MARITIME SAFETY COMMITTEE
87th session
Agenda item 18

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FORMAL SAFETY ASSESSMENT

FSA – Dangerous Goods Transport with Open-Top container vessels

Submitted by Denmark

SUMMARY

Executive summary:	This document reports on the FSA study on Dangerous Goods Transport with Open-Top container vessels carried out within the research project SAFEDOR. The study focused on the transport of packaged dangerous goods classified “on deck stowage only” in the holds of open top container vessels.
Strategic Direction:	12.1
High-level Action:	12.1.1
Planned output:	12.1.1.1
Action to be taken:	Paragraph 5
Related documents:	MSC 87/INF.2, MSC 72/16, MSC Circ.1023/MEPC Circ.392, MSC83/INF.2

1. The attached formal safety assessment is the sixth and final study performed within the research project SAFEDOR. The FSA considers Dangerous Goods Transport with Open-Top container vessels and focused on the transport of packaged dangerous goods classified “on deck stowage only” in the holds of open top container vessels.

2. Like the previous FSA’s also this study should be brought forward to the Organization for further consideration.

3. The main results of the FSA study are provided in the annex and a more comprehensive report is submitted as document MSC 87/INF.2.

Review of FSA studies within the Organization

4. The Maritime Safety Committee, at its 83rd session, agreed to convene an FSA Experts Group with the purpose of reviewing the FSA studies submitted to the Organization. The FSA Expert Group was established at MSC 86 under the provisions of the guidance on the use of human element analyzing process (HEAP) and formal safety assessment (FSA) in the rule-making process of IMO (MSC/Circ.1022 - MEPC/Circ.391).

Action requested of the Committee

5. The Committee is invited to consider the information provided, and to refer the FSA study reported to the FSA Expert Group for review, as appropriate.

ANNEX

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

1 SUMMARY

The currently accepted solution of the transport of packaged dangerous goods classified "on-deck stowage only" is the carriage of such goods on the open deck. This solution in general does not apply to open-top containerships. 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, a full Formal Safety Assessment (FSA) is performed to estimate the risk level of the – currently prohibited – transport in the holds of open-top containerships. By means of a comparative risk assessment it is analysed whether by introduction of suitable risk control options (RCOs) a level of safety could be achieved for the transport on open-top vessels that is equivalent to the level of safety of the transport on conventional containerships.

The FSA concluded that at present, with respect to "on-deck stowage only" dangerous goods, the level of safety for the transport in holds of the open-top vessel (possible future operation scenario) is lower than for the transport on deck on the conventional vessel (current situation). Notwithstanding, risk control options were identified that would yield a comparable or higher level of safety with respect to individual classes of dangerous goods. Some of these options can only be implemented on open-top vessels.

In the International Maritime Dangerous Goods (IMDG) Code, 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

In the FSA generic accident scenarios are identified that relate to the predominant type of hazards of each class with respect to potential loss of crew life.

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 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 study.
- 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 accepted solution, for a selection of the dangerous goods classes that are in focus of this study.

In this study the cost-effectiveness measures gross cost of averting a fatality (GCAF) and net costs of averting a fatality (NCAF), which were applied for decision making in previous FSAs, are only secondary criteria.

Several RCOs are shown to be suitable to achieve an equivalent level of safety for the open-top vessel, compared to conventional transport with respect to individual classes of dangerous goods:

- Installation of permanent high-volume ventilation in the cargo hold (RCO 1), with respect to DG classes 2.1, 2.2, 2.3 and 5.1
- Installation of flammable gas sensors in cargo holds (RCO 2), with respect to DG class 2.1
- Installation of foam extinguishing systems in cargo holds (RCO 4), with respect to DG class 4.2
- Installation of a fixed breathing air supply system in cargo hold (RCO 5), with respect to DG classes 2.3 and 6.1
- Provision of improved portable air supply (RCO 7b), with respect to DG classes 2.3 and 6.1
- Provision of improved protective clothing (RCO 7c) , with respect to DG classes 2.3 and 6.1

NCAF calculations yield that only RCO 2 can be considered cost-effective, according to the 3 million US$ criterion that is proposed in MSC 83/INF.2. For RCMs 7b and 7c the GCAF is higher than the criterion, but the net present value is not grossly disproportionate.

2 DEFINITION OF THE PROBLEM

Dangerous goods comprise 5 % to 10 % of all transported cargo, depending on the route. Transport insurers expect that the portion of packaged DG will increase further in the future. The transport of packaged dangerous goods and the outfitting of vessels are governed by the IMDG Code and SOLAS II-2/19. Whereas the IMDG Code is updated regularly to reflect current dangerous goods, SOLAS II-2/19 has been unchanged for about 22 years. The IMDG Code requires stowing of several dangerous goods on deck – which cannot be accomplished for open-top containerships. 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 with open-top containerships 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 study 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.

In an initial step the present safety levels with respect to transport of "on-deck stowage only" dangerous goods are compared for the conventional design in relation to the (hypothetic) transport on open-top containerships. Then, the risk-reducing effects of a selection of control options for the open-top design are determined, and the expected risk level that is achieved by the implementation of each RCO on the open-top vessel is compared to the level of risk that was determined for the conventional transport.

The present study 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 loss of human life. The likelihood of exposure to security risks is considered out of the scope of the present study since it is related to other safety issues. Occupational hazards with the potential of injuring, or causing fatalities are also not within the focus of this risk analysis.

3 BACKGROUND INFORMATION

Risk acceptance criteria

In this study a relative risk acceptance criterion was used. An accepted solution for the transport of "on-deck stowage only" dangerous goods exists in form of transport of these substances on the open deck. Hence, it is argued that the primary risk acceptance criterion for an alternative means of transporting these substances, such as in the holds of open-top containerships, should be defined to reach a level of safety that is at least as good as for the existing solution. At IMO the same argument is also applied, for instance, during the analysis of alternative designs according to MSC/Circ. 1002.

Cost proportionality was analysed, but is only of secondary importance in contrast to previous FSAs that were conducted in the SAFEDOR project.

Open-top containerships

"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 (about 120) open-top vessels currently in service 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 a limited number of DG containers.

Main differences between open-top design and conventional containership design occur for cargo access as well as for container securing, fire detection and fire extinguishing measures. Based on the “Interim Guidelines for open-top Containerships” (MSC/Circ. 608/Rev.1), selected design features of open-top containerships are:

- Cargo access:
  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.
  As on open-top containerships no hatch covers are installed, 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.
- Ventilation
  The ventilation capacity is at least two air changes per hour, based on the empty hold. Mechanical exhaust systems are installed (as required in MSC/Circ. 608/Rev.1). These mechanical systems either work by extraction from the bottom of the hold by means of an exhaust ventilator or with natural exhaust generated by a supply ventilator. With approximately 80 % of the volume of a hold filled with containers up to ten air changes per hour can be reached.
  The airflow on open-top ships is affected by air entering through the open holds. Due to the open structure, gases lighter than air can disappear even without mechanical ventilation.
- Bilge Pumps
  Compared with conventional containerships, open-top containerships are equipped with higher capacity bilge pumps in order to remove green water shipped in seagoing conditions and rain. At least three pumps are provided. At least one of these pumps must have the full required capacity. The combined output of at least two other pumps shall be no less than the required capacity
- Fire Detection
  Cargo holds for the transport of dangerous goods are always equipped with fire detection systems. On open-top containerships sample extraction smoke detection systems activated by smoke or ionisation are installed. 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.
- Electrical Installations
  Electrical installations are of a certified safe type[1] for use in the dangerous environments to which they may be exposed unless it is possible to completely isolate the electrical system.
- Fire Extinguishing
  The fire protection system for open-top container holds is based on the philosophy of containing the fire in the bay of origin and to cool adjacent areas to prevent structural damage. The holds are protected by a fixed water spray system which is capable of spraying water into the cargo hold from deck level downward. Spray nozzles are located circularly around each bay of the entire open cargo hold. In case of fire the container bay of origin can be isolated with a water curtain; meanwhile the adjacent containers and

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

structures can be cooled. On-deck measures include fire pumps, hydrants, hoses as well as portable fire extinguishers.

Classification of dangerous goods - The IMDG Code

The objective of the International Maritime Dangerous Goods (IMDG) Code is to enhance the safe transport of dangerous goods. It is intended for use not only by the mariner but also by all those involved in industries and services connected with shipping, and contains advice on terminology, packaging, labelling, markings, stowage, segregation, handling, and emergency response. As listed in the summary above, dangerous goods are categorised into 15 classes according to the predominant type of hazard they represent. The code is updated and maintained by the IMO every two years.

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 hazard identification (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.

However, it should be noted, that generally little information is available on the exact composition of cargo stowed in containers.

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 accidents;
- 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 is generally prescribed in cases where

- constant supervision is required,
- accessibility is particularly required, or
- there is a substantial risk of formation of explosive gas mixtures, development of highly toxic vapours, or unobserved corrosion of the ship.

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

General considerations that impose on-deck stowage include:

- 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 large amounts of water. Under deck damage to the ship structure may be caused if cargo is transported under deck.

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. 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 increase further in the future.

For the cargo covered by the regulations of the IMDG Code a review of DG statistics of the Hamburg port has been conducted. The Hamburg port is one of the biggest ports 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 1, 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.

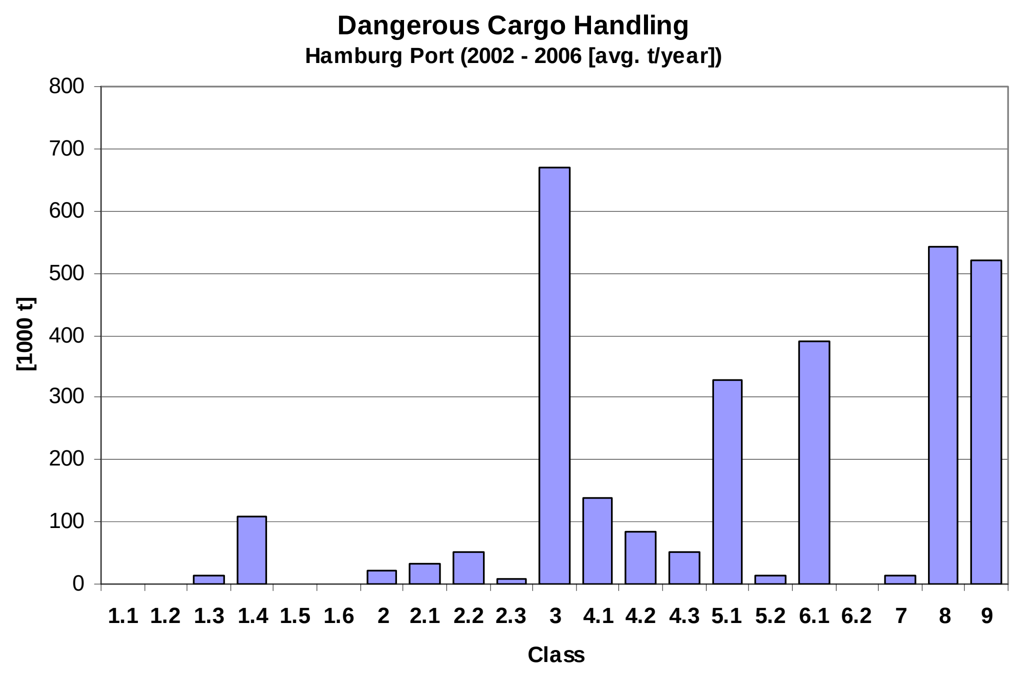

Figure 1: Hamburg Port Statistics: Handling of packaged dangerous goods

Based on a container safety study, 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.

Accident statistics

Extensive studies of DG incidents have been made by the Lund University, Sweden. In the work presented here, 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 2). When compared with the port statistics these classes also reflect the largest portions in DG transport. The most frequent incident types are corrosion, fire and explosion as well as release of toxic substances, see Figure 3.

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 2) in relation to their share in transport (Figure 1), 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.

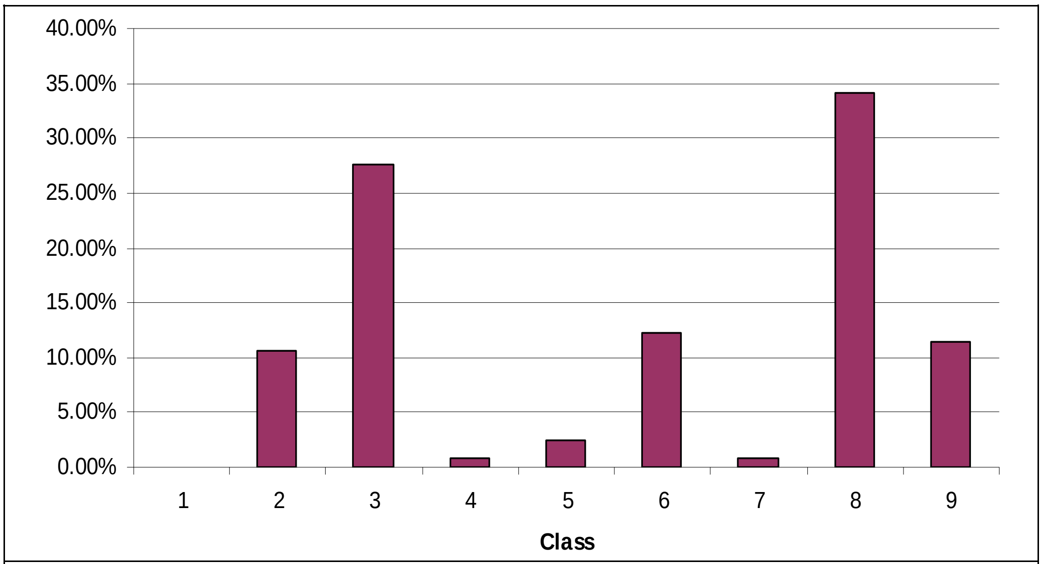

Figure 2: Distribution of dangerous goods classes involved in sea transport incidents; based on DG-vessel incidents, 1993-2004.

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, such as sea sloshing, heavy weather, fire, overheating due to bad stowage, grounding, collision, parametric roll and vibrations, are also involved, so that cumulative occurrence leads to an accident.

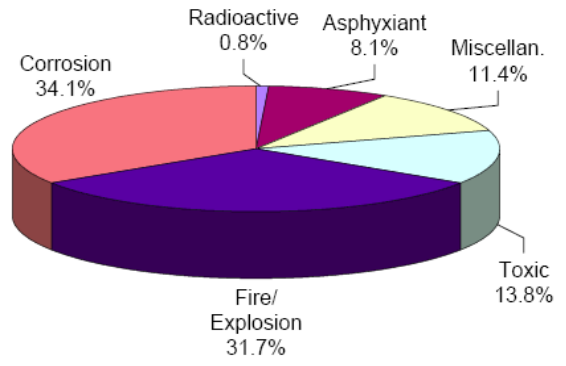

Figure 3: Distribution of incident types based on DG-vessel incidents, 1993-2004.

4 METHOD OF WORK

The 5 step FSA methodology outlined in the FSA Guidelines (MSC/Circ. 1032 and MSC 82/INF.2) has been used in this study. The FSA application has been carried out as a joint effort between Germanischer Lloyd (Germany), Peter Döhle Schiffahrts KG (Germany), SSPA Sweden AB (Sweden) and Wadan Yards (Germany). The project team was comprised of risk analysts, naval architects, dangerous goods experts, firemen and supported by other experts from the above partners as well as from Bremen Port Authority, the German Ship-owners Association, the City of Hamburg fire brigade, the German Federal Institute for Materials Research and Testing.

The FSA commenced with a HazID meeting in November 2007, an expert meeting on the identification and evaluation of risk control options was held in October 2008, and the final report with cost-benefit assessments and recommendations was completed in January 2009.

The HazID (step 1 of the FSA) was conducted as a two-day technical meeting including brainstorming sessions. The outcome of the HazID was a risk register containing the hazards by DG class and their subjective risk ratings from which a list of the highest ranked hazards could be extracted. Hazards were ranked individually by frequency and severity, by means of the scales of valuation proposed in MSC/Circ. 1023. A semi-quantitative ranking was performed for both, the on-deck transport on a conventional vessel and the transport in holds of an open-top vessel. Thus, an initial comparison of both transport options was possible.

The risk analysis (step 2 of the FSA) comprises a thorough investigation of accident statistics for dangerous goods transport as well as risk modelling utilizing event tree methodologies for the dangerous goods classes that were judged to impose the highest risks. Based on the survey of accident statistics and the outcome of the HazID, generic accident scenarios were selected for further risk analysis.

The risk analysis essentially contains two parts: a frequency assessment and a consequence assessment. For estimations of the initiating frequency of generic incidents, accident statistics have been utilized for the selected accident scenarios.

The consequence assessment was performed using event tree methodologies. First, conceptual risk models were developed for each dangerous goods class and event trees were constructed according to these risk models. Again, this step was performed separately for transport on conventional vessels and transport on open-top vessels. The event trees were subsequently quantified using different techniques for each branch probability according to what was deemed the best approach in each case. The approaches employed include utilizing accident statistics, damage statistics, simple calculations and modelling as well as elicitation of expert opinions.

The frequency and consequence assessments provide the risk associated with the transport of the different dangerous goods classes. These risks were summarized in order to estimate the individual and societal risks pertaining to the transport of dangerous goods. From this analysis a clearer view could be obtained on where the biggest effects of the vessel architecture and operations can be expected with respect to transport of dangerous goods.

At technical workshops risk control options were identified (step 3 of the FSA) and prioritized according to the attributes recommended in MSC 83/INF.2 Appendix 6.

Recommendations for decision-making (step 5 of the FSA) were suggested based on the effectiveness of a risk control option to reduce the level of risk associated with the transport of dangerous goods in holds of open-top containerships to a level of risk that is at most as high as for the currently practised transport on a conventional vessel. In the course of the cost-benefit assessment (step 4) the proportionality of costs was also investigated for risk control options, utilising the Gross Cost of Averting a Fatality (GCAF) < 3 million US$ and Net Cost of Averting a Fatality (NCAF) < 3 million US$. While cost criteria are a suitable indicator of the effectiveness of RCOs, particularly in economic terms, the selection of recommendations in this work was performed with focus on the risk reduction potential..

Cost-benefit assessments (step 4 of the FSA) were performed on selected risk control options based on the outcome of step 3. Particular emphasis was put on the effectiveness of an RCO for reducing the risk for the open-top vessel to a level that is equal or lower than for the conventional vessel. Secondly, for all risk control options the expected costs, economic benefit and risk reduction in terms of averted fatalities were estimated in terms of GCAF and NCAF. Cost estimates were based on information from suppliers, service providers, yards, technical experts or previous studies as deemed appropriate. The economic benefit and risk reduction ascribed to each RCO were based on the event trees developed during the risk analysis and on considerations on which accident scenarios would be affected. Uncertainties in valuations of effects and costs of RCOs were subjected to sensitivity analysis.

5 DESCRIPTION OF THE RESULTS ACHIEVED IN EACH STEP

STEP 1 – Hazard Identification

The HazID was conducted as a two-day workshop with participants from various sectors within the container shipping industry, including ship owners and operators, ship design office, classification society and port authority, as well as dangerous goods experts. During the HazID each DG substance was considered separately. In the course of the HazID a total of 59 hazards were identified and recorded in a hazard list. Consequences of hazards were evaluated with respect to human life. The top ranked hazards with respect to human life are listed in Table 1.

Table 1: Hazards with the highest Risk Index (RI)

RI	Substance/Class involved	Failure
9	Class 2.2 non-flammable, non-toxic gases	gas leakage
9	Class 2.3 toxic gases	gas leakage
9	Class 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 and rainfall, rupture of container)
8	Class 2.1 flammable gases	gas leakage
8	Class 2.2 non-flammable, non-toxic gases, subsidiary risk 5.1 (oxidizing substance)	gas leakage
7	Class 3 flammable liquids, packing group II	leakage
7	Class 4.2 substances liable to spontaneous combustion – packing group I	spontaneous ignition by itself after rupture of packaging/containment
7	Class 5.1 oxidizing substances	leakage from damaged packaging (self-decomposition is possible, but is limited to special substances)
7	Class 6.1 toxic substances, toxic by inhalation	leakage of packaging
7	Class 8 corrosive substances	leakage of liquids

STEP 2 – Risk 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.

Based on the available accident statistics and the results from the HazID, for the ten (sub-) classes of dangerous goods that are addressed by these hazards generic accident scenarios were defined for further analysis. The classes and sub-classes that were in focus of subsequent analyses are:

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

Following the selection of accident scenarios to be investigated, a frequency assessment was performed in order to estimate the initiating frequencies associated with each of the selected scenarios. It is acknowledged that U.S. waters, which are the area of ship operations that is covered by HMIS, may not be representative for world-wide operations. Yet, it is argued that this a well-maintained and currently available data source for the calculations that are required in this work. Hence, these data were deemed appropriate for the FSA study.

In subsequent steps of the risk analysis the expected consequences for each of the identified scenarios were addressed and quantified by means of event trees. Trees representing each generic accident scenario were constructed and quantified for open-top transport, as well as conventional transport. The two main classes of hazards are fire and toxicity.

In order to assign probabilities for the various escalating events and quantify the event trees a set of different approaches and techniques was used. For each sub-model and each branch of the event trees, the method that was found to be most practical and the information sources that were assumed most relevant was utilized. These methods are explained in DSC 14/INF.Y and in the full SAFEDOR reports together with illustrations of the complete event trees.

In the foundations of the risk modelling and the event tree construction and quantification, the contributions from the different accident scenarios to the total potential loss of lives (PLL) from dangerous goods transport was extracted. For these calculations, an expected lifetime of the ship of 25 years, a crew of 15 and three shifts of crews used in rotation throughout the year to operate the vessel continuously, were assumed. The risk summation for PLL resulting from carriage of goods requiring on-deck stowage in Table 2 is shown for stowage in the holds of open-top containerships and in Table 3 is shown for on-deck stowage on conventional containerships. These results indicate that PLL for both ship types is dominated by scenarios which result in fatalities from fire. For the fire scenarios it can be observed that:

- Open-top containerships had a slightly higher PLL from fire for Class 3.
- Open-top containerships 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.

It should be noted that the risk values in Table 2 and Table 3 are in an order of magnitude that, in relation to total risk is defined “negligible” in MSC 72/16. However, the values in these tables only denote risks specifically related to the transport of dangerous goods. The total risk for containership operations is significantly larger, see MSC 83/21/2 and DSC 14/INF.Y.

Table 2: Summary of PLL and individual risk for crew members for carrying dangerous goods requiring on-deck stowage in the holds of open-top containerships

Dangerous Goods Class	From Fire		From toxicity, etc.		Total	
	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

Table 3: Summary of PLL and individual risk for crew members for dangerous goods carried on deck of conventional containerships

Dangerous Goods Class	From Fire		From toxicity, etc.		Total	
	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

STEP 3 – Identification of Risk Control Options

The main risk drivers according to the risk analysis were presented to a group of experts in a workshop. Through a brainstorming session, a list of risk control options (RCOs) was produced, which in a further step were screened with respect to their effectiveness in risk reduction. Ultimately seven RCOs were prioritised (Table 4), where RCO 7 (improved personal protection) was later split into three separate risk control measures. Further descriptions of these risk control measured and risk control options can be found in DSC 14/INF.Y.

Table 4: RCOs selected for cost-benefit analysis

RCO	Description
RCO 1	Permanent high volume ventilation of cargo hold
RCO 2	Installation of fixed sensors for flammable gases in cargo holds
RCO 3	No stowage in lowest tier for containers which hold class 4.3. substances
RCO 4	Installation of foam extinguishing systems in cargo hold.
RCO 5	Provide air supply (fixed installation) for crew members entering the cargo hold
RCO 6	No stowage of class 8 substances close to relevant ship structures
RCO 7	Improved personal protection
RCM 7a	Equip crew with oxygen and CO_2-sensors and train crew in appropriate use!
RCM 7b	Provide air supply (self-contained breathing apparatus) for people entering the cargo hold (shall be mandatory)
RCM 7c	Provide personal protection equipment (set of skin protection suits, each for a limited number of substances)

STEP 4 – Cost-Benefit Assessment

Emphasis was put on the effectiveness of an RCO for reducing the risk for the open-top vessel to a level that is equal or lower than for the conventional vessel. Beyond risk reduction, only in a second phase for all risk control options the expected costs and economic benefit were estimated in terms of the Gross Cost of Averting a Fatality (GCAF) and the Net Cost of Averting a Fatality (NCAF). All costs and benefits were depreciated to a Net Present Value (NPV) using a depreciation rate of 5 % and assuming an expected lifetime of 25 years for a containership. A typical crew of 15 persons, working in three shifts throughout the year, were assumed.

Risk reduction

The existing event tree models from step 2 were revised to take the expected influence of each RCO into account. The results of the risk calculations with these revised models are summarised in Table 6. By means of the summary in Table 6 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. It should be noted that each RCO only has an effect on selected DG classes.

All calculations were performed on the assumption that each risk control option would be implemented exclusively. Possible amplifying or reducing effects that may arise from functional interdependencies in case of simultaneous implementation of several RCOs were not considered.

The data in Table 6 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 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.

In order to test sensitivity of these results to expert judgements, PLL calculations were also performed for maximum and minimum risk reduction potentials that were judged. If the calculation of PLL is performed using the minimum risk reductions, the results obtained from the average calculations are confirmed. In case the calculation is performed using the maximum risk reductions, also RCO4 appears suitable to lower the PLL for the open-top transport to the order of magnitude of the PLL of conventional transport.

Cost calculations
Calculations of costs, benefits and corresponding GCAF and NCAF values are summarised in Table 5.

STEP 5 – Recommendations

This analysis investigated if the transport of 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.

- RCO 1: Permanent high-volume ventilation

Additionally, for the remaining dangerous goods classes that were in focus of this study, 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).

- RCO 3: No stowage in lowest tier for containers which hold class 4.3. substances (affected DG class: 4.3)
- RCO 4: Installation of foam extinguishing systems in cargo hold. (affected DG class: 4.2)
- RCO 5: Provide air supply (fixed installation) for crew members entering the cargo hold (affected DG class: 6.1)

- RCM 7b: Provision of improved air supply (SCBA) for people entering the cargo hold (affected DG class: 6.1)
- RCM 7c: Provision of improved personal protection equipment (affected DG class: 6.1)

Table 5: Results of cost-benefit analysis

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

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.

- 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):

- RCM 7a: Equipping crew with oxygen and CO2-sensors
- RCM 7b: Provision of improved air supply (SCBA) for people entering the cargo hold
- RCM 7c: Provision of improved personal protection equipment

Table 6: 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.