 US$ in total.
Installation of additional/modified piping is expected to cost 20,000 US$ and result in annual maintenance costs of 200$, yielding a total NPV of 23,000 US$ for piping.

The proposed venting system yields an additional power consumption of 240 kWh (20 kWh per unit). With an assumed efficiency of the power generator of 40 % and a specific fuel oil consumption of 200 g/kWh the estimated consumption for operating the ventilation system is 1.1 tonne of fuel oil per day, i.e. 288 tonnes per year
Independently from the discount rate of 5 % that is used in these NPV calculations for hardware installations and maintenance activities, with respect to the oil price an average annual increase of 11.1 % is assumed. Taking the current bunker oil costs of 202 US$/tonne as a start value, the additional fuel costs from this RCO are 10,747,000 US$.

In summary the NPV of RCO 1 is 10,975,000 US$.
These costs are equivalent to 32 % of the newbuilding price of the vessel.

7.3.2 RCO 2 – Installation of flammable gas sensors in cargo holds

Inquiries at manufacturers yield that modern infrared multi-gas detection systems are available and certified for maritime use, which are capable of detecting flammable gases and in particular the majority of gases listed in section 6.2.2. In order to achieve a reliable detection each cargo hold would need to be equipped with an array of eight sensors, located in the corners at the bottom of the hold. The 24 sensors required in total for three cargo holds can be controlled by two analysis detection units. The purchase price of each unit is 58,000 US$, the price for maintenance and calibration performed on board by the manufacturer is 1,900 US$ per unit, and maintenance is required twice per year. Hence the NPV for two units is 221,000 US$.
The option to have maintenance tasks performed by crew was also considered, but does not yield financial gain. This is because annual maintenance by manufacturer is prescribed by regulators, and training of crew to perform the maintenance independently from the manufacturer would also cost about 1,900 US$ per year.

Initial installation costs for cabling and fittings are assumed to be 16,000 US$. With annual maintenance costs of 400 US$ the NPV for the cabling and fittings is 22,000 US$.

In summary the costs related to RCO 2 are 243,000 US$.
These costs are equivalent to 0.7 % of the newbuilding price of the vessel.

7.3.3 RCO 3 – No stowage in lowest tier for containers which hold class 4.3. substances

Implementation of this control option is not expected to result in additional costs. There may be indirect effects in circumstances, where additional planning effort is required for the loading process, in order to comply with this stowage restriction. However, experts judge that this effort is negligible.

7.3.4 RCO 4 – Foam extinguishing systems

A foam extinguishing system would have to be set up in such a way that heavy foam is generated at the top of the hold and then is directed towards the bottom. The installation costs for such a system are estimated to be 110,000 US$. These costs are dominated by pumping, stowage, connection to the emergency generator, and agent.
Annual maintenance of such systems comes at high costs (14,000 US$), as the agent is expensive and needs to be exchanged regularly (shelf-life 4 years).

In summary the NPV related to RCO 5 is 450,000 US$.
These costs are equivalent to 1.3 % of the newbuilding price of the vessel.

7.3.5 RCO 5 – Fixed air supply system in cargo hold

Costs were estimated for the installation specified in section 6.2.5.
Purchase costs of the breathing air compressor with pressurized air filter add up to 6,200 US$ with annual maintenance cost of 240 US$. Purchase costs for a hose wheel including breathing air hoses are 690 US$, with annual maintenance costs of 40 US$. A total of 18 hose wheels are required (six per hold).
Installation costs for the required piping are expected to be 60,000 US$, with annual maintenance costs of 600 US$.

In summary the NPV related to RCO 5 is 100,000 US$.
These costs are equivalent to 0.3 % of the newbuilding price of the vessel.

7.3.6 RCO 6 – No stowage of class 8 substances close to relevant ship structures

This measure does not yield additional costs, since it is current practice.

7.3.7 RCO 7 – Improved personal protection

Costs of risk control measures RCM7a through RCO 7c are calculated individually.

RCM 7a: Equip crew with oxygen and CO_2-sensors
It is recommended to provide two sets of portable sensor equipment aboard. Purchase costs for each set, consisting of multi-gas detection system and tubes, battery packs and chargers add up to 5,200 US$. Annual maintenance costs are estimated to be 700 US$ for each set.
The NPV for two sets of portable sensor equipment is 30,000 US$.
These costs are equivalent to less than 0.1 % of the newbuilding price of the vessel.

RCM 7b Provision of air supply (SCBA) for people entering the cargo hold
Experts recommend to keep at least four SCBAs on board, each with a capacity of no less than 60 minutes of breathing air. Each unit costs 2,800 US$ and causes annual maintenance costs of 360 US$, yielding an NPV of 7,900 US$ per unit, i.e. 32,000 US$ for four units.
These costs are equivalent to less than 0.1 % of the newbuilding price of the vessel.

RCM 7c Provide personal protection equipment
The purchase price of single-use suits is 210 US$. These suits do not yield maintenance costs, but is expected that once a year a situation might occur where a suit will need to be used or replaced, yielding a NPV of 3,900 US$ for four suits.
The purchase price of a gas-tight suit is 3,200 US$. Suits need to be decontaminated and tested after use. However, re-use might not be possible, because the condition of the protective layers cannot be assessed with the means available aboard. If stowed appropriately, suits need to be replaced every eight years, even

if they were not used. The NPV for two heavy suits is 17,800 US$. Annual training in the use of such suits needs to be provided, at an estimated cost of 2,000 US$ per annum.
In summary, the NPV for RCM 7c is 52,000 US$.
These costs are equivalent to 0.15 % of the newbuilding price of the vessel.

7.4 Economic Benefit of Implementing RCOs

Cost-effectiveness for risk control options are evaluated on the basis of GCAF. This calculation is affected by PLL values that are by factor 10 lower than for general risk levels achieved by containerships [23]. These risk levels were determined from data recorded the United States Office of Hazmat Safety's Hazardous Materials Incident Report System (HMIRS) which was analysed in Annex I. An effect of these low risk levels is that the risk reduction that is achieved by introduction of an RCO is also low, and hence the GCAF values are high.
A discussion of NCAF calculations is provided in section 7.4.3.

7.4.1 Assumptions for benefit calculations

For the benefit calculations the following assumptions were made:

- Crew size: 15
- Crew shifts per year: 3
- Expected lifetime T: 25 years
- Depreciation rate r: 5 %
- Newbuilding price: 34,000,000 US$
- Value of a (filled) 20ft container [34]: 20,000 US$

It should also be noted that the following calculation includes the implicit assumption that dangerous goods containers that are transported and marked according to regulations can be detected by crew and loading personnel. There is an indication from investigations of major accidents that dangerous goods may not have been transported according to the regulations.

7.4.2 GCAF calculations

7.4.2.1 RCO 1 – Permanent high-volume ventilation

The determined risk reduction of ΔR=3.68E-3 in combination with an NPV of 10,975,000 US$ yields a GCAF value of 2,986,000,000 US$.

7.4.2.2 RCO 2 – Installation of flammable gas sensors in cargo holds

The determined risk reduction of ΔR = 1.05E-3 in combination with an NPV of 243,000 US$ yields a GCAF value of 232,000,000 US$.

7.4.2.3 RCO 3 – No stowage in lowest tier for containers which hold class 4.3. substances

Avoiding stowage of class 4.3 substances in the lowest tier comes at no additional cost, i.e. GCAF = 0.
Hence, it should be considered to place this constraint, if the transport of class 4.3 substances in cargo holds of open-top containerships was to be allowed.

7.4.2.4 RCO 4 – Foam extinguishing systems

The determined risk reduction of ΔR = 6.08E-4 in combination with an NPV of 450,000 US$ yields a GCAF value of 748,000,000 US$.

7.4.2.5 RCO 5 – Fixed air supply system in cargo hold

The determined risk reduction of ΔR = 1.97E-4 in combination with an NPV of 101,000 US$ yields a GCAF value of 512,000,000 US$.

7.4.2.6 RCO 6 – No stowage of class 8 substances close to relevant ship structures

This RCO can be implemented at no extra costs and provides no additional benefit, as it represents requirements that are already established. Since no technical or operational solution could be found that would make it possible to store class 8 substances in cargo holds with the same level of safety as provided by current regulations, it is recommended to keep the “stowage on deck only” requirement for these substances.

7.4.2.7 RCO 7 – Improved personal protection

RCM 7a *Equip crew with oxygen and* CO_2*-sensors*

The determined risk reduction of ΔR = 1.15E-4 in combination with an NPV of 30,000 US$ yields a GCAF value of 265,000,000 US$.

RCM 7b *Provision of air supply (SCBA) for people entering the cargo hold*

The determined risk reduction of ΔR = 2.88E-4 in combination with an NPV of 32,000 US$ yields a GCAF value of 110,000,000 US$.

RCM 7c *Provide personal protection equipment*

The determined risk reduction of ΔR = 4.05E-5 in combination with an NPV of 52,000 US$ yields a GCAF value of 1,279,000,000 US$.

7.4.3 NCAF calculations

In the light of the high GCAF values that were obtained by calculations described in sections 7.4.2.1 through 7.4.2.7, it was decided to perform an initial estimation of NCAF values on the basis of conservative assumptions, before intensive work on detailed GCAF calculations is performed. Only RCOs 1, 2, 3, 4 and 6 have an effect with respect to property damage. RCOs 1 to 4 relate to accidents involving fires only, as in the HazID these were determined to be the dominant accident class with respect to property damage. Control option RCO 6 relates to structural damage as consequence of leak of dangerous goods class 8 corrosive substances; however, RCO 6 was excluded from NCAF considerations as effectively it states that existing stowage requirements should persist for class 8 dangerous goods.

In addition to the assumptions specified in section 7.4.1, for the calculations of the NCAF of RCOs addressing fire accidents it was assumed conservatively that each time an ignition occurs as a consequence of an accident involving the fire-related dangerous goods classes 2.1, 3, 4.2 or 4.3:

- A fire develops which leads to a loss of 105 loaded containers.
  (i.e. 75 % of the below-deck capacity of the largest hold)
- The value of a (filled) 20ft container is 20,000 US$ [34].
- Costs for ship repairs following a fire are estimated to be 500,000 US$.

Under these assumptions the NCAF values that are shown in Table 21 were determined

Table 21: GCAF and estimated NCAF values

	GCAF	NCAF
RCO 1	2,986,000,000	2,632,000,000
RCO 2	232,000,000	<0
RCO 3	0	<0
RCO 4	748,000,000	131,500,000

From these calculations it was observed that RCO 2 and RCO 3 yield negative NCAF values, which indicates that there should be an economic interest of the owner to implement of these RCOs.
Yet, the expected risk reduction that is achieved by implementation of these RCOs is not sufficient to achieve a level of risk that is equivalent to the transport on the open deck of a conventional vessel. Also, these RCOs only address DG classes 2.1 and 4.3.

For the remaining RCOs the NCAF values exceed the 3million US$ criterion by more than factor 43.

As even for these conservative assumptions it seems not feasible to obtain NCAF values that would justify the implementation of any of the remaining RCOs, we consider that a detailed calculation of NCAF is not sensible at this point.

7.5 RCOs that are not specific to open-top containerships

A number of RCOs were identified that are not specific to open-top containerships (Table 22). These are not included in the analysis as they are either relevant for all containership types.

Nevertheless these points are mentioned here as experts felt they should be raised to a wider community.

7.5.1 RCO 8 – Establishment of land-based support centres

The loading plan provides information on where dangerous goods containers are located as well as which dangerous goods classes are stowed. The variety of dangerous goods makes it impossible for the crew to judge what chemical reactions to expect. Experts recommended considering the installation of land-based services to make it possible for ship crews to get in touch with dangerous goods experts in case an incident involving dangerous goods is identified on board.
An example of such a system is TUIS, the Transport-Accident-Information- and Emergency-Response System of the German chemical industry[13].
This RCO does only have an effect on the consequences of an accident. While suitable equipment may not be available aboard for dealing with all types of chemical reactions, expert advice will provide the crew with details required for decision making.

Experts of the Delphi study judge that this measure would yield an expected reduction of probability of an accident developing fatal consequences of 17 % (with 21 % deviation, judgements ranging from 0 % to 40 % reduction).

7.5.2 RCO 9 – Training of personnel involved in transport chain

Experts agree that while there is still potential in increasing the safety of transport of containers by sea, e.g. as described in [15], many accidents occur as a consequence of improper handling of dangerous

[13] http://www.vci.de/TUIS/default2~cmd~shr~docnr~114675~nd~~rub~741~ond~tuis~c~0.htm

goods in parts of the logistics chain that are outside the control of the shipping industry [1]. Typical errors relate to packing and overfilling of containers, as well as improper loading, unloading and handling of containers during land transport. Experts recommended that persons who handle dangerous goods should be adequately trained, and their qualifications should be checked in regular intervals.

The consensus estimate obtained from the Delphi study concludes that this measure would yield an expected reduction of the probability of accidents by 53 %.

7.5.3 RCO 10 – Improvement information management

Currently, information on the positions of DG-containers is available on board in the stowage plan. However, information on the exact content of these containers is not available. Such information would be required in order to be able to determine the optimal response strategy to an incident involving dangerous goods. Consequently, it is recommended to improve information exchange about cargo content of containers between charterer and master, and ideally also between the customer and the charterer.

It is likely that knowledge about possible reactions is not available aboard the vessel. Information about the content of DG containers would be required, if experts based on land would be asked for advice (cf. RCO 8).
In the same manner as RCO 8 this risk control option does only have an effect on the consequences of an accident. While suitable equipment may not be available aboard for dealing with all types of chemical reactions, expert advice will provide the crew with details required for decision making.

Experts of the Delphi study judge that this measure would yield an expected reduction of the probability of fatal accidents occurring as the consequence of a dangerous goods release by 17 % (although it should be noted that expert opinions range from 0 %-40 % with a deviation of 21 %)

7.5.4 RCO 11 – Survey of DG-containers during loading

Visible damages of DG-container that occurred prior to entering the ship can be determined by the crew during loading, and damaged containers would be rejected. Due to economic pressures, time available for loading is limited. Yet, technologies such as Radio Frequency Identification (RFID) could be suitable, for instance, to raise attention and to focus attention of the crew to DG containers during loading.
It should be noted that many accidents in the past can be attributed to damages inside containers, which would not be visually apparent from the outside. Hence, experts of the Delphi study unanimously agree that this measure would yield an expected reduction of the probability of accidents 10 %.

7.5.5 RCO 12 – Introduction of specially equipped DG container

Beyond existing regulations for the packaging of dangerous goods, experts agreed that introduction of a special-purpose container could be beneficial for the transport of dangerous goods.
Such a container could be equipped with features that address:

- Accident frequency: e.g.
    - Water-proof containment to encapsulate the transported goods against external influences
    - Inert atmosphere
- Immediate accident consequences: e.g.
    - Integrated fire-fighting device that is suitable with respect to the transported goods
- Indirect accident consequences: e.g.
    - a smoke/heat detection system (e.g. melting plug), which provides an early warning to the crew, and thereby increases the time available to make a decision
    - barriers against the spread of the hazards inherent in the transported goods beyond the single container.

Maintenance effort for such container would be similar, perhaps lower than for reefer containers today.
The purchase price for such a container is 28,000 US$, compared to 1,800 US$ for a standard 20ft container. Additional logistics challenges are expected with respect to world-wide tracking and assignment of such containers. If for these challenges annual costs of 3,000 US$ are estimated (including maintenance and additional transport of empty containers), an NPV per container is 70,000 US$. The estimated share of DG containers is 5-10 % of the payload.

However, experts who participated in this study strongly agree that this measure would yield an expected reduction of the probability of accidents by 83 %.

7.6 Conclusions of cost-efficiency analysis

RCOs are discussed with respect to the overall risk-reducing potential and their cost effectiveness, which is judged by means of the GCAF criterion and, where applicable, NCAF criterion.

7.6.1 Risk reduction potential

The calculations of risk reduction (section 7.2) indicate that RCO1 may be a suitable measure on its own to reduce the current level of risk (PLL) for the transport of packaged dangerous goods requiring on-deck stowage to a level of risk that is equal to the level of risk that was determined for the transport of these goods on the open deck of a conventional containership. Additionally, if the maximum risk reduction potential judged by experts is applied, RCO4 achieves a PLL value that is close to the reference value for the conventional vessel.
RCO1 and RCO4 are the two control options that address the largest number of DG classes.

For the fire hazard the reference value (PLL per ship year) for the conventional reference vessel is 3.82E-04. In case RCO1 is implemented on the open-top containership, a PLL of 2.66E-04 could be achieved, if the average risk reduction potential judged by experts is used. The maximum reduction potential judged by the experts for RCO1 yields a PLL of 2.55E-04.
In case RCO4 is implemented on the open-top containership, a PLL of 3.77E-04 could be achieved, if the maximum risk reduction potential judged by experts is used. However, this value seems very optimistic, as it assumes a near-100 % success of this RCO in reducing the risks of the affected hazards. Given that there is no reference system so far, such an assumption is challenging.

Calculations of the risk reductions also back up the experts' opinion that none of the other identified RCOs, or suitable combinations thereof, would yield a risk reduction to a level that is similar to the PLL that was determined for the reference vessel. It is argued that, as RCOs are largely independent (cf. Table 17), the risk reduction that could be achieved by combination of RCOs would at most be as large as the sums of the risk reductions of the individual RCOs. The judgement that no suitable combinations exist is also based on cost effectiveness considerations.

7.6.2 Cost effectiveness

Calculations of the economic benefit (reduced economic risk) are summarised in Table 23. RCOs 2 and 3 yield negative NCAF values, which indicates that an implementation of these RCOs should be considered by owners because of the economic benefit. Hence, it is not deemed necessary to regulate these.

The comparably high GCAF values that were observed can be attributed to the fact that the risk values in the original risk models, which in section 5 were determined from data recorded in the United States Office of Hazmat Safety's Hazardous Materials Incident Report System, were already quite low. Consequently, the prospective risk reduction is even lower. As discussed in section 5, the operations in

US water, i.e. the area that is covered by HMIS, may not be representative for world-wide operations. It is argued that, for the time being, this is the most reliable and available data source for the calculations that are required in this work.
In order to illustrate that the general result of the GCAF and NCAF calculations are not influenced by this potential bias, the sensitivity of the GCAF and NCAF calculations was analysed regarding

- variations with respect to risk reduction potential, as discussed in section 7.2.8, as well as
- variations in costs of risk reduction (particularly with respect to the highly volatile oil prices).

This analysis shows that even if ten times higher risk reduction potential and a reduction of costs for the individual RCO by 50 % was assumed, the GCAF values would not fall below the 3M US$ limit. In the same manner, when a five times higher risk-reduction potential and a reduction of costs for RCO 1 or RCO 4 by 15 % was assumed, the corresponding NCAF value (estimated under conservative assumptions) still exceeds the 3M US$ limit.

Table 22: Identified RCOs (not specific to open-top containerships)

RCO	Operational consequence	Purpose	Focus	Focus of application	Type	Costs	Human Factors
Name ID	Description	(P)revention/ (M)itigation	(L)ife / (E)nv / (P)rop	(D)esign / (O)peration	(P)assive / (A)ctive measure	(H)igh (M)edium (L)ow	(I)nvolved / (C)ritical
RCO 8	Land-based expert service shall be established to support masters in decision making in case of accidents that are suspected to involve dangerous goods	M	L, E, P	O	A	L[1]	C
RCO 9	General shoreside training of people, especially with respect to packing and overfilling of containers and loading, unloading and handling of containers	P, M	L, E, P	O	A	L	I
RCO 10	Improvement information management, especially information exchange about cargo content of containers between charterer and master; position of DG-containers on stowage plan (today mandatory);	P. M	L, E, P	O	A	L	C
RCO 11	Survey of DG-containers during loading	P, M	L, E, P	O	A	M	C
RCO 12	Introduce DG-Container with automatic fire fighting device, smoke/heat detection (e.g. melting plug), inerting system for the container	P, M	L, E, P	D	A	H	-

[1] While a land-based expert service would need to be manned by highly qualified personnel, participants of the expert sessions argued that a land-based service would need to be financed by the shipping community, so the costs for the individual operator would remain low.

Table 23: Results

RCO	Risk reduction *ΔR*	Cost *ΔC*	*Benefit ΔB*	$GCAF = \frac{\Delta C}{\Delta R}$	$NCAF = \frac{\Delta C - \Delta B}{\Delta R}$
	# of saved lifes[1]	US$[1)2)]	US$	US$	US$ (10^6)
RCO 1: Permanent high-volume ventilation	3.68E-03	6,883,000	135,000	2,986,000,000	2,632,000,000
RCO 2: flammable gas sensors in cargo holds	1.05E-03	243,000	380,000	232,000,000	<0
RCO 3: No stowage in lowest tier for containers which hold class 4.3. substances	3.28E-04	0	12,000	0	<0
RCO 4: Foam extinguishing systems	6.08E-04	450,000	22,000	748,000,000	131,500,000
RCO 5: Fixed air supply system in cargo hold	1.97E-04	101,000	n/a	512,000,000	n/a
RCO 6: No stowage of class 8 substances close to relevant ship structures	0.00E+00	0	0	0	0
RCM7a: Equip crew with portable oxygen and CO_2-sensors	1.15E-04	30,000	n/a	265,000,000	n/a
RCM7b: Provide SCBA for people entering the cargo hold	2.88E-04	32,000	n/a	110,000,000	n/a
RCM7c: Provide set of skin protection suits	4.05E-05	52,000	n/a	1,279,000,000	n/a

1) Per ship lifetime, assumed to be 25 years
2) Includes NPV at 5 % per year where relevant

8 Recommendations

This analysis investigated if the transport of packaged dangerous goods classified “on-deck stowage only” on open-top containerships (possible future operation scenario) by means of suitable risk control options could be accomplished with an “acceptable” level of safety, compared to the presently accepted solution of transport of these goods on the open deck (current operation).

As the on-deck transport represents a currently accepted solution, in this work it is argued that the acceptance criterion for an alternative solution should be to achieve an equivalent level of safety. As this criterion was the main objective, cost implications are only the secondary focus of this work.

In summary, it can be concluded from this work (with respect to acceptance criterion “variant 1”) that no single RCO is suitable to address all types of hazards that originate from the dangerous goods classes that were in focus of the analysis. Hence, no recommendation can be given to generally allow the transport of dangerous goods on open-top containerships.

No RCOs were identified that would be suitable to control accidents with dangerous goods class 8 “corrosive substances”. Therefore, it is recommended that class 8 substances should remain “on-deck stowage only”.

With respect to acceptance criterion “variant 2”, an Administration might decide to allow the transport of selected DG classes, if suitable RCOs are implemented on an open-top vessel.
For instance, RCO 1 appears suitable to control hazards related to DG classes 2.1, 2.2, 2.3 and 5.1 and to reach a level of safety that may be considered equivalent to the conventional transport with respect to these DG classes.

Table 24: RCOs that may be recommended for further consideration at IMO due to high risk-reduction potential

No.	RCO
RCO 1	Permanent high-volume ventilation

Additionally, for the remaining dangerous goods classes that were in focus of this work, RCOs were identified that achieve a level of risk that is lower than for the conventional transport with respect to individual classes, in particular class 4.2 (RCO 4), class 4.3 (RCO 3) and class 6.1 (RCO 5, RCMs 7b and 7c).

Table 25: RCOs that may be recommended due to their risk reducing effect with respect to particular classes of dangerous goods

No.	RCO	Affected DG class
RCO 3	No stowage in lowest tier for containers which hold class 4.3. substances	4.3
RCO 4	Installation of foam extinguishing systems in cargo hold.	4.2
RCO 5	Provide air supply (fixed installation) for crew members entering the cargo hold	6.1
RCM 7b	Provision of improved air supply (SCBA) for people entering the cargo hold	6.1
RCM 7c	Provision of improved personal protection equipment	6.1

If the whole range of dangerous goods classes that are considered in this analysis was to be addressed, the risk reduction achieved by each of these RCOs individually is not suitable to reach a level of safety that can be considered equivalent to the transport on the open deck. This implies that transport of dangerous goods in holds can only be considered for individual classes for which a suitable control option is in place.

With respect to cost-effectiveness, RCO 2 and RCO 3 achieve negative NCAF, which suggest that the implementation of these RCOs can be recommended purely on economic considerations. Yet, these RCOs only address the dangerous goods classes 2.1 and 4.3. Again, when all DG classes that are in focus of this analysis are considered, the expected risk reduction that is achieved by implementation of these RCOs is not sufficient to achieve a level of risk that is equivalent to the transport on the open deck of a conventional vessel.

Table 26: RCOs recommended for consideration by owners due to low costs

No.	RCO
RCO 2	Installation of flammable gas sensors in cargo holds
RCO 3	No stowage in lowest tier for containers which hold class 4.3. substances

Beyond the control options in Table 15, no further RCO was considered to be cost-effective.
Finally, three RCOs can be recommended for further consideration at IMO because their implementation costs are not grossly disproportionate (i.e. cost of each RCO less than 2 % of vessel newbuilding price):

Table 27: RCOs recommended for further consideration at IMO as cost not grossly disproportionate

No.	RCO
RCM 7a	Equipping crew with oxygen and CO_2-sensors
RCM 7b	Provision of improved air supply (SCBA) for people entering the cargo hold
RCM 7c	Provision of improved personal protection equipment

9 References

[1] Blyth, A. 2002. "*Health, Safety, and Environment Specification, Quantitative Risk Assessment (QRA)*". Petroleum Development Oman.

[2] Catapult Technology Ltd. 2005. "*Hazardous Materials incident Reporting System HMIRS Data Definitions and Codes*". Report prepared for US department of Transportation Pipeline and Hazardous Materials Safety Administration, Office of Hazardous materials Safety.

[3] DAGOB project, "*Maritime Transport and Risks of Packaged Dangerous Goods*", 2006. Available from: www.dagob.info [December 2008]

[4] Det Norske Veritas, *"Cargo Fires on Container Carriers"*, Technical Paper, 2003

[5] European Industrial Gases Association. 2003. "*Guidelines for Transport by Sea of Vacuum Insulated Portable Tanks and Multiple Element Gas Containers (MEGCs)*". IGC Doc 41/03/E. EIGA, Brussels.

[6] Forsman, B., Ellis, J., Gehl, S., Langbecker, U., and K. Riedel. 2006. "*Risk Analysis for Container Ships*", SAFEDOR Deliverable D.4.4.

[7] GEGIS, Gefahrgut-Informationssystem, Hamburg Port Authority, 2002-2006

[8] Germanischer Lloyd. "*Guidelines for the Carriage of Refrigerated Containers on Board Ships*", In "Rules of Classification and Construction" vol 1, part 1, chap 19, Germanischer Lloyd, Hamburg, 2008.

[9] HANSA International Maritime Journal, "*Dangerous Goods – Club Manager warn of accident increase*", No.9, 2006

[10] Hazcheck Systems. 2005. "*Calcium carbide suspected as cause of RORO ship fire*". 19 January 2005. Available from: www.hazcheck.com [December 2008].

[11] Health and Safety Executive UK, "*Safety Assessment Principles for Nuclear Facilities*", Edition 2006.

[12] Hengst, S., Molenaar, W., 1995, "*A view on containerships considering safety requirements for the safe transport of dangerous cargoes*", Delft University of Technology, Netherlands. (DSC 1/INF.4)

[13] HSE. 2001. "*Reducing Risks, protecting people*". HSE books, 2001, ISBN: 0-7176-2151-0.

[14] Hoffmann, P., Roberts, P., Thomas, M. and Konovessis, D., "*FSA for Tanker Operation – Cost-Benefit Analysis*",Deliverable D-4.7.3 of SAFEDOR Integrated Project.

[15] International Chamber of Shipping, World Shipping Council, "*Safe Transport of Containers by Sea, Guidelines on best practice*", in print. (http://www.marisec.org/pubs)

[16] International Maritime Organisation (IMO) *"International Convention for the Safety of Life at Sea"*, 2004

[17] International Maritime Organisation (IMO). "*International Maritime Dangerous Goods Code including Amendment 33-06*". IMDG Code on CD Version 8, London, 2006.

[18] International Maritime Organisation (IMO): "*Guidelines for formal safety assessment (FSA) for use in IMO rule making process"*, MSC/Circ. 1023, MEPC/Circ. 392. 5 April 2002. IMO, London, UK. 2002.

[19] International Maritime Organisation (IMO): "*Consolidated text of the Guidelines for Formal Safety Assessment (FSA)*". MSC 83/INF.2, May 2007.

[20] International Maritime Organisation (IMO), Maritime Safety Committee "*Formal Safety Assessment, Decision parameters including risk acceptance criteria*", MSC /72/16, February 2000.

[21] International Maritime Organisation (IMO): "*Hazard Identification (HAZID) on the watertight integrity of the fore end of bulk carriers*", MSC 72/INF.4, 2000.

[22] International Maritime Organisation (IMO): "*Formal Safety Assessment of Life Saving Appliances for Bulk Carriers FSA/LSA/BC*", MSC 74/5/5, February 2001.

[23] International Maritime Organisation (IMO): "*FSA – Containerships, Details of the Formal Safety Assessment*", MSC 83/INF.8, July 2007.

[24] International Maritime Organisation (IMO): "*FSA − Liquefied Natural Gas (LNG) Carriers; Details of the Formal Safety Assessment*", MSC 83/INF.3, July 2007.

[25] International Maritime Organisation (IMO): "*FSA – Crude oil tankers*", MEPC 85/INF.2, July 2008.

[26] International Maritime Organisation (IMO): "*FSA – Cruise ships, Details of the Formal Safety Assessment*", MSC 85/INF.2, July 2008.

[27] International Maritime Organisation (IMO): "*FSA – RoPax ships, Details of the Formal Safety Assessment*", MSC 85/INF.3, July 2008.

[28] International Maritime Organisation (IMO): "*International Maritime Dangerous Goods Code", Edition 2006.*

[29] International Maritime Organisation (IMO), Maritime Safety Committee, *"Interim Guidelines for Open-Top Containerships"*, MSC/Circ 608/Rev.1, 1994

[30] International Maritime Organisation (IMO), Maritime Safety Committee, "*Reports on Marine Casualties and Incidents. Revised harmonized reporting procedures - Reports required under SOLAS regulation I/21 and MARPOL 73/78 articles 8 and 12*", MSC/Circ.953 and MEPC/Circ.372, 14 December 2000

[31] International Maritime Organisation (IMO), Maritime Safety Committee, "*Unified Interpretations of SOLAS Chapter II-2, The FSS Code, The FTP Code and Related Fire Test Procedures*", MSC/Circ. 1120, 4 June 2004.

[32] International Association of Classification Societies. 2002. "*Formal Safety Assessment – Overview and IACS Experience*". Presentation at MSC 75, 16 May 2002.

[33] Kristiansen, S.: *"Maritime Transportation- Safety Management and Risk Analysis"*, Elsevier Butterworth-Heinemann, 2005.

[34] Munich Re Group: "*Containers – Transport, Technology, Insurance*", 2002.

[35] Mullai, A., Larsson, E, *"Hazardous Material Incidents – Some Key Results of a Risk Analysis"*, Lund University, Sweden., 2007

[36] Norway: "*Formal Safety Assessment, Decision Parameters including Risk Acceptance Criteria*", MSC 72/16, Submitted by Norway to IMO, 2000

[37] Ojala, L. 2007. "*Safe and Reliable Transport Chains of Dangerous Goods in the Baltic Sea Region – Key Findings of the DaGoB Project 2006 – 2007*". DaGoB publication series 6:2007. DaGoB Project Office, Turku School of Economics, Turku, Finland.

[38] Papanikolaou A. (Ed.), *"Risk-Based Ship Design"*, Springer-Verlag, Berlin, March 2009.

[39] Papanikolaou A, Eliopoulou E, Mikelis N, Asku S. and Delautre S., 2006, "*Casualty analysis of tankers*" Proc. RINA Learning from Marine Incidents III, London, UK, January 2006.

[40] Povel, D. 2005. "*Cargo Safety – Qualitative Design Review (QDR)*". Deliverable SP 2.5.3 of SAFEDOR Integrated Project.

[41] Ronza, A., Vílchez, J.A., and J. Casal. 2007. "*Using transportation accident databases to investigate ignition and explosion probabilities of flammable spills*." Journal of Hazardous Materials 146 (2007) 106 – 123.

[42] Skjong, R., Vanem, E., Endresen, Ø., "*Risk Evaluation Criteria*", SAFEDOR Deliverable D4.5.2, Oct 2005, available from http://www.safedor.org [December 2008] .

[43] The Shipowners' Protection Limited. 2000. "*Recommendations on Carriage of Calcium Hypochlorite*". Circular to all members. November 2000. Available from: www.shipownersclub.com/library/circulars/circular.asp?value=33 [December 2008]

[44] Transport Safety Board of Canada. 2001. Marine Investigation Report, "*Container Fire, Containership Kitano off Chebucto Head, Nova Scotia 22 March 2001*". Report Number M01M0017. Available from: www.tsb.gc.ca/en/reports/marine/2001/ [December 2008].

[45] U.S. Department of Labor, Occupational Safety & Health Administration, "*Respiratory protection standard*", 29 CFR 1910.134, July 1997. (http://www.osha.gov) [December 2008]

[46] U.S. Department of Labor, Occupational Safety & Health Administration, "*Permit-required confined spaces*", 29 CFR 1910.146, Appendix D, Dec 1998. (http://www.osha.gov) [December 2008]

[47] U.S. Department of Transportation, Maritime Administration. 2008. "*Vessel Calls at U.S. Ports Snapshot, 2006*". Available from: http://marad.dot.gov/library_landing_page/data_and_statistics/Data_and_Statistics.htm [Dec 2008].

[48] U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration. 2008. Hazardous Materials Incident Data. Available from: http://hazmat.dot.gov/pubs/inc/incdata.htm [Accessed February 2008].

[49] U.S. Maritime Administration, Office of Statistical and Economic Analysis. 2005. "*Containership Market Indicators*". Available from: www.marad.dot.gov [December 2008].

[50] U.S. Maritime Administration, Office of Statistical and Economic Analysis. 2006. "*Vessel Calls at U.S. and World Ports 2005*". Available from: http://marad.dot.gov [December 2008].

[51] U.S. Maritime Administration, Office of Data and Economic Analysis. 2006. "*World Merchant Fleet 2001 – 2005*". Available from: http://marad.dot.gov [December 2008].

[52] Weeth, C.P. 2003. "*M/V Hanjin Pennsylvania: Explosions at Sea. Report prepared on behalf of the National Fireworks Association*". LaCross, Wisconsin. Available from: www.nationalfireworks.org/penn-ship.htm [December 2008].

10 Appendices

A.1: Acronyms

AR-AFFF	Alcohol-Resistant Aqueous Film Forming Foams
AR-FFFP	Alcohol-Resistant Film Forming Fluoroprotein
CBA	Cost-Benefit Analysis
DG	Dangerous Goods
FSA	Formal Safety Assessment
FSS Code	Fire Safety Systems Code
GCAF	Gross Cost of Averting a Fatality
HazID	Hazard Identification
HMIRS	Hazardous Materials Incident Report System
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
LFL	Lower Flammable Limit
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
NCAF	Net Cost of Averting a Fatality
NPV	Net Present Value
N.O.S.	Not Otherwise Specified
PLL	Potential Loss of Life
PSSA	Particularly Sensitive Sea Area
RCM	Risk Control Measure
RCO	Risk Control Option
RFID	Radio Frequency Identification
SCBA	Self-Contained Breathing Apparatus
SECA	SOx Emission Control Area

A.2: Participants in the FSA

The project team received input from a number of experts undertaking various roles in the maritime industry. These are listed below. The current report however, does not express the views and opinions of the listed experts explicitly, and the content of the report is the responsibility of the project team alone.

Experts involved in HazID:

Name	Affiliation	Background	Role
Ingo Doering	German Federal Institute for Materials Research and Testing	Specialist for Reactive Substances and Systems. Working Group, Assessment of Dangerous Goods/Substances	expert
Uwe Kraft	Bremen Port Authority	Dangerous Goods/IMDG Code specialist	expert
Rainer Brück	Peter Döhle Schifffahrts KG	Captain, Dangerous Goods Representative	expert
Kurt Riedel	Peter Döhle Schifffahrts KG	Naval Architect	observer
Friedo Holtermann	Germanischer Lloyd	Specialist for Dangerous Cargo, Fire Extinguishing Systems	expert
Frank Mönnig	Wadan Yards	Design Engineer, Cargo Holds	expert
Wolfgang Hintzsche	German Shipowners Association	Captain, Safety Management Representative	expert
Joanne Ellis	SSPA	Project Manager, Research Engineer	observer
Andreas Baumgart	Germanischer Lloyd	Project Manager, Research Engineer	facilitator/ recorder
Kay Dausendschön	Germanischer Lloyd	Project Manager, Research Engineer	facilitator/ recorder
Sandra Peter	Germanischer Lloyd	Student Intern	observer
Hinnerk Hatecke	Wadan Yards	Student Intern	observer

Experts involved in RCO brainstorming and Delphi sessions:

Name	Affiliation	Background
Joanne Ellis	SSPA	Project Manager, Research Engineer
Friedo Holtermann[1]	Germanischer Lloyd	Specialist for Dangerous Cargo, Fire Extinguishing Systems
Ingo Döring[1]	German Federal Institute for Materials Research and Testing	Specialist for Reactive Substances and Systems. Working Group “Assessment of Dangerous Goods/Substances”
Norbert Kusch[1]	City of Hamburg fire brigade	Deputy Fire Chief, Chief of Command Control and Communication Center, Deputy Chief of Maritime Intervention Group, Chemist
Manfred Lange	City of Hamburg fire brigade	Head of technical and environmental guard, (covering the Hamburg harbour)
Karsten Loer	Germanischer Lloyd	System Safety Engineer, Project Manager, Specialist in the fields of risk assessment, RAMS and human element
Kurt Riedel	Peter Döhle Schifffahrts KG	Naval Architect
Finn Vogler	Germanischer Lloyd	Naval Architect, Project Manager and safety analyst, Specialist in the fields process technology, fuel cells, gas as ship fuel
Capt. Jens-Uwe Zimmermann	Peter Döhle Schifffahrts KG	Designated Person/CSO, Dangerous Goods Advisor
[1] This expert also participated in the Delphi rounds on risk-reduction judgements of RCOs.		

A.3: Initial List of RCOs

The following risk control measures and options were considered at the expert session held at GL in October 2008.

General measures

1. Improvement information management, especially information exchange about cargo content of containers between charterer and master; position of DG-containers on stowage plan
2. General shoreside training of people, especially with respect to packing and overfilling of containers and loading, unloading and handling of containers
3. introduce DG-Container with CO_2 fire fighting, smoke/heat detection (align with MSC discussions)
4. Survey of DG-containers during loading

RCOs for hazard group "Gas Leakage (toxic, non-toxic, flammable)"

5. Provide self-contained breathing apparatus for crew, personal protection equipment (e.g. breathing, skin protection)
6. Establish procedure: Ventilation of cargo holds before any person enters a hold

RCOs for hazard group "Leakage of liquid (toxic, corrosive, flammable)"

7. Improve quality of containments/packaging
8. Permanent high volume ventilation (see item 10).

RCOs for hazard group "Leakage of other substances"

9. Ventilation should be suitable for gases heavier than air to avoid accumulation of gases on the floor of the cargo hold.
10. Permanent high volume ventilation
11. Oxygen sensors (fixed, personal protection); CO_2-sensor

RCOs for hazard group "Exposure of material to water and/or humidity"

12. Foam extinguishing systems might be useful as many substances react with water or cannot be extinguished with water. Use of alcohol persistent foams.
13. pressure Ventilation (bing in fresh air)
14. storge in special equipped containers to avoid water contact
15. stowage in lowest tier is not recommended
16. sensors for flammable gases
17. inerting of DG-container (only 2.1 and 4.3 substances)

RCOs for hazard group "Spontaneous ignition by itself after rupture of packaging / containment"

18. Improve quality of containments/packaging (see item 7)

RCOs for hazard group "Fire / Ignition"

19. ventilation
20. gas detection
21. cargo hold is equipped according Ex-requirements (certified)

RCOs for hazard group "Explosion"

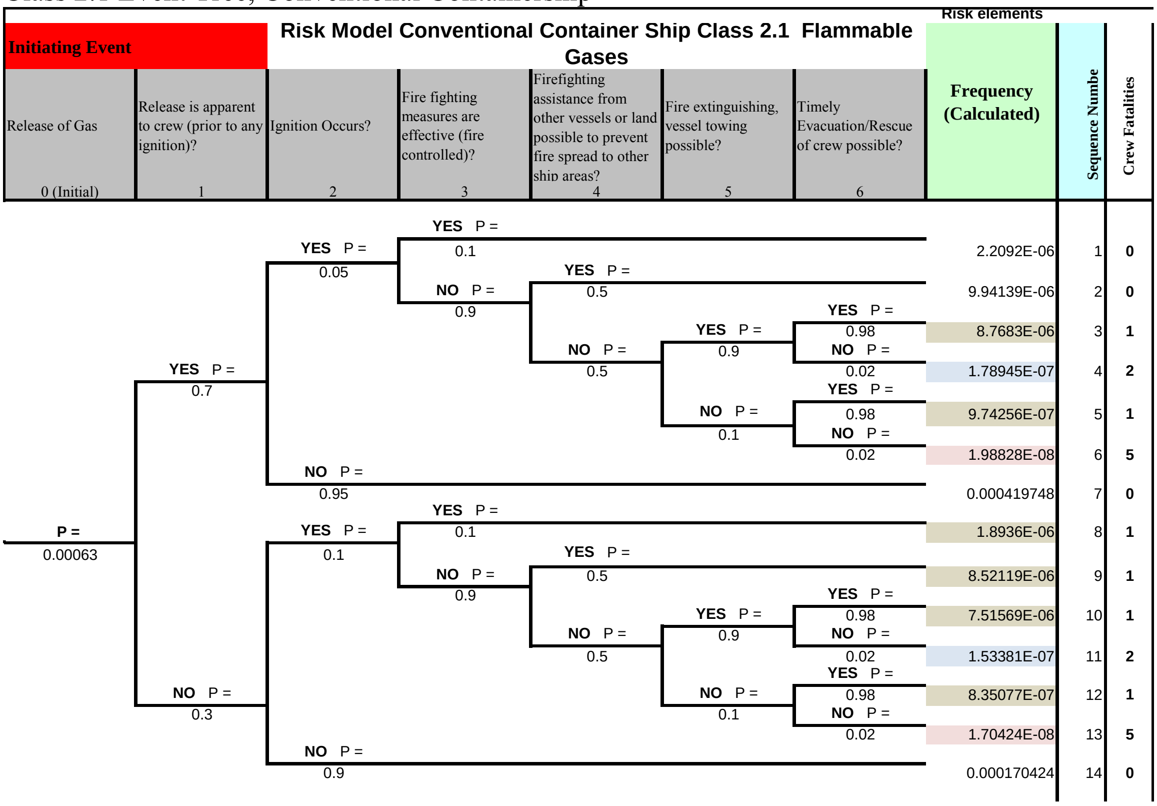
No additional RCOs.

RCOs for hazard group "corrosive substances"

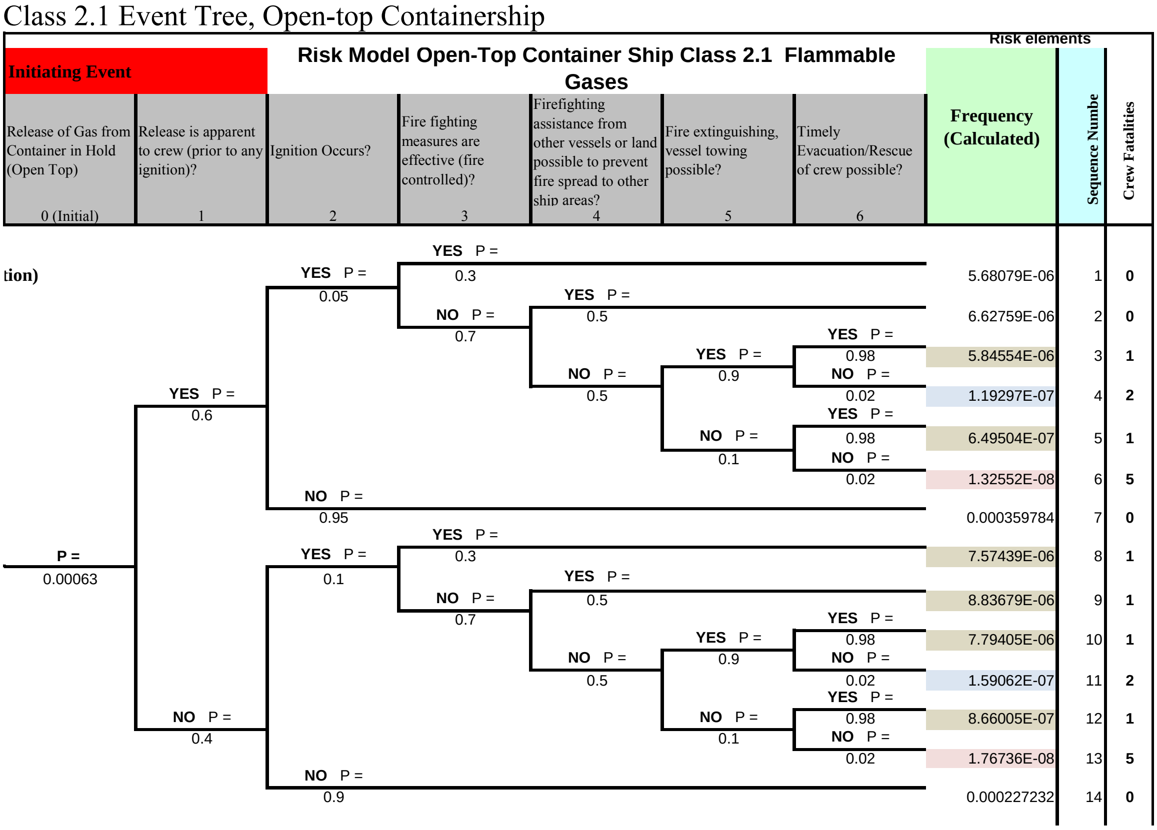
22. no stowage close to relevant ship structures → stowage on open deck recommended

A.4: Event Trees

Class 2.1 Event Tree, Conventional Containership



Class 2.1 Event Tree, Open-top Containership



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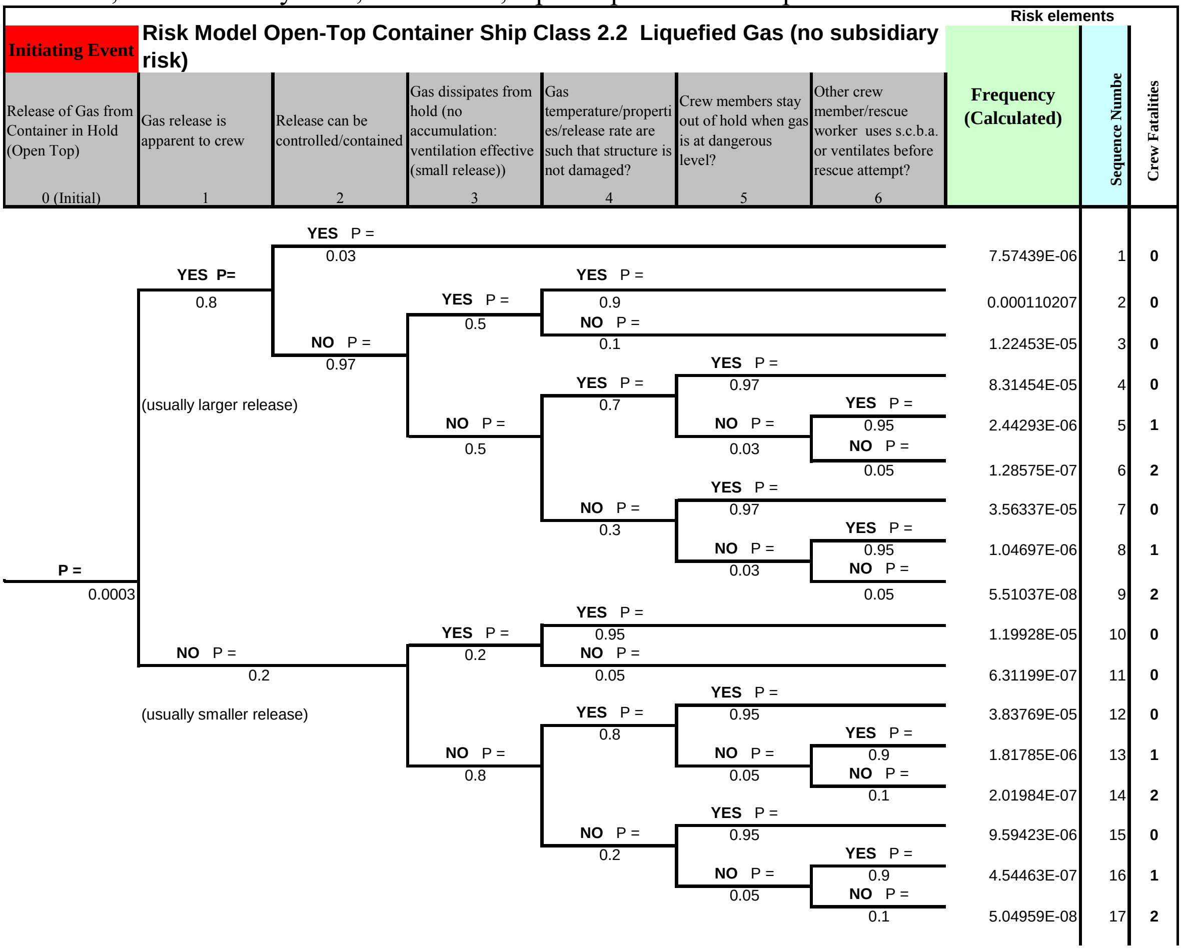
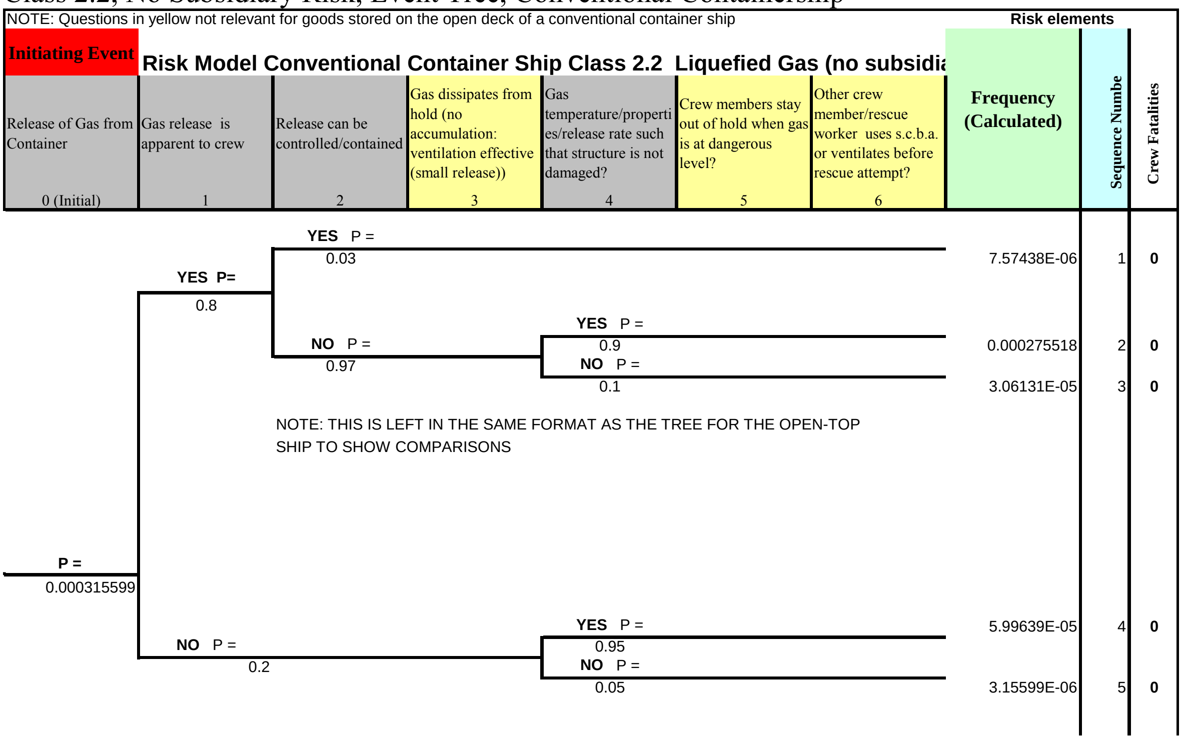
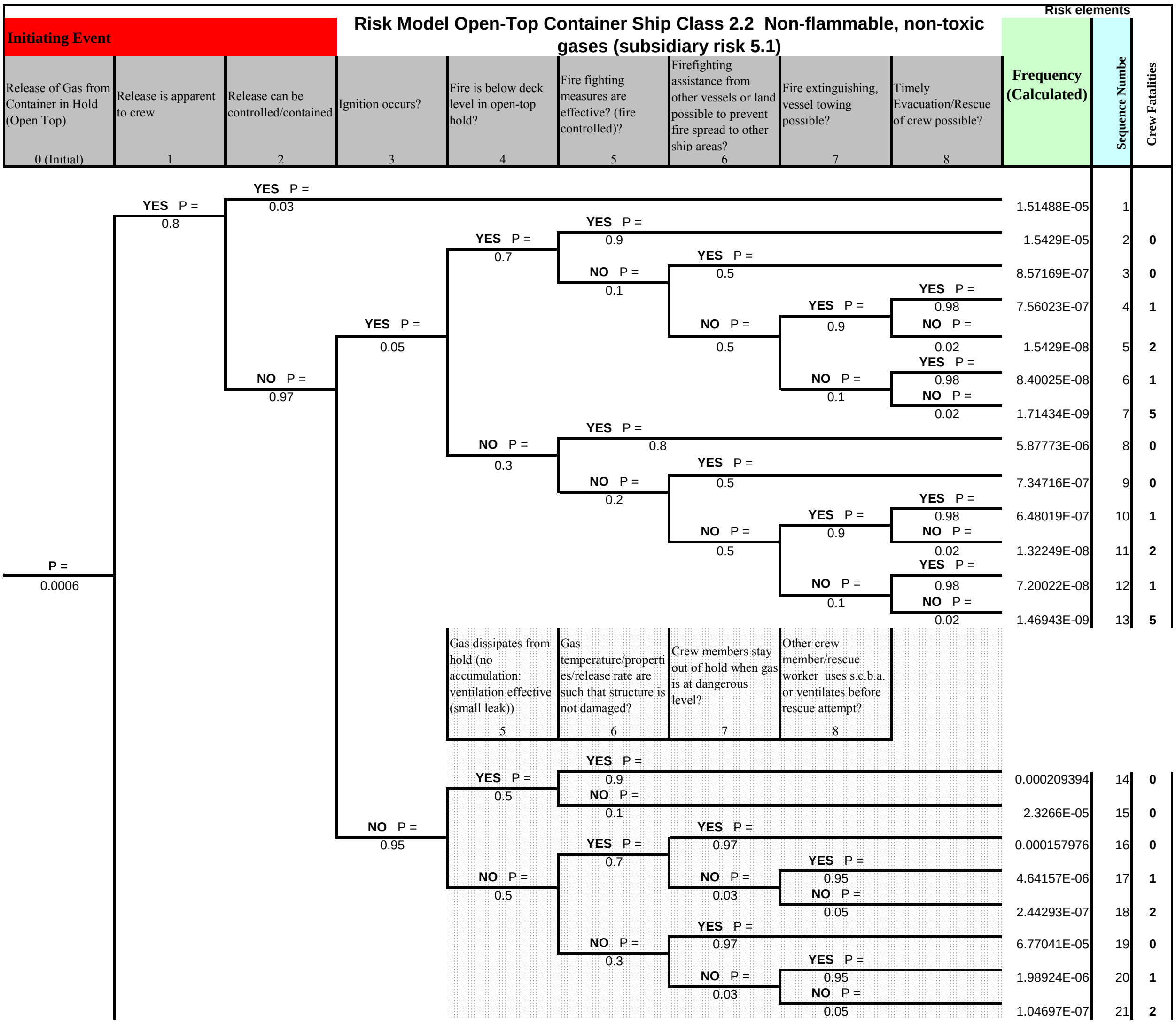


Class 2.2, No Subsidiary Risk, Event Tree, Conventional Containership

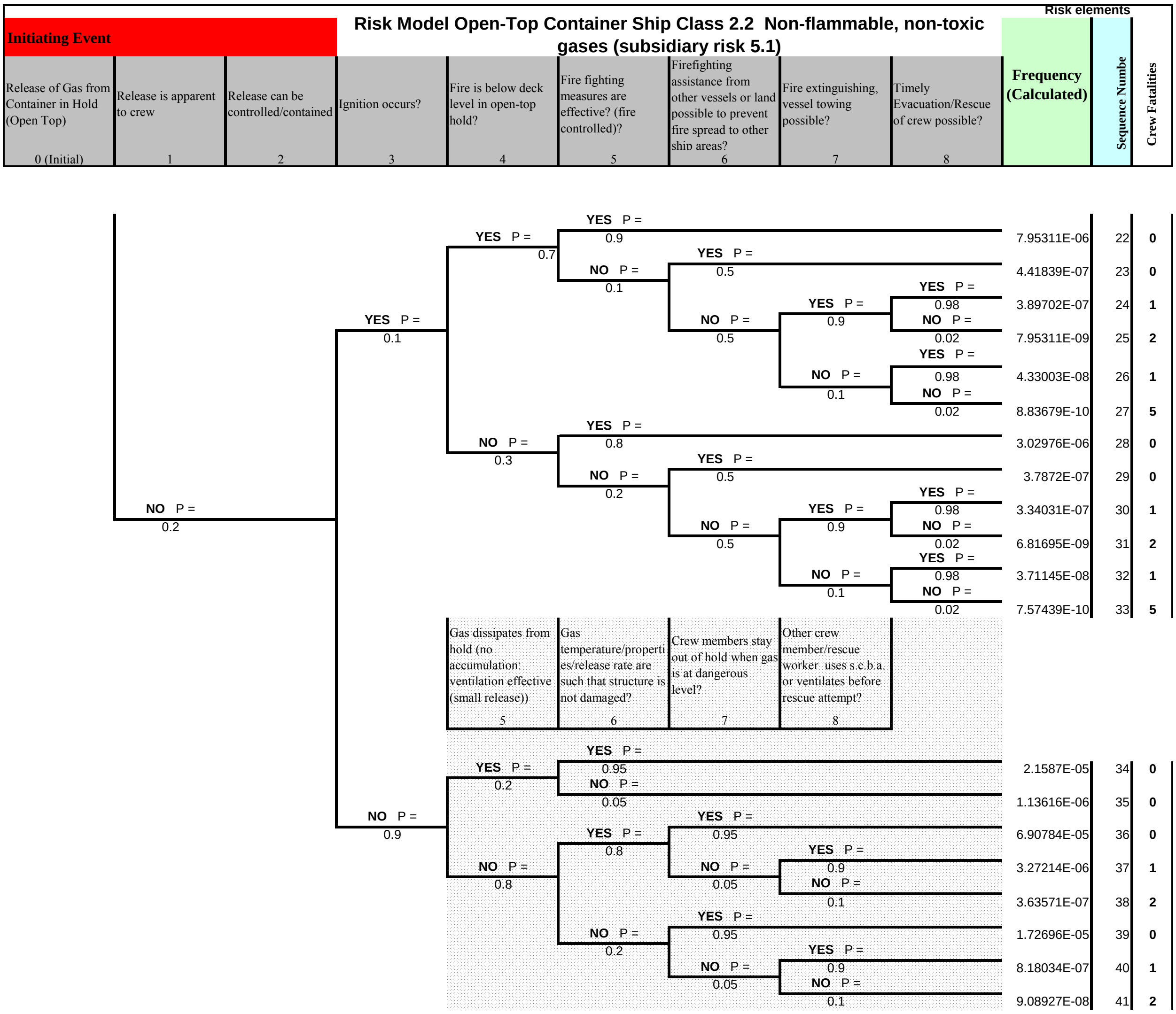


Class 2.2, Subsidiary Risk 5.1, Open-top Containership, Page 1 of 2

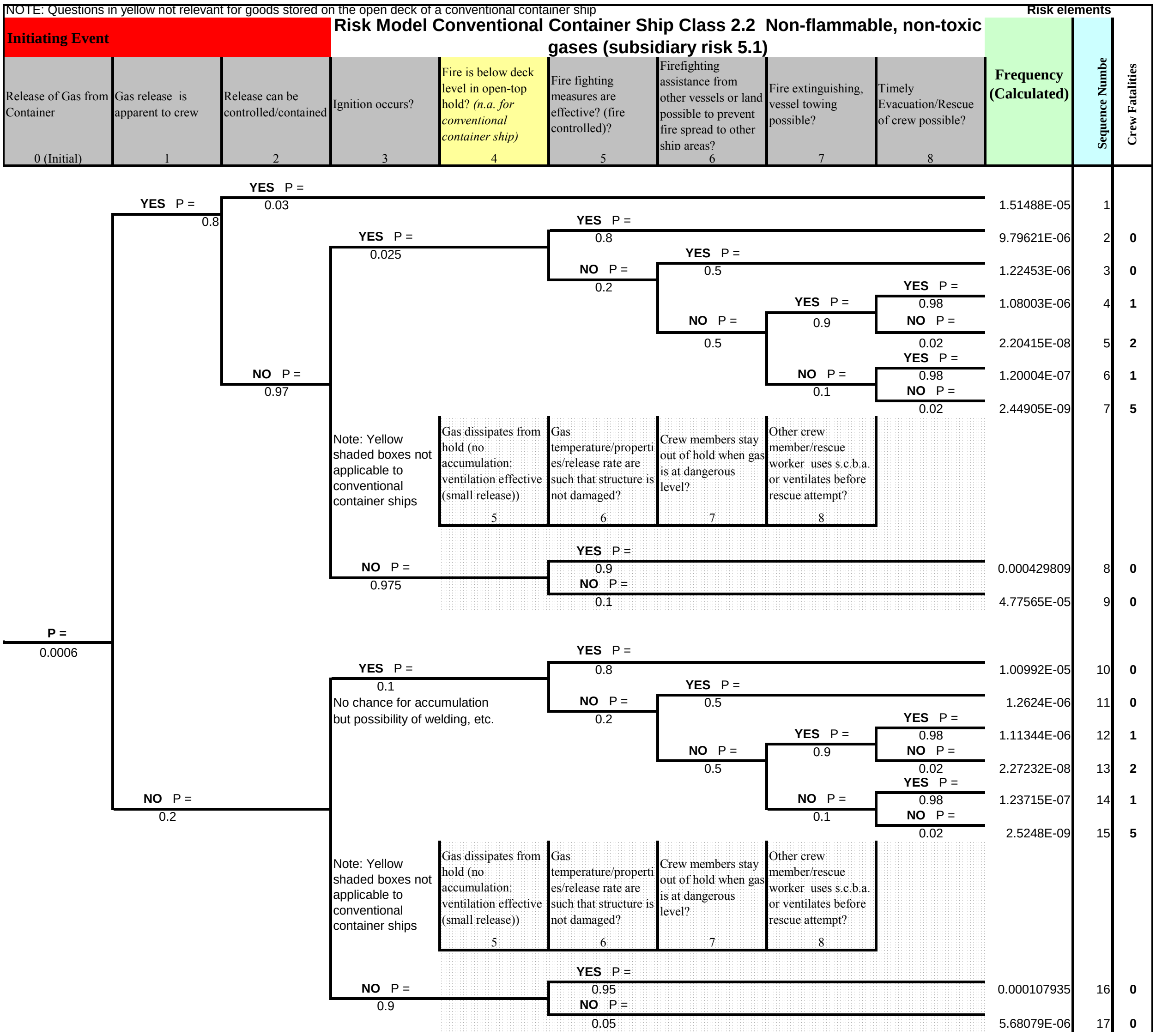


Frequency (Calculated)	Sequence Number	Crew Fatalities
1.51488E-05	1	
1.5429E-05	2	0
8.57169E-07	3	0
7.56023E-07	4	1
1.5429E-08	5	2
8.40025E-08	6	1
1.71434E-09	7	5
5.87773E-06	8	0
7.34716E-07	9	0
6.48019E-07	10	1
1.32249E-08	11	2
7.20022E-08	12	1
1.46943E-09	13	5
0.000209394	14	0
2.3266E-05	15	0
0.000157976	16	0
4.64157E-06	17	1
2.44293E-07	18	2
6.77041E-05	19	0
1.98924E-06	20	1
1.04697E-07	21	2

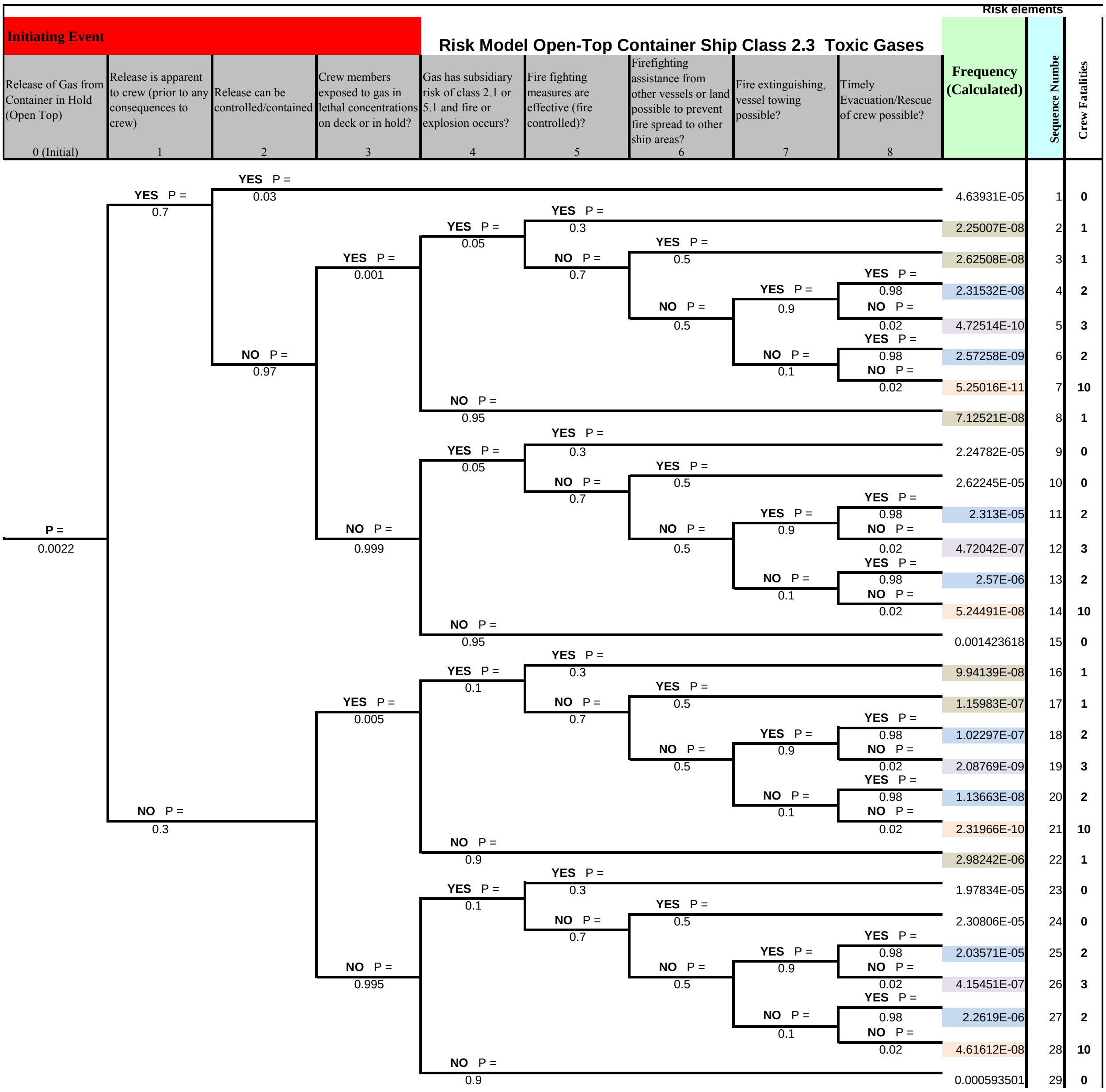
Class 2.2, Subsidiary Risk 5.1, Open-top Containership, page 2 of 2



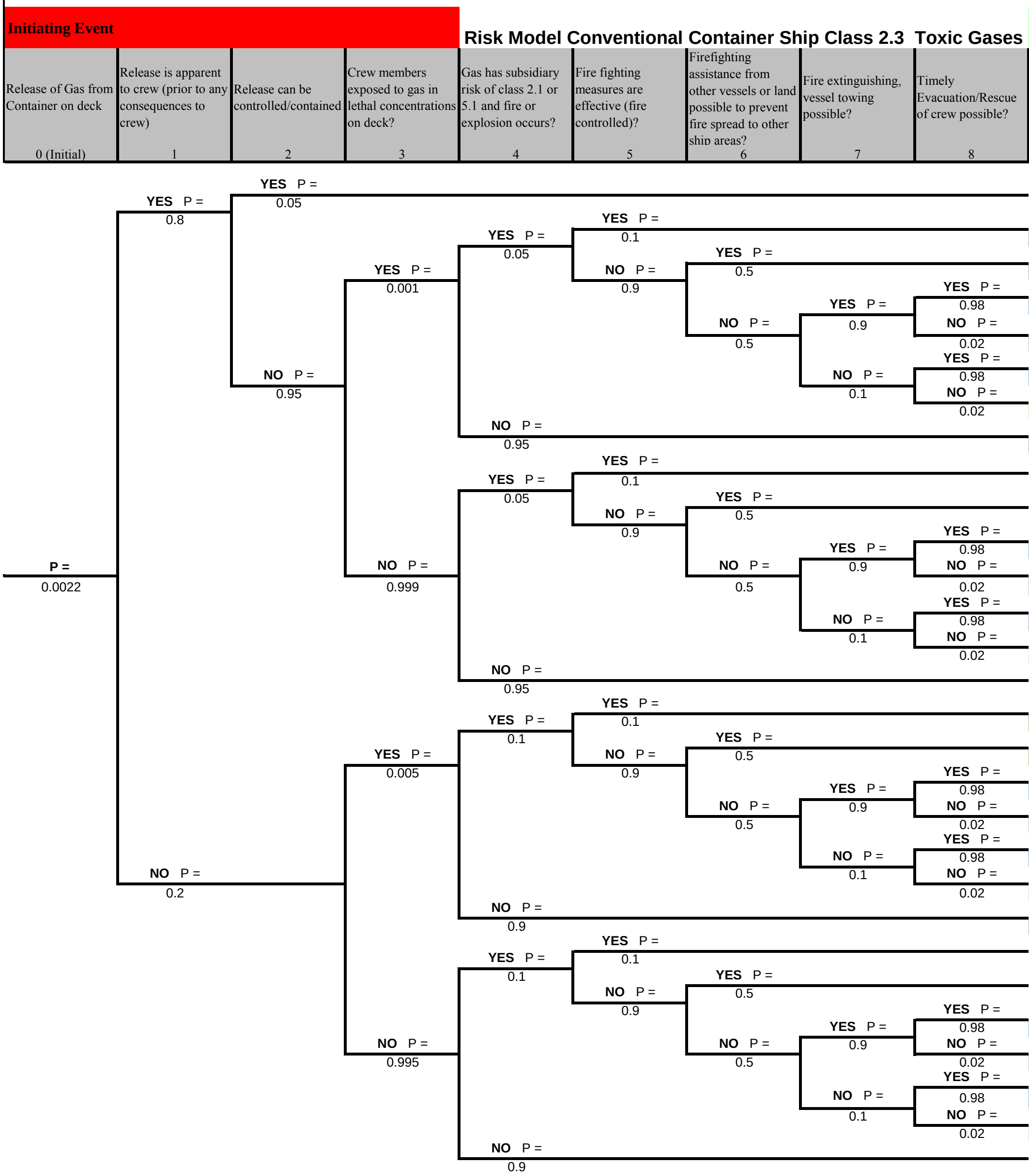
Class 2.2, Subsidiary Risk 5.1, Conventional Containership, On-deck stowage



Class 2.3 Event Tree, Open-top Containership



Class 2.3 Event Tree, Conventional Containership, On-deck storage



Frequency (Calculated)	Sequence Numbe	Crew Fatalities
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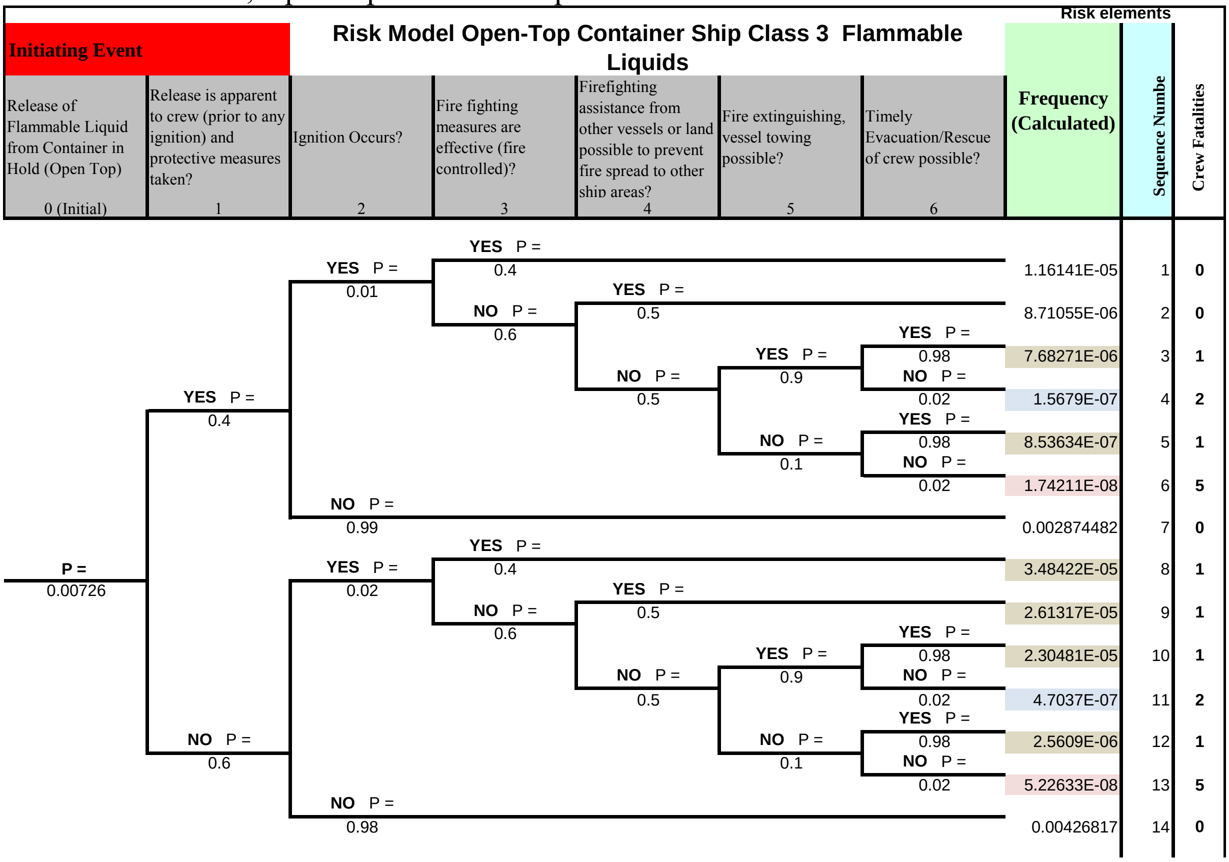
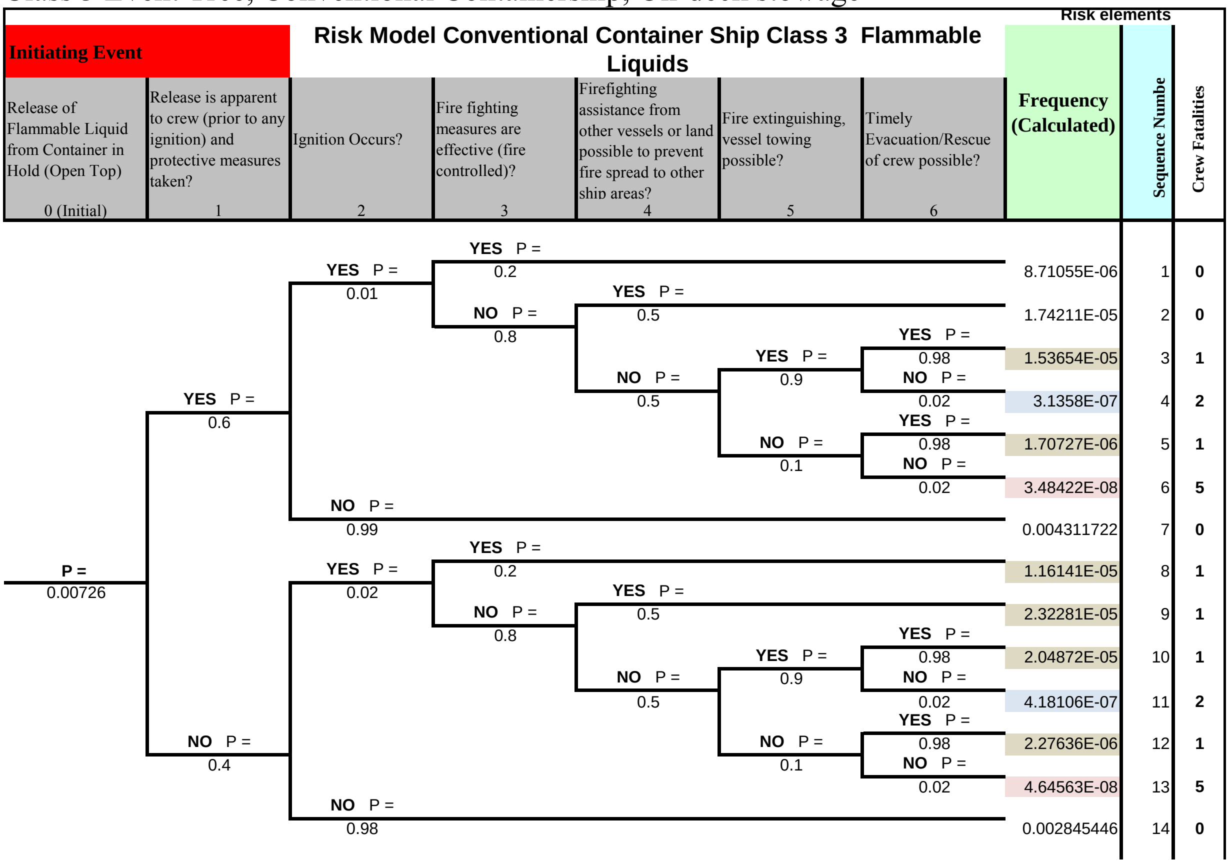
8.39495E-09	2	1
3.77773E-08	3	1
3.33196E-08	4	2
6.79991E-10	5	3
3.70217E-09	6	2
7.55546E-11	7	10
7.9752E-08	8	1
8.38656E-06	9	0
3.77395E-05	10	0
3.32862E-05	11	2
6.79311E-07	12	3
3.69847E-06	13	2
7.5479E-08	14	10
0.001593446	15	0
2.2092E-08	16	1
9.94139E-08	17	1
8.7683E-08	18	2
1.78945E-09	19	3
9.74256E-09	20	2
1.98828E-10	21	10
1.98828E-06	22	1
4.3963E-06	23	0
1.97834E-05	24	0
1.74489E-05	25	2
3.56101E-07	26	3
1.93877E-06	27	2
3.95667E-08	28	10
0.000395667	29	0

Risk elements

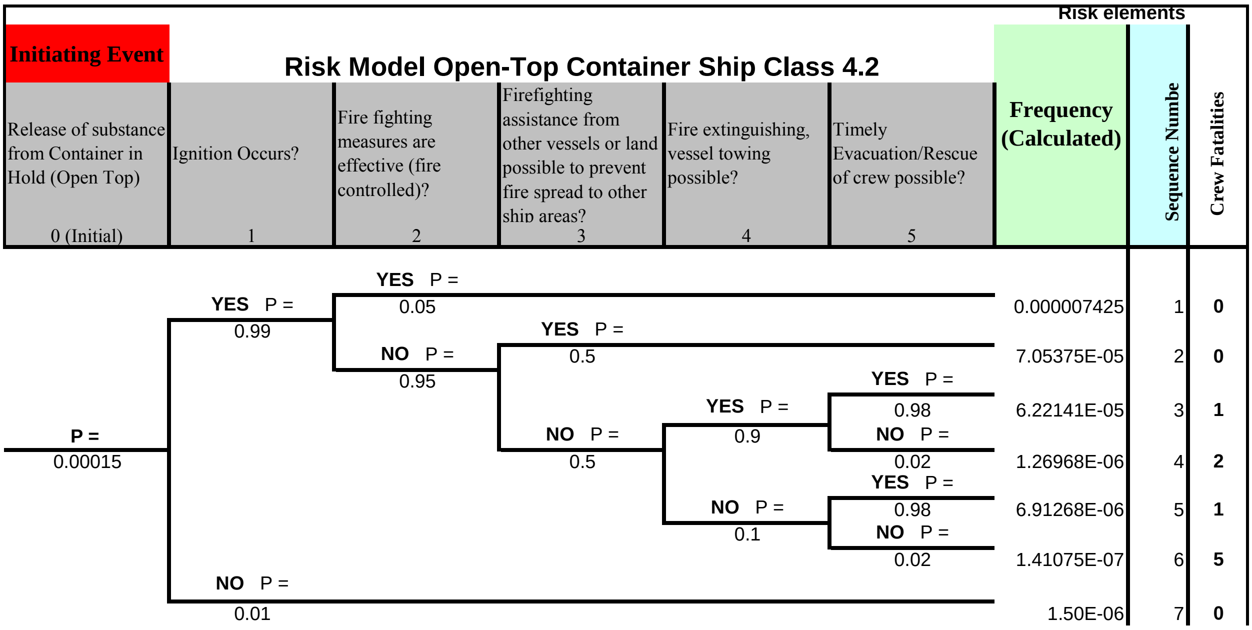
Class 3 Event Tree, Open-top Containership



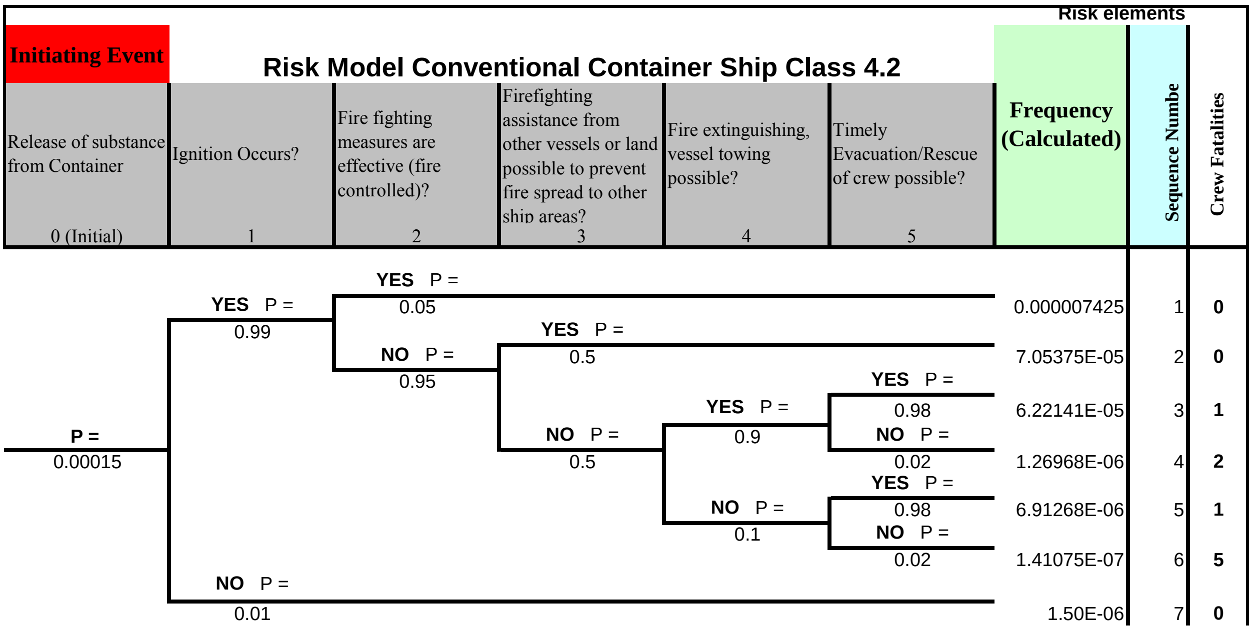
Class 3 Event Tree, Conventional Containership, On-deck stowage



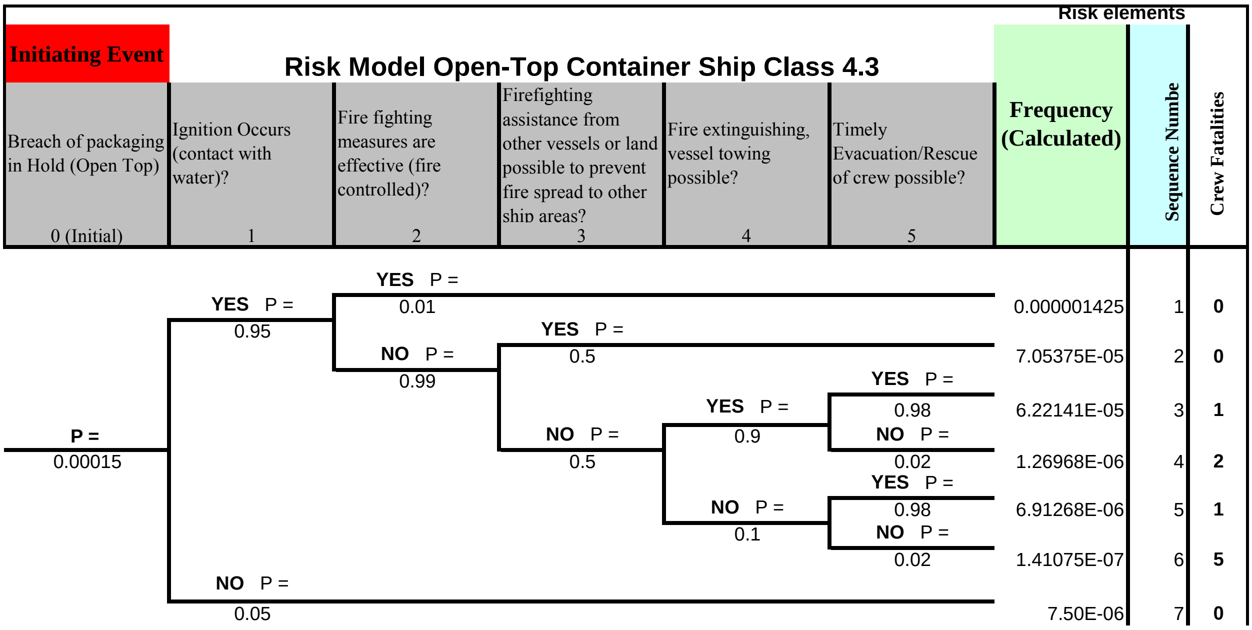
Class 4.2 Event Tree, Open-top Containership



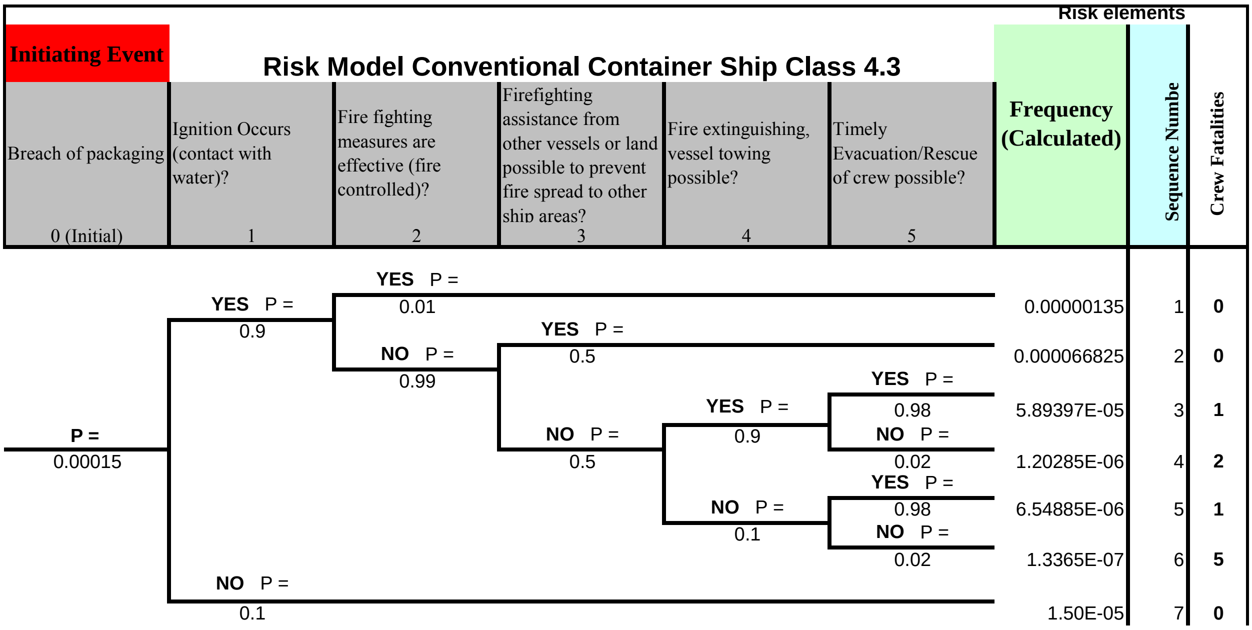
Class 4.2 Event Tree, Conventional Containership, On-deck stowage



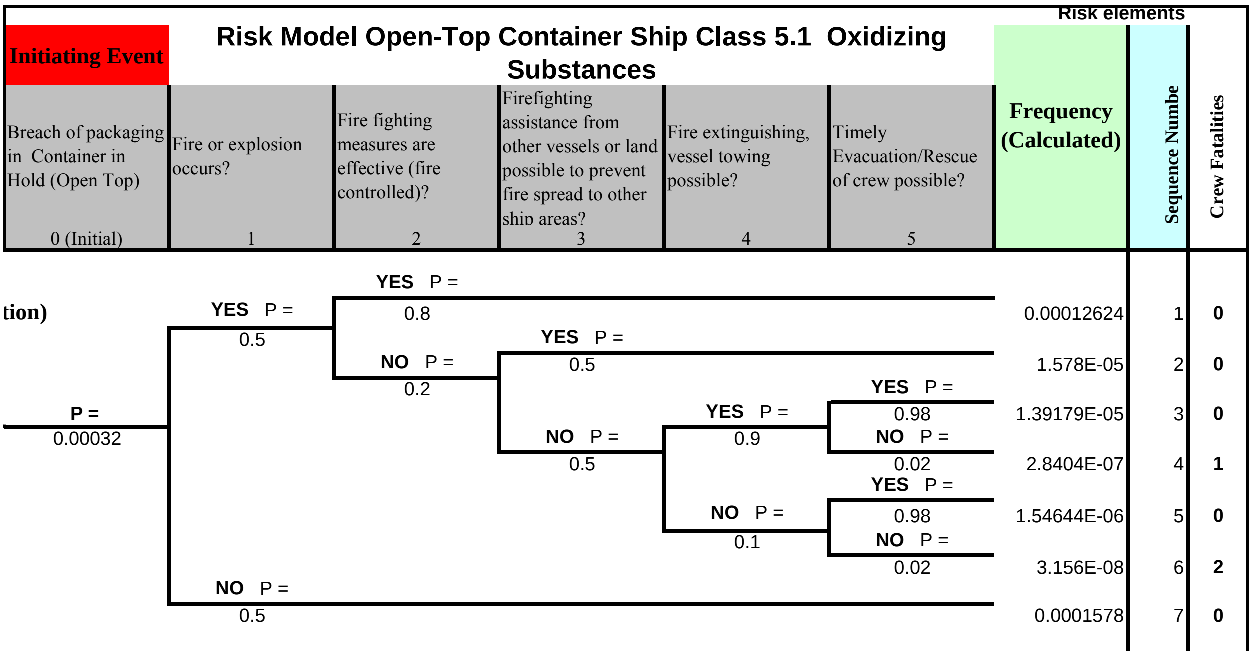
Class 4.3 Event Tree, Open-top Containership



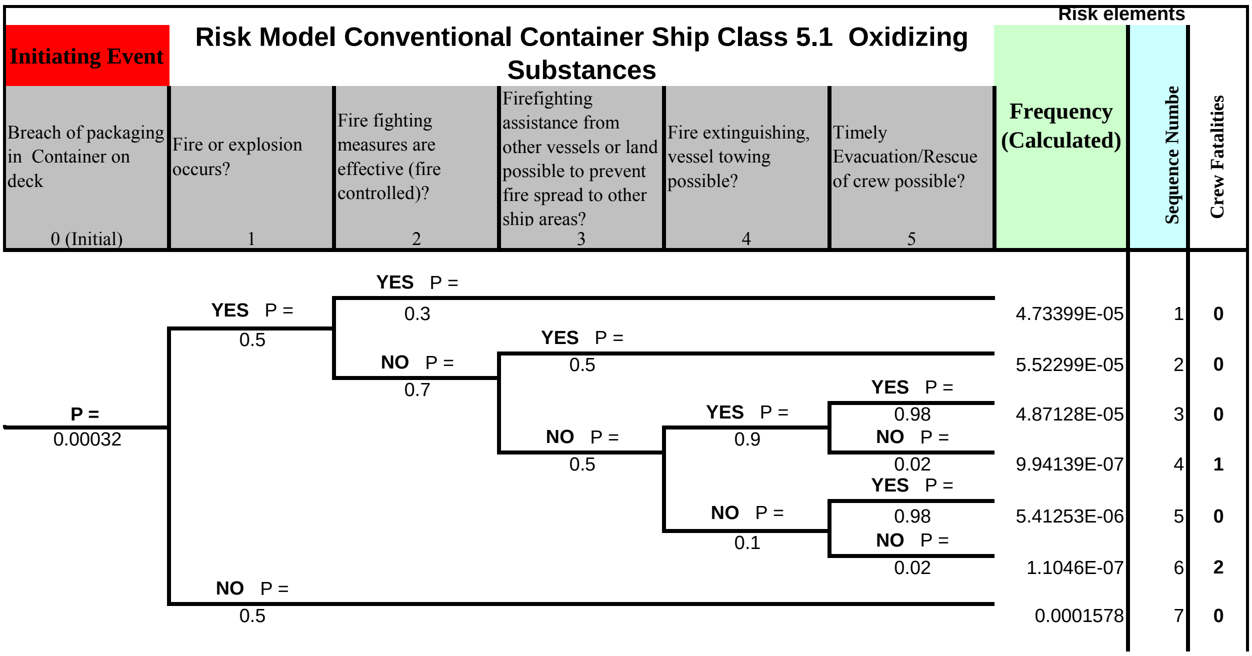
Class 4.3 Event Tree, Conventional Containership, On-deck stowage



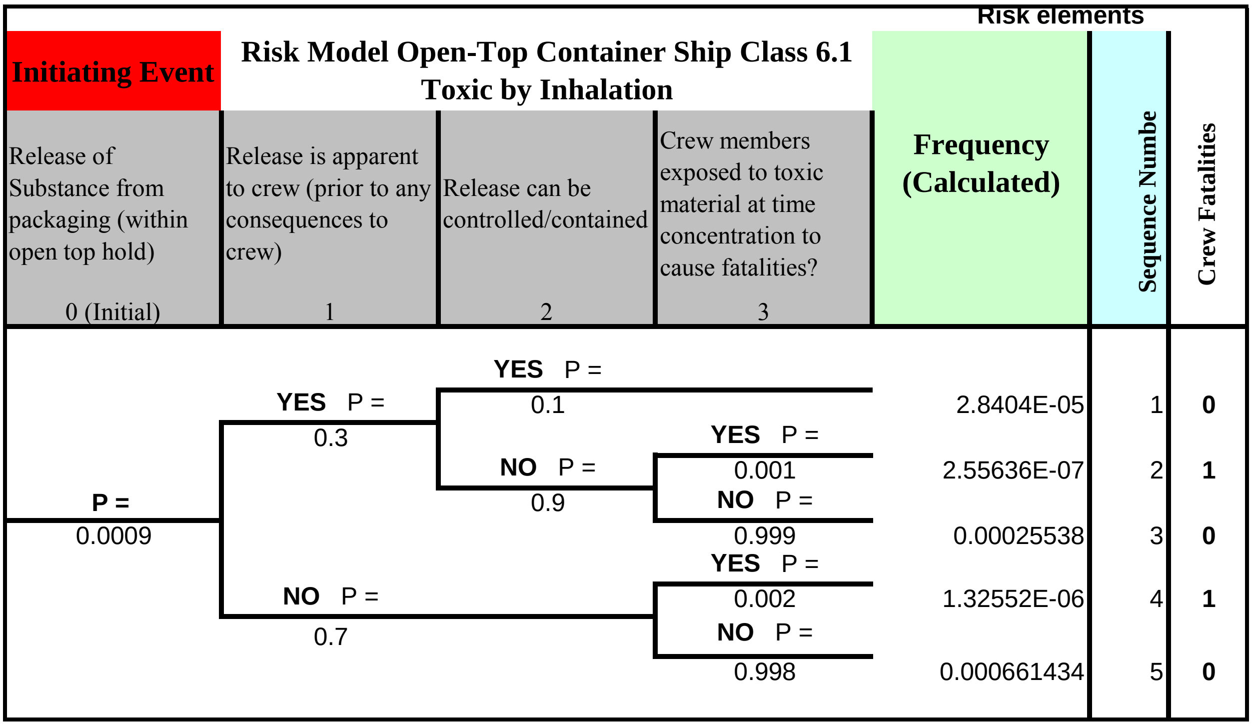
Class 5.1 Event Tree, Open-top Containership



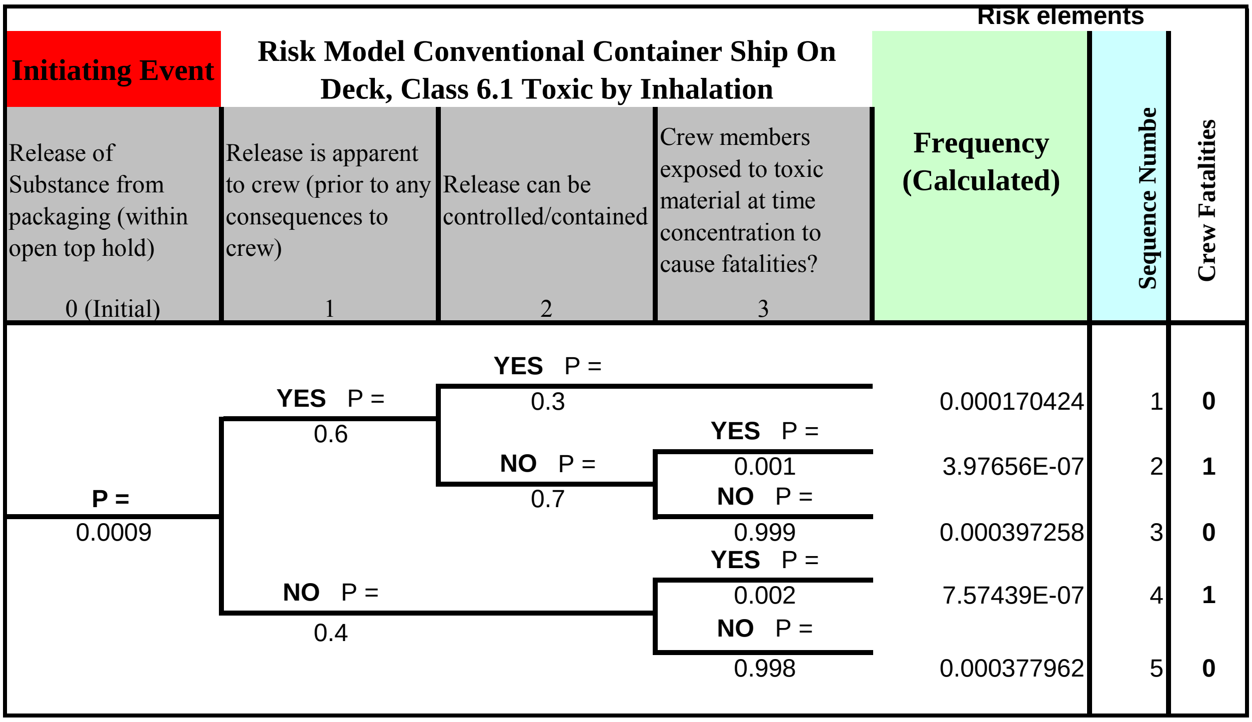
Class 5.1 Event Tree, Conventional Containership, On-deck stowage



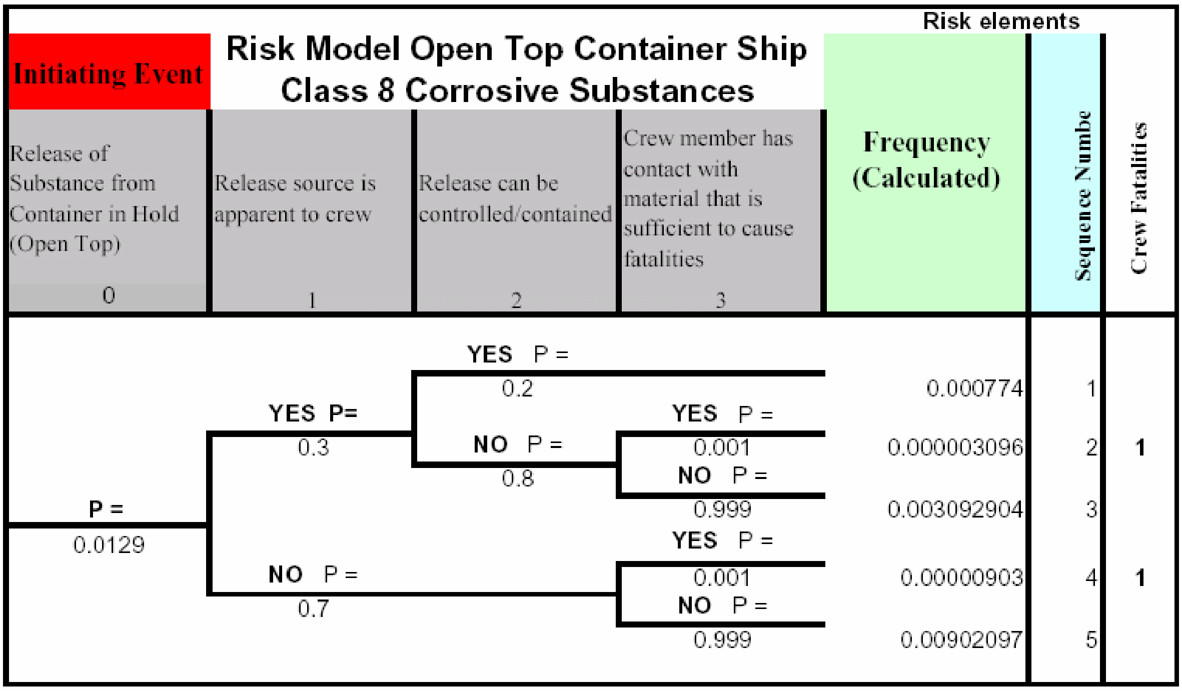
Class 6.1 Event Tree, Open-top Containership



Class 6.1 Event Tree, Conventional Containership, On-deck stowage



Class 8 Event Tree, Open-top Containership



Class 8 Event Tree, Conventional Containership, On-deck stowage