Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals

Sub-Committee of Experts on the Transport of Dangerous Goods **29 July 2013**

Forty-fourth session
Geneva, 25 November – 4 December 2013
Item 8 of the provisional agenda
Global harmonization of transport of dangerous goods regulations with the Model Regulations

Stowage of water-reactive materials

Summary report of the Formal Safety Assessment

Transmitted by the expert from Germany

SUB-COMMITTEE ON DANGEROUS GOODS, SOLID CARGOES AND CONTAINERS
16th session
Agenda item 6

DSC 16/INF.2
20 June 2011
ENGLISH ONLY

STOWAGE OF WATER-REACTIVE MATERIALS

Report of the Formal Safety Assessment

Submitted by Germany

SUMMARY

Executive summary:	The annex to this document contains the full version of the Report on the FSA – The Safe Sea Transport of Dangerous Goods which react dangerously with Water and/or Carbon Dioxide
Strategic direction:	5.2
High-level action:	5.2.3
Planned output:	5.2.3.6
Action to be taken:	Paragraph 2
Related documents:	MSC 83/25/6; DSC 15/8; DSC 15/18

Background

1 This document provides additional information to document DSC 16/6. The annex to this document contains the full version of the Report on the FSA – The Safe Sea Transport of Dangerous Goods which react dangerously with Water and/or Carbon Dioxide.

Action requested of the Sub-Committee

2 The Sub-Committee is invited to take note of the information provided, consider the results of the FSA and take action as appropriate.

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ANNEX

THE REPORT ON THE FSA – THE SAFE SEA TRANSPORT OF DANGEROUS GOODS WHICH REACT DANGEROUSLY WITH WATER AND/OR CARBON DIOXIDE

Department Risk Assessment and Mechanical Engineering / SO-ER

Formal Safety Assessment - FSA
Safe Sea Transport of Dangerous Goods which react dangerously with Water and/or Carbon Dioxide

Report No. SO-ER 2009.267A **Version 1.2/2011-06-14**

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Risk Assessment & Mechanical Engineering Department/SO-ER

Document Control Sheet

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Title:

Formal Safety Assessment – FSA
Safe Sea Transport of Dangerous Goods which react dangerously with Water and/or Carbon Dioxide

Content:

The research project carries out a safety assessment (Formal Safety Assessment - FSA). The report describes the method of a FSA and their implementation for the safe sea transport of dangerous goods which can react dangerously with water and/or carbon dioxide and therefore cannot be extinguished with standard onboard ship fire fighting systems. The containerized transport of the goods is considered.

The following recommendations were elaborated:

Recommendation 1	modifications to the IMDG Code regarding improved packing and stowage
Recommendation 2	adjustments to fire protection equipment
Recommendation 3	improvement of the EmS and the EmS F-G, respectively
Recommendation 4	additions to the fire-fighting training within the IMO Model Courses

(Translated from German report SO-ER 2009.267, version 1.3 from 2011-06-09)

Department: Risk Assessment and Mechanical Engineering/SO-ER

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Contents

1 Executive Summary

The aim of this research project is to develop organisational and technical measures that reduce the risks associated with dangerous goods transport. More specifically, the project focuses on the prevention of and protection against fires started from / near by dangerous goods that can react dangerously with the ship's available fire extinguishing systems such as water and carbon dioxide. For these goods the Emergency Schedule for Fire Golf (EmS F-G) will give guidance in the event of fire incidents. The research has been conducted in form of a safety assessment in accordance with FSA MSC 83/INF-2 (/6/) to be submitted to the International Maritime Organisation (IMO) Sub-Committee on Dangerous Goods, Solid Cargoes and Containers (DSC) of the Maritime Safety Committee (MSC).

First the report describes the background of the project and the basic structure of a Formal Safety Assessment (FSA); a formal project requirement. In Chapter 3 the framework and complexity of the study is presented along with the description the practise of containerised dangerous goods transport on ships.

Chapter 4 describes the data base for the analysis; namely the incident date bases of Lloyd's Maritime Information Unit (LMIU) and Lloyd's Register Fairplay (LRFP). Additionally, the data from existing IMO analyses, as well the IMO regulations of SOLAS and IMDG Code, have been evaluated. Furthermore, the analysis is based on the assessment by specialists of dangerous goods, sea transport and fire fighting.

The first step in the FSA, presented in Chapter 5, is the identification of hazards (HAZID). This is conducted by a Failure Modes and Effects Analysis (FMEA). A classification is assigned for different causes of ignition and impacts of the fire of the considered dangerous goods covered by the EmS F-G. The hazard identification (HAZID) is structured with respect to this classifications and divided into two parts: a deductive part "cause of fire" and an inductive part "effects of fire".

In Chapter 6, a detailed analysis of the previously identified main threats including their related scenarios is presented. For the deductive part of the analysis, fault trees are developed in order to investigate the various scenarios that can lead to dangerous goods fires. For the inductive part, event trees are developed in order to investigate the possible further escalation and consequences of the fire, considering possible fire-fighting attempts.

Chapter 7 documents the analysis of the feasibility of suggested risk reduction measures. Measures to increase the safety of sea transport of dangerous goods which react dangerously with water and or carbon dioxide are analysed. Analysed risk reducing measures include modifications of the EmS and EmS F-G, modifications of the IMDG Code with respect to packing and stowage of the considered goods in containers, an improvement of fire-

fighting equipment on board of ships carrying these goods and an adoption of additional training measures with respect to fire-fighting into the IMO Model Courses.

Finally, Chapter 8 formulates recommendations on implementation of risk reduction measures, with the aim of enhancing safety of the containerised sea transport of dangerous goods, which react dangerously with water and/or carbon dioxide.

2 Introduction

In this research project, a Formal Safety Assessment (FSA) is carried out. The report describes the general FSA process and how it is implemented for the safe sea transport of dangerous goods that react dangerously with water and/or carbon dioxide and therefore cannot be extinguished with standard onboard ship systems. Hereby, containerized transport is considered.

2.1 Background

There are substances that react dangerously with water and/or with carbon dioxide. For these reasons, the on board of ships available fire-fighting mediums: water on the weather deck and water and carbon dioxide in the cargo holds, are not only unfeasible, but dangerous. It is therefore necessary to develop specific requirements for the transport of such substances by sea. The Maritime Safety Committee (MSC) of the International Maritime Organization (IMO) has assigned this responsibility to the Sub-Committee on Dangerous Goods, Solid Cargoes and Containers (DSC).

In parts A and A-1 of chapter VII of the amended edition of the 1974 International Convention for the Safety of Life at Sea (SOLAS), the provisions for the transport of dangerous goods in packaged form are specified. Special requirements for the transport of dangerous goods on ships > 500 GT, with keels laid on or after the 1st of September 1984 are specified in regulation II-2/19 (II-2//54, respectively) of the SOLAS convention in force. Chapter VII prohibits the transport of dangerous goods, unless they are subject to the provisions of part A and A-1 of Chapter VII and the International Maritime Dangerous Goods Code (IMDG Code).

The EmS (Emergency Response Procedures for Ships carrying Dangerous Goods; Emergency Schedules) in the IMDG Code Supplement provide guidance for dealing with fires and spillage of dangerous goods onboard ships. During further development of the Emergency Schedule for Fire Golf (EmS F-G) in 2000, the commissioned correspondence group noticed that the contact of fire-fighting water to the water reactive substances imposes danger. The fire department of a large German chemical company has conducted fire tests with such substances, the results of which were submitted by Germany to the Sub-Committee (DSC 6/INF.4). In 2006, as shown in agenda item DSC 11 (DSC 11/18/1), the necessary investigations of the risks and modifications to the stowage, segregation and packing requirements of the IMDG Code for substances, dealt with in the Emergency Schedule for Fire Golf (EmS F-G), were identified.

Since the 1950's, goods (including dangerous goods) have been increasingly transported in containers. In January 2007 the world's container fleet consisted of 3.875 vessels with a gross tonnage of more than 100 GT. This represented about 10% of the world's complete merchant fleet (Lloyds Register Fairplay). The total capacity of the container fleet in January 2007 corresponded to about 9.4 millions TEUs (twenty-footy equivalent units), more than double the capacity of 1996.

In case of a fire with water reactive substances involved, the following recommendations from the Emergency Schedule for Fire Golf (EmS F-G) shall be taken: To lower the heat radiation and to reduce the exposed heat load on neighbouring cargo, it is recommended that for fire-fighting a large quantity of water is deployed at once. Small quantities of water shall be avoided due to the threat of the substances reacting with the water and increasing the fire. For cargo on the weather deck, it is recommended that they are left to burn, provided there isn't any adjacent cargo at risk. If this isn't possible, it is recommended that large quantities of water are used in order to cool the cargo, while taking precautions to preclude the ingress of water into the container. To extinguish fires in enclosed cargo spaces, the activation of a gas extinguishing system is recommended. If this is not possible, the air vents shall be opened and the cargo shall be cooled by large quantities of water. In any event, the contact of small quantities of fire-fighting water with water reactive substances shall be avoided.

The validity and practicability of the recommendations of the Emergency Schedule for Fire Golf (EmS F-G) are to be investigated within the research project.

2.2 Overall goal

This research project shall address the rapid growth in the sea transport of dangerous goods in containers. Organizational and technical measures in the areas of equipment and stowing shall be developed. The measures shall protect the ship's crew and also the environment. The research project shall also support the development of regulations by the relevant IMO committees.

2.3 Economic, scientific and technical importance

The research project aims to increase the safety by which water reactive substances are transported by sea. The necessity of modifying the international rules and regulations was pointed out by Germany during agenda item DSC 11/18/1. This research project develops measures to protect both, the ship's crew and the environment. The results of the project shall be submitted to the IMO Sub-Committee DSC, to serve as a basis for comprehensive and qualified discussions within IMO.

2.4 Formal Safety Assessment (FSA) methodology

To support the relevant committees of the IMO in the development of regulations, the research project is presented in the form of a "Formal Safety Assessment" (FSA) in accordance to MSC/Circ.1023 (/11/). Hence, it can be submitted by Germany to the relevant IMO Sub-Committees to support the rule making process. The amendments to MSC/Circ.1023 at MSC 80 (MSC/Circ.1180-MEPC/Circ.474) and MSC 82 (MSC-MEPC.2/Circ.5) are consolidated in MSC 83/INF.2.

A Formal Safety Assessment (FSA) is a structured and systematic method of assessing maritime safety and if necessary, proposing additional safety measures. Within the FSA risks to human life and to the environment are considered. Moreover, the FSA includes risk reduction measures and a cost-benefit analysis.

A FSA can be used by the IMO as a means of assessing new rules and regulations or comparing new and existing rules and regulations. This method ensures comprehensive consideration of technical and operational matters including safety, environmental impact and cost. During the decision making process within the IMO, a FSA can be applied with the benefit of highlighting regulation changes (e.g. ramifications for people or the environment). In the evaluation of recommendations, the advantages are compared against costs in order to assess the feasibility of their implementation.

The FSA method can be applied by Member States or organisations within the IMO and used to propose measures to improve safety or environmental protection in the respective Sub-Committees. It can also be used to assess and document the impact of proposed measures. The method can also be used by a committee or Sub-Committee to raise potential concerns with the existing regulations, to proposed modifications or to investigate the implications of the proposed modifications in more detail.

A FSA consists of five steps (/6/, /11/):

- Hazard Identification (HAZID);
- Risk quantification;
- Identification of risk mitigation measures;
- Cost-benefit analysis;
- Recommendations.

The steps of the FSA and their relationship to each other are shown in Figure 2.1 (according to /6/, /11/).

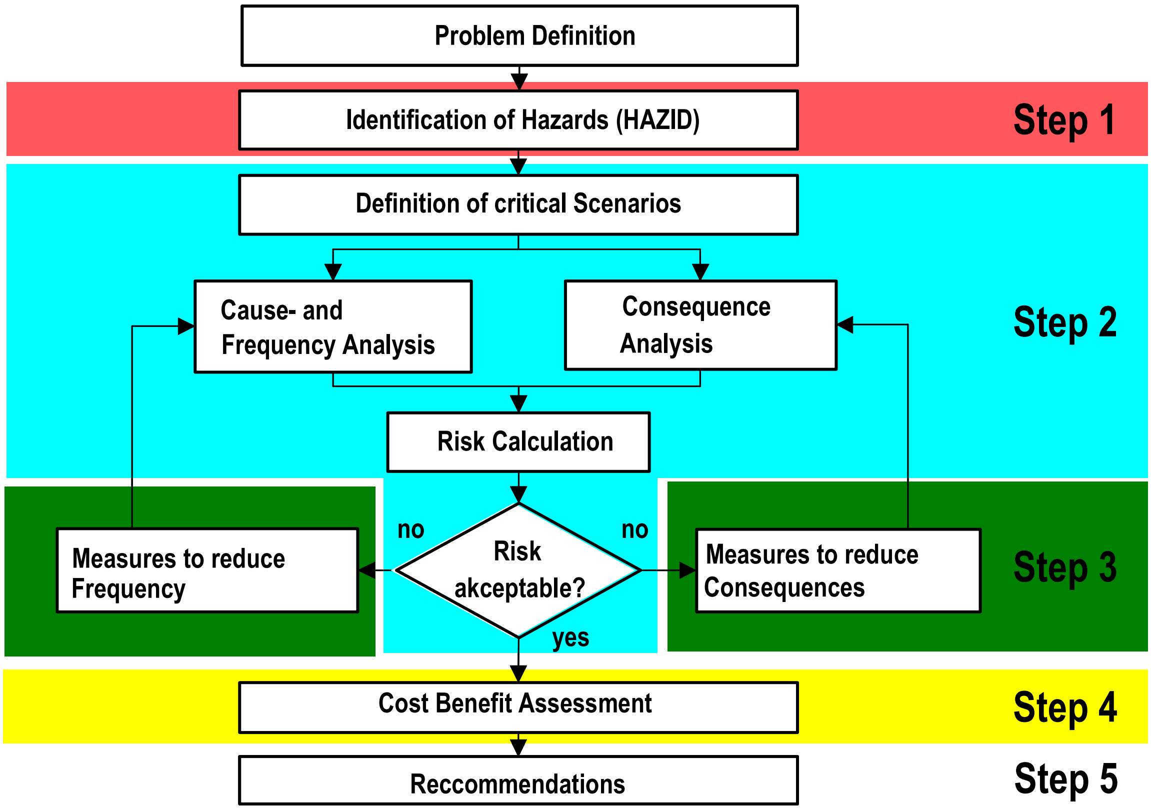


Figure 2.1: FSA flow diagram

<u>Step 1: Hazard Identification (HAZID):</u>

The aim of the first stage of the assessment is to identify the hazards and critical scenarios of the considerd problem. The identification of hazards should be conducted through creative and analytical methods. Creative methods, such as brainstorming in groups of experts, are included so as to ensure hazards are identified which may not have lead to accidents in the past. Analytical methods ensure that past incidents are considered and that this existing background information is integrated into the study. Such information might include existing legislation, accident statistic or documentation of past accidents.

The identified hazards are qualitatively assessed in order to prioritise them for further analysis. The assessment shall utilise both, the existing background information as well as the expertise of experts involved. The risk is assessed in terms of the frequency of occurrence and the severity of the consequence of incidents. One means of identifying hazards is through a Failure Modes and Effects Analysis (FMEA), using experts from the areas.

The result of this first step is a list of the problem related hazards and their qualitative assessed risk.

Step 2: Risk quantification:

In the second stage of the FSA the main hazards are investigated and quantified. This can be done by developing appropriate risk models. In such models, the main factors that influence each risk shall be identified and modelled explicitly. Depending on the problem, the risks to humans and the environment shall be considered separately.

Analysis techniques, such as fault or event trees can be utilised to quantify the risk. When quantifying the risk statistical data, calculations, simulations or other techniques, including expert's opinion can be used.

Step 3: Identification of mitigation measures:

In the third step, feasible and effective risk mitigation measures are developed. This step should typically focus on the main risks. In principle, there are measures that reduce the frequency of a certain event occurring, and measures that reduce the consequence of the outcome. The effectiveness of the proposed risk mitigation measures are evaluated and their effect incorporated in the risk model (step 2).

The interaction between different risk mitigation measures should be assessed qualitatively. The aim of this stage is to list the effectiveness of risk mitigation measures assessed. The effectiveness shall be documented along with how the interaction of different mitigation measures is considered.

Step 4: Cost-benefit assessment:

A cost-benefit analysis shall then be undertaken in order to compare costs and benefits of the risk mitigation measures identified in step 3. Thereby the risks before and after the implementation of the respective mitigation measure is considered. The cost of the respective measures shall be estimated. Then the cost efficiency of each measure shall be calculated by dividing the cost by the reduction of risk value. This makes it possible to rank the measures according to their cost efficiency.

The result of step 4 is a list of the risk mitigation measures classified by their cost efficiency.

Step 5: Recommendations:

In stage 5 the recommendations shall be presented. The recommendations should be based on a the comparison of the relevant hazards and their causes as well as all risk mitigation measures, taking into account their cost and effectiveness. Measures that are reasonable practical to reduce the risks should be recommended.

In summary, the results compare the various options available to potentially reduce the risk in areas where current regulations are being revised or supplemented. Furthermore, step 5 comprises a complete overview of the FSA documentation with references to the foregoing analysis.

3 Transport of dangerous goods on board of seagoing ships

The risk to human life resulting from the transport of substances referring to the Emergency Schedule for Fire Golf (EmS F-G) on board of seagoing ships was examined. The analysis considers the containerized transport of mentioned goods. Hazards arising during loading and unloading are not considered in the analysis. It is also assumed that transports are in accordance with the international requirements of SOLAS and the IMDG Code.

3.1 Dangerous goods referring to the EmS F-G

A list of the substances for which the IMDG Code is referring to the guidance of the Emergency Schedule for Fire Golf, is attached as Annex 1 to this document. These substances react dangerously with water and/or carbon dioxide.

3.2 Ship design and outfitting

The containerised sea-transport of dangerous goods will be primary conducted on board of container ships and in smaller amounts on board of multi purpose vessels. As only a marginal fraction of the considered dangerous goods is transported on Ro-Ro and Ro-Pax ships, these transports were not considered within the present study.

Containerships are specially designed for stowage and transport of containers. In the holds and on the weather deck up to 10 levels of containers can be stacked each. Despite not being exclusively designed for the transport of containers, stowage conditions for container are similar on multipurpose vessels. Equipment and scenarios of fire-fighting are similar for both ship types.

In the following the mandatory fire fighting equipment according to SOLAS II-2/10 and II-2/19 is described. The equipment represents the minimal requirements for ships carrying dangerous goods. The requirement are obligatory for vessels keel laid on or after 1984-09-01 of 500 GT or more.

Apart from portable fire-extinguishers, fire fighting agent on the weather deck is solely water. Extinguishing water will be supplied by the fire main and deck wash system, consisting of the fire main pumps, the fire main piping, hydrants, hoses and multi-purpose nozzles. In detail the requirements on fire-fighting equipment are:

- Distribution of hydrants on the weather deck in a manner, that every location of empty cargo holds and empty weather deck can be reached with fire-fighting water from four nozzles simultaneously, two of which with only one length of hoses each.

- Three additional sets of hoses and nozzles on vessels which transport dangerous goods.

- Two fire main pumps with a combined volume flow depending on the ships size, but at least capable of supplying four nozzles simultaneously with the required water pressure. A total volume flow of 180 m^3/h is considered sufficient.

- The mandatory minimum water pressure at the hydrants is 0.25 N/mm^2 for ships with less than 6,000 GT considering 4 nozzles used simultaneously, and 0.27 N/mm^2 for ships of 6,000 GT and above, respectively.

- Remote start of both fire pumps from suitable place required, to assure the availability of fire-fighting water at once, if required.

- Portable dry powder extinguishers with additional 12 kg extinguishing agent for transport of dangerous goods.

The required portable personal equipment consists of:

- Four self-contained breathing apparatus altogether,

- two heat protection suits, and

- four whole-body protection suits, suitable to protect from the specific transported cargo.

Personal protective suits and fire-fighting water supply have to be provided for simultaneous operation of up to four crew members.

For fire-fighting below deck, the cargo holds have to be equipped with a fixed CO_2 fire-extinguishing system according to SOLAS II-2/10.7.2. Alternatively, inert gas or similar systems are possible, but not used in current practise. Closure of hatch covers, hatches, vents and all other openings has to be ensured to allow for the effective application of a gas-based fire-fighting system. For container vessels with partially weather tight hatchway covers according to MSC/Circ.1087, an extended CO_2 supply is required to compensate for gas losses. The additionally required amount of extinguishing gas is calculated according to the design related gaps within the hatchway covers.

For fire detection cargo holds are to be equipped with a fixed fire-detection and alarm system. Commonly installed on board are smoke extraction alarm systems. These systems utilise the CO_2 flooding pipes to extract the air from the cargo hold. The extracted air is checked for smoke.

Cargo holds approved for the transport of explosives of class 1, with exception of class 1.4S, have to be equipped with a drencher system of a capacity of 5 l/m^2 and minute. This system is not intended for fire fighting, but for cooling of the explosives in case of fire in a neighbouring cargo hold or on the weather deck above.

4 Data basis

4.1 Historical accident statistics

Historical data is a source used to assess the relevance of a hazard. Statistics, accident databases and previous studies may be used to estimate the frequency of occurrence of possible accidents. In the following sections the information in the Lloyd's Maritime Information Unit and Lloyd's Register Fairplay accident databases are summarised.

4.1.1 Lloyd's Maritime Information Unit Casualty Database

In the FSA for container ships (/7/, /8/), the frequency of occurrence of different accidents from the Lloyd's Maritime Information Unit (LMIU) accident database (/17/) are evaluated. Between 1993 and 2004, 1,582 accidents are documented with a total of 80 casualties and 28 missing persons. The fraction of incidents due to fire and explosion is 6.9% (109 accidents). 42 of the 108 casualties and missing persons were related to these fire and explosion incidents; a relatively high amount given the number of accidents.

During the considered period the size of the container ship fleet is quoted as 30,682 ship-years (product of number of vessels multiplied by their time registered during the considered period). This results in an accident frequency of 3.55 $*10^{-3}$ accidents per ship-year and 1.37 $* 10^{-3}$ casualties per ship-year.

Figure 4.1 shows the distribution of the documented fire and explosion cases. It can be seen that about half of the incidents originated in machinery spaces and about a quarter in the cargo area.

The database doesn't provide information of the involvement of dangerous goods into the accidents.

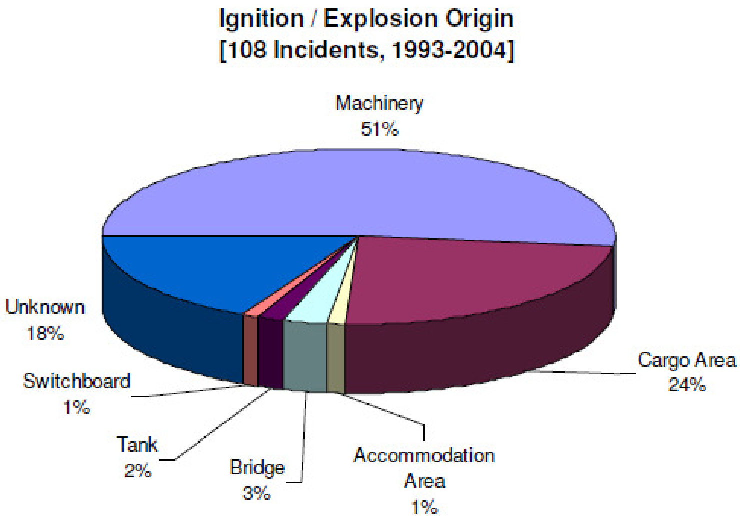


Figure 4.1: Source of fires / explosions origin according to LMIU (/17/).

4.1.2 Lloyds Register Fairplay

In preparation for the risk assessment, the accident databases from Lloyds Register Fairplay (LRFP) (/18/) in the period from January 1990 to September 2009 were evaluated. In total, there were 177 fires and explosions on ships with a gross tonnage greater than 1,000 GT, with a total of 626 casualties or missing persons. Accidents in dock yards or on sea trials were not considered. As well as accidents on container ships, accidents on Ro-Pax and Ro-Ro ships were also evaluated as these vessels transport containers with dangerous goods (on trailers) as well, as far as the stowage category of these goods is allowing for that transport (see section 4.2.2). Besides the mentioned ship types, containers can be transported on further vessels (e.g. multi-purpose or general cargo). Neither the number of these vessels capable of transporting dangerous goods, nor their impact on maritime accidents can not be extracted from the LRFP data base and will not be analysed further in this section.

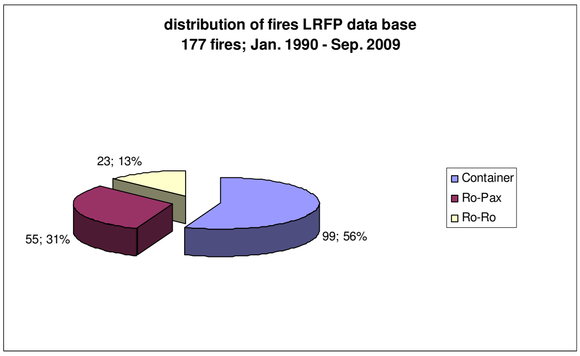
Figure 4.2 shows the distribution of documented accidents. The majority of the accidents were found to have occurred on container ships; 99 accidents or 56% of the total amount. On Ro-Pax vessels 55 accidents (31%) are registered and on Ro-Ro ships 23 accidents (13%) are registered. The evaluation of the accident database showed that 601 casualties and missed persons can be related to accidents on Ro-Pax ships. This corresponds to 96% of all victims. 3 casualties on Ro-Ro and 22 on container ships are registered.

The database doesn't provide any information regarding the involvement of dangerous goods to the accidents. It must be emphasized though, that because of their classified stowage category particularly dangerous goods are not allowed to be transported on Ro-Pax ships, or at least their transport is very restricted. Figure 4.3 shows a breakdown of the origin of fires that have occurred on Container, Ro-Ro and Ro-Pax ships. 37 accidents (21%) have been documented as originating in the cargo space. 86 accidents (48%) are categorized as having not originated in the cargo space, rather "another location". The remaining 31% of fires in the database have no information regarding the origin of the fires. Representing this in terms of the number of casualties, for 63% the origin of the fire is unknown. Only 4% of casualties were clearly victims of a fire originating in the cargo space. The remaining 33%, based on the LRFP, have the origin of the fire listed as "another location", but not a cargo space.

Moreover, the LRFP database also shows that of the 626 casualties of fire on Ro-Ro and Ro-Pax ships only 14 persons were victims of a fire originating in the cargo area. This equates to approximately 2% of the casualties.

If the dangerous goods considered in this paper are linked to a high hazard potential, then they are allocated to the stowage categories D or E of the IMDG Code. Hence, relevant accidents occur predominately on containerships. The scope of this analysis is restricted to containerships, Ro-Ro ships and Ro-Pax ships are not considered further. The origins of fires on container ships are shown separately in Figure 4.4. For container ship fires, the database indicates that 28 fire cases (28%) originated in the cargo space. 48% of the fires are classified as having an origin at a location "other than" the cargo space. In 24% of the cases in the LRFP database (/18/) the origin of the fire is unknown. An evaluation of the casualties demonstrates the true impact of cargo space fires. Namely, 36% are accounted for by cargo space fires. 32% of fires originated in areas "other than" cargo spaces, likewise 32% are listed as having an unknown fire origin.

In summary, it can be said that the LRFP database allows an assessment of the frequency of fires and their origin, but does not contain information regarding the involvement of dangerous goods.



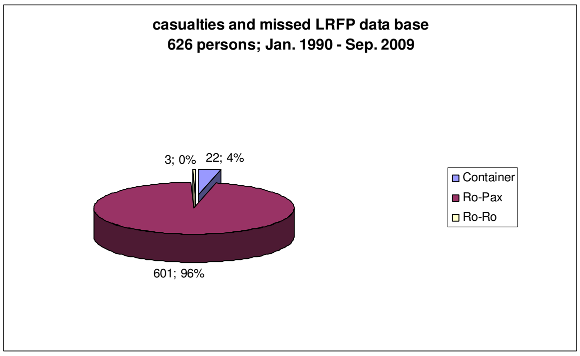
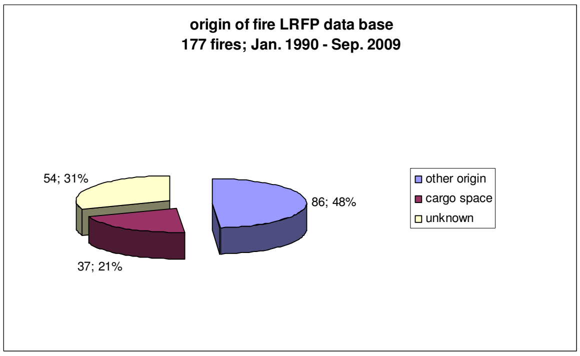


Figure 4.2: Fire and explosion accidents according to LRFP (/18/) for container, Ro-Ro and Ro-Pax ships (left: number of accidents, right: number of casualties)



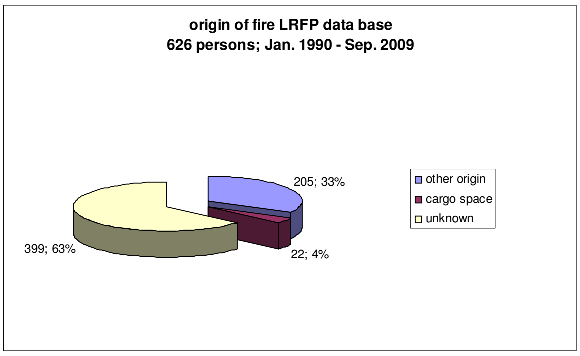
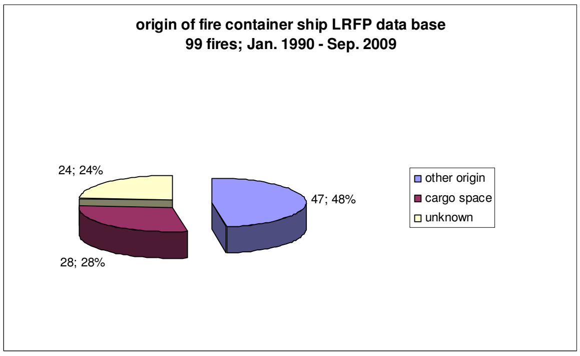


Figure 4.3: Fire origin (left: number of accidents, right: number of casualties; /18/)



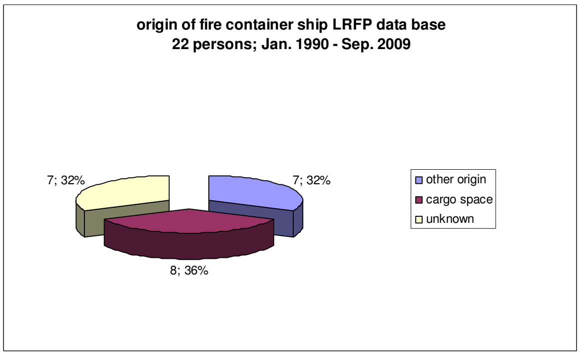


Figure 4.4: Fire origin on container ships (left: number of accidents, right: number of casualties; /18/)

4.1.3 IMO publications

In the course of a Formal Safety Assessment for the transport of dangerous goods on board open top container ships (/2/), the societal risks are determined and presented in the form of a FN-diagram within the SAFEDOR project. The societal risks indicates the frequency per ship-year F, of an accident occurring resulting in N or more casualties. Figure 4.5 shows the societal risk for container ships . Each line on the FN-diagram represents a different accident type with the total accidents also plotted.

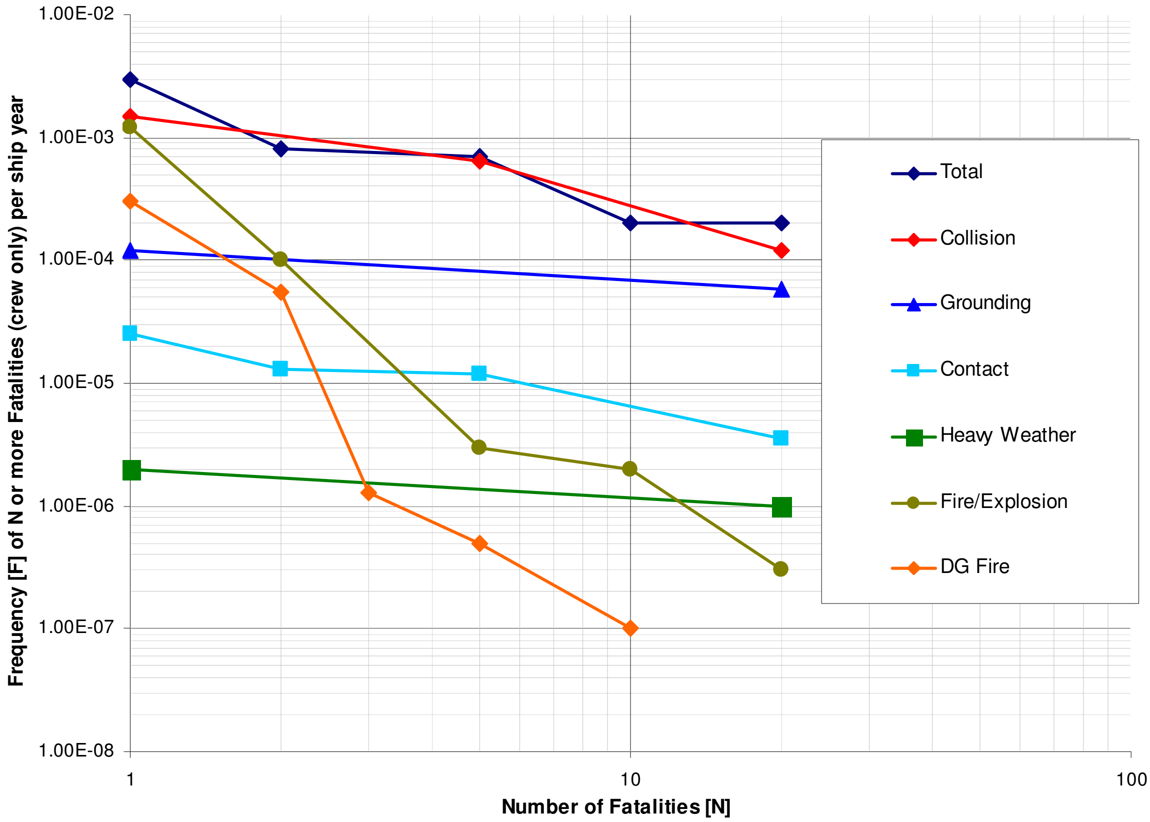


Figure 4.5: **FN-Diagram: transport of dangerous goods onboard container ships (SAFEDOR Report D 4.8.2 /2/, Dangerous Goods Transport with Open-Top Container Vessels – Risk Analysis)**

The possible causes for fires evaluated in the risk model during the SAFEDOR Project (D 4.8.2; /2/) for the transport of dangerous goods on container ships include:

- fire/explosion in vicinity of a container stowed on the deck (bridge, accommodation);
- fire/explosion below deck (machinery spaces, below decks);
- technical failure of equipment on the weather deck;

- repair work;
- arson.

In an additional FSA to the safety of container ships (/7/, /8/) submitted to the IMO by Denmark, the following causes of fire in the cargo hold areas were highlighted:

- improper stowage of dangerous goods (not or poorly marked goods);
- insufficient cooling of the goods prior to packing;
- electric faults or malfunctions in the refrigeration units of reefer containers;
- stowage location is too warm;
- insufficient ventilation;
- collision or extreme ship motion resulting in damage to the container and potential release of flammable materials.

4.2 Existing regulations

4.2.1 SOLAS chapter II-2 regulation 19 and SOLAS chapter VII

SOLAS chapter II-2, regulation 19 ´Construction – Fire protection, fire detection and fire extinction; Carriage of Dangerous Goods´ (/1/) regulates the equipment onboard ships that transport dangerous goods. In accordance with SOLAS chapter VII „Carriage of Dangerous Goods“ (/16/) it is required that the transport of dangerous goods in packaged form complies with the provisions of the IMDG Code (/6/).

4.2.2 IMDG Code

The transport of dangerous goods is prohibited, if not compliant with the relevant provisions of SOLAS chapter VII; supplemented by the International Maritime Dangerous Goods Code (IMDG Code; /6/). Compliance with the codes ensures harmonization of common practices and procedures for the transport of dangerous goods by sea. Furthermore, it assures compliance with the mandatory provisions of the SOLAS Convention and Annex III of MARPOL 73/78.

The Code specifies requirements applicable to individual substances and items. The Maritime Safety Committee (MSC) of the International Maritime Organisation (IMO) is authorized by the assembly of the organization to approve amendments to the Code, thus allowing the IMO to quickly respond to developments in the transportation of dangerous goods.

In addition to describing the classification of the goods in the code, chapter 3 contains a dangerous goods list which outlines special rules and exemptions for goods. The dangerous goods list includes, in addition to a short description of the material properties of the goods, the latest version of the stowage and segregation regulations and a link to the applicable Emergency Schedule for Fire.

In chapter 7 of the IMDG Code the rules for transportation are given. For the stowage of dangerous goods (excluding Class 1 goods, not relevant for dangerous goods of EmS F-G) ships are classified into one of two groups:

1. cargo or passenger ships with a limited number of passengers; maximum of 25 passengers or one passenger per 3 m of overall ships length (whatever is greater),
2. other passenger ships which have a passenger number which exceeds the aforementioned value.

Table 4.1 lists the permissible storage locations for dangerous goods in terms of their stowage category. Dangerous goods for which the EmS F-G applies are represented in all stowage categories. Goods with a high hazard potential are classified in the stowage categories D or E.

Table 4.1: Stowage categories A to E and the permissible stowage locations (X) onboard.

stowage category	limited number of passengers		passenger ships	
	on deck	under deck	on deck	under deck
A	X	X	X	X
B	X	X	X	–
C	X	–	X	–
D	X	–	–	–
E	X	X	–	–

Furthermore, the IMDG Code chapter 7.2, contains provisions regarding the segregation of goods. In the dangerous goods list (IMDG Code chapter 3) it is stated which goods must be separated from one another. The segregation provisions of the dangerous good list are defined along with their application in different types of sea transport in chapter 7.2 of the IMDG Code.

The Emergency Schedule for Fires are included in the IMDG Code Supplement.

4.2.3 Emergency Schedule for Fire Golf of the IMDG Code Supplement

The Emergency Schedule for Fires in the IMDG Code Supplement gives recommendations to the ship's crew regarding dangerous goods fire fighting procedures. In the dangerous goods list, contained in chapter 3 of the

IMDG Code, the Emergency Schedule for Fire relevant to each of the substances is specified. For the substances examined in this study the Emergency Schedule for Fire Golf (EmS F-G) is applicable.

In principle, the EmS F-G recommends, in the case of fire, that a large quantity of water be deployed at once to lower the heat radiation of the fire and to cool adjacent cargo. According to the schedule, a possible intensification of the fire is considered as a secondary effect. In any event, the application of small amounts of water with the goods shall be avoided.

For a fire in a container stowed on the deck, it is recommended to the let the fire burn, provided other containers aren't at risk of catching fire. If there is a risk of spreading, then the container shall be cooled with large quantities of water, avoiding the ingress of water into the container.

For a fire in containers in the hold, the vents should be closed and the ventilation turned off. If available, the fixed gas extinguishing system should be activated. If this is not successful, it should be avoided in any case to use water for fire fighting purposes in enclosed spaces; deck vents are to be opened and large quantities of water should be applied in order to cool neighboring cargo. Application of small amounts of water shall be avoided under all circumstances.

4.3 Transport volume

Estimating the transport volume helps to quantify the frequency of occurrence of hazards. In particular, this assists the development of the risk models in the quantitative risk analysis. A summary of the estimates of the transport volume of dangerous goods from the SAFEDOR project are presented. As the project progresses, estimates from experts can be made. These are developed during the HAZID or in the development of the risk models for the quantitative analysis.

According to the Global Insight Trade Database (Cargo Safety – Qualitative Design Review (QDR) SAFEDOR D 2.5.3;/19/), in 2004 more than 71.4 million TEU of goods were transported in containers. The goods are broken down according to their fire behaviour according to the NST/R standard (Nomenclature uniforme des marchandises pour les Statistiques de Transport, Révisée). Figure 4.6 illustrates the distribution of different goods and their fraction of the total world container trade. In order to quantify the fire behaviour of the transported goods, the goods are classed according to their speed of fire spreading using the NFPA (National Fire Protection Association) method (see Table 4.2). Taking into account both packaging materials and goods statistics, 33.8% of the transported volume consists of goods with a fast or very fast fire spread speed (see Figure 4.7).If the packaging is omitted, a fraction of goods transported in containers with a fast or very fast fire spread speed of 22.2% is remaining.

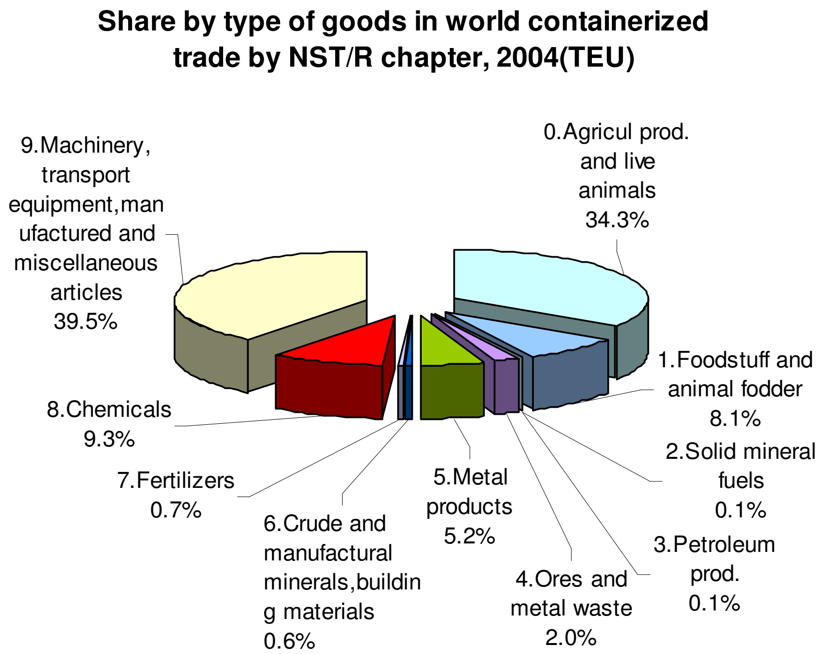


Figure 4.6: Distribution of goods in world containerized trade

Table 4.2: NFPA classification according to fire spread speed

Class	Fire spread speed	Growth time t_g (s)	Modified fire intensity coefficient $\alpha=1000/t_g^2$ (kW/s²)
1	Very fast	75	0.188
2	Fast	150	0.047
3	Moderate	300	0.012
4	Slow	600	0.0029
5	Very slow	900	0.00124
6	Non combustible	∞	0.00
t_g = Time taken for the fire to reach the optimum combustion heat release rate of 1000 BTU/sec (1055 kW).			

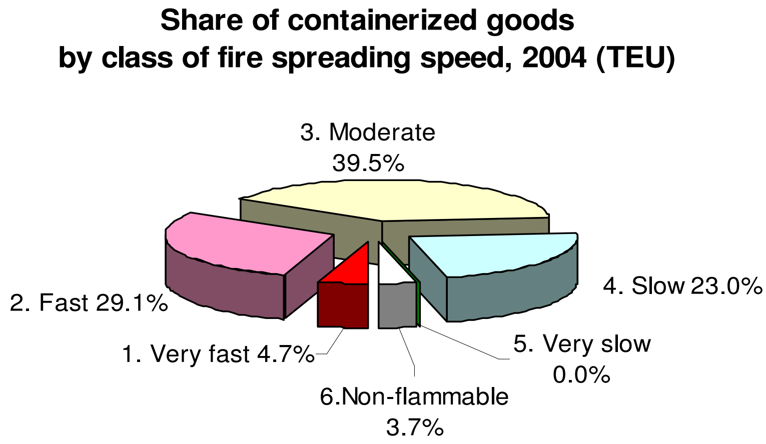


Figure 4.7: Distribution of containerized goods according to fire spreading speed.

In the IMO FSA for container ships (/7/, /8/) it is assumed that dangerous goods account for 6 % of the total goods transported on ships. In the aforementioned FSA it is also assumed that dangerous goods are involved in 30% of fires.

The transport volume of goods in containers can be approximated as follows:

- In 2004, 3,178 container ships were in service worldwide, with a total capacity of 6,477,300 TEU (Lloyds Register Fairplay, 01/2004; /17/); January 2007 already 3,875 container ships were in service with about 9,411,196 TEU (/7/, /8/).
- In 2003 and 2004, European Union ports handled approximately 50,000,000 TEU per year (imports and exports, Eurostat; /3/). The distribution of transport units according to their size is given in Table 4.3.
- The amount of goods handled in German ports has continuously grown in recent years (2000 - 2007) by at least 1% / year. In 2007, 37.8% of the goods handled were containers (gross weight, Eurostat; /3/).
- In 2004 worldwide more than 71.4 Mio TEU were transported in containers (Global Insight Trade Database, Cargo Safety – Qualitative Design Review (QDR) SAFEDOR D 2.5.3, /19/).
- About 6% of the annual transport volume consists of dangerous goods (FSA Container Ships; /7/, /8/). This would result for 2004 in an equivalent of approximately 4.3 Mio. TEU.

Table 4.3: Distribution of container sizes handled in the European Union ports 2003/2004 (/3/)

Container size	Percentage %	
	TEU	Quantity
20 feet	28.0	43.7
40 feet	65.7	51.3
Between 20 and 40 feet	1.4	1.4
> 40 feet	2.7	1.9
Unknown	2.2	1.7

4.4 Boundary conditions and limitations

Basic condition fort he analysis is hat the containerised sea transport is following the prevailing rules and regulations. This includes:

- outfitting of vessels according to the provisions of SOLAS, especially fort he transport of dangerous goods,
- dangerous goods are correctly labelled, their packing, consignment, stowage and segregation is according to the IMDG_Code,
- instructions, especially the emergency schedules, are followed by the crew,
- education and training of crew according to IMO standards.

4.4.1 Ship types considered

The considered dangerous goods with high hazard potential usually have stowage category D or E according to the IMDG Code (/6/) (see Annex 1) and therefore may not be transported on passenger vessels with more than 25 people onboard, or more than one passenger per 3m of overall ships length. Additionally, accidents statistics from Lloyd Register Fairplay (/17/) show that only 2% of casualties on Ro-Pax ships were victims of fires originating in the cargo space. On container ships, 36% of casualties were victims of fires identified as originating in the cargo space.

Due to the relatively low occurrence of cargo space fires on Ro-Pax ships, along with the low transport volume of the considered dangerous goods, this study focuses on container ships. Therefore the different transport conditions on non-container-ships are not considered within this study. This includes the potentially much larger distance between the containers, the transport in partly enclosed spaces on board or the simultaneous transport of containers and for example vehicles.

4.4.2 Risk categories considered

The FSA concentrates on the risk to persons and the environment, which are the main criterion in FSA studies at the IMO. The risks of damage to property (cargo and ship) are considered implicitly within the SOLAS fire fighting standards and can be captured in principal using the methodology presented in this paper. Acceptance criteria for the assessment of risk of damage to property are not published at the IMO yet.

In the following table the IMO recommendations for acceptance criteria for fatalities are presented. The values shown are valid for the ship's crew and are used in a large number of previous IMO FSA studies. The maximum acceptable risk for ship's crew is based on the maximum acceptable risk for workers in general, as documented in the UK HSE (/4/).

Table 4.4: Acceptable criteria for fatalities of crew

risk level	**accident fatality rate** (in accidents per person per year)
maximum acceptable risk for the crew	10E-3
negligible risk	10E-6

For a calculated risk that exceeds the maximum acceptable value of 10E-3, risk mitigation measures shall be applied under all circumstances. For a calculated risk under the maximum allowable value and greater than the level of neglectance, the risk shall be reduced ALARP (as low as reasonably practical) through the application of cost effective risk mitigation measures.

For the dangerous goods considered in this study, the risk to the environment is more difficult to assess. Discharge of chemicals into the sea are rapidly diluted. In these cases, no effective means of damage control are known. Also the possible harms to the environment as a result of such a chemical spill is largely unknown.

4.4.3 Quantitative data availability

The preceding investigation has shown that reliable transport volume data of the goods of the Emergency Schedule for Fire Golf cannot be extracted from available statistics. This is primarily due to the fact that no statistics are available for the transport of dangerous goods in accordance with the applicable Emergency Schedule for Fires. On the other hand, statistics listed by dangerous goods type are not providing further information on the ship type that is used for sea transport. Quantification of the sea transport volume of goods in containers for which EmS F-G applies was therefore not possible.

From the documented cases of fire at sea it is evident that the cause of the accidents is often difficult or impossible to determine. Thus, although the cargo space is in many cases identified as the origin of the fire, the originating container is only identifiable in rare instances. In assessing the involvement of EmS F-G goods in accidents there is no reliable data. Additionally, in most cases, fires that have just started do not exceed the containment of the container itself and go out on their own. These self extinguishing fires are usually not noticed until the container is unloaded at its destination. In most cases, such fires are not documented in any ship specific statistics.

In the absence of quantitative data, during further analysis risk models will be established based on the valuation of experts. This is deemed adequate, as the absolute frequency of incidents is of only minor importance for the assessment of existing hazards and implemented measures.

5 Hazard identification

For the FSA (Formal Safety Assessment) to be carried out, initially the main risks need to be qualitatively determined with a hazard identification. The hazard identification is carried out in form of a Failure Mode and Effect Analysis (FMEA). In the FMEA the potential hazards are identified and rated by means of an established evaluation into main risks which will be qualitatively investigated through additional analyses.

5.1 Method of hazard identification

Hazards are identified using the method of hazard identification. The following paragraphs are summarizing the general method and results of the risk analysis.

The hazard identification is an inductive and deterministic method to identify possible dangerous conditions. The structure and procedure of this method is based on the Failure Mode and Effect Analysis (FMEA, /5/). With it, the frequency and consequences of various undesirably events are identified and evaluated.

The aim of hazard identification is to find vulnerabilities in the system and the interfaces as well as detecting potential single failure or single events, which, when encountered may lead to an accident. Risk analysis usually investigates only single events or failures, and no event or failure combinations.

The analysis can serve as proof that a system or process is installed and operated in a way that the risk (e.g., risk to persons, the environment or property values) can be ruled out as far as possible. Those responsible will obtain a current picture of the existing risks and their potential impact.

With the help of the analysis, persons involved can be informed of relevant risks. At the same time, the results can aid in providing information to optimize safety during installation, operation or maintenance. The analytical results can be considered for the improvement of safety standards.

The analyses are to be revised as soon as the operating systems undergo changes, extensions or alterations, or if certain events such as malfunctions, critical incidents or near-critical malfunctions require the same. In the case that a major change occurs, a new risk assessment has to be carried out.

A change, extension or alteration should be considered important when changes in processes are having an impact on the overall safety of the facility or safety related installations.

The hazard identification is usually carried out by a team consisting of 4 to 8 people, who are experts in the particular system under consideration.

The steps of a hazard identification are:

- A list of all participating systems or system components;
- Identification of undesired events and failure modes;

- Identification of the consequences / effects;
- A list of existing protective measures (constructive, organizational);
- Estimation of the frequency of occurrence;
- Evaluation of severity of the failure;
- Determination of the *Risk Priority Number* (RPN) through the combination of frequency of occurrence and the severity of the failure.

When required:

- Development of additional protective measures;
- Estimation of the frequency of occurrence after implementing the additional protective measures;

Determination of the *Risk Priority Number* (RPN) through the combination/ addition of the frequency of occurrence and severity of the failure.

5.2 Hazard identification for dangerous goods which react dangerously with water and / or carbon dioxide

The basic diagram of hazard identification in this project is shown in Figure 5.1.

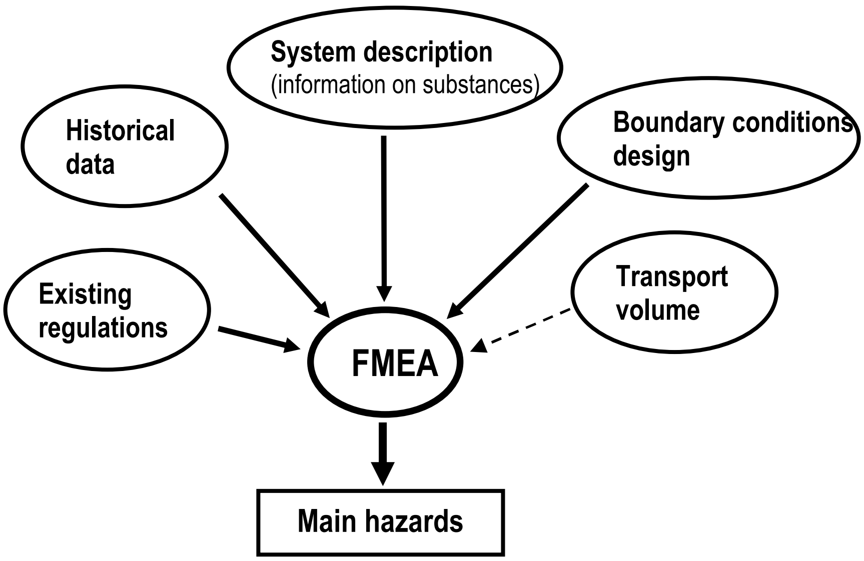


Figure 5.1: Process of hazard identification (HAZID)

The following input parameters are taken into account in determining the main hazards:

- Historical data
  - LMIU (Lloyds Maritime Information Unit) accident database;
  - LRFP (Lloyds Register Fairplay) accident database;
  - Publications of IMO (FSA Container Ships, FSA Open Top Container Ships).
- Existing regulations
  - SOLAS II-2/19 „Construction – Fire protection, fire detection and fire extinction; Carriage of Dangerous Goods“;
  - SOLAS VII „Carriage of Dangerous Goods“;
  - IMDG Code (International Maritime Dangerous Goods Code);
  - Emergency Schedule for Fire - Golf (EmS F-G) des IMDG Code Supplement.
- System description (System: substances)
- Boundary conditions:
  - Sea transport in container;
  - Type of vessel and design;
  - Fire fighting equipment.
- Transport volume (relevant for quantification)
  - Estimations of the SAFEDOR project.
  - Estimation by experts (in the context of the hazard identification).

The process of FMEA includes the following:

- Brief introduction of formal safety analyses and the integration of the planned HAZID in the FSA of the current research project;
- Brief introduction of HAZID;
- Introduction of the team of experts;
- FMEA, Explanation of procedures and charts;
- Execution of the FMEA.

5.3 Participating experts

The quality of the FMEA and the dependability of the results depend on the expertise of the participating experts. The expertise in the areas of ship technology, regulations and risk methods were supplied by Germanischer Lloyd, as part of the research project. To get the expertise from all areas described below, members of the work group for difficult extinguishable fires “Arbeitskreis schwerlöschbare Brände” were called in for the workshop.

Fire fighting

Experts with knowledge in the handling of fires with dangerous goods, in particular for water-reactive substances of the emergency Schedule for Fire - Golf will be included in the analysis.

Chemistry

The chemical behaviour of substances and in particular the chemical reactions have a crucial impact on the possibility of fighting the fire. Experts with knowledge of the chemical properties of the considered water-reactive substances of the EmS F-G are involved in the analysis.

Logistics in container shipping

Special operational procedures and operational constraints have to be taken into account during the process, therefore logistics experts with a focus on container shipping are to be involved.

Regulations (SOLAS, IMDG Code)

The transport of dangerous goods which react dangerously with water and/or carbon dioxide, is carried out in accordance with the regulations of SOLAS and the IMDG Code. Experts of those standards accompany the analysis.

Ship technology

Expertise on the existing technical systems will be integrated for the analysis of fire-fighting with the equipment on board. This mainly concerns the usually installed systems for fire-fighting and fire detection on container ships and Ro-Ro-/Ro-Pax-ships.

Risk assessments (FSA, FMEA)

Experts in risk methods are responsible for moderation, management and documentation of the risk analysis.

The following table lists the people which participated in FMEA on February 2, 2010:

Table 5.1: FMEA-participants

Name	Organisation	Specialty
Gudula Schwan	Federal Ministry of Transport, Building and Urban Development	Transport dangerous goods, Regulations
Arno Dittmann	Henkel AG	Fire-fighting chemical fires
Ingo Döring	BAM Federal Institute for Material Research and Testing	Chemistry, chemical fires
Rainer Koch	BSH Federal Maritime and Hydrographic Agency	Regulations, ship technology
Uwe Kraft	Bremen Port Authority	Regulations, logistic in container shipping
Norbert Kusch	Fire department Hamburg	Fire-fighting chemical fires
Dr. Urs Vogler	GL	Risk assessment, Regulations, Ship technology
Kay Dausendschön	GL	Risk assessment, Logistics container shipping
Friedo Holtermann	GL	Regulations, transport of dangerous goods, fire-fighting
Michael Kämpf	GL	Fire-fighting, ship technology

5.4 Use of the data sheet for qualitative risk assessment

A standardised data sheet (Table 5.2) is used to ensure a systematic approach. With the data sheet the necessary information for risk assessment can be systematically queried and displayed in a logical context. A separate set of data sheets is used for each system to be analyzed.

In addition to the general identification of possible causes of the fire and their consequences, dangerous incidents are also divided into categories of frequency of occurrence and consequences (see tables below) based on a list of substances (see annex 2). This preliminary evaluation will assist in the subsequent creation of the risk models.

The tables used in the FMEA workshop record essential information in several steps for both the deductive and the inductive parts.

- Step 1: Identification of the risk (How did the fire start, what are the resulting risks, etc.);
- Step 2: Corse division of the frequency of occurrence and consequence ;
- Step 3: Risk reducing measures (additional to the already implemented).

Table 5.2: Data sheet of qualitative risk assessment

Title	**Description**
Step 1: Identification	
No.	Unique identification number of the scenario
Substance	Considered substance, if only valid for set of the EmS F-G substances
Cause	Possible cause of identified risk, including course of errors which lead to the dangerous scenario
Resulting risks	Considered resulting risks
Existing measures for prevention	Existing organisational and technical measures to prevent the risk (prevention of the cause and/ or escalation).
Step 2: Risk	
Frequency	Category of the frequency of cause and of the described chain of errors, respectively. Categorization according Table 5.3
Severity of consequence	Category of the severity of consequence for subsequent risks, Table 5.4
Step 3: RRM Risk Reducing Measures	
Additional/Alternative measures	Measures identified during the risk analysis to reduce the risk (reducing the frequency and / or consequence)

As an example, the following is a sample table with entries for the thermal ignition of certain dangerous goods represented in Figure 5.2. The complete charts are provided in Annex 3.

The evaluation criteria for qualitative estimation of the frequency of causes and severity of possible consequences are clarified in Table 5.3 and Table 5.4, respectively.

Table 5.3: Categories for the frequency of risk scenarios

Frequency	Frequency of occurrence	Qualitative description
1	very unlikely	Less than 1 case per 1000 ships per year
2	rare	1 case per 1000 ships per year or more
3	often	1 case per ship per year or more

Table 5.4: Categories for the severity of consequences

Severity	Consequence	Qualitative description
1	low	Damage of 1 Container, no casualties
2	significant	Damage of 10 Containers, ship structure; casualties
3	serious	Serious consequences

GL

HAZID - Transport of dangerous goods

Event: Thermal ignition

Step 1: Identification					Step 2: Risks		Step 3: RCM
No.	**Substance**	**Cause**	**Possible consequence**	**Existing measures for prevention**	**Frequency**	**Severity of the consequence**	**Additional/alternative measures**
D2.1		Neighbouring installations, regular operations (tank heaters, etc.) > Thermal stress due to thermal conduction, long-term	Fire	Stow on deck	1	2	Position of stowed goods
D2.2		Unintented thermal stress (short-term, i.e. welding work); potential malfunctions	Fire		1	2	Briefing (operative instructions)
D2.3		Direct sunlight	Fire		1 (very low)	1	Stowed position, not in the upper stacks
D2.4		Other heated goods are released and consequential heating of the considered goods in the EmS F-G	Fire		extreme rare	1	Regulations for stowage
D2.5		Fire (can be at a distance)	Fire		1	2	
D2.6		Self-heating (Release of the heat is not warrented, i.e. caused by faulty packaging)	Fire	Keep cool	1	1	

Figure 5.2: FMEA Table in the event of thermal ignition

5.5 Categorising risks

The analysis of risks, which originate from the considered dangerous goods, is divided into a deductive part (before the fire) and an inductive part (after the outbreak of the fire).

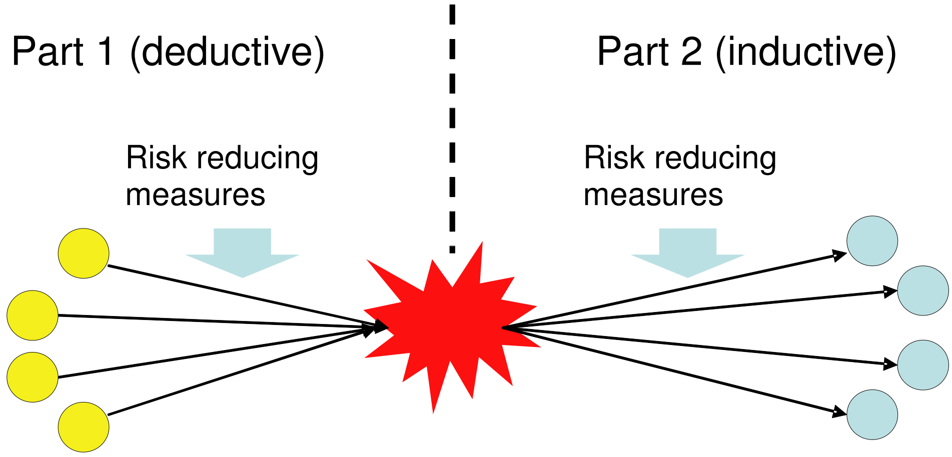


Figure 5.3: Division of FMEA

5.5.1 Deductive risks – ignition

The following risks have been identified, whereby substances of the EmS F-G cause a fire or explosion:

- Mechanical impact (e.g. vibrations, friction,…);
- Thermal impact (heat exposure);
- Ignition due to contact with water (sea water, extinguishing water, humidity,…);
- Spontaneous ignition due to contact with air.

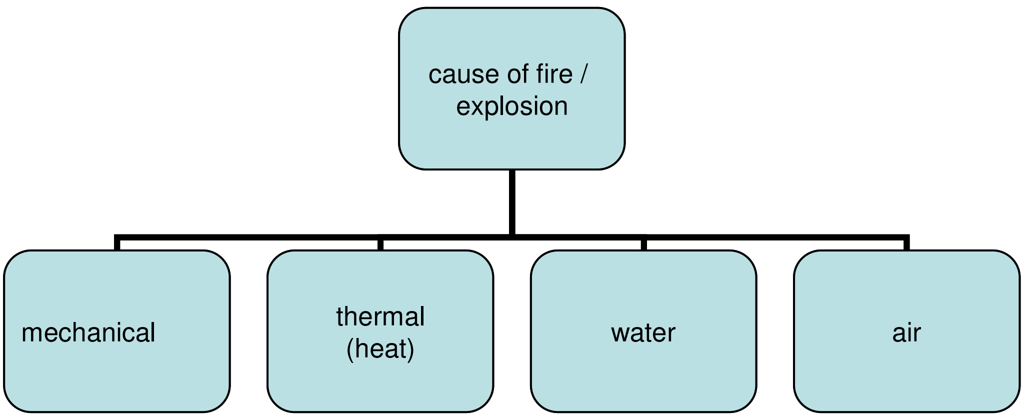


Figure 5.4: Deductive risks - ignition

5.5.2 Inductive risks – advancement of fire

Additional risks which can occur with substances of the EmS F-G when coming in contact with the extinguishing water in existing fires:

- Release of hydrogen;
- Release of other flammable gases;
- Release of dangerous non-flammable gases;
- Release of oxygen;
- Ignition when coming in contact with other substances.

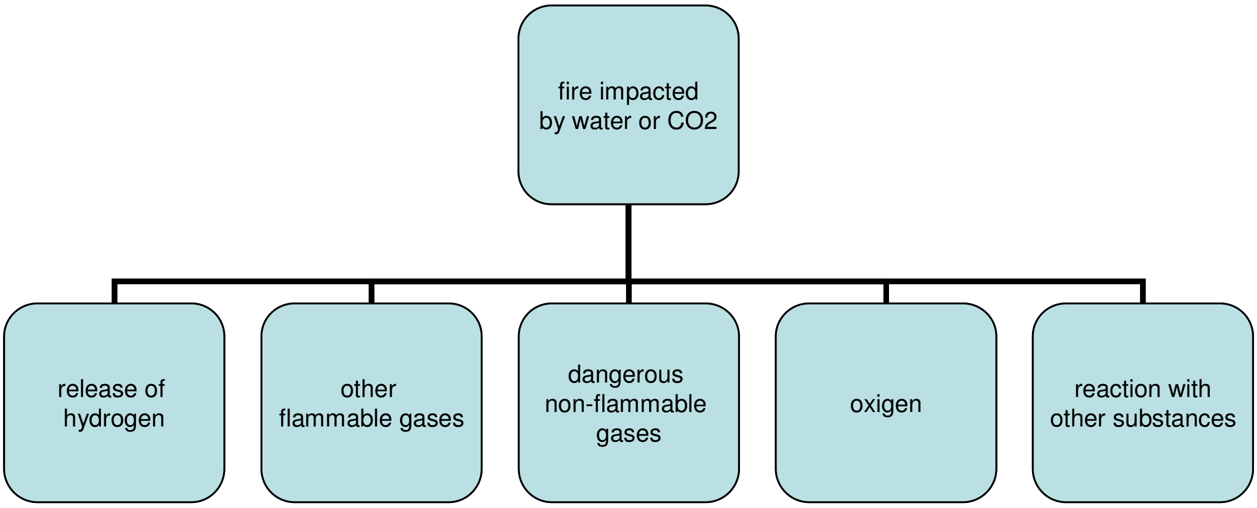


Figure 5.5: Inductive risks – fire promoting

5.6 Identified main risks and scenarios

From the results of the FMEA the main risks are selected based on the probability of occurrence (in the deductive part) and the severity of the consequence (in the inductive part), and listed in Table 5.5 and Table 5.6. These will be examined in greater depth in the subsequent risk assessment (Chapter 6).

Table 5.5: Deductive risk scenarios with the highest frequency of occurrence

No.	Cause	Resulting risk	Frequency index
D3.1 Class 5.1	Different external temperature at loading/transport (transport across climate zones) → condensation in the container → softening of packaging → substance reacts with organic packaging	Fire	3
D3.2	Cleaning of container before loading/ loading of container in rain (snow, moisture) → wet container (high humidity) → reaction with released gas	Corrosion/ fire conceivable	3
D3.3	Sea water enters (through ventilation, flaws in the container)	Corrosion/ fire conceivable	3

Table 5.6: Inductive risk scenarios with severe consequences

No.	Cause	Resulting risk	Severity of consequence
I2.3	Release of flammable gases, venting of flammable liquids and gases	Reaction inside the container, ignition and destruction of container	2 on deck 3 below deck
I2.4	Release of flammable gases, venting of flammable liquids and gases	Reaction outside the container, ignition	2 on deck 3 below deck
I4.3	Substance reacts with water with the release of corrosive gases (e. g. HCl-gas -> hydrochlorid acid)	Toxic effect on people, extreme corrosion **On deck**: possible structural damage **Below deck:** significant structural damage	2 on deck 3 below deck
I5.1	EmS F-G substance reacts due to damaged packaging (e. g. due to fire/attempt at extinguishing the fire) with released gases/ liquids from other substances in fire	Advances the fire; combination between substances which don't allow any fire-extinguishing methods (e. g. chlorine and oxidizing agents)	3

6 Risk quantification and identification of risk reducing measures

In this section, the previously identified major risk scenarios see Table 5.5 and Table 5.6, will be examined in more detail further and evaluated. A simplified overview of the applied risk model is represented in Figure 6.1.

The following analyses are dealing with the dangerous goods for which the EmS F-G applies. In the following paragraphs these goods are defined as „**Dangerous goods**“ without any explicit reference to the EmS F-G. Furthermore, containers transporting dangerous goods, for which the EmS F-G applies, are described with the term „**Container with dangerous goods**“.

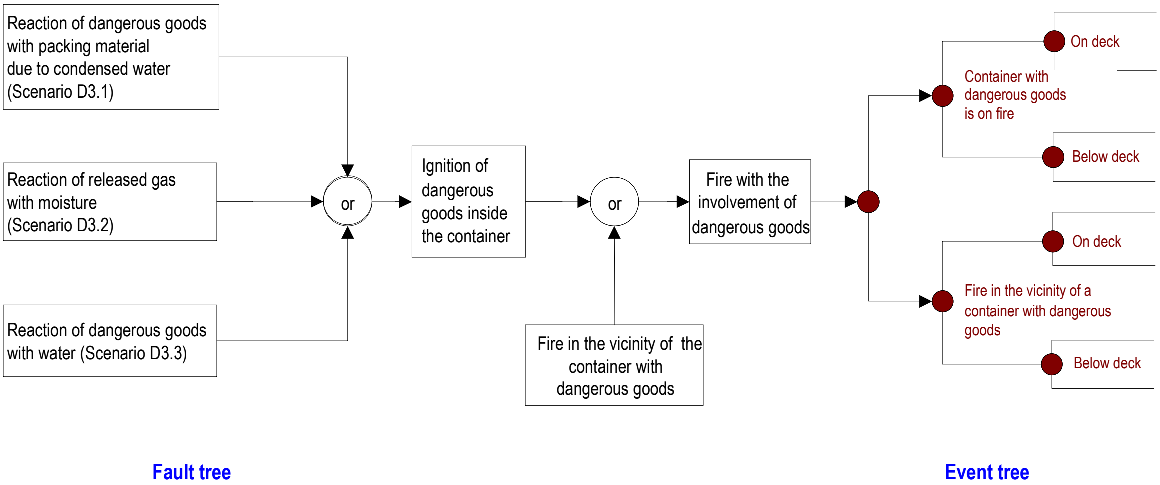


Figure 6.1: Overview risk model

In the deductive part of the analysis, the most common cause of fire start with the involvement of dangerous goods, see Table 5.5 is examined in more detail. All these scenarios lead to ignition of the dangerous goods or of their flammable packaging within the container. In most cases, the fire does not spread beyond the effected container and self-extinguishes after a short time so that the incident goes unnoticed and is not included in statistics. An ignition under fire favouring circumstances rarely leads to fire spreading beyond the effected container. This is the reason why the frequency of considered ignitions with 3 cases per ship per year (according to expert estimates in the hazard identification, see Chapter 5) is approx. 3 times higher than the frequency of fire accidents statistically recorded.

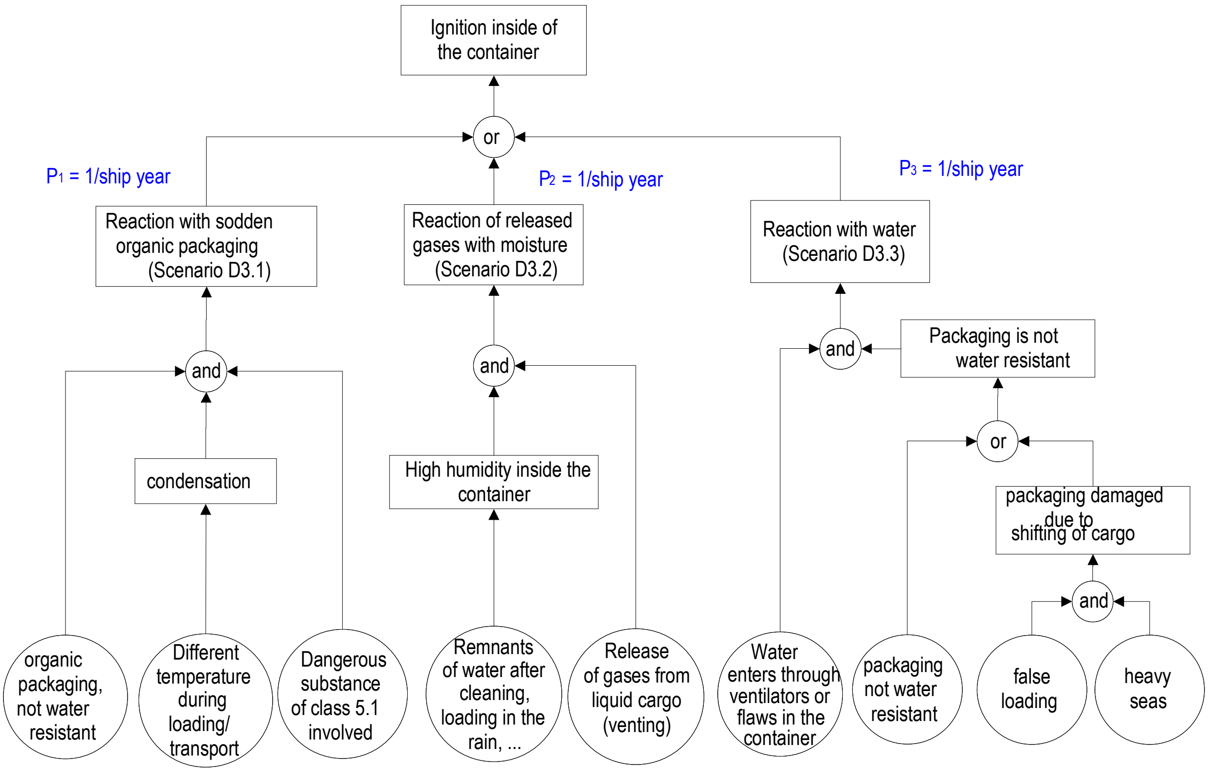
In the inductive part of the analysis the risk for the listed scenarios in Table 5.6 are analysed with the help of the event tree. Based on a fire with the involvement of dangerous goods, different scenarios are analysed as a consequence thereof. It has been distinguished between the scenarios of dangerous goods themselves on fire, or of a fire in the vicinity of dangerous goods. In the latter case the dangerous goods pose an additional risk.

Detailed statistics of the occurrence of each incident are required to quantify the risk. However, since there are no reliable databases (see Section 4.4.3), the following analysis is based on qualitative assessments by experts.

6.1 Deductive risks – Fault tree analysis

For fire start in connection with dangerous goods, the scenarios D3.1, D3.2 and D3.3 are to be considered in terms of risk. The fault tree used for the analysis of deductive scenarios is represented in simplified form in Figure 6.2.

Basic incidents are shown at the lowest level of the fault tree. The basic incidents are marked with a circle. „Heavy seas“ is an example of a basic incident. A basic incident or a combination of basic incidents (which are logically linked with each other through AND/OR-connections) can result in higher-level incidents, which are marked with a square. Possible transitions between incidents are illustrated with directional arrows. These transitions are probabilistic outcomes. For example, the combination of „false loading“ and „high seas“ can lead to damage of the packaging, but doesn’t have to happen. The probabilities of occurrences (P1, P2, P3) for the deductive scenarios D3.1, D3.2 and D3.3 are estimated by experts about 1 time per ship year.



Firgure 6.2: Overview of the deductive scenarios

6.1.1 Reaction of dangerous goods with sodden organic packaging (Scenario D3.1)

Condensation can occur inside the container during the transport of dangerous goods across different climate zones. For example, the cargo was brought on board in a tropical area, where the temperature and humidity are high. This means that the air in the container between the packages and within the package contains relatively large amounts of water. When the ship sails into a colder climate zone the air gets colder and cannot absorb as much water. The excess water is condensed, so that water droplets form between the different packaging units in the container, as well as inside the packaging.

Depending on the properties of the packing material, the water from condensation can sodden the packaging, so that the dangerous goods get in contact with water and cause a dangerous reaction. In particular, the dangerous goods of class 5.1 (e.g. Potassium persulfate) react with the sodden organic packing material (paper, cardboard, etc.) and ignite.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

   (1) Packing into container only during dry conditions. (regulation exists);

   (2) Use of water resistant packaging for sea transport, as far as not required yet;

   (3) Reducing condensation with moisture absorbing material, for example silica gel;

   (4) Good ventilation inside the container impedes the development of condensation;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the crew: no measures identified.

6.1.2 Reaction of released gases with moisture in the container (Scenario D3.2)

Some liquid dangerous goods are transported inside sea container packed in tanks or similar packages that have pressure relieve devices. It is necessary to equalize over pressure which occurs with the increase in temperature and could damage the tank and therefore lead to the emission of the dangerous goods. Small amounts of dangerous flammable gases can leak through the pressure relieve device.

If the humidity in the container is high and the dangerous gases in the air reach a critical concentration, a reaction is imminent. As a result, the gas/ air mixture can ignite spontaneously. Another possible risk is the formation of corrosive substances which corrode the container and ship structure.

High humidity in the container can occur when the container is packed in rain or snow, for example. Another possible cause could be due to remaining water in the container after cleaning.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

Packing into container only during dry conditions. (regulation exists);

c) Instructions in the EmS F-G: no measures identified;

d) Training of the crew: no measures identified.

6.1.3 Reaction of dangerous goods with water (Scenario D3.3)

Some of the considered dangerous goods react with water or steam generating excessive heat or releasing toxic or explosive gases. There is a risk of fire when these substances are in contact with water. Here, the fire itself can be triggered by small amounts of water or moisture. When speaking of contact with water in the following section, it should be understood to also mean contact with moisture or small amounts of water.

As the dangerous goods are transported in the specified packaging, the contact with water happens only when in addition to the water entering into the cargo space (container, hold) the packaging doesn't offer sufficient protection from water (or moisture).

Common causes for water entering into the container are:

- Water enters through ventilation or flaws in the container;
- In heavy seas, water can enter into the containers placed on deck or in the hold;
- A ship collision or a leak can result in larger amounts of water entering into the cargo space.

If water has already entered the container, the packaging is the only protection from the fire. If the packaging is not water resistant, there is no protection. Even the water-resistant packaging can be substantially damaged which will then let water through.

Possible causes for previous damage to the packaging are:

- Shifting of the cargo inside the container;
- Error in packaging or faulty packing material;
- Failure of the container structure that can be caused through shifting of the container during sail or fatigue of material.

Damage to the packaging may also arise due to the same events that caused the water leak in the first place. The following scenarios are possible:

- Contact with water can sodden the packing material and damage it;
- A ship collision in which the packaging of the cargo was damaged.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

   (1) Use of water-resistant packing material;

   (2) Containers with dangerous goods are stowed protected from sea water;

   (3) Use of Containers which are designed to prevent the contact between the dangerous goods and the fire extinguishing water or sea water.

c) Instructions in the EmS F-G: no measures identified;

d) Training of the crew: no measures identified.

6.2 Inductive risks – Event tree analysis

In the inductive part of the risk assessment, dangerous scenarios that arise as a result of a fire involving the considered dangerous goods will be analysed. For this, the event tree analysis will be used as a method.

In order to evaluate the measures for fire fighting, which are recommended in the Emergency Schedule for Fire Golf, the event trees are structured according to the following general scheme:

Triggering events are fire involving dangerous goods or fire in the vicinity of dangerous goods. Then it is assumed that the fire fighting measures are applied in accordance with the EmS F-G. The risks, which arise out of the chain of events thereafter, are taken into consideration. The following risks are considered: the risk independent of the fire fighting measures; and risks arising from the fire fighting measures (such as a reaction with the extinguishing water, etc.). In particular, the inductive main risks listed in Table 5.6 are considered.

The measures taken as per the Emergency Schedule for Fire Golf (EmS F-G) and the severity of the resulting consequences in the chains of events are dependent on the stowage position of the dangerous goods (on deck or below deck). As a result, the triggering events are divided into the following four scenarios:

1. Container with dangerous goods is on fire on deck;
2. Container with dangerous goods is on fire below deck;
3. Fire in the vicinity of dangerous goods on deck;
4. Fire in the vicinity of dangerous goods below deck.

Fires without the involvement of dangerous goods will not be considered any further. The four scenarios named above will be analysed in the following pages, separate from each other.

6.2.1 Scenario 1: Container with dangerous goods is on fire on deck

When a container with dangerous goods is on fire on deck, the ship's crew, according to the EmS F-G, has to first assess whether fire could spread to neighbouring cargo. If the crew has assessed that there is no risk of fire spreading, measures to fight the fire are taken. However, if the ship's crew finds that there is a risk of fire spreading, the EmS F-G recommends that the burning container with dangerous goods is cooled with large quantities of water.

The event tree, based on the fire of a container with dangerous goods on deck, is represented in simplified form in Figure 6.3. All possible event chains are described in detail on the basis of the branches G 1.1 to G 1.7.

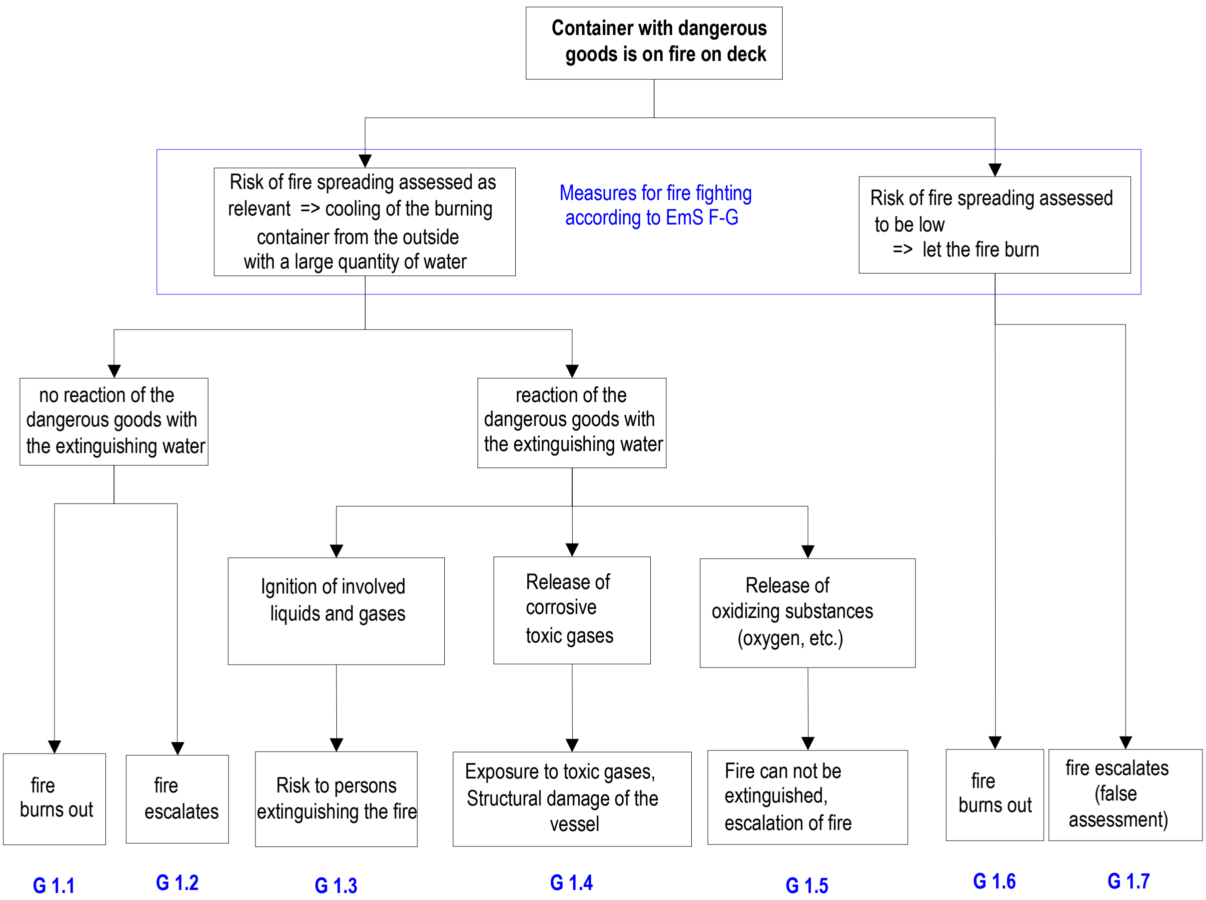


Figure 6.3: Scenario 1: Container with dangerous goods is on fire on deck

Branch G 1.1: Fire burns out - no reaction of the dangerous goods with the extinguishing water

This chain of events (branch) occurs when the ship‘s crew initially assess as that there is a risk of the fire spreading and cools the burning container containing dangerous goods with a large quantity of water, after which the fire burns out. A successfully extinguished fire, without affecting the dangerous goods of the EmS F-G, has only minor consequences. Generally, this branch of the event tree appears to have no specific impact on the dangerous goods, and therefore no risk reducing measures have been identified.

Branch G 1.2: Fire escalates - no reaction of the dangerous goods with the extinguishing water

This chain of events (branch) occurs when the ship‘s crew initially assess as that there is a risk of the fire spreading and cools the burning container containing dangerous goods with a large quantity of water. If no sufficient cooling can be achieved (e.g. due to insufficient water, poor accessibility to the container on fire, etc.), then the fire can spread and possibly escalate.

<u>Possible consequences</u>

The following consequences are possible:

– Loss of several containers;
– Significant structural damage of the vessel;

Additional possible consequences:

– Risk to the entire ship‘s crew and cargo due to escalation of the fire.

In the branch G 1.2 there is no specific influence of the dangerous goods on the event chain. Hence, identified risk control measures are universally valid for container ship fires.

<u>Risk reducing measures</u>

a) Equipment on ship:

(1) Sufficient equipment for fire-fighting in the vicinity of the fire is necessary for cooling the container with dangerous goods;

(2) The use of mobile fire-fighting monitors can prevent the spread of the fire. An escalation of the fire can be prevented in many cases.

b) Regulations for stowage and packaging: no measures identified;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 1.3: Ignition of liquids and gases due to a reaction with the extinguishing water

This chain of events (branch) occurs when the ship's crew assesses that there is a the risk of fire spreading and cools the burning container containing dangerous goods with a large quantity of water. Dangerous goods in liquid form are involved in the fire. Those substances generally are transported in packages or tanks with pressure relieve devices. The fire can lead to the release of large quantity of gases or can leak the liquid dangerous goods itself. Those substances react heavily with the extinguishing water or water vapour and may explode. When the ignition occurs inside the container, it can lead to an explosion, due to the build-up of over pressure, and consequential leads to the destruction of the container. When the liquids and gases ignite outside the container it can increase the spread of the fire.

Possible consequences

The following consequences are possible:

- Explosion of the container;
- Loss of several containers due to spread of the fire;
- Structural damage of the vessel;
- Risk for several persons, involved in the fire-fighting.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

  (1) Limiting the amount of dangerous goods per container reduces the severity of the consequences;

  (2) Stowage of the container, so that the container with dangerous goods can possibly burn out in the case of a fire or that the extinguishing water can drain if necessary;

  (3) Use of containers which are designed to prevent contact between dangerous goods and extinguishing water (not very effective because the container structure can be damaged by the fire).

c) Instructions in the EmS F-G:

  The EmS F-G should include detailed instructions on how to handle fire involving dangerous goods in liquid form;

d) Training of the ship's crew: no measures identified.

Branch G 1.4: Formation of corrosive toxic gases due to reaction with extinguishing water

This chain of events (branch) occurs when the ship‘s crew assesses the risk of the fire spreading and cools the burning container containing dangerous goods with a large quantity of water. As a result, the dangerous goods can react with the extinguishing water. Upon the reaction, corrosive or dangerous gases (e.g. HCl-gas, hydrochloric acid) are produced.

Possible consequences

The following consequences are possible:

- Structural damage of the container;
- Structural damage of the vessel;
- Risks to persons involved in the fire-fighting from released toxic gases.

Risk reducing measures

a) Equipment on ship:

Respirator for fire-fighting can reduce the risk of poisoning. (Regulation exists).

b) Regulations for stowage and packaging:

(1) Regulations for packaging have a small impact on the event chain. Likely the packaging will be damaged by the fire so that it no longer offers sufficient protection from the extinguishing water;

(2) Use of containers which are designed to prevent contact between dangerous goods and extinguishing water;

(3) Stowage of the container, so that the container with dangerous goods can burn out in the case of a fire or that the extinguishing water can drain if necessary;

(4) Installing of fire detection devices (smoke detectors, ...) and other monitoring devices (thermometer, hygrometer, ...) inside of the container to detect a fire or the risk of a fire in the container with dangerous goods early. These functions can also be monitored by mobile devices that are installed on demand in any container.

c) Instructions in the EmS F-G: no measures identified.

d) Training of the ship’s crew: no measures identified.

Branch G 1.5: Forming of oxidizing substances due to reaction with extinguishing water

This chain of events (branch) occurs when the ship‘s crew assesses that there is a risk of the fire spreading and cools the burning container containing dangerous goods with a large quantity of water. As a result, the dangerous goods can react with the extinguishing water. Upon the reaction, oxidizing substances are released which promote intensification and spread of the fire. These can result in combinations of substances which make an effective fire-fighting impossible (e.g. chlorine and oxidizing agent).

Possible consequences

The following consequences are possible:

– Loss of several containers;
– Significant structural damage of the vessel;
– Risk for persons involved in the fire-fighting due to spread of fire and possible explosion.

Additional possible consequences:

– Loss of nearly all cargo of the vessel;
– Total loss of vessel due to escalation of fire and/or explosions;
– Risks for the entire ship’s crew due to escalation of the fire.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

(1) Limiting the amount of dangerous goods per container reduces the severity of the consequences;

(2) Segregation of goods in containers: dangerous goods have to be packed separated from other flammable goods to allow fire fighting.

(3) Segregation of containers on board ships: To prevent combinations of flammable substances, that make effective fire-fighting impossible, containers containing these substances must be stowed separately;

(4) Stowage of the container, so that the container with dangerous goods can burn out in the case of a fire or that the extinguishing water can drain if necessary;

(5) Installing of fire detection devices (smoke detectors, ...) and other monitoring devices (thermometer, hygrometer, ...) in the container to detect a fire or the risk of a fire in the container with dangerous goods early. These functions can also be taken over by mobile devices that are installed on demand in any container;

(6) Using specially equipped containers for transporting such dangerous goods.

c) Instructions in the EmS F-G:

The EmS F-G should contain information to the fact that there are fires that cannot be handled with the resources available on board. In such cases, it is to be considered to minimize the risk to persons and forgo the fire-fighting measures and prepare the abandonment of the vessel;

d) Training of the crew:

With training, the crew and officers can learn to better judge when the fire-fighting is too dangerous and therefore not recommended or when to recommend abandonment instead.

Branch G 1.6: No risk of the fire spreading as assessed by the ship's crew – fire burns out

This chain of events (branch) occurs when the ship's crew assesses that there is no risk of fire spreading and leaves the container to burn out. Thereafter, the fire extinguishes. A successfully extinguished fire has only minimal consequences, therefore no risk reducing measures are identified.

Branch G 1.7: Fire escalates due to false assessment by the ship's crew

This chain of events (branch) occurs when the crew assesses that there is no risk of fire spreading and leaves the container to burn out. Despite the assessment of the ship's crew, the fire spreads to neighbouring cargo and after that escalates.

Possible consequences

The following consequences are possible:

- Loss of a few to a large number of containers;
- Structural damage of the vessel to total loss of the vessel;
- Escalation of the fire with imminent risk to the vessel and crew.

Risk reducing measures

a) Equipment on the ship: no measures identified;

b) Regulations for stowage and packaging: no measures identified;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew:

With training, the ship's crew and/or officer can learn to better assess the risk of fire spreading.

6.2.2 Scenario 2: Container with dangerous goods is on fire below deck

When a container with dangerous goods is on fire below deck, in accordance with the EmS F-G, the fire is fought with a CO_2 fire extinguishing system. Before CO_2 flooding, the ventilation systems should be shut down and the vents should be closed. If this is not possible, the neighbouring cargo should be cooled with a large quantity of water with open vents. No water should come in contact with the dangerous goods on fire.

The event tree, based on the fire of a container with dangerous goods below deck, is represented in simplified form in Figure 6.4. All possible chain of events is described in detail on the basis of the branches G 2.1 to G 2.8.

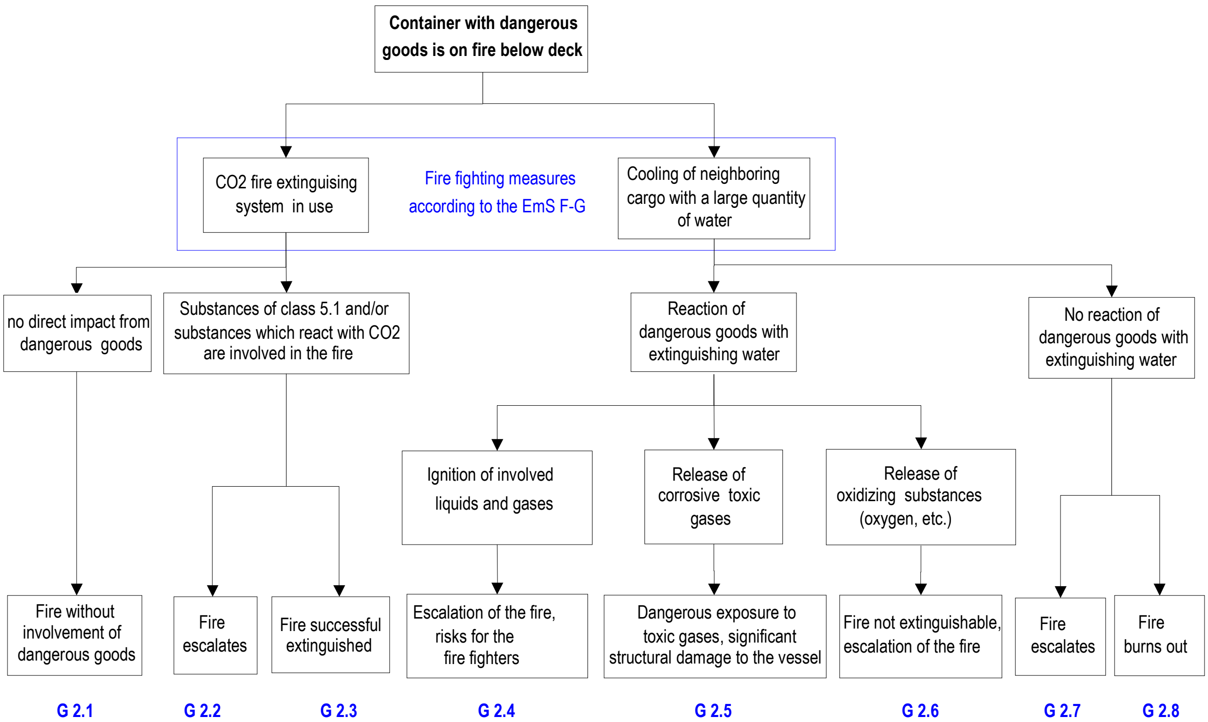


Figure 6.4: Scenario 2 – Container with dangerous goods is on fire below deck

Branch G 2.1: Fire fighting with the CO_2 - fire extinguishing system without impact from dangerous goods.

This chain of events (branch) occurs when the initial attempt to extinguish the fire is done using the CO_2 – fire extinguishing system. No dangerous goods of class 5.1 or substances that react dangerously with CO_2 are involved in the fire. Therefore the dangerous goods of the EmS F-G have no special impact on the success or failure of fighting the fire with the CO_2 – fire extinguishing system. The chain of events in branch G 1.2 is independent from the dangerous goods of the EmS F-G and will therefore not be considered in more detail.

Branch G 2.2: Attempt to extinguish the fire with CO_2 fails due to impact of dangerous goods.

This chain of events (branch) occurs when the initial attempt to extinguish the fire is done using the CO_2 – fire extinguishing system. Dangerous goods of class 5.1 or substances which react dangerously with CO_2 are involved in the fire. The dangerous goods of class 5.1 decompose in the fire and release oxygen. If a large quantity of the oxygen is released the attempt to extinguish the fire with the CO_2 will be ineffective. The fire can spread and potentially escalate.

Possible consequences

The following consequences apply:

– Loss of a few containers up to the loss of the entire cargo in the cargo hold;

– Structural damage to the vessel;

– Fire escalates with risk for the crew and the vessel.

Risk reducing measures

a) Equipment on ship:

 (1) Appropriate dimensioning of the CO_2 fire extinguishing system may increase the chance of success to extinguish the fire;

b) Regulations for stowage and packaging:

 (1) Limiting the amount of the dangerous goods of class 5.1 per container reduces the risk of the fire escalating;

 (2) For fighting fires with involvement of dangerous goods of class 5.1 in the hold, the by the EmS F-G recommended CO_2 fire fighting attempt will be not effective. Therefore these substances should be stowed on deck.

c) Instructions in the EmS F-G: no measures identified.

d) Training of the ship’s crew: no measures identified.

Branch G 2.3: Attempt to extinguish the fire with CO_2 is successful despite the impact of dangerous goods.

This chain of events (branch) occurs when the initial attempt to extinguish the fire is done with the CO_2 – fire extinguishing system. Dangerous goods of class 5.1 or substances which react dangerously with CO_2 are involved in the fire. The dangerous goods of class 5.1 decompose in the fire and release oxygen. The amount of the released oxygen is however not enough to keep the fire going long-term and/or to advance the spread of the fire. The fire control is successfully. The fire extinguishes.

<u>Possible consequences</u>

The following possible consequences apply:

– Loss of a few containers up to a large number of containers.

<u>Risk reducing measures</u>

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

   (1) Limiting the amount of dangerous goods of class 5.1 per container reduces the severity of the consequences;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 2.4: Ignition of liquids or gases due to reaction with extinguishing water

This chain of events (branch) occurs when the fire-fighting with the CO_2- extinguishing system is not applicable or unsuccessful. As per the EmS F-G, the neighbouring cargo is cooled with a large quantity of water. Dangerous goods in liquid form are involved in the fire. When these goods are transported in packages or tanks with pressure relieve devices, the fire can trigger the release of large quantities of gases and/ or leak the liquid dangerous goods. When those substances come in contact with the extinguishing water (cooling water for neighbouring goods) and/ or water vapour, it leads to a strong reaction and ignition. If an ignition happens inside the container, it can lead to an explosion due to the rising pressure and therefore to the destruction of the container. An ignition outside of the container can also lead to an explosion if the volume of the cargo hold is limited. In addition, an ignition of the liquids and gases outside of the container can lead to spread of the fire.

<u>Possible consequences</u>

The following possible consequences apply:

– Loss of several containers;
– Significant structural damage to the ship due to potential explosion below deck;
– Risks to persons involved in fire-fighting due to potential explosion below deck;
– Escalation of the fire with risks to vessel and ship's crew.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

(1) Limiting the amount of dangerous goods per container reduces the severity of the consequences;

(2) Stowing the container with dangerous goods with a large distance to other flammable goods can prevent the spread of the fire;

(3) Detection devices (smoke detectors, ...) and other monitoring devices (thermometer, hygrometer, ...) in the container can detect a fire or the risk of a fire in the container with dangerous goods early on. These functions can also be monitored by mobile devices that are installed on demand in any container;

c) Instructions in the EmS F-G:

(1) The EmS F-G should include detailed instructions on how to handle the fire involving dangerous goods in liquid form;

d) Training of the ship's crew: no measures identified.

Branch G 2.5: Formation of corrosive or toxic gases due to a reaction with extinguishing water

This chain of event (branch) occurs when the fire cannot be fought with the CO_2-extinguishing system or it failed. As per the EmS F-G, the neighbouring cargo is cooled with large quantities of water. Here it can come to a reaction between the dangerous goods and the extinguishing water which result in the formation of corrosive and dangerous gases.

Possible consequences

The following possible consequences apply:

- Significant structural damage to the container;
- Significant structural damage to the vessel;
- Risk to personnel involved in fire-fighting due to the release of toxic gases.

Risk reducing measures

a) Equipment on ship:

(1) Respirator masks for fire-fighting can reduce the risk of poisoning. (regulation exists);

b) Regulations for stowage and packaging:

   (1) Stowage below deck to be avoided;

   (2) Use of container, which are designed to eliminate the contact between dangerous goods and extinguishing water (only limited effective because the shell of the container could be damaged in the fire);

   (3) Detection devices (smoke detectors, ...) and other monitoring devices (thermometer, hygrometer, ...) in the container can detect a fire or the risk of a fire in the container with dangerous goods early on. These functions can also be taken over by mobile devices that are installed on demand in any container;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 2.6: Formation of oxidizing substances due to the reaction with extinguishing water

This chain of event (branch) occurs when the fire cannot be fought with the CO_2-extinguishing system or it failed. As per the EmS F-G, the neighbouring cargo is cooled with large quantities of water. As a result to the reaction between the dangerous goods and the extinguishing water, oxidizing substances are formed which advance the intensification and the spread of the fire. With such, combinations of substances can develop which make it impossible to fight the fire (e.g. chlorine and oxidizing agent).

Possible consequences

The following possible consequences apply:

- Loss of several container;
- Significant structural damage to the vessel;
- Risk to persons involved in the fire fighting due to possible spread of the fire and explosion.

Additional possible consequences:

- Loss up to the entire cargo of the vessel;
- Total loss of the vessel due to escalation of the fire and/or explosion;
- Risk to the entire ship's crew due to escalation of the fire.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

(1) Limiting the quantity of dangerous goods per container reduces the severity of the consequences;

(2) Segregation of containers on board ships: To avoid combinations of oxidising substances, which make effective fire fighting impossible, containers containing such substances must be stowed separate;

(3) Segregation of goods in containers: To avoid combinations of oxidising substances, which make effective fire fighting impossible, dangerous goods should not be packed in one container with other flammable cargo.

(4) Detection devices (smoke detectors, ...) and other monitoring devices (thermometer, hygrometer, ...) in the container can detect a fire or the risk of a fire in the container with dangerous goods early on. These functions can also be taken over by mobile devices that are installed on demand in any container;

(5) The use of special equipped containers for transporting dangerous goods accordingly;

c) Instructions in the EmS F-G:

(1) The EmS F-G should contain information to the fact that some fires cannot be handled with the equipment on board. In such cases, the risk to persons are minimized by considering to forgo the fire-fighting measures and prepare the abandonment;

d) Training of the ship's crew:

(1) With the right training the ship's crew and/or the officer can better assess when fire-fighting becomes too dangerous and when to initiate the preparations to abandon ship.

Branch G 2.7: Fire escalates without direct impact from dangerous goods.

This chain of events (branch) occurs when the fire cannot be fought with the CO_2-extinguishing system or it fails. As per the EmS F-G, the neighbouring cargo is cooled with large quantities of water. If sufficient cooling cannot be achieved (e.g. too little water, poor accessibility at the scene of the fire etc.), the fire can spread and perhaps escalate without any impact of dangerous goods of the EmS F-G. The described chain of events of the branch G2.7 is independent of the dangerous goods of the Ems F-G and is therefore not considered further in detail.

Branch G 2.8: Fire extinguished without direct impact from dangerous goods.

This chain of events (branch) occurs when the fire cannot be fought with the CO_2-extinguishing system or it fails. As per the EmS F-G, the neighbouring cargo is cooled with large quantities of water. Subsequently, the fire extinguishes. In the branch G 2.8, the goods of the Ems F-G have no impact of the chain of events.

A successfully extinguished fire without the impact of dangerous goods of the EmS F-G has only minor consequences. It is understood, that this branch of the event tree has no specific impact from dangerous goods; therefore no risk reducing measures are identified.

6.2.3 Scenario 3: Fire in the vicinity of dangerous goods on deck

If a container with dangerous goods is in the vicinity of a fire on deck, the EmS F-G recommends trying to remove the dangerous goods from the fire area. If this is not possible, it is recommended to cool the container with the dangerous goods with large quantities of water.

The event tree, based on the fire in the vicinity of a container with dangerous goods on deck, is represented in Figure 6.5. The possible chain of events is described in more detail on the basis of the branches G 3.1 through G 3.7.

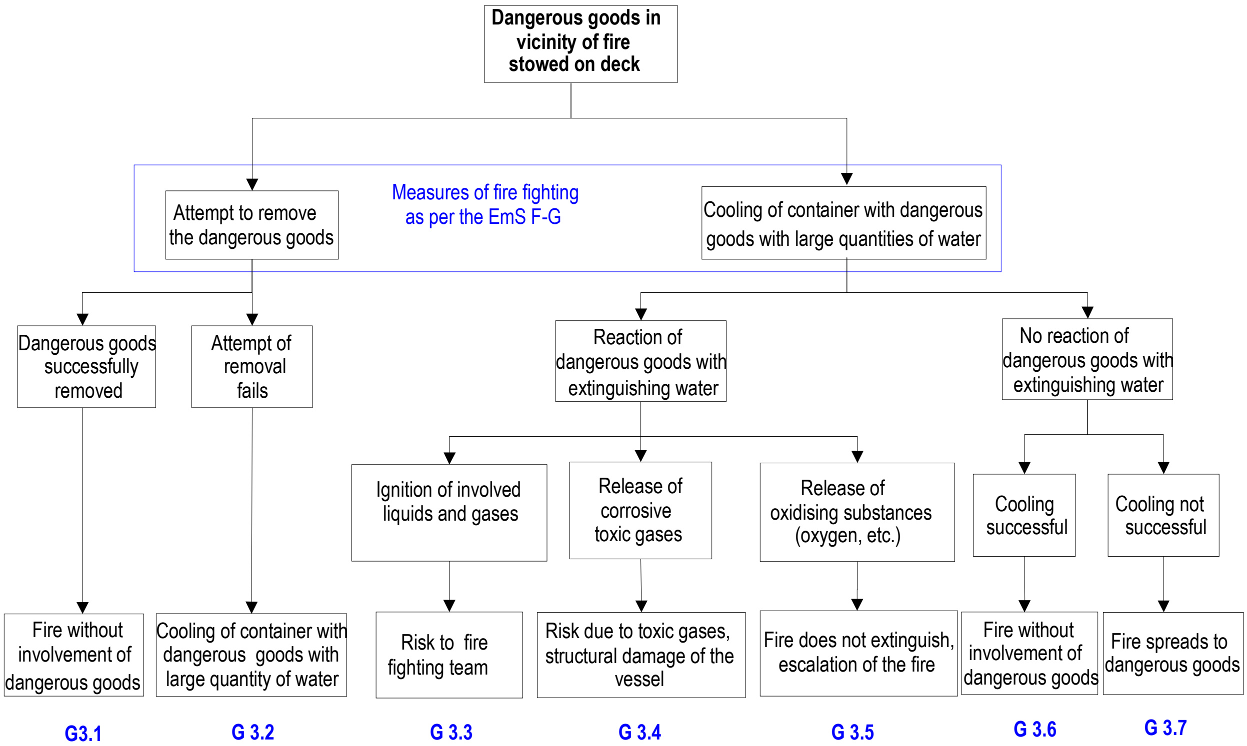


Figure 6.5: Scenario 3: Fire on deck in the vicinity of dangerous goods

Branch G 3.1: The dangerous goods were successfully removed

This chain of events (Branch) occurs when the affected dangerous goods are removed from the area of the impact of the fire. The further development of the fire takes place without the involvement of the dangerous goods.

The removal of a container with the dangerous goods from the vicinity of a fire on deck is only possible with the following prerequisites:

- The vessel is equipped with cargo cranes;
- The container with dangerous goods is stowed in a location that is directly accessible by the cargo cranes;
- Calm seas;
- Sufficient distance from the fire;
- Sufficient crew members for the reloading.

In practice these conditions are extremely rare; the removal of the dangerous goods would be possible only if the container is accessible and when the door can be opened and the packages can be handled.

Branch G 3.2: Attempt of removal fails

This chain of events (branch) occurs when the attempt to remove the affected dangerous goods from the impact zone of the fire fails. For example, this will be the case if accessibility is restricted or the fire has already progressed. As per the EmS F-G, the container with the dangerous goods will be cooled with large quantities of water.

Possible consequences

The following possible consequences apply:

- Risk for persons during the attempt to remove dangerous goods from the impact zone of the fire;
- Fire spreads to the dangerous goods and risk of a possible reaction of dangerous goods with the extinguishing water (the risks and the respective risk reducing measures are analysed in detail in the following branches).

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging: no measures identified;

c) Instructions in the EmS F-G: no measures identified

d) Training of the ship's crew: no measures identified.

Branch G 3.3: Ignition of liquids and gases due to a reaction with the extinguishing water

This chain of events (branch) occurs when the removal of the dangerous goods from the impact zone of the fire is not possible. As per the EmS F-G, the container with the dangerous goods is cooled with large quantities of water. When the dangerous goods in liquid form are transported in packages or tanks with pressure relieve devices, the temperature rise in the vicinity of the fire which can lead to the release of a large quantity of gases and/or a leak of the liquid dangerous goods. During the attempt to cool the container, the released gases and/or the liquids can ignite due to a reaction with the extinguishing water.

An ignition inside the container leads to a fire in the container with dangerous goods. There is a risk of explosion and destruction of the container if there is a large quantity of liquids and/or gases in the container during ignition.

If the gases ignite outside of the container it can lead to the spread of the fire.

Possible consequences

The following possible consequences apply:

– Loss of several containers;

– Spread of the fire to dangerous goods;

– Structural damage to the vessel due to a possible spread of the fire or explosions;

– Risks for several persons involved in fire-fighting due to a possible explosion.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

   (1) Use of containers which are designed to avoid contact between dangerous goods and extinguishing water which prevents an ignition inside the container with dangerous goods;

   (2) Good ventilation of the container prevents dangerous concentration of flammable gases in the container;

   (3) A limit of the quantity of dangerous goods per container reduces the severity of the consequences;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 3.4: Formation corrosive toxic gases due to the reaction with extinguishing water

This chain of events (branch) occurs when the removal of the dangerous goods from the impact zone of the fire is not possible. As per the EmS F-G, the container with the dangerous goods is cooled with large quantities of water. This leads to the entry of water into the container with dangerous goods. If the packaging of the dangerous goods doesn't provide sufficient protection, it comes to a reaction of the dangerous goods with the extinguishing water. Corrosive and toxic gases are formed as a result of that reaction.

Possible consequences

The following possible consequences apply:

- Structural damage of the container;
- Structural damage of the vessel;
- Risk to persons involved in fire-fighting due to released toxic gases.

Risk reducing measures

a) Equipment on ship:

   (1) Respirator masks for fire-fighting can reduce the risk of poisoning (regulation exists);

b) Regulations for stowage and packaging:

   (1) Water resistant packaging prevents direct contact of the dangerous goods with the extinguishing water;

   (2) A limit of the quantity of dangerous goods per container reduces the severity of the consequences;

   (3) Use of container which are designed to avoid contact between dangerous goods and extinguishing water;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 3.5: Formation of oxidizing substances due to a reaction with extinguishing water

This chain of events (branch) occurs when the removal of the dangerous goods from the impact zone of the fire is not possible. As per the EmS F-G, the container with the dangerous goods is cooled with large quantities of water. This leads to the entry of water into the container with dangerous goods. If the packaging of the dangerous goods doesn't provide sufficient protection, it comes to a reaction of the dangerous goods with the extinguishing water. Oxidizing substances are released as a result of the reaction which advances the intensification and the spread of the fire. Combinations of substances can form that make an effective fire fighting impossible (e.g. Chlorine and oxidizing agents).

Possible consequences

The following possible consequences apply:

- Spread of the fire to dangerous goods;
- Loss of several containers.

Additional possible consequences:

- Loss up to the entire cargo of the ship;
- Total loss of the ship due to escalation of the fire;
- Risks for entire ship's crew due to escalation of the fire.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

(1) Water resistant packaging prevents direct contact of the dangerous goods with the extinguishing water;

(2) A limit of the quantity of dangerous goods per container reduces the severity of the consequences;

(3) Segregation of containers on board ships: To prevent combinations of oxidising substances, which make an effective fire fighting impossible, containers with oxidising substances must be stowed separately;

(4) Placement of the container in a way that in case of a fire, the container with dangerous goods can burn out and/or the extinguishing water can drain where necessary;

(5) Use of containers which are designed to avoid contact between dangerous goods and extinguishing water;

(6) Use of special equipped containers for transport of certain dangerous goods;

c) Instructions in the EmS F-G:

(1) The EmS F-G should contain information to the fact that some fires cannot be handled with the equipment on board. In such cases, risks to persons are minimized by considering to forgo the fire-fighting measures and to prepare abandoning;

d) Training of the ship's crew:

(1) With the right training, the ship's crew and/or the officer can better assess when fire-fighting becomes too dangerous and therefore not appropriate, and when to initiate the preparations to abandon ship.

Branch G 3.6: Cooling of the dangerous goods was successful – no reaction of the dangerous goods with the extinguishing water

This chain of events (branch) occurs when the removal of the dangerous goods from the impact zone of the fire is not possible. As per the EmS F-G, the container with the dangerous goods is cooled with large quantities of water. The cooling prevents successfully the spread of the fire to the container with dangerous goods. The branch G 3.6 represents that the goods of the Ems F-G have no impact on the chain of events. It is assumed, that this branch of the event tree is not impacted by the dangerous goods, and therefore no risk reducing measures are specified.

Branch G 3.7: Cooling of the dangerous goods was not successful – no reaction of the dangerous goods with the extinguishing water

This chain of events (branch) occurs when the removal of the dangerous goods from the impact zone of the fire is not possible. As per the EmS F-G, the container with the dangerous goods is cooled with large quantities of water. If sufficient cooling cannot be achieved (e.g. too little water, poor accessibility to the scene of the fire etc.) the fire can spread to the dangerous goods, even without a reaction of the dangerous goods with the extinguishing waters. The fire spreads to the dangerous goods.

Possible consequences

The following direct consequences apply:

– Fire of dangerous goods on deck. (The detailed analysis for this case was carried out in paragraph 6.2.1.)

Risk reducing measures

a) Equipment on board:
   (1) Sufficient equipment for fire-fighting in the vicinity of the fire is necessary for cooling the container with dangerous goods;
   (2) The use of mobile fire-fighting monitors can prevent the spread of the fire. An escalation of the fire can be prevented in many cases.
b) Regulations for stowage and packaging:
   (1) Container with dangerous goods has to be stowed in a way that sufficient accessibility is guaranteed;
c) Instructions in the EmS F-G: no measures identified;
d) Training of the ship’s crew: no measures identified.

6.2.4 Scenario 4: Fire in the vicinity of dangerous goods below deck

When there are dangerous goods in the vicinity of a fire, the EmS F-G recommends removing the dangerous goods from the scene of the fire. If this is not possible, it recommends cooling the dangerous goods with large quantities of water.

The event tree, based on the fire in the vicinity of a container carrying dangerous goods below deck, is depicted in Figure 6.6.

All possible chain of events is described in more detail on basis of the branches G 4.1 through G 4.9.

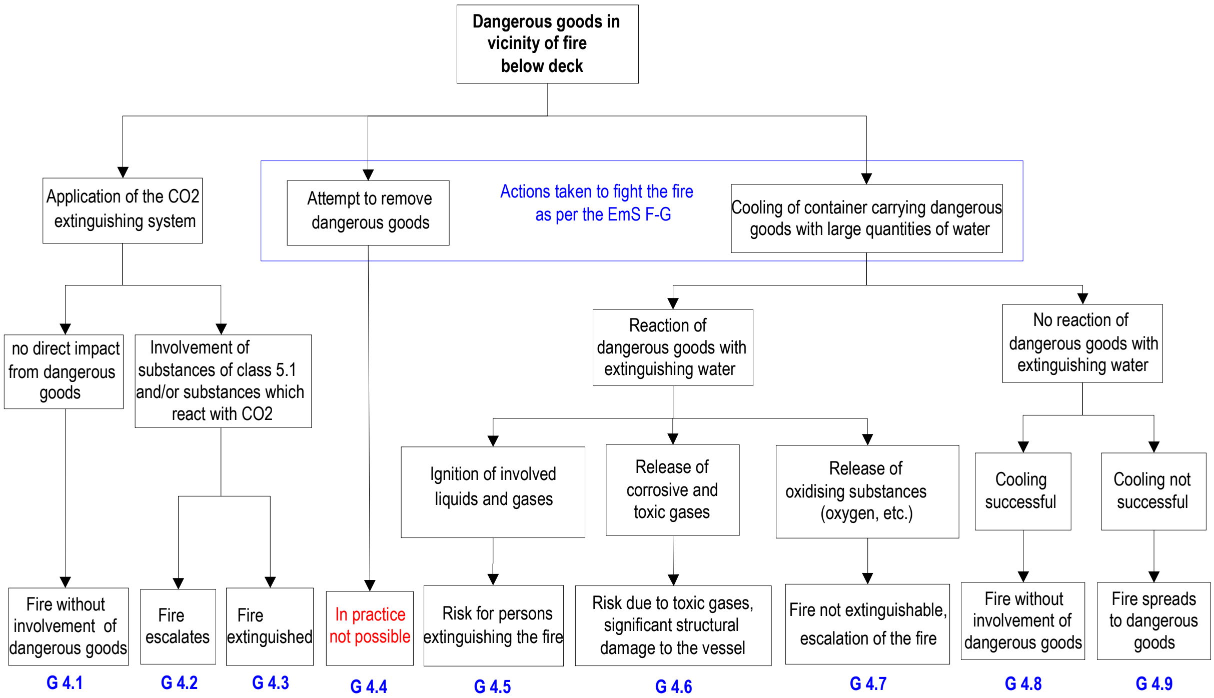


Figure 6.6: Scenario 4 – Dangerous goods are stowed in the vicinity of a fire below deck

Branch G 4.1: CO_2-fire fighting without the impact of dangerous goods

This chain of events (branch) occurs when initially an attempt is made to extinguish the fire with the CO_2-extinguishing system. This step is taken to control the fire below deck and is not part of the EmS F-G. There are no dangerous goods of class 5.1 or substances which react dangerously with CO_2 stowed in the vicinity of the fire. The dangerous goods of the EmS F-G are not adding any additional risk. The described chain of events of branch G 4.1 is independent from dangerous goods of the EmS F-G and is not studied further in detail.

Branch G 4.2: Attempt to extinguish the fire with CO_2 fails due to impact of dangerous goods

This chain of events (branch) occurs when initially an attempt is made to extinguish the fire with the CO_2-extinguishing system. Dangerous goods of class 5.1 or substances which react dangerously with CO_2 are involved in the fire. Due to the heat from the fire, the dangerous goods of class 5.1 decompose and release oxygen. The oxygen can leak into the cargo room if packaging is not air-tight or damaged. With the release of a large quantity of oxygen, the attempt to extinguish the fire with the CO_2 –system is ineffective. The fire can spread and possibly escalate.

Possible consequences

The possible consequences apply:

– Loss of a few up to a large number of containers;

– Escalation of the fire with risks for vessel and crew.

Risk reducing measures

a) Equipment of the ship:

   (1) Improving the capacity of the CO_2-extinguishing system can increase the chance of success to extinguish the fire;

b) Regulations for stowage and packaging:

   (1) A limitation on the quantity of dangerous goods of class 5.1 per container reduces the risk of the fire escalating;

   (2) No stowage of class 5.1 goods below deck;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 4.3: Attempt to extinguish with CO_2 was successful despite impact from dangerous goods

This chain of events (branch) occurs when initially an attempt is made to extinguish the fire with the CO_2-extinguishing system. Dangerous goods of class 5.1 or substances which react dangerously with CO_2 are involved in the fire due to the heat from the fire the dangerous goods of class 5.1 decompose and release oxygen. The fire is successfully extinguished with CO_2 if the packaging doesn't leak the produced oxygen and/ or the amount of the released oxygen is not enough to advance the fire long-term and/or to aid the spread of the fire. Thereafter the fire extinguishes.

Possible consequences

The following possible consequences apply:

– Loss of a few up to a large number of containers.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

(1) Limitation of the amount of dangerous goods per container reduces the severity of the consequences;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 4.4: Attempt to remove the dangerous goods from the impact zone of the fire

This chain of events (branch) occurs when extinguishing the fire with the CO_2-extinguishing system is not applicable or not successful. The EmS F-G recommends removing the container with the dangerous goods from the impact zone of the fire. It is noted, that the removal of a container with dangerous goods below deck is virtually impossible. As a result, the instructions in the EmS F-G have to be revised for the case of fire in the vicinity of a container with dangerous goods. It is assumed that in practice this chain of events does not occur as such and therefore no consequences or risk reducing measures will be identified here.

Branch G 4.5: Ignition of liquid and gases due to a reaction with the extinguishing water

This chain of events (branch) occurs when extinguishing the fire with the CO_2-extinguishing system is not applicable or not successful. As per the EmS F-G the container with dangerous goods is cooled with a large quantity of water. Dangerous goods in liquid form are stowed in the container. When these goods are transported in tanks with pressure relief devices the rise of temperature in the vicinity of the fire can lead to the release of large quantities of gases and/ or leak the liquid dangerous goods. During the attempt to cool the container, the released gases and/ or liquids ignite as a result of a reaction with the extinguishing water.

If the ignition takes place inside the container, it can lead to a fire inside container with dangerous goods. Due to the resulting excess pressure it can lead to an explosion and finally the destruction of the container. An ignition outside the container can also lead to an explosion if the volume of cargo room is limited. Aside from that, an ignition of liquids and gases outside the container can lead to the spread of the fire.

Possible consequences

The following possible consequences apply:

- Loss of many containers;
- Spread of the fire to dangerous goods;
- Structural damage of the ship due to possible explosion;
- Risks for persons involved in extinguishing the fire due to possible explosions below deck;
- Escalation of the fire with risks for vessel and crew.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

   (1) Limitation of the amount of dangerous goods per container reduces the severity of the consequences;

   (2) Use of containers designed to prevent the contact between dangerous goods and extinguishing water. This in turn would prevent an ignition inside the container;

   (3) Good ventilation of the container prevents a dangerous concentration of flammable gases in the container;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 4.6: Formation of corrosive toxic gases due to a reaction with extinguishing water

This chain of events (branch) occurs when extinguishing the fire with the CO_2-extinguishing system is not applicable or not successful. As per the EmS F-G the container with dangerous goods is cooled with a large quantity of water. Water penetrates into the container with dangerous goods. If the packaging of the dangerous goods does not provide sufficient protection then it will lead to a reaction of the dangerous goods with the extinguishing water. Corrosive and/ or toxic gases form as a result of the reaction.

Possible consequences

The following possible consequences apply:

- Structural damage of the container;
- Significant structural damage of the vessel;
- Risks to persons involved in the fire-fighting due to the release of toxic gases.

<u>Risk reducing measures</u>

a) Equipment on ship:

(1) Protective respirators during fire-fighting can reduce the risk of poisoning (regulation exists);

b) Regulations for stowage and packaging:

(1) Avoid stowage below deck;

(2) Water resistant packaging prevents direct contact of the dangerous goods with the extinguishing water;

(3) Limitation of the quantity of dangerous goods per container reduces the severity of the consequences;

(4) Use of containers designed to prevent the contact between dangerous goods and extinguishing water;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

Branch G 4.7: Formation of oxidising substances due to a reaction with extinguishing water

This chain of events (branch) occurs when extinguishing the fire with the CO_2-extinguishing system is not applicable or not successful. As per the EmS F-G the container with dangerous goods is cooled with a large quantity of water. Water penetrates into the container with dangerous goods. If the packaging of the dangerous goods does not provide sufficient protection then it will lead to a reaction of the dangerous goods with the extinguishing water. As a result of the reaction, oxidising substances can be released this could advance the intensification and/or spread of the fire. This in turn can form combinations of substances which will make it impossible to successfully extinguish the fire (i.e. Chloride and oxidising agent).

<u>Possible consequences</u>

The following possible consequences apply:

– Intensification of the fire;

– Spread of the fire to dangerous goods.

Additional possible consequences:

– Losses up to the entire cargo of the ship;

– Total loss of the vessel due to escalation of the fire and/or explosion;

– Risks to the entire crew due to escalation of the fire.

Risk reducing measures

a) Equipment on ship: no measures identified;

b) Regulations for stowage and packaging:

   (1) Use of containers which are designed to prevent contact between the dangerous goods and extinguishing water;

   (2) Water resistant packaging prevents direct contact of the dangerous goods with extinguishing water;

   (3) A limitation of the quantity of dangerous goods per container reduces the severity of the consequences;

   (4) Segregation of containers on board ships: Containers holding flammable substances have to be stowed separately to avoid combinations of flammable substances which make successful fire-fighting impossible;

c) Instruction in the EmS F-G:

   (1) The EmS F-G should contain information to the fact that some fires cannot be handled with the equipment on board. In such cases risks to persons are minimized by considering to disclaim the fire-fighting measures and prepare abandoning;

d) Training of the ship's crew: no measures identified.

Branch G 4.8: Cooling of the dangerous goods was successful – no reaction of the dangerous goods with the extinguishing water

This chain of events (branch) occurs when fire-fighting with CO_2 is not applicable or unsuccessful. As per the EmS F-G, the container with the dangerous goods is cooled with a large quantity of water. The cooling successfully prevents the spread of the fire to the dangerous goods. The branch G 4.8 shows no reaction of the dangerous goods with the extinguishing water. In this branch of the event tree it is assumed that there is no specific impact from the dangerous goods. Therefore, no risk reducing measures are identified.

Branch G 4.9: Cooling of the dangerous goods not successful – no reaction of the dangerous goods with the extinguishing water

This chain of events (branch) occurs when fire-fighting with CO_2 is not applicable or unsuccessful. As per the EmS F-G, the container with the dangerous goods is cooled with a large quantity of water. If sufficient cooling cannot be achieved (e.g. too little water, poor accessibility to the fire etc.), the fire can spread to the dangerous goods which leads to a fire with involvement of dangerous goods.

Possible consequences

The following possible consequences apply:

– Dangerous goods are on fire below deck (a detailed analysis was carried out in paragraph 6.2.2).

Risk reducing measures

a) Equipment on ship:

   (1) Sufficient fire-fighting equipment in the vicinity of the fire is necessary for cooling the container with dangerous goods;

b) Regulations for stowage and packaging:

   (1) Container with dangerous goods should be stowed in a way that sufficient accessibility is guaranteed;

c) Instructions in the EmS F-G: no measures identified;

d) Training of the ship's crew: no measures identified.

7 Evaluation of risk reducing measures according to effectiveness and costs

In the following, the in previous chapter identified risk reducing measures will be evaluated for effectiveness and costs to implement these measures.

Effectiveness of a measure is defined as to what extent this contributes to reduce the frequency of occurrence or the consequence of the observed risk scenarios. Within the analysis the effectiveness of a risk reducing measure is first analysed for each scenario separately and later summarised into an overall effectiveness of the measure.

The costs to implement an action arises, depending on the type of measure, from the consideration of the necessary cost, planning and management, care and maintenance, training, etc., if they occur.

Costs consists of considered both material costs as well as staff costs. In addition, the time required to implement the measure is also considered.

In the first subsection, the evaluated risk-reducing measures are compiled. In the second subsection, the rating system will be explained. The detailed evaluation of each measure will take place in the third subsection.

7.1 Set of to-be-evaluated risk-reducing measures

The risk-reducing measures to-be-evaluated are summarised in Table 7.1.

Table 7.1: Set of risk-reducing measures

No.	Action/ measure	Category
1	Sufficient fire-fighting equipment in the vicinity of the fire	Equipment
2	Improved capacity of the CO_2-extinguishing system	Equipment
3	Improved packaging and loading of the container	Regulations for packaging and container packaging
4	Improved stowage of the container with dangerous goods on ship	Regulations for stowage
5	Special equipment for container with dangerous goods	Regulations for stowage
6	Amendments and/or improvements of the EmS F-G	Guidelines for fire-fighting
7	Training of the crew in regards to the handling of fires by involvement of dangerous goods	Training of the crew

Each of these measures can have more than one sub-measure. The sub-measures and their mode of action are described in the following:

Sufficient fire-fighting equipment in the vicinity of the fire

To perform the fire-fighting on a burning container and/ or the cooling of adjacent containers with water effectively, adequate water supply to all essential areas is absolutely necessary. This relates mainly to the systematic fitting out of the ship with fire hydrant and hose material as well as the performance of fire pumps. A mandatory requirement is that the accessibility of the burning container and/ or of the containers to be cooled must be ensured, which primarily has an impact on the general positioning of the containers. With reference to the FSA Container Fire on deck /13/, /14/, /20/, This measure contains the use of mobile water monitors as well as the upgrading of pumps and hydrant capacities. Detailed contents are in the above named documents and are listed in the recommendations in the final section of this document.

Improved capacity of the CO_2-extinguising system

CO_2 extinguishing systems are used for fighting fires in cargo holds below deck. In case of a fire, first the ventilation systems are turned off and the air vents of the cargo space are closed to prevent the air supply. Afterwards the hold is flooded with CO_2. With the addition of CO_2 the oxygen ratio within the space will be reduced so far that the fire will not have enough oxygen and finally extinguishes. Through the use of the CO_2 the cargo hold is additionally cooled. This is due to the fact that CO_2 is stored in liquid form, and with the transition to the gas (expansion) occurs the cooling effect in the cargo hold. However, this effect is only secondary for the fire-fighting.

Some of the considered dangerous goods are substances of class 5.1, which decompose when exposed to heat, thereby releasing oxygen. In a fire involving these materials, additional oxygen is produced which has a negative impact on the attempt to extinguish the fire by CO_2.

To counter this negative impact of dangerous goods, the capacity of the CO_2 extinguishing system should be improved accordingly. First, the amount of the deployed CO_2 can be increased. This may mean that more CO_2 must be stored on board. The other possibility is, to increase the feed rate of CO_2 extinguishing system. This means that more CO_2 can be let in into the hold in the same amount of time, and therefore the hold is flooded with CO_2 much faster and reduces the oxygen content more quickly. In this way, the fire can be fought effectively.

Improved packaging and loading of the container

This measure contains the following sub-measures:

- For certain dangerous goods, a limitation should be introduced on the amount to be transported per packaging unit and/or per container;
- Stowage only by dry weather for all dangerous goods for which the EmS F-G applies;
- As far as not required yet: the use of moisture resistant packaging;
- Reducing condensation water with the application of moisture absorbents for example silica gel;
- Dangerous goods should be stowed separately from other flammable goods inside the container. In particular substances, when in combination make the fire-fighting in case of a fire impossible, should be identified and stowed separately. Goods of class 5.1 for which the EmS F-G applies should not be transported in consolidated containers for sea transport.

Improved positioning of the stowed container with dangerous goods on the ship

This measure contains the following sub-measures:

- Certain dangerous goods should not be stowed below deck. Instead those substances should be stowed on deck, but from sea water protected. This applies to:
  - Substances of class 5.1 which release oxygen when in contact with water and/or exposed to heat;
  - Substances which release dangerous and corrosive gases when in contact with water and/or exposed to heat;
- Positioning of the container with dangerous goods so that sufficient accessibility for fire-fighting are guaranteed;
- Positioning of the container with dangerous goods so that letting the container with dangerous goods burn out would be possible in case of fire (not near the bridge).

Special equipment for container with dangerous goods

Containers intended for transporting dangerous goods should have additional features which fulfil the increased safety requirements for transporting dangerous goods. The additional requirements are in particular:

– Good ventilation of the container to keep the concentration of inflammable gases released from transported dangerous goods low. There is a risk of explosion exceeding a certain level of concentration of inflammable gases. A good ventilation of the container can also reduce condensation water;

– Fire detection devices (smoke detector, …) and other surveillance devices (temperature gauge, hygrometer, …) inside the container to recognise that there is a fire and/or the risk of a fire inside a container with dangerous goods at a very early stage. These functions can also be taken over by mobile devices which could be installed in a normal container if needed;

– Use of containers designed to prevent contact between dangerous goods and extinguishing water.

Optionally special containers designed for transporting certain substances should be used.

Amendments and/ or improvements of the EmS und EmS F-G

The instructions of the EmS F-G should be revised in regard to the following points:

– The EmS F-G should contain references to the fact that there are fires that are not extinguishable with the equipment on board. In such cases, the risk to persons has to be minimised by consideration of forgo fire-fighting measures and to prepare to abandon ship;

– The EmS F-G should contain detailed information for fighting fires involving dangerous goods in liquid form;

Training of the crew in regards to fire-fighting of fires involving dangerous goods

As risk reducing measure, the part of the training to handle fires involving dangerous goods should include the following:

– Assessment for the spread of a fire involving dangerous goods. This makes it possible to judge whether it is possible to let the fire on deck burn out or whether fire-fighting measures should be initiated;

– Assessment when fire-fighting with involvement of dangerous goods is to dangerous or when preparation to abandon ship should be initiated.

This content can on one hand be integrated into the general part of the EmS or in the IMO Model Courses.

7.2 Rating system

Based on the expert-assessed frequency of occurrence and consequences for each risk scenario, the effectiveness of risk reducing measures for this risk scenario will be evaluated. The evaluation criteria for qualitative assessment of the effectiveness of risk reducing measures on fires involving dangerous goods, for which the fire emergency card Golf applies, are explained in Table 7.2.

Table 7.2: Categories of the effectiveness of risk reducing measures

Effectiveness	Qualitative description
0	Not effective, none to negligible effectiveness
1	Effective, reduces the frequency (denoted with „F“, see Table 5.3) and/ or the severity of the consequence (denoted with „S“, see Table 5.4) by less than one category.
2	Very effective, reduces the frequency (denoted with „F“, see Table 5.3) and/ or the severity of the consequence (denoted with „S“, see Table 5.4) by one or more than one category.
3	Event can be virtually eliminated by the risk reducing measures.

Afterwards the overall effectiveness for the measure will be determined. This assessment is based partly on the effectiveness of each scenario. Second, the number and frequency of occurrence has to be considered of the scenarios in which the measure took effect. In particular, the consequences of all scenarios will be considered. The overall effectiveness is a measure of the expected reduction of the overall risk.

Table 7.3: Categories of the overall effectiveness of risk reducing measures

Overall effectiveness	Qualitative description
-	Negative effectiveness, the additional risks that arise from the action overbalance the risk reducing effect. It is expected that the measure increases the risk.
0	Not effective, the effectiveness of the action is negligible small
(+)	Less effective
+	Effective
++	Very effective

The costs to implement the risk-reducing measures is assessed by the following categories:

Table 7.4: Categories of Costs to implement the risk reducing measures

Costs	Qualitative description
0	None to negligible costs
1	Little costs (moderate material costs, barely staff costs, quickly implemented)
2	Medium costs (high cost of materials or extensive maintenance or high personnel costs or implementation takes very long)
3	High costs (significant high material costs or significant extensive maintenance or significant high personnel costs or implementation takes excessively long)

7.3 Detailed evaluation

In the following, the effectiveness of risk reduction measures on the various risk scenarios will be evaluated. Only the scenarios in which the measure is relevant are considered.

7.3.1 Sufficient fire-fighting equipment in the vicinity of the fire

7.3.1.1 Effectiveness

The evaluation of the effectiveness of adequate fire-fighting equipment in the vicinity of the fire is summarised in Table 7.5. The effectiveness indices are listed in Table 7.2. Adequate fire fighting equipment has no influence on the start of the fire. Therefore, only the inductive risk scenarios are considered.

Table 7.5: Evaluation of the effectiveness of adequate fire-fighting equipment in the vicinity of the fire

Effectiveness of adequate fire fighting equipment in the vicinity of the fire		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 1: Container with dangerous goods is on fire on deck		
• G 1.2 (fire escalates – no reaction of the dangerous goods with the extinguishing water)	2 (F)	The application of mobile fire-fighting monitors can prevent the spread of the fire. An escalation of the fire can be prevented in many cases.
Inductive risk scenario 3: Fire in the vicinity of dangerous goods on deck		
• G 3.7 (Cooling of dangerous goods was not successful – no reaction of the dangerous goods with the extinguishing water)	2 (S)	An effective cooling of the container, for example with the mobile fire-fighting monitors, prevents the spread of the fire. Additionally sufficient space for executing the measure must be provided.
Inductive risk scenario 4: Fire in the vicinity of dangerous goods below deck		
• G 4.9 (Cooling of dangerous goods was not successful – no reaction of the dangerous goods with the extinguishing water)	1 (S)	An effective cooling of the container prevents the spread of the fire. Additionally sufficient space for executing the measure must be provided.
Overall effectiveness	**+**	Experience has shown that there is not enough space available between the containers, so that adequate accessibility of the burning or the adjacent containers cannot be ensured in all cases. Nevertheless, especially since most goods are on deck, a good accessibility of goods in total can constitute an effective measure to reduce risk.

7.3.1.2 Costs

To ensure adequate fire fighting equipment in the vicinity of the fire, alterations on the ship itself (adding hydrants and piping) and possibly an adaptation of mounting system of containers on the ship are necessary. The costs are therefore assessed as **medium**.

7.3.2 Improved capacity of the CO_2- extinguishing system

7.3.2.1 Effectiveness

The evaluation of the effectiveness of the improved capacity of the CO_2-extinguishing system is summarised in Table 7.6. The effectiveness indices are listed in Table 7.2. The CO_2-fire-fighting measure has no influence of the start of the fire. Therefore, only the inductive risk scenarios are considered.

Table 7.6: Evaluation of effectiveness of the improved capacity of the CO_2-extinguishing systems

Effectiveness of the improved capacity of the CO_2-extinguishing systems		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 2: Fire of a container with dangerous goods below deck		
• G 2.2 (Attempt to extinguish fire with CO_2 system fails due to impact from dangerous goods)	0	In this case the CO_2-extinguishing system has no impact on the fire inside the container with dangerous goods, because oxygen is produced by the dangerous goods. This measure can only prevent the fire from spreading. This measure achieves only a small reduction of the frequency of occurrence of this scenario.
Inductive risk scenario 4: Fire in the vicinity of a container with dangerous goods below deck		
• G 4.2 (Attempt to extinguish fire with CO_2 system fails due to impact from dangerous goods)	1 (F)	The CO_2-extinguishing system can handle the source of the fire. The success of the fire-fighting is dependent on the position of the dangerous goods in relation to the fire. If the dangerous goods which are producing the oxygen stowed underneath with little distance to the fire then it can supply the fire with oxygen. In this case the CO_2-extinguishing system is not effective.
Overall effectiveness	1(inductive) 0	This measure only has an effect if the dangerous goods itself are not on fire but it is overall not effective.

7.3.2.2 Costs

The costs to implement this measure is estimated to be **small** if only the amount of the CO_2 is increased. For a ship the CO_2 reserves are calculated for the cargo space with the largest volume in empty condition. Therefore, a certain provision is already available when the fire occurs in a potentially smaller and loaded cargo space. More costs are required if the CO_2 feed rate should be increased. The capacity of the CO_2 pipes must be extended accordingly, which means structural measures must be carried out. In this case, the costs are estimated as **medium**.

7.3.3 Improved packaging and stowage of dangerous goods inside the container

7.3.3.1 Effectiveness

The evaluation of the effectiveness of improved packaging and stowage of dangerous goods inside this container is represented in Table 7.7. The effectiveness indices are listed in Table 7.2.

Table 7.7: Evaluation of effectiveness of improved packaging and stowing inside the container

Effectiveness of improved packaging and stowing inside the container		
Risk scenarios	**Effectiveness**	**Comment**
Deductive risk scenarios		
• D 3.1 (Ignition due to condensation water)	1 (F)	Reducing condensation water with the use of moisture absorbents (e.g. Silica gel)
• D 3.2 (Ignition due to a reaction of the emitting gases with water)	1 (F)	Use of water-resistant packaging
• D 3.3 (Ignition due to a reaction of dangerous goods with water)	1 (F)	Use of water-resistant packaging
Inductive risk scenario 1: Fire of a container with dangerous goods stowed on deck		
• G 1.3 (Ignition of liquids and gases due to reaction with extinguishing water)	1(S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.
• G 1.4 (Release of corrosive toxic gases due to reaction with extinguishing water)	0	The packaging of the dangerous goods is heavily damaged during the fire and does not provide any protection anymore.
• G 1.5 (Formation of oxidising substances due to a reaction with extinguishing water)	2(S)	Segregation of substances, which make effective fire fighting impossible.
• G 1.7 (False assessment by the crew about the development of the fire)	1(S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.

Effectiveness of improved packaging and stowing inside the container		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 2: Fire of a container with dangerous goods stowed on deck		
• G 2.2 (The attempt to extinguish the fire with CO_2 fails due to the impact of dangerous goods)	1(F)	A limitation of the amount of dangerous goods (in this case class 5.1) per container improves the chance of success of the attempt to extinguish the fire with CO_2.
• G 2.4 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.
• G 2.5 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	0	The packaging of the dangerous goods is heavily damaged during the fire and does not provide any protection anymore.
• G 2.5 (Formation of oxidising substances due to a reaction with extinguishing water)	2(S)	Segregation of substances, which make effective fire fighting impossible.
Inductive risk scenario 3: Fire in the vicinity of a container with dangerous goods stowed on deck		
• G 3.3 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.
• G 3.4 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(F)	Water resistant packaging prevents the contact between dangerous goods and extinguishing water. This only works if the packaging is not damaged by heat.
• G 3.5 (Formation of oxidising substances due to a reaction with extinguishing water)	2(F)	Segregation of substances, which make effective fire fighting impossible. Water resistant packaging prevents the contact between dangerous goods and extinguishing water. This only works if the packaging is not damaged by heat.

Effectiveness of improved packaging and stowing inside the container		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 4: Fire in the vicinity of a container with dangerous goods stowed below deck		
• G 4.2 (The attempt to extinguish the fire with CO_2 fails due to impact of dangerous goods)	1 (F)	The CO_2-extinguishing system can handle the source of the fire. The success of the fire-fighting is dependent on the amount of the involved dangerous goods (class 5.1) which produce oxygen. A limitation on the amount of the dangerous goods (class 5.1) per container reduces the amount of the releases oxygen and improves the chance of success in the attempt to extinguish the fire.
• G 4.3 (The attempt to extinguish the fire with CO_2 is successful despite impact of dangerous goods)	1 (S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.
• G 4.5 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.
• G 4.6 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(F)	Water resistant packaging prevents the contact between dangerous goods and extinguishing water. This only works if the packaging is not damaged by heat.
• G 4.7 (Formation of oxidising substances due to a reaction with extinguishing water)	2(F)	Segregation of substances, which make effective fire fighting impossible; water resistant packaging prevents the contact between dangerous goods and extinguishing water. This only works if the packaging is not damaged by heat.
• G 4.9 (Cooling of dangerous goods was not successful)	1(S)	A limitation of the amount of dangerous goods per container reduces the severity of the consequence.
Overall effectiveness	**+**	This measure reduces the frequency of occurrence and/ or the severity of the consequence in almost all considered risk scenarios.

7.3.3.2 Costs

The implementation of improved packaging and stowage of dangerous goods within the container affect not only the transport but also the production of the dangerous goods. This is the case for the water-resistant packaging and/ or the limitation of the amount of substances per packaging unit and for goods of Class 5.1, not to have a mixed stowage of different goods within a container. The costs in relation to the affected goods can therefore be regarded as high. However, this measure affects only a small number of goods, which are transported in small amounts so that the costs in relation to the total transported goods can be estimated as **low**.

7.3.4 Improved stowage position of the container with dangerous goods on ship

7.3.4.1 Effectiveness

The evaluation of the effectiveness of improved stowage position of the container with dangerous goods is represented in Table 7.8. The effectiveness indices are listed in Table 7.2. This measure has no influence on the start of the fire. Therefore, the deductive risk scenarios will not be considered.

Table 7.8: Evaluation of effectiveness of improved stowage position of container with dangerous goods on the ship

Effectiveness of improved stowage position of container with dangerous goods on the ship		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 1: Container with dangerous goods on deck is on fire		
• G 1.3 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(F)	Positioning of the container, that in case of a fire it would be possible to let the container with dangerous goods burn out and/ or that the extinguishing water can drain where necessary. As a result, the frequency of a reaction with extinguishing water can be reduced.
• G 1.4 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(F)	same as G 1.3
• G 1.5 (Formation of oxidising substances due to a reaction with extinguishing water)	1(F)	same as G 1.3

Inductive risk scenario 2: Container with dangerous goods below deck is on fire		
• G 2.2 (The attempt to extinguish the fire with CO_2 fails due to impact of dangerous goods)	3	Certain substances (class 5.1) should not be stowed below deck. Those should be stowed on deck and protected from sea water.
• G 2.5 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	3	Should not be stowed below deck, see G 2.2
Inductive risk scenario 3: Fire on deck in the vicinity of a container with dangerous goods		
• G 3.7 (cooling of the dangerous goods not successful)	1(F)	Positioning of the container, that a good accessibility can be guaranteed. As a result, the container with dangerous goods can be cooled and a spread of the fire to the dangerous goods prevented.
Inductive risk scenario 4: Fire below deck in the vicinity of a container with dangerous goods		
• G 4.2 (The attempt to extinguish the fire with CO_2 fails due to impact of dangerous goods)	3	Certain substances (class 5.1) should not be stowed below deck. Those should be stowed on deck and protected from sea water.
• G 4.6 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	3	These substances should be stowed on deck and protected from sea water. With this measure, this branch (chain of events) does not occur anymore. New risks are revealed with the stowage of these substances on deck. The evaluation is drawn from the comparison of risks on and below deck.
• G 4.9 (cooling of the dangerous goods not successful)	1(F)	Positioning of the container, that a good accessibility can be guaranteed. As a result, the container with dangerous goods can be cooled and a spread of the fire to the dangerous goods prevented.
Overall effectiveness	**+**	With the stowage of certain substances (class 5.1) on deck, certain risk scenarios below deck do not occur anymore. Although new risks are revealed on deck which is considered in the overall effectiveness.

7.3.4.2 Costs

The implementation of an improved stowage of the container with dangerous goods on the ship affects mainly the loading of the ship.

- The material costs are low;
- The modifications have to be specifically elaborated, communicated and executed.

Overall, the costs are to be viewed as **low to medium**.

In addition, disadvantages arise:

- Lower flexibility for stowage of containers on board.

7.3.5 Special equipment for container with dangerous goods

7.3.5.1 Effectiveness

The evaluation of the effectiveness of special equipment for container with dangerous goods is represented in Table 7.9. The effectiveness indices are listed in Table 7.2.

Table 7.9: Evaluation of effectiveness of special equipment for container with dangerous goods

Evaluation of effectiveness of special equipment for container with dangerous goods		
Risk scenarios	**Effectiveness**	**Comment**
Deductive risk scenarios		
• D 3.1 (Ignition due to condensation water)	1(F)	Good ventilation inside the container prevents the formation of condensation water
• D 3.2 (Ignition due to reaction of released gases with water)	1(F)	Good ventilation inside container prevents high concentration of flammable gases and reduces the frequency of spontaneous ignitions.
• D 3.3 (Ignition due to reaction of dangerous goods with water)	1(F)	The use of containers which are designed to prevent the contact between the dangerous goods and water.

Evaluation of effectiveness of special equipment for container with dangerous goods		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 1: Fire of container on deck with dangerous goods		
• G 1.3 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	Early fire detection through fire detectors inside the container improves the chances of success to extinguish the fire.
• G 1.4 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(S)	see G 1.3
• G 1.5 (Formation of oxidising substances due to a reaction with extinguishing water)	1(S)	see G 1.3
Inductive risk scenario 2: Fire of container below deck with dangerous goods		
• G 2.4 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(F)	Early fire detection through fire detectors inside the container improves the chances of success to extinguish the fire.
• G 2.5 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(F)	see G 2.4
• G 2.5 (Formation of oxidising substances)	1(F)	see G 2.4
Inductive risk scenario 3: Fire on deck in the vicinity of a container with dangerous goods		
• G 3.3 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(F)	Good ventilation prevents concentration of flammable gases. The use of containers which are designed to prevent contact between dangerous goods and extinguishing water.
• G 3.4 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(F)	The use of containers which are designed to prevent contact between dangerous goods and extinguishing water.
• G 3.5 (Formation of oxidising substances due to reaction with extinguishing water)	1(F)	see G 3.4

Inductive risk scenario 4: Fire below deck in the vicinity of a container with dangerous goods		
• G 4.2 (The attempt to extinguish the fire with CO_2 fails due to impact of dangerous goods)	0	An early detection of the fire with the fire detector inside the container with dangerous goods is not possible because container itself is not on fire.
• G 4.5 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(F)	The use of containers which are designed to prevent contact between dangerous goods and extinguishing water.
• G 4.6 (Release of corrosive toxic gases due to a reaction with the extinguishing water)	1(F)	see G 4.5
• G 4.7 (Formation of oxidising substances due to reaction with extinguishing water)	1(F)	see G 4.5
Overall effectiveness	**+**	

7.3.5.2 Costs

The costs to implement special equipment for containers with dangerous goods are depended on how far a modification of the container structure is required. The material cost for a fire detector is, for example, low. However, to install the fire detector inside the container and to connect it to the fire detection system of the ship involves high logistic costs. The use of special containers for dangerous goods is only feasible with high costs. One problem with the use of special containers for dangerous goods is providing those containers to the shipper world-wide. Overall, the costs is ascertained as **high**.

7.3.6 Amendments and improvements of the EmS F-G

7.3.6.1 Effectiveness

The evaluation of the effectiveness of amendments and improvements of the EmS F-G is represented in Table 7.10. The effectiveness indices are listed in Table 7.2. The EmS F-G contains instructions for fire-fighting and has no influence on the start of the fire. Therefore, the deductive risk scenarios are not considered.

Table 7.10: Evaluation of the effectiveness of amendments and improvements of the EmS F-G

Evaluation of the effectiveness of amendments and improvements of the EmS F-G		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 1: Fire of container with dangerous goods on deck		
• G 1.3 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	Detailed instructions on how to handle the fire when dangerous goods in liquid form are involved.
• G 1.5 (Formation of oxidising substances due to reaction with extinguishing water)	1(S)	The EmS F-G should contain information in regards to that there are fires which cannot be extinguished with the equipment on board. In such cases, the risk to persons should be minimised by considering to forgo fire-fighting measures and to preparing to abandon ship.
Inductive risk scenario 2: Fire of container with dangerous goods below deck		
• G 2.4 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	Detailed instructions on how to handle the fire when dangerous goods in liquid form are involved
• G 2.6 (Formation of oxidising substances due to reaction with extinguishing water)	1(S)	The EmS F-G should contain information in regards to that there are fires which cannot be extinguished with the equipment on board. In such cases, the risk to persons should be minimised by considering to forgo fire-fighting measures and to preparing to abandon ship.
Inductive risk scenario 3: Fire on deck in vicinity of container with dangerous goods		
• G 3.3 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	Detailed instructions on how to handle the fire when dangerous goods in liquid form are involved
• G 3.5 (Formation of oxidising substances due to reaction with extinguishing water)	1(S)	The EmS F-G should contain information in regards to that there are fires which cannot be extinguished with the equipment on board. In such cases, the risk to persons should be minimised by considering to forgo fire-fighting measures and to preparing to abandon ship.

Evaluation of the effectiveness of amendments and improvements of the EmS F-G		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 4: Fire below deck in vicinity of container with dangerous goods		
• G 4.5 (Ignition of liquids and gases due to a reaction with extinguishing water)	1(S)	Detailed instructions on how to handle the fire when dangerous goods in liquid form are involved
• G 4.7 (Formation of oxidising substances due to reaction with extinguishing water)	1(S)	The EmS F-G should contain information in regards to that there are fires which cannot be extinguished with the equipment on board. In such cases, the risk to persons should be minimised by considering to forgo fire-fighting measures and to preparing to abandon ship.
Overall effectiveness	**(+)**	This measure reduces the risk to persons, which are involved in fighting the fire, and to the crew, in case of escalation of the fire.

7.3.6.2 Costs

The costs to implement the amendments and improvements of the EmS F-G are estimated as **low**.

7.3.7 Improved training of the crew in regard to handling the fire with the involvement of dangerous goods

7.3.7.1 Effectiveness

The evaluation of the effectiveness of improved training of the crew in regard to handling the fire with the involvement of dangerous goods is represented in Table 7.11. The effectiveness indices are listed in Table 7.2. This measure has no influence on the start of the fire. Therefore, the deductive risk scenarios are not considered.

Table 7.11: Evaluation of the effectiveness of improved training of the crew in regard to handling the fire with the involvement of dangerous goods

Evaluation of the effectiveness of improved training of the crew in regard to handling the fire with the involvement of dangerous goods		
Risk scenarios	**Effectiveness**	**Comment**
Inductive risk scenario 1: Fire of container with dangerous goods on deck		
• G 1.5 (Formation of oxidising substances due to reaction with extinguishing water)	1(S)	Assessment when fire-fighting with involvement of dangerous goods becomes too dangerous and therefore not advisable. Where appropriate, preparations to abandon ship are initiated to avoid personal injuries.
• G 1.7 (False assessment of the development of the fire by the crew)	1(F)	Assessment if fire with involvement of dangerous goods is spreading. With this, one can evaluate whether it is possible to let the fire burn out and/ or if fire-fighting measures should be initiated.
Inductive risk scenario 2: Fire of container with dangerous goods below deck		
• G 2.5 (Formation of oxidising substances due to reaction with extinguishing water)	1(S)	Assessment when fire-fighting with involvement of dangerous goods becomes too dangerous and therefore not advisable. Where appropriate, preparations to abandon ship are initiated to avoid personal injuries.
Overall effectiveness	**(+)**	The training of the crew has already a high standard.

7.3.7.2 Costs

The costs for improved training is heavily depended on the method of how this content can be integrated into the already extensive training of the crew. It is advisable to integrate this content into the IMO Model courses. In this case the costs are estimated as **medium**.

7.4 Overall evaluation

The following table summarises the overall evaluations of each risk reducing measure. This summary compares the overall effectiveness and the costs of each measure. The measures 1, 3, 4, 6 and 7 are recommended for implementation.

Table 7.12: Overview on the overall evaluations of the different risk reducing measures

Nb.	**Measure**	**Overall-effectiveness**	**Costs**
1	Sufficient equipment for fire-fighting in the vicinity of the fire	**+**	Medium Effort
2	Improved capacity of the CO_2-extinguishing system	**0**	Low to medium Effort
3	Improved packaging and loading of the containers	**+**	Low Effort
4	Improved stowage of containers with dangerous goods on the ship	**+**	Low to medium Effort
5	Special equipment for containers with dangerous goods	**+**	High Effort
6	Amendments and improvements of the EmS F-G	**(+)**	Low Effort
7	Training of the crew with regard to handling fires with involvement of dangerous goods	**(+)**	Medium Effort

Based on the above summary, the effectiveness of the measures is between „ slightly effective“ and „effective“. None of the studied risk reducing measures achieved a high effectiveness, which would justify a high effort on implementation.

The effectiveness of the measure 5 „Special equipment for containers with dangerous goods“ is not proportional with the necessary costs which was rated as extensive. The measure 2 „Improved capacity of the CO_2-extinguishing system“ is not recommended due to the negligible effectiveness. The measure 3 „Improved packaging and loading of the container“ and 4 „Improved stowage of the container with dangerous goods on the ship“ are determined as best measures with regard to effectiveness and costs. The latter requires only a low to medium costs, yet offers a significant reduction of risks to persons by fire in connection with dangerous goods as per EmS F-G. Measures 1, 6 and 7 are also recommended.

8 Recommendations

In the performed formal safety assessment (Formal Safety Assessment - FSA), the risks from fires involving dangerous goods, covered by the Emergency Schedule for Fire Card Golf (EMS FG), were analysed. This is primarily for dangerous goods that react with water. In addition, substances were considered, because of a possible reaction leading to the reduced efficiency of the CO_2 fire extinguishing system.

The FSA was performed in accordance with the IMO-Guidelines MSC 83/INF.2 (/6/) and is divided in 5 steps:

1. Risk identification (HAZID)
2. Risk quantification
3. Identification of risk reducing measures
4. Cost-benefit-Analysis
5. Recommendations

Because only very limited quantitative data were available for the accident scenarios of the studied dangerous goods, steps 2, 3 and 4 were carried out with the aid of expert assessments. From the considerations and results the following recommendations can be derived:

Recommendation 1 **Modifications to the IMDG Code regarding improved packaging and stowage**

This recommendation includes the following requirements for the packaging and container loading of substances for which the EmS F-G applies:

- For certain dangerous goods, a limitation on the quantity of transported goods per packaging unit and/or per container should be introduced;
- Packaging of containers only in dry conditions for all dangerous goods for which the EmS F-G applies;
- Use of moisture resistant packaging;
- Reducing condensation water with the use of moisture absorbents, for example Silica gel;

- Dangerous goods should be stowed separate from other flammable goods within the container. In particular substances, which when in combination make effective fire-fighting impossible, have to be identified and stowed separately from each other. Goods of class 5.1 should not be transported in containers with mixed goods.

Additionally, the following requirements should apply for the stowage of containers on ship:

- Certain dangerous goods should not be stowed below deck. Instead, these substances should be stowed on deck protected from sea water. This applies to the following:
  - Substances of class 5.1, which release oxygen when in contact with water and/ or with heat;
  - Substances, which release dangerous corrosive gases when in contact with water and/or heat;
- Placement of the container with dangerous goods in such a way that sufficient accessibility and good fire control is guaranteed.
- Placement of the container with dangerous goods in such a way that the container with dangerous goods burn out would be possible in case of a fire (not in the vicinity of the bridge).

Recommendation 2 Adjustments to fire protection equipment

With reference to the FSA „Container fire on deck“ /13/, /14/, /20/ the following requirements for the fire protection equipment are recommended for vessels of 30,000 GT and higher with container on deck:

- Increase of the required pump capacity of 180 m^3/h (SOLAS II-2/10.2.2.4.1.2) to 250 m^3/h;
- Increase of the required pressure at hydrants from 0.27 N/mm^2 to 0.4 N/mm^2 (similar to the passenger ships from 4,000 GT);

– At least one hydrant between two neighbouring stacks of containers on each side of the ship;

– At least two mobile monitors, and for vessels with more than 30 m widths at least four mobile monitors with the corresponding pump capacity and pressure for reaching the full height of a container stack..

These indicated measures increase the success during fire–fighting and therefore reduce the probability of the spread of the fire and thus the expected consequences.

Since the effort for these measures vary depending on local conditions on board, this recommendation can only be granted, if the implementation is possible with reasonable effort. In other cases, these measures are to be classified as not cost effective.

Recommendation 3 **Modification of the EmS and/or EmS F-G**

The EmS and/or the instructions in the EmS F-G should be revised in regards to the following points:

– The EmS and/or the instructions in the EmS F-G should contain information to the fact that there are fires which cannot be extinguished with the equipment on board. In such cases, risks to persons are to be minimized by considering to forgo fire-fighting measures and initiate preparations to abandon ship;

– The EmS and/or the instructions in the EmS F-G should contain detailed instructions for fire-fighting with the involvement of dangerous goods in liquid form;

– The general part of the EmS should contain information on the spread of a fire in case of dangerous goods involved.

Recommendation 4 **Supplement of the training for fire-fighting as part of the IMO Model Courses**

As risk reducing measure, part of the training for fire-fighting of fires with the involvement of dangerous goods, the following should be included:

- Assessment of the spread of a fire with the involvement of dangerous goods. With this should be determined whether it is possible to let the fire on deck burn out or whether a fire-fighting measure should be initiated;

- Assessment, when fire-fighting with dangerous goods is too dangerous and therefore not appropriate; and when preparation should be initiated to abandon ship.

This content can be integrated into the general part of the EmS or into the IMO Model Courses 1.20

Generally, it can be stated, that the existing safety measures are already at a high safety standard, even if higher consequences, including total loss of the ship, cannot be ruled out for any fire involving the considered dangerous goods.

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Annex 1: Dangerous goods for which EmS F-G applies

The following table lists the dangerous goods for which EmS F-G applies. Additionally the stowage category, dangerous goods class, and subsidiary risks (if applicable) are specified.

Table A1-1: List of dangerous goods for which EmS F-G applies:

UN-No.	Proper Shipping Name (PSN)		EmS	Stowage category	Class	Subsidiary risk(s)
1183	ETHYLDICHLOROSILANE		F-G	D	4.3	3/8
1242	METHYLDICHLOROSILANE		F-G	D	4.3	3/8
1295	TRICHLOROSILANE		F-G	D	4.3	8/3
1309	ALUMINIUM POWDER, COATED		F-G	A	4.1	
1323	FERROCERIUM		F-G	A	4.1	
1333	CERIUM	slabs, ingots or rods	F-G	A	4.1	
1339	PHOSPHORUS HEPTASULPHIDE	free from yellow or white phosphorus	F-G	B	4.1	
1340	PHOSPHORUS PENTASULPHIDE	free from yellow or white phosphorus	F-G	D	4.3	4.1
1343	PHOSPHORUS TRISULPHIDE	free from yellow or white phosphorus	F-G	B	4.1	
1358	ZIRCONIUM POWDER, WETTED	with not less than 25% water (a visible excess of water must be present) chemically produced, particle size less than 840 microns	F-G	E	4.1	
1358	ZIRCONIUM POWDER, WETTED	with not less than 25% water (a visible excess of water must be present) mechanically produced, particle size less than 53 microns	F-G	E	4.1	
1360	CALCIUM PHOSPHIDE		F-G	E	4.3	6.1
1376	IRON OXIDE, SPENT	obtained from coal gas purification	F-G	E	4.2	
1376	IRON SPONGE, SPENT	obtained from coal gas purification	F-G	E	4.2	
1380	PENTABORANE		F-G	D	4.2	6.1
1383	PYROPHORIC ALLOY, N.O.S.		F-G	D	4.2	
1383	PYROPHORIC METAL, N.O.S.		F-G	D	4.2	
1389	ALKALI METAL AMALGAM, LIQUID		F-G	D	4.3	
1390	ALKALI METAL AMIDE		F-G	E	4.3	
1391	ALKALI METAL DISPERSION		F-G	D	4.3	
1391	ALKALINE EARTH METAL DISPERSION		F-G	D	4.3	
1392	ALKALINE EARTH METAL AMALGAM, LIQUID		F-G	D	4.3	
1393	ALKALINE EARTH METAL ALLOY, N.O.S.		F-G	E	4.3	
1394	ALUMINIUM CARBIDE		F-G	A	4.3	
1395	ALUMINIUM FERROSILICON POWDER		F-G	A	4.3	6.1
1396	ALUMINIUM POWDER, UNCOATED		F-G	A	4.3	
1397	ALUMINIUM PHOSPHIDE		F-G	E	4.3	6.1
1398	ALUMINIUM SILICON POWDER, UNCOATED		F-G	A	4.3	
1400	BARIUM		F-G	E	4.3	

UN-No.	Proper Shipping Name (PSN)		EmS	Stowage category	Class	Subsidiary risk(s)
1401	CALCIUM		F-G	E	4.3	
1402	CALCIUM CARBIDE		F-G	B	4.3	
1403	CALCIUM CYANAMIDE	with more than 0.1% calcium carbide	F-G	A	4.3	
1404	CALCIUM HYDRIDE		F-G	E	4.3	
1405	CALCIUM SILICIDE		F-G	B	4.3	
1407	CAESIUM		F-G	D	4.3	
1408	FERROSILICON	with 30% or more but less than 90% silicon	F-G	A	4.3	6.1
1409	METAL HYDRIDES, WATER-REACTIVE, N.O.S.		F-G	D	4.3	
1410	LITHIUM ALUMINIUM HYDRIDE		F-G	D	4.3	
1411	LITHIUM ALUMINIUM HYDRIDE, ETHEREAL		F-G	D	4.3	3
1413	LITHIUM BOROHYDRIDE		F-G	E	4.3	
1414	LITHIUM HYDRIDE		F-G	E	4.3	
1415	LITHIUM		F-G!	E	4.3	
1417	LITHIUM SILICON		F-G	A	4.3	
1418	MAGNESIUM ALLOYS POWDER		F-G!	A	4.3	4.2
1418	MAGNESIUM POWDER		F-G!	A	4.3	4.2
1419	MAGNESIUM ALUMINIUM PHOSPHIDE		F-G	E	4.3	6.1
1420	POTASSIUM METAL ALLOYS, LIQUID		F-G	D	4.3	
1421	ALKALI METAL ALLOY, LIQUID, N.O.S.		F-G	D	4.3	
1422	POTASSIUM SODIUM ALLOYS, LIQUID		F-G	D	4.3	
1423	RUBIDIUM		F-G	D	4.3	
1426	SODIUM BOROHYDRIDE		F-G	E	4.3	
1427	SODIUM HYDRIDE		F-G	E	4.3	
1428	SODIUM		F-G	D	4.3	
1432	SODIUM PHOSPHIDE		F-G	E	4.3	6.1
1433	STANNIC PHOSPHIDE		F-G	E	4.3	6.1
1435	ZINC ASHES		F-G	A	4.3	
1436	ZINC DUST		F-G	A	4.3	4.2
1436	ZINC POWDER		F-G	A	4.3	4.2
1449	BARIUM PEROXIDE		F-G	A	5.1	6.1
1457	CALCIUM PEROXIDE		F-G	A	5.1	
1472	LITHIUM PEROXIDE		F-G	A	5.1	
1476	MAGNESIUM PEROXIDE		F-G	A	5.1	
1483	PEROXIDES, INORGANIC, N.O.S.		F-G	A	5.1	
1491	POTASSIUM PEROXIDE		F-G	B	5.1	
1504	SODIUM PEROXIDE		F-G	B	5.1	
1509	STRONTIUM PEROXIDE		F-G	A	5.1	
1516	ZINC PEROXIDE		F-G	A	5.1	
1567	BERYLLIUM POWDER		F-G	A	6.1	4.1
1714	ZINC PHOSPHIDE		F-G	E	4.3	6.1
1854	BARIUM ALLOYS, PYROPHORIC		F-G	D	4.2	
1855	CALCIUM ALLOYS, PYROPHORIC		F-G	D	4.2	

UN-No.	Proper Shipping Name (PSN)		EmS	Stowage category	Class	Subsidiary risk(s)
1855	CALCIUM, PYROPHORIC		F-G	D	4.2	
1869	MAGNESIUM	in pellets, turnings or ribbons	F-G	A	4.1	
1869	MAGNESIUM ALLOYS	with more than 50% magnesium in pellets, turnings or ribbons	F-G	A	4.1	
1870	POTASSIUM BOROHYDRIDE		F-G	E	4.3	
1928	METHYLMAGNESIUM BROMIDE IN ETHYL ETHER		F-G	D	4.3	3
1932	ZIRCONIUM, SCRAP		F-G	D	4.2	
2004	MAGNESIUM DIAMIDE		F-G	C	4.2	
2008	ZIRCONIUM POWDER, DRY		F-G	D	4.2	
2009	ZIRCONIUM, DRY	finished sheets, strip or coiled wire	F-G	D	4.2	
2010	MAGNESIUM HYDRIDE		F-G	E	4.3	
2011	MAGNESIUM PHOSPHIDE		F-G	E	4.3	6.1
2012	POTASSIUM PHOSPHIDE		F-G	E	4.3	6.1
2013	STRONTIUM PHOSPHIDE		F-G	E	4.3	6.1
2210	MANEB		F-G	A	4.2	4.3
2210	MANEB PREPARATION	with not less than 60 % maneb	F-G	A	4.2	4.3
2257	POTASSIUM		F-G	D	4.3	
2441	TITANIUM TRICHLORIDE MIXTURE, PYROPHORIC		F-G	D	4.2	8
2441	TITANIUM TRICHLORIDE, PYROPHORIC		F-G	D	4.2	8
2463	ALUMINIUM HYDRIDE		F-G	E	4.3	
2466	POTASSIUM SUPEROXIDE		F-G	E	5.1	
2545	HAFNIUM POWDER, DRY		F-G	D	4.2	
2546	TITANIUM POWDER, DRY		F-G	D	4.2	
2547	SODIUM SUPEROXIDE		F-G	E	5.1	
2624	MAGNESIUM SILICIDE		F-G	B	4.3	
2793	FERROUS METAL BORINGS	in a form liable to self-heating	F-G	A	4.2	
2793	FERROUS METAL CUTTINGS	in a form liable to self-heating	F-G	A	4.2	
2793	FERROUS METAL SHAVINGS	in a form liable to self-heating	F-G	A	4.2	
2793	FERROUS METAL TURNINGS	in a form liable to self-heating	F-G	A	4.2	
2805	LITHIUM HYDRIDE, FUSED SOLID		F-G	E	4.3	
2813	WATER-REACTIVE SOLID, N.O.S.		F-G	E	4.3	
2830	LITHIUM FERROSILICON		F-G	E	4.3	
2835	SODIUM ALUMINIUM HYDRIDE		F-G	E	4.3	
2844	CALCIUM MANGANESE SILICON		F-G	A	4.3	
2845	PYROPHORIC LIQUID, ORGANIC, N.O.S.		F-G	D	4.2	
2846	PYROPHORIC SOLID, ORGANIC, N.O.S.		F-G	D	4.2	
2858	ZIRCONIUM, DRY	coiled wire, finished metal sheets, strip (thinner than 254 microns but not thinner than 18 microns)	F-G	A	4.1	
2870	ALUMINIUM BOROHYDRIDE		F-G	D	4.2	4.3
2870	ALUMINIUM BOROHYDRIDE IN DEVICES		F-G	D	4.2	4.3
2878	TITANIUM SPONGE GRANULES		F-G	D	4.1	
2878	TITANIUM SPONGE POWDERS		F-G	D	4.1	

UN-No.	Proper Shipping Name (PSN)		EmS	Stowage category	Class	Subsidiary risk(s)
2881	METAL CATALYST, DRY		F-G	C	4.2	
2950	MAGNESIUM GRANULES, COATED	particle size not less than 149 microns	F-G	A	4.3	
2965	BORON TRIFLUORIDE DIMETHYL ETHERATE		F-G	D	4.3	3/8
2968	MANEB PREPARATION, STABILIZED	against self-heating	F-G	B	4.3	
2968	MANEB, STABILIZED	against self-heating	F-G	B	4.3	
2988	CHLOROSILANES, WATER-REACTIVE, FLAMMABLE, CORROSIVE, N.O.S.		F-G	D	4.3	
3078	CERIUM	turnings or gritty powder	F-G	E	4.3	
3089	METAL POWDER, FLAMMABLE, N.O.S.		F-G	B	4.1	
3094	CORROSIVE LIQUID, WATER-REACTIVE, N.O.S.		F-G	D	8	4.3
3096	CORROSIVE SOLID, WATER-REACTIVE, N.O.S.		F-G	D	8	4.3
3121	OXIDIZING SOLID, WATER-REACTIVE, N.O.S.		F-G	-	5.1	4.3
3123	TOXIC LIQUID, WATER-REACTIVE, N.O.S.		F-G	D	6.1	4.3
3125	TOXIC SOLID, WATER-REACTIVE, N.O.S.		F-G	D	6.1	4.3
3129	WATER-REACTIVE LIQUID, CORROSIVE, N.O.S.		F-G	D / E	4.3	8
3130	WATER-REACTIVE LIQUID, TOXIC, N.O.S.		F-G	D / E	4.3	6.1
3131	WATER-REACTIVE SOLID, CORROSIVE, N.O.S.		F-G	D / E	4.3	8
3132	WATER-REACTIVE SOLID, FLAMMABLE, N.O.S.		F-G	-	4.3	4.1
3133	WATER-REACTIVE SOLID, OXIDIZING, N.O.S.		F-G	-	4.3	5.1
3134	WATER-REACTIVE SOLID, TOXIC, N.O.S.		F-G	D / E	4.3	6.1
3135	WATER-REACTIVE SOLID, SELF-HEATING, N.O.S.		F-G	-	4.3	4.2
3137	OXIDIZING SOLID, FLAMMABLE, N.O.S.		F-G	-	5.1	4.1
3148	WATER-REACTIVE LIQUID, N.O.S.		F-G	E	4.3	
3170	ALUMINIUM REMELTING BY-PRODUCTS	packing group II	F-G	B	4.3	
3170	ALUMINIUM SMELTING BY-PRODUCTS	packing group III	F-G	B	4.3	
3189	METAL POWDER, SELF-HEATING, N.O.S.		F-G	C	4.2	
3194	PYROPHORIC LIQUID, INORGANIC, N.O.S.		F-G	D	4.2	
3200	PYROPHORIC SOLID, INORGANIC, N.O.S.		F-G	D	4.2	
3208	METALLIC SUBSTANCE, WATER-REACTIVE, N.O.S.		F-G	E	4.3	
3209	METALLIC SUBSTANCE, WATER-REACTIVE, SELF-HEATING, N.O.S.		F-G	E	4.3	4.2
3292	BATTERIES, CONTAINING SODIUM		F-G	A	4.3	
3292	CELLS, CONTAINING SODIUM		F-G	A	4.3	

UN-No.	Proper Shipping Name (PSN)		EmS	Stowage category	Class	Subsidiary risk(s)
3385	TOXIC BY INHALATION LIQUID, WATER-REACTIVE, N.O.S.	with an inhalation toxicity lower than or equal to 200 ml/m³ and saturated vapour concentration greater than or equal to 500 LC50	F-G	D	6.1	4.3
3386	TOXIC BY INHALATION LIQUID, WATER-REACTIVE, N.O.S.	with an inhalation toxicity lower than or equal to 1000 ml/m³ and saturated vapour concentration greater than or equal to 10 LC50	F-G	D	6.1	4.3
3391	ORGANOMETALLIC SUBSTANCE, SOLID, PYROPHORIC		F-G	D	4.2	
3392	ORGANOMETALLIC SUBSTANCE, LIQUID, PYROPHORIC		F-G	D	4.2	
3393	ORGANOMETALLIC SUBSTANCE, SOLID, PYROPHORIC, WATER-REACTIVE		F-G	D	4.2	4.3
3394	ORGANOMETALLIC SUBSTANCE, LIQUID, PYROPHORIC, WATER-REACTIVE		F-G	D	4.2	4.3
3395	ORGANOMETALLIC SUBSTANCE, SOLID, WATER-REACTIVE		F-G	E	4.3	
3396	ORGANOMETALLIC SUBSTANCE, SOLID, WATER-REACTIVE, FLAMMABLE		F-G	E	4.3	4.1
3397	ORGANOMETALLIC SUBSTANCE, SOLID, WATER-REACTIVE, SELF-HEATING		F-G	E	4.3	4.2
3398	ORGANOMETALLIC SUBSTANCE, LIQUID, WATER-REACTIVE		F-G	E	4.3	
3399	ORGANOMETALLIC SUBSTANCE, LIQUID, WATER-REACTIVE, FLAMMABLE		F-G	E	4.3	3
3401	ALKALI METAL AMALGAM, SOLID		F-G	D	4.3	
3402	ALKALINE EARTH METAL AMALGAM, SOLID		F-G	D	4.3	
3403	POTASSIUM METAL ALLOYS, SOLID		F-G	D	4.3	
3404	POTASSIUM SODIUM ALLOYS, SOLID		F-G	D	4.3	
3476	FUEL CELL CARTRIDGES	containing water-reactive substances	F-G	A	4.3	
3476	FUEL CELL CARTRIDGES CONTAINED IN EQUIPMENT	containing water-reactive substances	F-G	A	4.3	
3476	FUEL CELL CARTRIDGES PACKED WITH EQUIPMENT	containing water-reactive substances	F-G	A	4.3	
3482	Alkali metal dispersion, flammable or alkaline earth metal dispersion, flammable		F-G	D	4.3	3
3490	Toxic by inhalation liquid, water reactive, flammable, N.O.S.	with an inhalation toxicity lower than or equal to 200 ml/m3 and saturated vapour concentration greater than or equal to 500 LC50	F-G	D	6.1	4.3, 3

UN-No.	Proper Shipping Name (PSN)		EmS	Stowage category	Class	Subsidiary risk(s)
3491	Toxic by inhalation liquid, water reactive, flammable, N.O.S.	with an inhalation toxicity lower than or equal to 1000 ml/m3 and saturated vapour concentration greater than or equal to 10 LC50	F-G	D	6.1	4.3, 3

Annex 2: Risk potential of various substances

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UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Vibration					
1339	PHOSPHORUS HEPTASULPHIDE	B	4.1		Yellow solid. Ignites readily by friction. Develops heat in contact with moist air, evolving toxic and flammable gases. Forms explosive mixtures with oxidizing substances. Harmful if swallowed or by dust inhalation.
1340	PHOSPHORUS PENTASULPHIDE	D	4.3	4.1	Yellow solid. Ignites readily by friction. Develops heat in contact with moist air, evolving toxic and flammable gases. Forms explosive mixtures with oxidizing substances. Harmful id swallowed or by dust inhalation.
1343	PHOSPHORUS TRISULPHIDE	B	4.1		Yellow solid. Ignites readily by friction. Develops heat in contact with moist air, evolving toxic and flammable gases. Forms explosive mixtures with oxidizing substances. Harmful id swallowed or by dust inhalation.
1383	PYROPHORIC METAL, N.O.S.	D	4.2		Liable to ignite spontaneously in air. If shaken, may produce sparks. In contact with water, evolves hydrogen, a flammable gas.
1323	FERROCERIUM	A	4.1		Alloy derived from cerium or mischmetal, with the addition of 10% to 65% iron. Emits sparks when struck.
1333	CERIUM	A	4.1		Contains 94% to 99% rare earth metals. In contact with water or moist air, evolves hydrogen, a flammable gas. Emits sparks when scratched or struck.
1396	ALUMINIUM POWDER, UNCOATED	A	4.3		In contact with water, caustic alkalis or acids, evolves hydrogen, a flammable gas. When finely divided aluminium dust is scattered, it is easily ignited by naked lights, causing explosion. May explode when in contact with oxidizing substances. Reacts with liquid halogenated hydrocarbons.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
1397	ALUMINIUM PHOSPHIDE	E	4.3	6.1	Crystals or powder. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin or by inhalation.
1411	LITHIUM ALUMINIUM HYDRIDE, ETHEREAL	D	4.3	3	Clear, colourless solution of lithium aluminium hydride in ether. Reacts readily with water, evolving hydrogen, a flammable gas. Evaporates readily to leave a residue which is easily ignited by spark or by friction.
1449	BARIUM PEROXIDE	A	5.1	6.1	White powder. Particularly if wetted with small quantities of water, a mixture with combustible materials may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen. Toxic if swallowed, by skin contact or by dust inhalation.
1457	CALCIUM PEROXIDE	A	5.1		White or yellowish powder. Particularly if wetted with small quantities of water, a mixture with combustible materials may ignite following impact or friction. When involved in a fire, or on contact with water or acids, decomposes, evolving oxygen.
1472	LITHIUM PEROXIDE	A	5.1		White powder. Soluble in water. Solution in water is an alkaline corrosive liquid. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Heat					
1242	METHYLDICHLOROSILANE	D	4.3	3/8	Colourless, very volatile liquid with a pungent odour. Flashpoint: -26 °C c.c. Explosive limits: 4.5 % to 70 %. Boiling point: 41 °C. Immiscible with water. Reacts violently with water or steam to produce heat which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1295	TRICHLOROSILANE	D	4.3	8/3	Colourless, very volatile, flammable and corrosive liquid. Flashpoint: below -50 °C. Explosive limits: 1.2 % to 90.5 %. Boiling point: 32 °C. Reacts with water or steam to produce heat, which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1183	ETHYLDICHLOROSILANE	D	4.3	3/8	Colourless, very volatile liquid with a pungent odour. Flashpoint: -1 °C c.c. Immiscible with water. Reacts violently with water or steam to produce heat which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1376	IRON OXIDE, SPENT	E	4.2		Obtained from coal gas purification. Strong odour which may taint other cargo. Liable to heat and ignite spontaneously. May evolve hydrogen suphide, suphur dioxide and hydrogen cyanide which are toxic gases. The substance should have been cooled and weathered for not less than we eight weeks before shipment, unless packed in a metal drum.
1411	LITHIUM ALUMINIUM HYDRIDE, ETHEREAL	D	4.3	3	Clear, colourless solution of lithium aluminium hydride in ether. Reacts readily with water, evolving hydrogen, a flammable gas. Evaporates readily to leave a residue which is easily ignited by a spark or friction.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
2210	MANEB	A	4.2	4.3	Yellow powder, liable to heat and to ignite spontaneously with air. May evolve toxic, irritating or flammable fumes when wet, when involved in a fire or in contact with acids. Used as fungicide.
2793	FERROUS METAL BORINGS	A	4.2		These cargoes are liable to self-heating and to ignite spontaneously, particularly when in a finely divided form, wet or contaminated with such materials as cutting oil, oily rags, and other combustible matter. Self-heating or inadequate ventilation may cause dangerous depletion of oxygen in stowage spaces. Excessive amounts of cast iron borings or organic materials may encourage heating. The swarf should be protected from moisture prior to and after loading. If, during loading, the weather is inclement, hatches should be closed or otherwise protected to keep the material dry.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Water					
1183	ETHYLDICHLOROSILANE	D	4.3	3/8	Colourless, very volatile liquid with a pungent odour. Flashpoint: -1 °C c.c. Immiscible with water. Reacts violently with water or steam to produce heat which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1242	METHYLDICHLOROSILANE	D	4.3	3/8	Colourless, very volatile liquid with a pungent odour. Flashpoint: -26 °C c.c. Explosive limits: 4.5 % to 70 %. Boiling point: 41 °C. Immiscible with water. Reacts violently with water or steam to produce heat which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1295	TRICHLOROSILANE	D	4.3	8/3	Colourless, very volatile, flammable and corrosive liquid. Flashpoint: below -50 °C. Explosive limits: 1.2 % to 90.5 %. Boiling point: 32 °C. Reacts with water or steam to produce heat, which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1391	ALKALI METAL DISPERSION	D	4.3		Finely divided alkali or alkaline earth metal, e.g. metallic sodium, suspended in a flammable liquid such as toluene, xylene, naphtha, kerosene, etc. Reacts violently with moisture, water or acids, evolving hydrogen, which may be ignited by the heat of the reaction.
1393	ALKALINE EARTH METAL ALLOY, N.O.S.	E	4.3		When containing a substantial proportion of alkaline earth metals, readily decomposed by water and reacts violently with acids, evolving hydrogen, which may be ignited by the heat of then reaction.
1394	ALUMINIUM CARBIDE	A	4.3		Yellow crystals or powder. In contact with water, rapidly evolves methane, a flammable gas. Reacts violently with acids.
1407	CAESIUM	D	4.3		White, ductile, soft metal. Reacts violently with moisture, water or acids, evolving hydrogen, which may be ignited by the heat of the reaction. Highly reactive, sometimes with an explosive effect.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
1411	LITHIUM ALUMINIUM HYDRIDE, ETHEREAL	D	4.3	3	Clear, colourless solution of lithium aluminium hydride in ether. Reacts readily with water, evolving hydrogen, a flammable gas. Evaporates readily to leave a residue which is easily ignited by a spark or friction.
1415	LITHIUM	E	4.3		White, ductile, soft metal. Floats on water. Readily decomposes in water and reacts violently with acids, evolving hydrogen, which may be ignited by the heat of the reaction. For fire-fighting purposes, dry lithium chloride powder, dry sodium chloride or graphite powder should be carried onboard when this substance is transported.
1420	POTASSIUM METAL ALLOYS, LIQUID	D	4.3		Soft, silvery metal liquid. Floats on water. Reacts violently with moisture, water or acids, evolving hydrogen, which may be ignited by the heat of the reaction. Highly reactive, sometimes with explosive effect.
1421	ALKALI METAL ALLOY, LIQUID, N.O.S.	D	4.3		Flows like mercury at ordinary temperatures. Not volatile. Reacts violently with moisture, water or acids, evolving hydrogen, a flammable gas, and developing considerable heat which may ignite the gas.
1422	POTASSIUM SODIUM ALLOYS, LIQUID	D	4.3		Soft, silvery metal liquid. Floats on water. Reacts violently with moisture, water or acids, evolving hydrogen, which may be ignited by the heat of the reaction. Highly reactive, sometimes with explosive effect.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Air					
1380	PENTABORANE	D	4.2	6.1	Colourless liquid. Boiling point range: 48 °C to 63 °C. Ignites spontaneously in air. Decomposes in contact with water, evolving hydrogen, a flammable gas. Toxic if swallowed, by skin contact or by inhalation.
1383	PYROPHORIC METAL, N.O.S.	D	4.2		Liable to ignite spontaneously in air. If shaken, may produce sparks. In contact with water , evolves hydrogen, a flammable gas.
1419	MAGNESIUM ALUMINIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1432	SODIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1433	STANNIC PHOSPHIDE	E	4.3	6.1	Silver-white solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1435	ZINC ASHES	A	4.3		In contact with moisture or water, liable to evolve dangerous gases, including hydrogen, a flammable gas.
1854	BARIUM ALLOYS, PYROPHORIC	D	4.2		
1855	CALCIUM ALLOYS, PYROPHORIC	D	4.2		
1932	ZIRCONIUM, SCRAP	D	4.2		Particle size larger than 840 microns. Readily flammable; may ignite spontaneously in air. In contact with water, may evolve hydrogen, a flammable gas.
2004	MAGNESIUM DIAMIDE	C	4.2		White powder. Ignites spontaneously in air. Reacts violently in contact with water.
2008	ZIRCONIUM POWDER, DRY	D	4.2		Amorphous powder. Liable to ignite spontaneously with air. Forms explosive mixtures with oxidizing substances.
2009	ZIRCONIUM, DRY	D	4.2		Hard, silvery metal, liable to ignite spontaneously in air.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
2210	MANEB	A	4.2	4.3	Yellow powder, liable to heat and to ignite spontaneously with air. May evolve toxic, irritating or flammable fumes when wet, when involved in a fire or in contact with acids. Used as fungicide.
2545	HAFNIUM POWDER, DRY	D	4.2		Black amorphous powder. Insoluble in water. Liable to ignite spontaneously in air. Forms explosive mixtures with oxidizing substances.
2546	TITANIUM POWDER, DRY	D	4.2		Grey powder. Liable to ignite spontaneously in air. Forms explosive mixtures with oxidizing substances.
2870	ALUMINIUM BOROHYDRIDE	D	4.2	4.3	Liquid. Ignites spontaneously in air. Reacts with water or steam to produce heat or hydrogen, which may form explosive mixtures with air.
2881	METAL CATALYST, DRY	C	4.2		Liable to ignite spontaneously in air.

Induktive:

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Emission of Hydrogen					
1333	CERIUM	A	4.1		Contains 94% to 99% rare earth metals. In contact with water or moist air, evolves hydrogen, a flammable gas. Emits sparks when scratched or struck.
1383	PYROPHORIC METAL, N.O.S.	D	4.2		Liable to ignite spontaneously in air. If shaken, may produce sparks. In contact with water, evolves hydrogen, a flammable gas.
1389	ALKALI METAL AMALGAM, LIQUID	D	4.3		Silvery liquid, consisting of metal alloyed with mercury. Reacts with moisture, water or acids, evolving hydrogen, a flammable gas. When heated, evolves toxic vapours.
1391	ALKALI METAL DISPERSION	D	4.3		Finely divided alkali or alkaline earth metal, e.g. metallic sodium, suspended in a flammable liquid such as toluene, xylene, naphtha, kerosene, etc. Reacts violently with moisture, water or acids, evolving hydrogen, which may be ignited by the heat of the reaction.
1392	ALKALINE EARTH METAL AMALGAM, LIQUID	D	4.3		Consists of metal alloyed with mercury. Contains 2% to 10% alkaline earth metals and may contain up to 98% mercury. Reacts with moisture, water or acids, evolving hydrogen, a flammable gas. When heated, evolves toxic vapours.
1393	ALKALINE EARTH METAL ALLOY, N.O.S.	E	4.3		When containing a substantial proportion of alkaline earth metals, readily decomposed by water and reacts violently with acids, evolving hydrogen, which may be ignited by the heat of then reaction.
1395	ALUMINIUM FERROSILICON POWDER	A	4.3	6.1	In contact with water, caustic alkalis or acids, evolves hydrogen, a flammable gas. Impurities may, under similar circumstances, produce phosphine and arsine, which are highly toxic gases.
1396	ALUMINIUM POWDER, UNCOATED	A	4.3		In contact with water, caustic alkalis or acids, evolves hydrogen, a flammable gas. When finely divided aluminium dust is scattered, it is easily ignited by naked lights, causing explosion. May explode when in contact with oxidizing substances. Reacts with liquid halogenated hydrocarbons.
1397	ALUMINIUM PHOSPHIDE	E	4.3	6.1	Crystals or powder. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin or by inhalation.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
1405	CALCIUM SILICIDE	B	4.3		In contact with water, evolves hydrogen, a flammable gas. If calcium carbide is present as an impurity, acetylene will also be evolved. In contact with acid evolves silane, a spontaneously flammable gas.
1407	CAESIUM	D	4.3		White, ductile, soft metal. Reacts violently with moisture, water or acids, evolving hydrogen, which may be ignited by the heat of the reaction. Highly reactive, sometimes with an explosive effect.
1411	LITHIUM ALUMINIUM HYDRIDE, ETHEREAL	D	4.3	3	Clear, colourless solution of lithium aluminium hydride in ether. Reacts readily with water, evolving hydrogen, a flammable gas. Evaporates readily to leave a residue which is easily ignited by spark or by friction.
1413	LITHIUM BOROHYDRIDE	E	4.3		Crystalline, hygroscopic solid. In contact with water, acids and moisture evolves hydrogen, which may be ignited by the heat of the reaction.
1414	LITHIUM HYDRIDE	E	4.3		Solid. In contact with water, acids or moisture, evolves hydrogen, which may be ignited by the heat of the reaction.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Emission of Oxygen					
2466	POTASSIUM SUPEROXIDE	E	5.1		Yellow flakes. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite, following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen. Highly irritating to skin, eyes and mucous membranes.
1449	BARIUM PEROXIDE	A	5.1	6.1	White powder. Particularly if wetted with small quantities of water, a mixture with combustible materials may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen. Toxic if swallowed, by skin contact or by dust inhalation.
1457	CALCIUM PEROXIDE	A	5.1		White or yellowish powder. Particularly if wetted with small quantities of water, a mixture with combustible materials may ignite following impact or friction. When involved in a fire, or on contact with water or acids, decomposes, evolving oxygen.
1472	LITHIUM PEROXIDE	A	5.1		White powder. Soluble in water. Solution in water is an alkaline corrosive liquid. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen.
1476	MAGNESIUM PEROXIDE	A	5.1		White powder. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen. Harmful if swallowed.
1483	PEROXIDES, INORGANIC, N.O.S.	A	5.1		Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen.
1491	POTASSIUM PEROXIDE	B	5.1		Yellow powder. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen. Highly irritating to skin, eyes and mucous membranes.
1504	SODIUM PEROXIDE	B	5.1		Pale yellow coarse powder or granules. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen. Highly irritating to skin, eyes and mucous membranes.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
1509	STRONTIUM PEROXIDE	A	5.1		Colourless powder. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen.
1516	ZINC PEROXIDE	A	5.1		White powder. Particularly if wetted with small quantities of water, a mixture with combustible material may ignite following impact or friction. When involved in a fire, or in contact with water or acids, decomposes, evolving oxygen.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Emission of flammable gases					
1394	ALUMINIUM CARBIDE	A	4.3		Yellow crystals or powder. In contact with water, rapidly evolves methane, a flammable gas. Reacts violently with acids.
1714	ZINC PHOSPHIDE	E	4.3	6.1	Grey crystals or powder. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances.
1398	ALUMINIUM SILICON POWDER, UNCOATED	A	4.3		In contact with water, caustic alkalis or acids, generates heat and evolves hydrogen, a flammable gas. May also evolve silanes, which are toxic and may ignite spontaneously.
1403	CALCIUM CYANAMIDE	A	4.3		Powder or granules. Contains calcium carbide as an impurity. In contact with water, evolves ammonia and acetylene, which is a highly flammable gas. Reacts vigorously with acids.
1405	CALCIUM SILICIDE	B	4.3		In contact with water, evolves hydrogen, a flammable gas. If calcium carbide is present as an impurity, acetylene will also be evolved. In contact with acid evolves silane, a spontaneously flammable gas.
1417	LITHIUM SILICON	A	4.3		Shiny lumps, crystals or powder, with sharp irritating odour. Reacts readily with water, evolving hydrogen and silane, flammable gases. Enough heat may be generated to ignite the gas mixture in air.
1419	MAGNESIUM ALUMINIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1432	SODIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1433	STANNIC PHOSPHIDE	E	4.3	6.1	Silver-white solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
2011	MAGNESIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
2012	POTASSIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
2013	STRONTIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
Emission of flamable gases					
1183	ETHYLDICHLOROSILANE	D	4.3	3/8	Colourless, very volatile liquid with a pungent odour. Flashpoint: -1 °C c.c. Immiscible with water. Reacts violently with water or steam to produce heat which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1242	METHYLDICHLOROSILANE	D	4.3	3/8	Colourless, very volatile liquid with a pungent odour. Flashpoint: -26 °C c.c. Explosive limits: 4.5 % to 70 %. Boiling point: 41 °C. Immiscible with water. Reacts violently with water or steam to produce heat which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1295	TRICHLOROSILANE	D	4.3	8/3	Colourless, very volatile, flammable and corrosive liquid. Flashpoint: below -50 °C. Explosive limits: 1.2 % to 90.5 %. Boiling point: 32 °C. Reacts with water or steam to produce heat, which may lead to self-ignition; toxic and corrosive fumes will be evolved. May react vigorously in contact with oxidizing substances. Causes burns to skin, eyes and mucous membranes.
1390	ALKALI METAL AMIDE	E	4.3		Small crystals. Decomposes in contact with water or acid, evolving ammonia vapour and producing highly caustic alkaline solutions.
1419	MAGNESIUM ALUMINIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1432	SODIUM PHOSPHIDE	E	4.3	6.1	Solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.

UN Number	Proper Shipping Name (PSN)	Stowage category	Class	Subsidiary Risk(s)	Properties and Observations
1433	STANNIC PHOSPHIDE	E	4.3	6.1	Silver-white solid. Reacts with acids or decomposes slowly in contact with water or damp pair, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances. Toxic if swallowed, by skin contact or by inhalation.
1714	ZINC PHOSPHIDE	E	4.3	6.1	Grey crystals or powder. Reacts with acids or decomposes slowly in contact with water or damp air, evolving phosphine, a spontaneously flammable and highly toxic gas. Reacts violently with oxidizing substances.
1339	PHOSPHORUS HEPTASULPHIDE	B	4.1		Yellow solid. Ignites readily by friction. Develops heat in contact with moist air, evolving toxic and flammable gases. Forms explosive mixtures with oxidizing substances. Harmful if swallowed or by dust inhalation.
1340	PHOSPHORUS PENTASULPHIDE	D	4.3	4.1	Yellow solid. Ignites readily by friction. Develops heat in contact with moist air, evolving toxic and flammable gases. Forms explosive mixtures with oxidizing substances. Harmful is swallowed or by dust inhalation.

Annex 3: HAZID tables

Deductive analysis:

Event: Ignition due to vibration

Step 1: Identification					Step 2: Risks		Step 3: RCM
No.	**Substance**	**Cause**	**Possible consequences**	**Existing measures for prevention**	**Frequency**	**Severity of the consequence**	**Additional/alternative measures**
D1.1		Damage of the packaging due to mechanical stress (poor stowage, extreme loads during transport (heavy seas))	Release of the sustance, direct reaction with water, air, etc.	**packing regulations**	3		Intensified checks, improved training
D1.2		Failure of the structural framework of the container	Damage of the packaging > see above	CSC-approval of container (Container Safety Convention)	1		

Event: Thermal ignition

Step 1: Identification					Step 2: Risks		Step 3: RCM
No.	**Substance**	**Cause**	**Possible consequence**	**Existing measures for prevention**	**Frequency**	**Severity of the consequence**	**Additional/alternative measures**
D2.1		Neighbouring installations, regular operations (tank heaters, etc.) > Thermal stress due to thermal conduction, long-term	Fire	Stow on deck	1	2	Position of stowed goods
D2.2		Unintented thermal stress (short-term, i.e. welding work); potential malfunctions	Fire		1	2	Briefing (operative instructions)
D2.3		Direct sunlight	Fire		1 (very low)	1	Stowed position, not in the upper stacks
D2.4		Other heated goods are released and consequential heating of the considered goods in the EmS F-G	Fire		extreme rare	1	Regulations for stowage
D2.5		Fire (can be at a distance)	Fire		1	2	
D2.6		Self-heating (Release of the heat is not warrented, i.e. caused by faulty packaging)	Fire	Keep cool	1	1	

Event: Ignition due to contact with water

Step 1: Identification					Step 2: risks		Step 3: RCM
No.	**Substance**	**Cause**	**Possible consequences**	**Existing measures for prevention**	**Frequency main inicident**	**Severity of the consequence**	**Additional/alternative measures**
D3.1	Class 5.1; i.e. Potassium persulfate (F-A), Ferrosilicon	diffrent tempretures loading / tranport (transport across climate zones) -> condensation in container -> soaking of packing -> substance reacts with organic packing material	Fire	Regulation for stowage, dry loading	3	1	Dehumidifying the container (I.e. silica gel); water resistant packaging; (ventilation); inner packaging; Regulations for transport IMDG-Code 7.4.2.5.3 (not only class 4.3)
D3.2		cleaning of container before loading / loading of container in rain (snow, moisture) -> wet container (hich humidity) -> reaction with boil off gas	Corrosion / fire potential	Regulation for stowage, dry loading	3	1	Regulations for transport IMDG-Code 7.4.2.5.3 (not only class 4.3)
D3.3		sea water ingress (ventilation or flaws in container)			3	1	Container stowed protected from sea water; water resistant container or packaging
D3.4		large amounts of water in the hold (unplanned: leakage, collision,...)	Fire / explosion - > serious consequences		1	3	
D3.5		fire.fighting water from adjacent fire (large amounts)	Fire / explosion - > serious consequences		1	2	Waterproof packaging
D3.6		fire.fighting water from adjacent fire small amounts) below deck			1	2	

Inductive analysis:

Incident: Hydrogen release

Nr.	Substance	Cause	Possible consequences	Existing measures for prevention	Frequency	Severity of the consequence	Additional/alternative measures
	Step 1: Identification				**Step 2: Risk**		**Step 3: RCM**
I1.1		Reaction of the substance with water (substance is stowed in the vicinity of the fire)	Explosion on deck	large amounts of water	very unlikely	2	
I1.2		Reaction of the substance with water (substance is stowed in the vicinity of the fire)	Explosion below deck, RoRo (also small quantities)	Flood spraying - (danger if in contact with the substance)	very unlikely		No stowage below deck, CO2 extinguishing
I1.3		Reaction of the substance with water (substance is flammable)	Release of larger amounts of hydrogen instead of extinguishing > explosion				
I1.4	Especially critical: metals (magnesium)	Reaction of the substance with water (substance is flammable)	Release of larger amounts of hydrogen instead of extinguishing > explosion	EmS F-G			Do not extinguish, allow to burn out. Dry sand, powder. Abandon ship, as fire cannot be extinguished

Event: Relase of (other) flammable gases

Nr.	Substance	Cause	Possible consequences	Existing measures for prevention	Frequency	Severity of the consequence	Additional/alternative measures
	Step 1: Identification				**Step 2: Risk**		**Step 3: RCM**
I2.1	Organic substances, inorganic e.g. calcium carbide	Reaction of the substance with water (substance is stowed in the vicinity of the fire)	Acceleration, explosion	EmS F-G		2	
I2.2	Organic substances	Reaction of the substance with water (substance is flammable)	Acceleration, explosion	EmS F-G		2	
I2.3		excessive pressure equalization of flammable liquids and gases	Reaction inside of the container, ignition and destruction of the container			2 on Deck 3 below deck	
I2.4			Reaction outside of the container, ingnition			2 on Deck 3 below deck	Question: Distress System?

Event: Release of Oxygen

Step 1: Identification					Step 2: Risk		Step 3: RCM
No.	**Substance**	**Cause**	**Possible consequences**	**Existing measures for prevention**	**Frequency**	**Severity of the consequence**	**Additional/alternative measures**
I3.1	All 5.1 substances	Packaging damaged - substance releases oygen (more release with heat addition)	Promotion of the fire (particularly in closed cargo spaces) - increased danger from flammable substances / CO2 extinguishing and oxygen deprivation difficult	Cool /extinguish the remaining cargo with water (not CO2)	1	2	Water instead of CO2, note of ineffective use of CO2 extinguishing system (contradicting recommendation EmS F-G)

Event: Release of other, non-flammable gases, through contact with water

Step 1: Identification					Step 2: Risk		Step 3: RCM
Nr.	**Substance**	**Cause**	**Possible consequences**	**Existing measures for prevention**	**Frequency**	**Severity of the consequence**	**Additional/alternative measures**
I4.1		substance is flammable and releases poisonous gases (e.g. carbon monoxide)	toxic effect to humans	use of breathing apparatus		2	
I4.2		substance reacts with extinguishing water and releases toxic gases	toxic effect to humans	use of breathing apparatus, fire fighting with CO2		2	
I4.3	e.g. stearoyl chloride, potassium peroxide …	reacts with water during release of corrosive gases (e.g. HCl-Gas -> hydrocloric acid)	**below Deck: toxic effect to humans, extreme corrosive effect to unprotected metal surfaces (significant structural damage)**	use of breathing apparatus, fire fighting with CO2		3	alternative: below deck Stauung vermeiden
I4.4	s.o.	s.o.	**on Deck: toxic effect to humans, extreme corrosive effect to unprotected metal surfaces (possible structural damage)**	use of breathing apparatus, expulsion of the gases / fluids with water		2	

Event: Reaction with other substances

Step 1: Identification					Step 2: Risk		Step 3: RCM
No.	**Substance**	**Cause**	**Possible consequences**	**Existing measures for prevention**	**Frequency**	**Severity of the consequence**	**Additional/alternative measures**
I5.1 I5.2	e.g. Reaction of substance (e.g. 5.1) with other organic substances	EmS F-G substance reacts due to defective packaging (e.g. from fire or attempted extinguishing) with released gases/fluids or other flammable substance	Promotion of the fire; combination of substances may leave no way to extinguish (e.g. chlorine and oxidizing agent) Caustic/toxic substances, explosion	Rules for division of cargo	1	3	Limits of quantity