Translation

Study

on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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Title:

Studie zum Brandschutz bei der Beförderung von Fahrzeugen mit Elektroaggregaten oder mit Elektroantrieb auf RoRo- und RoPax-Schiffen

Abstract:

In der vorliegenden Studie wurde im Auftrag des BMVBS untersucht, ob vom vermehrten Transport elektrisch angetriebener Fahrzeuge sowie Fahrzeugen mit Brennstoffzellen und Fahrzeugen mit Kühlaggregaten auf RoRo und RoPax- Schiffen eine erhöhte Brandgefahr ausgeht und ob Maßnahmen erforderlich sind, um die Sicherheit beim Transport dieser Fahrzeuge zu erhöhen. Im vorliegenden Bericht sind die getroffenen Annahmen sowie die Ergebnisse der Gefahrenanalyse dargestellt. Daraus abgeleitet wurden mögliche Maßnahmen zur Erhöhung der Sicherheit sowie weiterer Untersuchungsbedarf.

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1. List of abbreviations

BEV	Battery electric vehicle
BMBF	Federal Ministry of Education and Research
BMVBS	Federal Ministry of Transport, Building and Urban Development
FC	Fuel cell
CNG	Compressed natural gas
f	Frequency [1/ship year]
FI	Frequency index
FMECA	Failure mode, effects and criticality analysis
FSA	Formal safety assessment
HEV	Hybrid electric vehicle
IACS	International Association of Classification Societies
IMO	International Maritime Organization
RU	Refrigeration unit
Li	Lithium
HGV	Heavy goods vehicle
LPG	Liquefied petroleum gas
NiMH	Nickel metal hydride
LTFC	Low temperature fuel cell
RI	Risk index
RI h	Human-related risk index (human risk)
RI p	Property-related risk index (property risk)
Ro-pax	Combined ro-ro and passenger ship
Ro-ro	Roll-on/roll-off
SI	Severity index
SI h	Human-related severity index
SI p	Property-related severity index

Summary

The Federal Ministry of Transport, Building and Urban Development commissioned this study to examine whether an increase in transport operations of electrically powered vehicles and vehicles with refrigeration units on ro-ro and ro-pax ships results in a higher risk of fire and if measures are required to increase safety when transporting such vehicles.

The results presented in this report show that the transport of electrically powered vehicles (BEV and HEV) results in an increased risk of fire, in particular if the vehicles are connected to the ship's power distribution system for charging. It is expected that the majority of fires will be limited to the power cable and that there will not be any dangerous consequences for the passengers, the crew or the ship. In order to minimize the risk of cable fires, the experts involved in the study recommend that only tested cables provided on board the ship be used and that the laying and connecting of the cables be performed only by trained crew members.

In the event of a lithium ion battery catching fire, it is important to note that such a fire reaches very high temperatures, produces toxic gases and is inextinguishable. Before a battery catches fire, it will, in most cases, emit gases that can be detected with the help of special sensors. However, such sensors are currently not used on ships. To effectively prevent the battery fire from spreading, it is necessary to cool the area surrounding the fire effectively. This requires large quantities of water. Moreover, it could make sense to use high pressure water mist systems and add additives to the extinguishing water.

Fuel cell vehicles present a special risk if hydrogen is used as fuel. The hydrogen is stored in the vehicle tank under high pressure. When heated strongly, e.g. due to a fire on the same deck or the one below, the pressure in the tank will increase until the overpressure relief valve opens and the hydrogen is discharged. Since hydrogen is lighter than air, it will primarily collect under the ceiling of the vehicle deck and might cause a severe explosion with catastrophic consequences for the ship and the persons on board. Escaping hydrogen cannot be detected by the sensors currently in use on ships. The applicable provisions for the prevention of explosions are targeted at gases that are heavier than air and require appropriate explosion protection on vehicle decks only for installations near the floor. On the basis of these findings, the experts involved in this study recommend that hydrogen vehicles only be transported on open loading decks.

Vehicles with refrigeration units that are connected to the ship's power distribution system during the crossing also present an increased fire risk. As with vehicles connected to the ship's power distribution system for the purpose of charging their batteries, it is expected that the majority of fires will be limited to the cable and that there will be no dangerous consequences for the ship and the persons on board. As with the charging cables

for electric vehicles, the experts involved in the study recommend that only tested cables provided on board the ship be used and that their laying and connecting be performed only by trained crew members.

Any fire poses a special risk to the search and rescue teams that enter the vehicle decks. Therefore, the experts involved in the study consider it important to inform the crews of the risks the individual vehicle types present (training) and to adapt the personal protective equipment accordingly. Moreover, it is important for the crew to know whether such vehicles are present on board and where they are located. A clear marking of these vehicles for the duration of the crossing should be considered.

2. Introduction

Given the growth to be expected in the area of electric mobility, the demand for the transport of electrically powered vehicles on ro-ro and ro-pax ships will increase as well. The various fires on ships in European waters over the past years is clear evidence of the fire risks caused by electric generators.

Based on this, the Federal Ministry of Transport, Building and Urban Development needs an analysis of the current fire safety situation on ro-ro/ro-pax ships and an assessment of the measures required for the safe transport of vehicles with electric generators as well as electrically powered vehicles. This study focuses on new and innovative technologies in the field of electric mobility as well as on existing electrical installations on board - e.g. for the supply of power to refrigeration units.
Against the background of the growing number of such battery-powered vehicles and refrigeration units, the risks they present - both as a direct cause of, e.g., a fire but also in terms of being indirectly involved in a fire - are not immediately clear.
This study is to determine to which extent these changed framework conditions of transport operations with ro-ro/ro-pax ships make it necessary to adapt the current or to develop new forward-thinking rules for maritime transport operations. The study is divided into the following two work packages (WP):

- WP 1: Analysis of the current fire safety situation on ro-ro/ro-pax ships.
- WP 2: Assessment of the measures required for the safe transport of vehicles with refrigeration units and electrically powered vehicles.

Specifically, the risks posed by the following are examined:

- Battery-powered vehicles that are
    - transported without their batteries being charged
    - transported with their batteries being charged during the crossing;

- innovative drive concepts and units, e.g. fuel cell technology,
- floating wiring for the supply of electric power during the crossing,
- the connection of refrigerated containers/refrigerated semi-trailers to the ship's power distribution system.

Since there is so far no statistically relevant experience regarding the risks these new technologies present, a semi-quantitative assessment of the fire risk is conducted that examines the probability of occurrence as well as the expected consequences.

3. Basic information

The following sections 3.1 to 3.8 summarize the information provided by the participating experts in the form of brief presentations at the beginning of the workshop. The presentations can be found in the annex to this report.

3.1. Types of ships

The study deals with ro-ro and ro-pax ships.
Ro-ro ships (roll-on/roll-off ships) transport wheeled cargo that is loaded and unloaded through the side, bow or stern doors. In ro-ro ships, cars, HGVs and trains can drive onto decks which extend over the entire length of the ship. In many cases, the height of the decks on ro-ro ships can be changed. Bulky or heavy general cargoes can be brought on board ro-ro ships with HGVs or forklifts, without the need for port facilities. This shortens the waiting times; therefore, ro-ro ships are often operated on short routes, e.g. as ferries.
Ro-pax ships are combined cargo and passenger ships. These ships, too, have several vehicle decks on which HGVs, trailers, trains and passenger cars can be transported. Ro-pax ships additionally have cabins, restaurants and other facilities for the passengers.

3.2. Reference ship

In order to gain a better understanding of the situation on board, a reference ship was chosen. The selected ship is the ro-pax ferry "Mecklenburg-Vorpommern". A ro-pax ship was selected because this type of ship has the characteristics of a ro-ro ship and since, in addition, there is a higher risk to human safety in the event of fires due to the greater number of passengers on board. Moreover, ro-pax ships transport relevant numbers of passenger cars, whereas ro-ro ships almost exclusively transport HGVs, trailers and trains. The year 2020 was selected as the reference year for the study; it is expected that by then, a significantly higher number of electric vehicles than today will be on the roads and that the ro-ro/ro-pax fleet of ships will still include a significant number of the ships in operation today. For 2020, it is expected that predominantly passenger cars will be powered electrically. As regards commercial vehicles, a stock of merely 50,000 electric vehicles is expected in Germany in 2020 (NPE, 2011); most of these vehicles will be smaller vehicles used in urban transport. For commercial vehicles used in long-distance transport, it is expected that these technologies will only be used to a relevant extent at a later point in time.

The "Mecklenburg-Vorpommern", which was built in 1996, operates between Rostock and Trelleborg. Ferries of this age normally remain in service for another 15-20 years. Accordingly, the fire safety situation on this ship is a suitable basis for the risk analysis in this study. The ship has three loading decks: the lower one (deck 3) can be used for railway wagons as well as for HGVs and passenger cars; deck 4 and 5 are used for HGVs and passenger cars. The uppermost deck (deck 5) has an open loading deck astern. Annex 1 contains an overview of the technical specifications as well as plans and photos of the vehicle decks.

Figure 1: Reference ship "Mecklenburg-Vorpommern"

3.3. Supply of energy on board ships

The typical power distribution system of a seagoing ship is designed in such a way that the consumer is supplied by the main switchboard, either directly or through sub-distribution boards. The supply voltage in the distribution networks is 400 V at a supply frequency of 50 Hz or 440 V at a supply frequency of 60 Hz.

During the crossing, the refrigeration units of HGVs/semi-trailers and refrigerated containers with refrigerated goods have to be supplied with power from the ship's power distribution system, since the operation of diesel generators is not permitted during this period. For the supply of power to the refrigeration units, sockets are provided in the loading area. See Annex 2 for the technical provisions.

Ships' power distribution systems are designed in such a way that failures in the event of overcurrents or short circuits are covered both within the ship's power distribution system as well as downstream from the high-voltage sockets towards the vehicles. In the event of a failure, the ship's protection facilities shut the system down. Failures in the ship's power distribution system cannot affect downstream consumers, i.e. the connected vehicles.

The electrical installations on ships are not only the responsibility of the shipping company but are also subject to supervision by the classification societies.

3.4. Fires on ro-ro and ro-pax ships

In the following, a brief overview of relevant fires on ro-ro and ro-pax ships is provided. The special characteristic of the fires is that they involve electrically powered vehicles or such with electric generators (e.g. refrigeration units).

In June 2010, a refrigerated HGV trailer caught fire on the ro-ro ferry *"Commodore Clipper"*. The fire spread to neighbouring vehicles. The cause was a defective plug connection of the supply cable for the refrigeration unit.

In October 2010, a refrigerated HGV caught fire on the open, roofed loading deck of the ro-pax ferry *"Lisco Gloria".* The fire spread rapidly, requiring the evacuation of the ship. It was not possible to conclusively determine the cause of the fire; it is assumed that there was a failure in the refrigeration unit of the HGV.

On 17 November 2010, the battery of a hybrid electric passenger car caught fire while the latter was charging on the vehicle deck of the ro-ro ferry *"Pearl of Scandinavia"*. The fire spread to neighbouring vehicles. The cause of the fire could not be determined conclusively; it was however possible to rule out the charging cable as the cause.

Only two days later, there was a fire on the closed vehicle deck of the ro-ro ferry "Mecklenburg-Vorpommern". The source of the fire was the battery of a minibus which was loaded on a HGV trailer as cargo.

Further information on the fires is provided in Annex 3.

3.5. Fire protection arrangements on ro-ro and ro-pax ships

In this section, a brief overview of the currently applicable fire protection provisions is given.

Fire protection on ro-ro and ro-pax ships is governed by the "*International Convention for the Safety of Life at Sea*“ (SOLAS II-2) and the „*International Code for Fire Safety Systems*“ (FSS Code).

Regarding the fire protection insulation of cargo spaces on ro-ro and ro-pax ships, the following applies (SOLAS II-2/9.2):

- Divisions from adjoining spaces are to be constructed in accordance with class "A-60". This means that the surface temperature on the side not exposed to the fire increases by a maximum of 180 °C

within 60 minutes. For adjoining open decks, wet areas, tanks, void spaces and auxiliary machine rooms with no or a low risk of fire, other requirements apply.

- Form 1 July 2014, stricter insulation requirements will enter into force for new ships as regards the insulation between cargo spaces and between the latter and escape routes as well as control stations (IMO MSC.338(91)).

The following applies to electrical equipment and wiring (SOLAS II-2/20)

- Equipment with unprotected sources of ignition is not permitted.
- The equipment has to be suitable for use in hazardous areas in which explosive gas atmospheres exist in accordance with IEC 60079.
- With the exception of special category spaces from 450 mm above deck, protection by means of a flameproof enclosure is possible, provided the frequency of air changes in the cargo space is at least ten per hour.
- Scuppers must not lead to engine rooms or other spaces with unprotected sources of ignition.

The ventilation system must meet the following requirements (SOLAS II-2/20)

- A minimum of ten air changes per hour (for ro-ro cargo ships: 6 air changes) is required.
- The ventilation must be independent of other ventilation systems.
- The fans must be continuously in operation while vehicles are on board.
- It must be possible to operate the fans and fire dampers from outside the cargo space.
- For the loading and unloading periods, 20 air changes are required in most cases.

The fire detection and alarm system consists of fire detectors (smoke or heat detectors) as well as manually operated call points and must meet the following requirements:

	Maximum monitoring area	Maximum distance between detectors	Maximum distance to bulkheads
Heat detectors	37 m²	9 m	4.5 m
Smoke detectors	74 m²	11 m	5.5 m

The call points must be arranged in such a manner that they are available within 20 m and present at every exit.

The following alternatives are permitted:

- continuous fire watch (hardly relevant in practice),
- sample extraction smoke detection system in combination with CO_2 fire-extinguishing system (only in enclosed ro-ro cargo spaces on cargo ships).

A water spraying system (also referred to as deluge or drencher system) is the standard system for fire fighting. It must be activated manually and ensure sprinkling in the amount of at least 5 l/m^2 per minute. Alternatively, water mist systems in accordance with MSC.1/Circ.1272 (2008) may be used; however, so far, such systems are rarely fitted. (Note: from 1 July 2014, water spray/water mist systems must be designed exclusively in accordance with the requirements of IMO MSC.1/Circ.1430 (2012), as brought into force by Resolution MSC.339(91) (2012)).

In enclosed ro-ro cargo spaces on cargo ships, CO_2 fire-extinguishing systems may be installed as an alternative to water-based systems.

Furthermore, fire hydrants are required to be present for fire fighting; they have to be arranged in such a way that every location in the cargo space can be reached with extinguishing water from two spray nozzles. On board ro-pax ships, the hydrant extinguishing system has to be under pressure at all times.

Moreover, a portable foam applicator unit and three water mist L pipes as well as portable fire extinguishers have to be present and available within 20 m.

3.6. Description of the fire safety situation

In the following, a summary of the findings of the *Institut für Sicherheitstechnik/Schiffssicherheit (ISV)* (Institute for safety engineering/ship safety) is provided:

Fire detection systems

The installed fire detection systems are only designed to detect aerosols, temperatures, temperature changes or flames. In some cases, the installations themselves do not take into account the structural, air- and temperature-related conditions required for their effectiveness.

Gas detectors

The installed gas detectors are highly selective electro-chemical sensors that are primarily located near the floor.

All installed fire detectors follow physical principles for the recognition of dangers, and their parameters are aligned to the different fire by-products (combustion gases). In general, the following applies:
the fire by-product has to reach the sensor to trigger a danger signal. For some ships, the reality of the installed fire detection systems looks different. The effectiveness is in some cases limited by the local situation, i.e. individual sensors or entire monitoring sections are ineffective. The reasons for this are unsuitable installation locations, e.g. sensors were installed in ceiling panels in such a way that heat barriers form underneath them, preventing fire by-products from reaching them. See Annex 4 for details.

3.7. Battery systems in electrically powered vehicles

The following section is to provide a brief overview of the different types of batteries used in electric vehicles as well as of the most important risks they present. In Annex 5, details on the battery systems and the internal battery safety mechanisms are provided.

In principle, there are two battery technologies that can be used for electric mobility. Lithium ion and nickel metal hydride cells. Lithium ion cells and batteries play a dominant role in portable applications and are now increasingly entering the field of automotive applications.

Under extreme circumstances, such as in the event of an accident or overcharging, lithium ion accumulators tend to develop a self-amplifying reaction (*thermal runaway*). This can lead to a fire or deflagration. If, despite all internal battery safety mechanisms, a lithium ion battery catches fire, this can result in temperatures far beyond 1,000 °C. The fire itself can only be extinguished with special metal fire extinguishers (class D). In fire extinguishing trials carried out by the fire brigade, water was determined to be the most effective fire-fighting agent; while the fire cannot be extinguished with water, the cooling effect (removal of heat) can prevent neighbouring battery modules from getting into the thermal runaway as a result of the introduction of heat from the outside and prevent vehicle components from catching fire. As with the vast majority of fires, battery fires, too, produce toxic gases - approx. 25 per cent by volume of carbon monoxide, but also traces of phosphine, aldehyde and hydrogen fluoride. The latter reacts with the moisture in the air to form hydrofluoric acid which is highly corrosive and highly toxic. Approximately 15 per cent by volume are hydrogen which can mix with the atmospheric oxygen to form explosive oxyhydrogen.

Nickel metal hybrid batteries have been used in large numbers for many years (e.g. in the Toyota Prius). This technology has few safety issues; however, insufficient energy and power densities, limited cold and cycle stability as well as a high self-discharge rate are obstacles to their use in Battery Electric Vehicles (BEV). Under extreme circumstances, such as in the event of an accident or overcharging, the aqueous alkaline

electrolyte, which has corrosive properties, could escape. Overcharging can result in the battery heating up and in the formation of elementary hydrogen. If released, the latter can form an explosive mixture (oxyhydrogen) with the atmospheric oxygen (see Annex 5).

3.8. Fuel cell vehicles

In this section, the technology used in fuel cell-powered vehicles as well as the risks arising from it are briefly summarized.

So far, for fuel cell-powered passenger cars, low temperature fuel cells (LTFC) with hydrogen have been used almost exclusively. These fuel cells operate at temperatures of around 80 - 100 °C and directly transform the hydrogen into electric power. The general safety features comprise pressure-resistant hydrogen tanks, safety valves for the controlled discharge of hydrogen in the event of overpressure in the fuel tank (e.g.in the case of a fire), gas sensors in the passenger compartment as well as a suitable positioning of the hydrogen tanks to reduce the potential impact of traffic accidents.
As compared with conventional vehicles, additional risks resulting from the use of fuel cell systems in road vehicles may arise from the use of gaseous fuels and their storage in pressure tanks. Further risks may result from the use of battery systems with a comparatively higher voltage level and from the use of lithium ion batteries (see 3.7). The risks are, for the most part, known due to the successful use of vehicles using compressed natural gas (CNG) as fuel, the use of liquefied petroleum gas (LPG) and the use of hybrid electric vehicles. The additional risks for fuel cell-powered vehicles compared with these systems depend on the alternative fuels used. Apart from hydrogen, this is mainly methanol.

A general distinction is made between a fuel cell engine powered by a flammable liquid (e.g. methanol) and a fuel cell engine powered by a flammable gas (e.g. hydrogen), see Annex 6.

4. Analysis

4.1. Method

The analysis of the danger situations was carried out in the form of a workshop in which experts with knowledge of the technical areas relevant to the study participated. They are listed in section 4.2. Unfortunately, the expert for the operation of ferries from the Scandlines shipping company was not able to attend the workshop. Therefore, questions were clarified with Scandlines and the Stena Line shipping company, which is currently operating the reference ship, before and after the workshop.

The risk analysis was carried out in a structured and systematic form on the basis of the FMECA method (Failure Modes, Effects and Criticality Analysis). Here, failure modes that can present risks to the ship, e.g. fires involving batteries in electric vehicles or gas leaks, were identified for the considered vehicle types (fully electric, hybrid- and fuel cell-powered vehicles). In addition, the risk potential of electrically powered vehicles when subjected to high temperatures, e.g. as a result of a fire on board, was analysed. Moreover, the risks resulting from the charging of vehicle batteries during the crossing were examined. For the other vehicles with electric generators, i.e. refrigerated HGVs or HGVs with refrigerated semi-trailers or refrigerated containers, an analysis was carried out to identify the risks that can result from connecting them to the ship's power distribution system and, in particular, from the floating wiring on the loading decks.

Once a failure mode was identified, the first step was to record the potential cause; subsequently, it was analysed which effect the failure could have on the ship in terms of the fire risk. When assessing the effects, the facilities and the usual measures for fire protection, fire/gas detection and for fire fighting required on ro-ro/ro-pax ships today were taken into account and documented in the analysis of each failure mode.

The risk associated with the occurrence of the failure is derived from the combination of the failure's probability to occur and the resulting failure scenario as well as the severity of the effects on the ship and on persons; possible damage to the cargo, i.e. to vehicles on the loading deck, was not taken into consideration. Since, due to the novelty and the low market penetration of electric vehicles, no evaluable statistics are available on failures of such drive systems or even on incidents with such vehicles on board ships, the experts mainly assessed the risk on the basis of their experience and information.

To determine the risk, a risk matrix and risk indices (RI) were used, following the *"IMO Guidelines for Formal Safety Assessment"* (IMO, 2002, hereinafter referred to as IMO FSA Guidelines). The risk of an identified failure or danger consists of the probability or frequency of occurrence and the severity of the effects associated with the failure/danger. For both, frequency and severity, indices are used. The IMO FSA Guidelines propose four categories of frequency: *frequent, reasonably probable, remote, extremely remote.*

For these, frequencies are defined that differ from one another by a magnitude of one. The same applies to the severity of the effects. There are four different categories: *minor, significant, severe, catastrophic.* Here, too, the categories differ from one another by a magnitude of one. On the basis of this proposal, categories for the frequency and severity of the effects were created for this study to allow the experts to make assessments for the individual failures/risks. These are shown in Table 1 and Table 2.

Table 1: Frequency index (based on IMO FSA Guidelines)

FI	Frequency	Definition	in the entire ro-pax fleet (2833 ships)	Frequency (per ship year)
1	Extremly remote	once in 20 years in a fleet of 5000 ships	once in 35 years	1.00E-05
1,55			once in 10 years	3.53E-05
2	very remote	once in 2 years in a fleet of 5000 ships	once in 3.5 years	1.00E-04
2,55			once per year	3.53E-04
2,85			twice per year	7.06E-04
3	remote	once per year in a fleet of 1000 ships	3 times per year	1.00E-03
3,55			10 times per year	3.53E-03
4	unlikely	once per year in a fleet of 100 ships	30 times per year	1.00E-02
5	reasonably probable	once per year in a fleet of 10 ships	300 times per year	0.1
6	probable	once per year on one ship	3000 times per year (every year on every ship)	1
7	frequent	once per month on one ship	every month on every ship	10
8	very frequent	once or twice a week on one ship	1-2 x per week on every ship	100

Table 2: Severity index (based on IMO FSA Guidelines)

SI	Severity	Effects on human safety	Property (ship)
1	minor	single or minor injuries	Ship: local equipment/structural damage € 10.000
			€ 50.000
2	significant	1 severe or 10 minor injuries	Ship: non-severe ship damage € 100.000
2,7		5 severe or 50 minor injuries	€ 500.000
3	severe	single fatality or 10 severe injuries	Ship: severe damage (yard repair required, downtime 1 week) € 1 Mio
3,7		5 fatalities or 50 severe injuries	€ 5 Mio
4	catastrophic	multiple fatalities (10)	Ship: very severe damage € 10 Mio
5	desatrous	Large number of fatalities (100)	Ship: total loss € 100 Mio

By adding the frequency index (FI) to the severity index (SI), the risk was assessed for every failure mode in the form of a risk index (RI). The higher the risk index, the higher the risk associated with the failure mode.

Table 3: Risk index (based on IMO FSA Guidelines)

Risk index (RI)						
		Severity (SI)				
		1	2	3	4	5
FI	Frequency	minor	significant	severe	catastrophic	disastrous
1	extremely remote	2	3	4	5	6
2	very remote	3	4	5	6	7
3	remote	4	5	6	7	8
4	unlikely	5	6	7	8	9
5	reasonably probable	6	7	8	9	10
6	probable	7	8	9	10	11
7	frequent	8	9	10	11	12
8	very frequent	9	10	11	12	13

The approach described above is referred to as semi-quantitative. The term "semi-quantitative" means that no calculations are performed with explicit occurrence probabilities derived from statistically available failure rates, and that effects are not quantified by means of calculation, but that the probability and severity of the effects are assessed using qualitative terms and categories, and that the quantification is performed by way of the individual indices.

On the basis of the risk assessment, the identified failure modes can be prioritized in accordance with the risk. A list of the failure modes with the highest risk is provided in section 5.1.

As regards the elaboration of recommendations for the reduction of risks in work package 2, the focus is generally on failure modes associated with a higher risk. The threshold value beyond which a risk is considered to be too high can be coordinated within the group of experts with the aim of paying less attention to those failure modes that are associated with an acceptable risk. However, no such threshold value was specified in this study.

Failure modes for which the effects on the ship could not be assessed or could only be assessed with great uncertainty are candidates for further examination, as formulated in work package 2.

During the workshop, the analysis was documented on pre-prepared work sheets (see Annex 7). After the workshop, it was followed up with questions that had arisen and required clarification by GL, and then it was again presented to the experts with the corresponding comments. The expert feedback is reflected in this version of the report.

4.2. Participant

Name	Company	Workshop day 1	Workshop day 2	Expertise
Dr Jochen Mähliß	batteryuniversity GmbH	x	x	Battery systems
Dirk Sedlacek	Institut für Sicherheitstechnik Schiffssicherheit (ISV)	x	x	Fire protection and fire protection systems
Ulrich Fielitz	Institut für Sicherheitstechnik Schiffssicherheit (ISV)	x	x	Fire protection and fire protection systems
Simon Trippler	GTE Industrieelektronik GmbH	x	x	Fire detection, detectors
Uwe Lohmann	Federal Ministry of Transport, Building and Urban Development (BMVBS)		x	Commissioning authority
Andreas Herold	BG Verkehr, Dienststelle Schiffssicherheit	x	x	Dangerous Goods Transport
Lars Langfeld	Future Ship GmbH	x	x	Fuel cells, hydrogen
Markus Frost	Future Ship GmbH	x	x	Risk analyses for fires, active member of the volunteer fire brigade
Peter Securius	Germanischer Lloyd SE	x	x	Presentation FMEA, risk analyses
Joachim Zipfel	Germanischer Lloyd SE	x	x	Electrical systems on ships
Michael Kämpf	Germanischer Lloyd SE	x	x	Fire extinguishing systems and equipment on ships
Andreas Ullrich	Germanischer Lloyd SE	x	x	Structural fire protection on ships
Nina Kähler	Germanischer Lloyd SE	x	x	Presentation, risk analyses

4.3. Assumptions

The analysis is based on the following assumptions and agreements:

Electric vehicles

For the purposes of this study, a distinction is made between the following electric vehicles:

a. Battery electric vehicles (BEV, also fully electric vehicles): these vehicles are exclusively powered by batteries. For charging, they have to be connected to the mains supply.

b. Hybrid electric vehicles (HEV): these vehicles use two or more energy systems - usually a battery and an internal combustion engine. In conventional HEVs, the battery is charged by means of regenerative breaking; only very short distances can be travelled purely on electricity; charging the battery via the mains supply is not intended. Plug-in-hybrid electric vehicles (PHEV) are primarily powered by a battery, but they are also equipped with an internal combustion engine that powers the vehicle when the battery is depleted. The battery is charged by connecting it to the mains supply.

c. Fuel cell vehicles (FC vehicles): in these vehicles, the energy required for operation is generated from hydrogen or methanol by means of a fuel cell. A battery serves as a buffer.

d. Vehicles equipped with a refrigeration unit (RU): such refrigeration units are of no significance to powering the vehicle; they ensure that goods are transported at the ideal temperature. The refrigeration units are normally powered by the HGV's diesel engine. During transport on the ferry, the unit has to be supplied via the ship's power distribution system. The study does not make a distinction between refrigerated HGVs, refrigerated semi-trailers and refrigerated containers.

Currently, there are still relatively few electrically powered vehicles on the roads; in 2011, the proportion of alternatively powered vehicles in Germany was only 1.5 % (TAB, 2012). The majority of those vehicles were gas vehicles; only 0.08 % were electric vehicles. The Federal Government has declared electric mobility an essential element of future mobility and set a target of a minimum of 1 million electric vehicles on German roads by 2020 and 6 million by 2030. Since the study looks at the medium-term future, the year 2020 is taken as the reference year for the study.

The forecasts for the proportion of electric vehicles in 2020 differ significantly from one study to the next (list in TAB, 2012). In most studies, the proportion of electric vehicles is indicated as share of the expected new

vehicle registrations, whose number itself is highly uncertain. On average, it is expected that, in 2020, about 20 % of all newly registered passenger cars will be electric vehicles.

To estimate the proportion of electric vehicles in the vehicle stock for 2020, the study uses the numbers for Germany for simplification purposes. For 2020, a vehicle stock of 50 million is expected in Germany (Shell, 2009). It is assumed that the Federal Government's target will be achieved and that, in 2020, 1 million electric vehicles will be registered in Germany. The proportion of electric vehicles in the passenger car stock will thus be approximately 2 %.

This is also the proportion the analysis assumes for the proportion of electric vehicles on the ferry. Regarding the vehicles, a distinction is made between hybrid and fully electric vehicles; no assumption is made concerning their respective share in the electric vehicle stock. Furthermore, the study does not make a distinction between passenger cars and commercial vehicles.

It is expected that the majority of the electric vehicles will use lithium ion batteries. Since no numbers are available, the analysis estimates that one third of the electric vehicles are equipped with nickel metal hydride (NiMH) and two thirds with lithium ion batteries.

Electric cycles, electrically-driven wheelchairs and similar vehicles are not considered in the study.

Failures in the electric drive system of vehicles were not examined, since its components are no longer a source of danger, once the ignition has been switched off.

For fuel cell vehicles (FC vehicles), the introduction of commercial models is expected only from 2014/2015 onwards (TAB, 2012). For the reference year 2020, it is thus expected that such vehicles will only be transported on ferries in isolated cases. For the purposes of this study, it is assumed that their share will be around 5 % of the electric vehicles (BEV and HEV). It is assumed that fuel cell-powered buses/coaches will also be transported on ferries. The study makes no assumption as to the ratio between passenger cars and buses/coaches; accordingly, there is no distinction between FC passenger cars and FC buses/coaches or commercial vehicles.

Due to their flexible operating characteristics and their high power density, vehicles mainly use polymer electrolyte membrane (PEM) fuel cells; these are low temperature fuel cells (LTFC) with operating temperatures of up to approx. 100 °C.

It is expected that the majority of fuel cell vehicles will use hydrogen (H_2) as an energy source and store it in pressure tanks (up to 700 bar). Current developments in the automotive industry suggest that liquid hydrogen is not likely to be used as a source of energy. Methanol is also considered as an energy source.

The proportion of vehicles with refrigeration units is assumed to be 10 % of all transported lorries (source: Scandlines Deutschland GmbH and StenaLine for the reference ship).

Requirements to be met by the ship

The study assumes that the ship complies with the applicable rules, that the technical systems are operational and that all provisions are met.

Loading and unloading operations as well as the manoeuvring of the vehicles on the loading decks are not part of this study; it is assumed that all vehicles were parked and secured on the loading deck in accordance with the regulations.

Fire frequency

Following the Formal Safety Assessment (FSA, 2008, assessment period 1994 - 2004), the figures below are taken as a basis:

The frequency of fires on ro-pax ships is indicated to be $8.28*10^{-3}$ per ship and year (ship year); i.e., statistically, in a fleet of 1000 ships, there will be fires on 8 ships every year. Thus, considering the stock of ro-pax ships, which is indicated to be 2833 in the FSA, there will be fires on approx. 23 ships of this type.

According to the FSA (2008), 12 % of these fires occur on the vehicle deck; i.e., every year, vehicle deck fires occur on approx. 3 ro-pax ferries (23 * 0.12 = 2.76). The FSA moreover indicates that 29 % of these fires escalate - i.e., one per year (3 * 0.29 = 0.87).

In the workshop, the present experts assessed how often the identified failures/risks with the described consequences will occur as compared to the vehicle deck fires described in the FSA (2008). For reasons of clarity, the number of fires per year in the entire ro-pax fleet (2833 ships; FSA, 2008) was always taken as a basis for the considerations.

The calculation of the frequency f [1/ship year] is based on the estimated number n per year:

$$f = \frac{n}{2833}$$

This serves as a basis for the calculation of the associated frequency index (FI) in accordance with the IMO FSA Guidelines.

$$FI = \log(f) + FI(f = 1)$$
$$FI = \log(f) + 6$$

Note: For very low frequencies of $\leq 10^{-6}$, the calculation renders results of FI ≤ 0. In such cases, the FI was set to 0.1 in this study.

Table 4: Frequencies of fires on ro-pax ships (FSA 2008)

Total number of ro-pax ships:					2833	
	fires on (all) ro-pax ships:				23	per year
		of those, fires on vehicle decks (12 %):			3	per year
			of those, fires that escalate (29 %):		1	per year

In Table 5, Table 6 and Table 7, the frequency estimates are summarized and substantiated. The names of the failures/risks in the first column refer to the names used in the detailed documentation of the workshop (Annex 7).

Table 5: Failures/Risks related to electric vehicles not connected to the ship's power distribution system

Failure/Risk	Frequency estimate (in the ro-pax fleet per year)	Reasons
HEV1 (battery fire, lithium ion)	0.08	Lithium ion batteries catch fire more frequently (estimate: by a factor of 2) than conventional batteries. However, only 2/3 of all electric vehicles have such batteries. It is estimated that by 2020, about 2 % of all vehicles will be powered electrically. According to the FSA, there are 3 fires per year involving conventional vehicles. 2*2/3*0.02*3=0.08
HEV2 (escalation 1: to other vehicles)	0.08	Same frequency as HEV1
HEV3 (escalation 2: to entire deck)	0.004	Estimate: 1 of 20 fires escalates as described: 1/20 of HEV2: 1/20*0.08=0.004
HEV5 (Battery fire, NiMH)	0.017	Fires occur less frequently (2.5/year) than with lithium ion batteries; only used in 1/3 of the electric vehicles. 2.5*1/3*0.02=0.017
HEV6 (escalation 1)	0.006	1/3 of HEV5 (1/3 of the fires escalate as is the case with conventional vehicles (FSA, 2008)) 1/3*0.017=0.006
HEV7 (escalation 2)	0.0003	1/20 of HEV6 (see HEV3) 1/20*0.006=0.0003
BEV1 (battery fire)	0.08	Same as HEV1, since the batteries are the same.
BEV2 (escalation 1)	0.053	Lower than for HEV2, as fully electric vehicles do not have a petrol tank and fires thus cannot spread as a result of petrol leakage. It is estimated that 2/3 of the fires (BEV1) spread. 2/3*0.08=0.053
BEV3 (escalation 2)	0,003	1/20 of BEV2 (same ratio as between HEV2 and HEV3) 1/20*0.053=0.003
FC1 (battery fire)	0.004	1/20 of BEV1, as 5 % of the electric vehicles are FC vehicles 1/20*0.08=0.004
FC2 (escalation 1)	0.0002	1/20 of BEV2 (same ratio as for BEV and HEV) 1/20*0.004=0.0002
FC3 (escalation 2)	0.0002	1/20 of BEV3 1/20*0.003=0.0002

Failure/Risk	Frequency estimate (in the ro-pax fleet per year)	Reasons
FC4 (H2 leakage)	0.005	FC6 multiplied by 0.5 0.5*0.01=0.005
FC5 (H2 leakage)	0.01	Estimate (1 time in 100 years)
FC6 (H2 leakage)	0.01	Same as FC5

Table 6: Failures/Risks related to electric vehicles connected to the ship's power distribution system

Failure/Risk	Frequency estimate (in the ro-pax fleet per year)	Reasons
HEV8 (battery fire, lithium ion)	0.24	Charging the battery makes fires more likely. Estimate: by a factor of 3 (compared to vehicles whose batteries are not charging) 3*0.08=0.24
HEV9 (escalation 1)	0.24	3 times as often as with HEV2, 3*0.08=0.24
HEV10 (escalation 2)	0.012	3 times as often as with HEV3, 3*0.004=0.012
HEV11 (cable fire)	300	Estimate: 300 times per year, i. e. on 1 out of 10 ships
HEV12 (escalation 1)	1	Estimate: once a year (1/300 of HEV11)
HEV13 (failure of the ship's power distribution system)	-	
HEV14	-	
BEV5 (battery fire, lithium ion)	0.24	Same as HEV8, since the batteries are the same.
BEV6 (escalation 1)	0.16	Lower likelihood of escalation, as BEVs do not have a petrol tank and fires thus cannot spread as a result of petrol leakage. Estimate: 2/3 of HEV9 2/3*0.24=0.16
BEV7	0.008	2/3 of HEV10 (reasons: see BEV6), 2/3*0.012=0.008

Failure/Risk	Frequency estimate (in the ro-pax fleet per year)	Reasons
(escalation 2)		
BEV8 (cable fire)	300	Same as HEV11
BEV9 (escalation 1)	1	Same as HEV12
BEV10 (failure of the ship's power distribution system)	-	
RU2 (cable fire)	100	Estimate
RU3 (HGV fire)	0.33	1/3 of HEV12; 1/3*1=0.33
RU4 (escalation 1)	0.33	Same as RU3
RU5 (escalation 2)	0.033	Estimate: 1 of 10 fires escalates 1/10 of RU4 0.1*0.01=0.033
RU5a (plug)	-	
RU6 (overheating)	0.33	Estimate: same frequency as RU3
RU7 (escalation 1)	0.33	Same as RU6
RU8 (escalation 2)	0.033	1/10 of RU6

Table 7: Dangers caused by fire on board

Failure/Risk	Frequency estimate (in the ro-pax fleet per year)	Reasons
HEV15 (battery fire, lithium ion)	0.16	Every vehicle is surrounded by 8 other vehicles, 2 % of which are electric vehicles = 0.16. Therefore, this risk is present in 16 % of all escalating fires (1/year, see FSA). 0.16*1=0.16
HEV16 (NiMH)	-	
BEV11 (battery fire, lithium ion)	0.16	Same as HEV15
BEV12 (NiMH)	-	
FC11 (release of H2)	0.72	The engine room is located below the vehicle deck. Every year 4.3 fires escalate in the engine room (FSA, 2008). 0.1 % of the vehicles on board are FC vehicles. If we assume a capacity of 500 vehicles, one FC vehicle is present in 1 out of 2 voyages. With 3 decks, there is one FC vehicle on the lower deck in 1 out of 6 voyages. 4.3/1*6=0.72
FC12 (release of H2)	0.167	According to the FSA, 1 fire per year escalates on the vehicle deck. In 1 out of 6 voyages, a FC vehicle will be present on the same deck (see FC11). 1/6*1=0.167
FC13 (release of H2)	0.055	1/3 of the fires (FC12) escalate (as in FSA), 1/3*0.167=0.055

5. Results

In the following sections, the results of the analysis are presented. Section 5.3 contains suggestions for improvements which are based on these results. Section 5.4 states where further investigation is required, and section 5.5 formulates recommendations for action.

Estimating the frequency of occurrence and the severity of the effects of failures and associated potential fire scenarios permits a rough prioritization of risks (see section 5.1).

As regards risk analyses, experience has shown that identified failures are assumed to occur more frequently than is actually the case. This applies in particular where no statistical data is available on such failures in the past that would permit a "calibration" of one's own assessment. For this reason, section 5.2 contains an overview of all failure scenarios and their estimated frequencies of occurrence. The aim is to obtain an estimate of the number of fires involving electric vehicles. This makes it possible to verify the consistency of the estimate in terms of magnitude and to assess, on the basis of the estimate, the increase in the number of fires due to electric vehicles.

The complete analysis of the fire safety situation within the framework of the two-day workshop can be found in Annex 7. It was carried out in three steps:

1. Vehicles on the vehicle deck of the ferry are not connected to the ship's power distribution system.
   (Scenarios HEV 1 - HEV 7, BEV 1 - BEV 4, FC 1 - FC 7)

2. Electric vehicles (HEV and BEV) as well as vehicles with a refrigeration unit (RU) are connected to the ship's power distribution system.
   (Scenarios HEV 8 - HEV 14, BEV 5 - BEV 10, RU 2 - RU 8) and

3. Electric vehicles (BEV, HEV and FC vehicles) are exposed to extreme heat, such as caused by a fire.
   (HEV 15 - HEV 16, BEV 11 - BEV 12, FC 11- FC 14)

5.1. Failures/Risks with the greatest indices

All identified failures and associated scenarios were analysed by the experts in the framework of the workshop with a view to the risks they present to the persons on board (risk index RI h) and to the ship (risk index RI p). The ship's risk is calculated on the basis of the probability of occurrence of a failure and the associated fire scenarios and the severity of the effects on the ship. This means that damage to transported vehicles which results from fire was not taken into account.

The maximum risk index, as explained in section 4.1 and shown in Table 3, is 13. The following tables show that the fire scenario estimates resulted in a maximum value of 5.5 with regard to human risk and 6.3 with regard to the ship. Based on Table 3, this would correspond to an average to low risk - neither intolerably high nor negligibly small.

Risk values are high whenever the fire spreads from its original source at the electric vehicle, the refrigeration unit or power cable to other vehicles (escalation 1) and possibly to the entire loading deck (escalation 2), also referred to as "great escalation" in the study. Here, it was assumed that the fire is no longer under control and that the ship needs to be evacuated. It was also assumed that several fatalities have to be expected in this scenario. In accordance with a conservative assessment, the total loss of the ship must be expected in such a scenario.

Tables 8 and 9 show that charging the batteries of hybrid or fully electric vehicles generally increases the risk of fire and its escalation as compared to electric vehicles which are not connected to the ship's power distribution system.

Additional risks are attached to scenarios with hybrid or fully electric vehicles as well as refrigeration units due to their connection to the ship's power distribution system. On the one hand, this concerns the refrigeration units. On the other hand, the supply of power to the refrigeration units or electric cars through floating cables can pose risks, specifically in the form of smouldering fires in the connector or cable (see Table 9).

As regards smouldering fires in power cables, the risk index is mainly influenced by the relatively high number of such failures and not so much by the severity of the effects.

Electric vehicles with fuel cells have a higher risk because of their fuel tank if hydrogen is used as fuel (see Table 10). Here, the risk for the persons on board is higher if a vehicle is affected by a fire on the deck below than it is in the event of a fire on the same deck. In the latter case, the person checking the deck and/or the

fire-fighting team know what to expect and/or are prepared for the situation, in the former not. If, however, a fire breaks out on the deck below, this may cause fuel cell-powered vehicles on the deck above to heat up. Built-up pressure can be relieved by means of an equalization valve in the tank. However, as the hydrogen discharges unnoticed and requires very little energy to ignite, persons checking the deck might be surprised by the start of a fire and/or an explosion.

Table 8: Fires caused by HEV, BEV and FC vehicles not connected to the ship's power distribution system

RI h	RI p	No.	Description
4.2	5.2	FC4	Escape of hydrogen from the pressure tank due to defective overpressure relief valve
4.1	5.1	HEV3	Hybrid vehicle: battery fire (lithium ion) with “great escalation”
4.1	5.1	BEV3	Fully electric vehicle: battery fire (lithium ion) with “great escalation”
4.1	5.1	HEV7	Hybrid vehicle: vehicle fire caused by NiMH battery with “great escalation”
4.1	5.1	FC3	FC vehicle: battery fire (lithium ion) with “great escalation”

Table 9: Fires caused by HEV and BEV vehicles as well as vehicles with refrigeration unit (RU) connected to the ship's power distribution system.

RI h	RI p	No.	Description
5.5	5.5	RU2	Vehicle with refrigeration unit: power cable fire
5.1	6.1	RU5	Vehicle with refrigeration unit: cable fire with “great escalation”
5.1	6.1	RU8	refrigeration unit fire with “great escalation”
5.0	5.1	HEV11	Hybrid vehicle: power cable smouldering fire
5.0	5.1	BEV8	Fully electric vehicle: power cable smouldering fire
4.6	5.6	HEV10	Hybrid vehicle: battery fire (lithium ion) with “great escalation”
4.5	5.5	BEV7	Fully electric vehicle: battery fire (lithium ion) with “great escalation”

Table 10: HEV, BEV and FC vehicles affected by fire on board

RI h	RI p	No.	Description
5.4	5.4	FC11	Release of hydrogen from the tank due to temperature increase caused by a fire below the vehicle deck
5.3	6.3	FC13	Release of hydrogen from the tank due to temperature increase caused by a fire on the same vehicle deck, “great escalation“

5.2. Estimated number of fires on the vehicle deck

The FSA (2008), which was taken as a basis for fires on ro-pax ships, shows that, during the period under evaluation (1994 to 2004), it was expected that approximately three fires per year would break out on the vehicle deck ($f=1.06*10^{-3}$ for 2833 ships). There is no reference in the FSA study as to whether fires involving supply cables leading to refrigeration units on semi-trailers or HGVs were accounted for. The present study assumes that this is not the case because power cable smouldering fires generally do not result in major damage and are therefore not included in the FSA accident statistics.

The evaluation of the hazard analysis for this study shows that, due to the electric and fuel cell vehicles as well as the vehicles with a refrigeration unit, additional fires are to be expected.

Table 11 summarizes the number of fires to be expected if the vehicles are not connected to the ship's power distribution system:

- Based on the results of the analysis, an additional 0.33 fires per year are to be expected in the entire ro-pax fleet due to hybrid electrical vehicles (HEV) and fully electric vehicles (BEV) (see Failures/Risks HEV 1- HEV 7 and BEV 1- BEV 4 in Annex 7). This corresponds to a frequency of $1.16*10^{-4}$ per ship year.

- The transport of fuel cell vehicles, on the other hand, is only expected to cause 0.03 additional fires per year ($1.06*10^{-5}$/ship year, see FC 1-FC 6 in Annex 7).

Thus, a total of 0.36 additional fires per year are expected in the ro-pax fleet if the vehicles are not connected to the ship's power distribution system. This signifies an increase of 12 % in the number of fires that occur per year.

If vehicles are connected to the ship's power distribution system, the number of the expected fires increases, especially since numerous cable fires are anticipated in this case.

- If all HEV and BEV were connected to the ship's power distribution system for charging (Table 12), this would mean 602.9 additional fires per year due to HEV and BEV according to the hazard analysis (see HEV 8 – HEV 14 and BEV 5 - BEV 10). 600 of these fires would be limited to the power cable and would not have dangerous consequences for the passengers, the crew or the ship.

- As a result of the connection of refrigeration units to the ship's power distribution system (RU 2 – RU 8), 101.4 fires per year are expected in the entire ro-pax fleet (3.58*10-2 per ship year), 100 of them limited to the power cable.

700 of the 704.3 fires per year forecast to break out because of HEV, BEV and vehicles with a refrigeration unit connected to the ship's power distribution system would be limited to a cable fire (no escalation, no dangerous consequences for the crew, the passengers or the ship). Only 4.3 fires would have larger implications.

A realistic estimate of additional fires caused by electric vehicles, fuel cell powered vehicles and vehicles with refrigeration units assumes that all BEV and all vehicles with a refrigeration unit are connected to the ship's power distribution system, while all HEV and fuel cell powered vehicles are not connected (Table 13).

Based on this assumption, 403 additional fires are to be expected in the ro-pax fleet if no additional measures are introduced. Their distribution is as follows:

- 0.19 caused by HEV (not connected to the ship's power distribution system)
- 301.4 caused by BEV (connected to the ship's power distribution system)
- 0.03 caused by FC vehicles (not connected to the ship's power distribution system)
- 101.4 caused by vehicles with a refrigeration unit (connected to the ship's power distribution system)

In order to be able to compare this figure with those of FSA 2008, 400 fires (300 caused by charging BEV and 100 by refrigeration unit power cables) which are limited to cable fires (no escalation, no dangerous consequences for the crew, the passengers or the ship) are deducted from it, since it is assumed that such fires were not accounted for in FSA (2008) either. This implies: If BEV, HEV and vehicles with fuel cells or refrigeration units are transported, 3 additional fires per year are expected within the ro-pax fleet (not counting cable fires). This means that – in comparison with the FSA figures – the number of fires on the vehicle deck caused by the transport of such vehicles is expected to double if no appropriate measures are introduced.

Table 11: Fires caused by HEV, BEV and FC vehicles not connected to the ship's power distribution system

Vehicle type	Scenarios	Number of fires per year (sum of individual scenarios)	Frequency (1/ship year) (sum of individual scenarios)	Of those minor (SI h and SI p <4)	Of those major (SI h or SI p >=4)
HEV	HEV1-7	0.19	6.71E-5	97.7 %	2.3%
BEV	BEV1-4	0.14	4.94E-5	97.8%	2.2%
Sum 1: HEV+BEV		0.33	1.16E-4	97.7 %	2.3%
FC	FC1-6	0.03	1.06E-5	82.3%	17.7%
Total sum: HEV+BEV+FC		0.36	1.27E-4	96.5%	3.5%

Table 12: Fires caused by HEV, BEV, FC and RU vehicles not connected to the ship's power distribution system

Vehicle type	Scenarios	Number of fires per year (sum of individual scenarios)	Frequency (1/ship year) (sum of individual scenarios)	Of those minor (SI h and SI p <4)	Of those major (SI h or SI p >=4)
HEV	HEV8-14	301.5	1.06E-1	99.7%	0.3%
BEV	BEV5-10	301.4	1.06E-1	99.9%	0.1%
Sum 1: HEV+BEV	HEV8-14, BEV5-10	602.9	2.13E-1	99.8%	0.2%
RU	RU2-8	101.4	3.58E-2	99.9%	0.1%
Total sum: HEV+BEV+RU	HEV8-14, BEV5-10, RU2-8	704.3	2.49E-1	99.8%	0.2%

Table 13: Fires caused by HEV, BEV, FC or RU vehicles; assumption: all BEV and RU vehicles are connected to the ship's power distribution system, all HEV and FC vehicles are not connected.

Vehicle type	Scenarios	Number of fires per year in the ro-pax fleet	Of those minor (SI h and SI p <4)	Of those major (SI h or SI p >=4)
HEV (not connected)	HEV 1-7	0.19	97.7 %	2.3%
BEV (connected)	BEV 5-10	301.4	99.9%	0.1%
FC (not connected)	FC1-6	0.03	82.3%	17.7%
RU (connected)	RU2-8	101.4	99.9%	0.1%
Sum		403.0	99.9%	0.1%

5.3. Possible improvements

To provide a better overview, the improvements discussed during the workshop are divided into the fields of fire protection, fire detection, fire fighting as well as organisational and structural measures and described in the following:

5.3.1. Fire Protection

From the scenarios discussed during the workshop it has become clear that fire protection for electric and fuel cell powered vehicles should be improved and expanded.

If FC vehicles are to be transported in closed loading decks, the potentially explosive atmospheres must be extended. When defining the potentially explosive atmospheres in the lower part of the loading deck and explosion group (II A) of the currently applicable SOLAS regulations on fire protection in loading decks, mainly explosive gases heavier than air were considered (petrol and propane, see SOLAS II-2/20.3.2.1 and IACS UI SC 43 (2007)). As hydrogen is lighter than air, it would accumulate under the ceiling when escaping. Therefore, all on-site installations (lighting, fans, etc.) would require explosion protection in accordance with group II C, as very little energy is required to ignite hydrogen within its explosive limits.

To avoid damage to cables and sockets used to charge electric vehicles and to connect refrigeration units which, in turn, might result in fires, only lockable sockets should be used. This prevents cables from being disconnected while they carry current, which usually results in premature wear of the connector contacts and thus increases the risk of fire. The corresponding provisions can be found in the class rules (e. g. GL: I, 1 Seagoing ships, 3 Electrical Installations, Section 11C, 1.4).

It is recommended that all sockets used for the above purposes be capable of being switched off from one central location outside the vehicle deck. In the case of a fire, the power supply can then be disconnected from a safe place in order to prevent additional energy from flowing to vehicle batteries to be charged or to the refrigeration units.

5.3.2. Detection

As regards the detection of failures in connection with electric vehicles, it was concluded during the workshop that in the main the below improvements can be considered.

Lithium ion battery fires cannot be extinguished. However, even before the battery starts burning, gases or gas mixtures escape from the battery housing. Their concentration is sufficient for measurement and detection purposes. Table 14 illustrates a test carried out with a lithium ion battery. The battery in the right-hand column is faulty. Individual cells are opening, however, no fire has started yet. The battery in the left-hand column is in a state of thermal runaway which ultimately leads to the battery catching fire.

While faulty NiMH batteries do not start to burn, the increase in such a battery's temperature, too, is so strong that it may lead to a vehicle fire. In such a case, NiMH batteries, too, release gases that can be detected.

Therefore, detecting gases or gas mixtures which escape from faulty batteries at the earliest opportunity is desirable because this makes it possible to locate and fight beginning fires already at a very early stage. If sufficient amounts of extinguishing water are available, the affected vehicle can be cooled down and the fire might be prevented from spreading to neighbouring vehicles.

As regards fuel cell vehicles operated with hydrogen, there is a risk that results from hydrogen escaping from the pressure tank. This may be due to defects in the vehicles themselves or due to the pressure tank being exposed to severe heat caused by a fire in the loading space (including that below the FC vehicle) which causes the pressure in the tank to rise and eventually results in the discharge of gaseous hydrogen through the pressure relief valve. The crew is not able to notice whether hydrogen escapes or not. In addition, it is a substance that burns with an almost invisible flame. Hydrogen is a gas which, when exposed to air, forms a flammable gaseous mixture that requires only a very small input of energy for ignition. Therefore, the escape of hydrogen on a closed or even a semi-open deck can easily lead to a deflagration or an explosion followed by a fire.

For this reason, the experts at the workshop were of the opinion that fuel cell-powered vehicles operated with hydrogen should exclusively be transported on open loading decks.

On closed decks, means of detecting escaping hydrogen are indispensable to be able to protect passengers from deflagrations, explosions or fire and to prevent a fire which has already started from spreading as early as possible.

Results of gas analyses

	unit	Overcharge autoclave 60Ah SAMSUNG BMZ1307a_60Ah_GAS_02		thermal stability autoclave 60Ah SAMSUNG BMZ1307a_60Ah_GAS_04
kind of event		thermal runaway, venting, fire		cell opening, electrolyte evaporation, venting, no fire
volume of autoclave	l	45		45
p peak event	mbar	23700		13000
calculated total volume at normal pressure	l	1066.5		585
p final after event	mbar	8000		5390
volume of emitted gas	l	360		242.55
Fluorine concentration in the air of the autoclave	µg/l	353.3		90.2
O2	vol %	1.3		1.0
N2	vol %	13.7		19.1
H2	vol %	14.2		14.9
CO2	vol %	22.4		26.0
CO	vol %	15.2		16.9
Ar	vol %	0.1		0.2
Phosphin	mg/m3	0.1		0.07
Formaldehyde:	µg/m3	<2		<2
Acetaldehyde:	µg/m3	1720		1960
Propionaldehyde:	µg/m3	214		174
Butyraldehyde:	µg/m3	112		256
Valeraldehyd:	µg/m3	<2		<2
Methane:	vol%	8.70		7.4
Ethan:	vol%	4.5		1.8
Ethen:	ppm (vol)	34000		48000
Propane:	ppm (vol)	4900		2200
Propene:	ppm (vol)	17000		23000

calculatrion total amount = concentration * (volume autoclave + volume emitted gas)

Table 14: Escaping gases and gas concentration in the case of faulty battery cells (right-hand side) and fire (left-hand side). Source: batteryuniversity.eu GmbH

Gases that can be detected by corresponding sensors are also produced as a result of cable or smouldering fires of connection cables linking the ship's power distribution system to the electric vehicle for charging purposes or to the refrigeration unit for the supply with power. In consequence, the cable fire could be prevented from spreading to other vehicles by early detection and the prompt fighting of the fire.

Improving fire and gas detection with regard to the type of vehicles dealt with in this study can in principle be achieved by expanding the wording of the protection objectives in the SOLAS Convention, i.e., in Chapter II-2, Regulation 7 Detection and Alarm). Here, specifications can also be made as to the level from which onwards the risk of a fire must be detected and the substances to be considered as being involved in fires in the first place.

When specifying the fire protection objectives, a further distinction can be made between the

- detection of gases,
- detection of smouldering fires (fires with some smoke development but no open fire),
- detection of open fire with smoke development.

With appropriate environmental monitoring, gas, smoke and open fire should be detected reliably within a large area. Here, it should be borne in mind that the environmental conditions for detection can change. This can, for example, be due to variations in the stowage of HGVs and passenger cars that result in areas with better or worse air circulation or due to the loading deck fans being operated as extractor or forced-draft fans. In addition, the loading/unloading conditions must be considered. While the ship is being loaded or unloaded, it might be necessary to deactivate the sensors temporarily in order to prevent false alarms.

The detection of gases and fires also depends on whether the areas to be monitored are open, semi-open or closed loading decks. The ventilation regime of the individual loading decks also plays a role.

Currently, smoke and open fire can be detected on open loading decks. However, detecting gases is not technically feasible. Daylight and infrared cameras are used for monitoring purposes. Here, the cameras should be arranged in such a manner that optimum coverage of the space above the vehicles is achieved.

In the case of semi-open or closed loading decks, optical or thermic point detectors can be used to detect fires with open flames and smoke development as well as possibly also smouldering fires. However, the devices currently in use are not able to detect gases.

Given these circumstances, smoke extraction systems seem to make sense. These systems work independently of the loading deck ventilation system and actively take in air from the loading deck. With the help of pipes, the installation can be adapted to the structural and ventilation conditions of the ship in order to achieve the best possible detection coverage on the loading deck. In combination with a gas detection system, not only smoke from fires, but also gases can be detected.

Another advantage that comes with a smoke extraction system is that is draws in ambient air: due to its low convection heat, smoke that results from smouldering fires might not even rise to the loading deck ceiling

where smoke detectors are usually installed and would then not be detected. The extraction system, by contrast, can guide this smoke past its integrated sensors and can then notify the crew of the fire.

General remarks on the installation of a fire and gas detection system:

Fire and gas detection system always have to be adapted to the local conditions. These conditions have to be known and need to be taken into account during the systems' design and installation in order to facilitate effective detection. The aim during the design and installation of the detection system should be the earliest possible detection of the quantities to be recognized so as to prevent fires from starting or to stop them from spreading as early as possible.

To this end, the following amendments to SOLAS Chapter II-2, Regulation 7 can be considered:

- Planning

  Designing fire/gas detection systems for loading decks of ro-ro/ro-pax ships is a step-by-step process which must take into account the following points:

  - design of the loading decks and potential natural air circulation
  - possible ventilation concepts
  - stowage plans for the vehicles to be carried, sorted by drive system (electric vehicles with lithium ion battery, fuel cell-powered vehicles)
  - vehicles to be connected to the ship's power distribution system (electric vehicles with rechargeable battery, refrigerated containers, vehicles with refrigeration units)

- Installation

  In order to ensure that a gas and/or fire detection system works efficiently,

  - it is advisable to establish and document the ventilation parameters on the loading decks prior to the installation and
  - to compare the design values to the actual values.

  If these differ, changes can be made to the arrangement of the installation and documented accordingly. After every modification and/or change of use, a re-testing of the effectiveness of the system should be considered.

- Installation and maintenance firms

  Experience has shown that sometimes fire detection systems do not work or do not work efficiently in some sections because they were not installed properly. It should therefore be considered whether to introduce a certification procedure for installation and maintenance firms carrying out such work that guarantees a sufficient level of experience and qualification on the part of the personnel.

- Inspections and tests

  Performance tests in accordance with the FSS Code Chapter 9/10 should be carried out and documented by qualified personnel. In addition to the FSS Code, it could be considered whether to test the effectiveness of the gas and fire detection system in every section. These tests should also be carried out and documented by sufficiently qualified personnel.

5.3.3. Fire fighting

The workshop held in the framework of this study has shown that fires resulting from the types of vehicles analysed differ from other ship fires, because, for example in the case of battery fires, the temperatures are very high and toxic gases as well as dangerous liquids (electrolyte, hydrofluoric acids) can escape. In addition, there is a risk of explosion due to the hydrogen involved. Escaping hydrogen can also burn with a nearly invisible flame. The training and equipment (protective clothing, respiratory protection, possibly thermal-imaging cameras) of the rescue workers might need to be adapted to these risks.

In the case of fires involving or near electrically and fuel cell-powered vehicles, it is especially important to cool down the material that is on fire as well as its surrounding area. This requires large quantities of water. Therefore, and in order to avoid endangering the stability of the ship with the extinguishing water, ensuring the unhindered runoff of the extinguishing water is of special importance. The size and arrangement of the runoffs is laid down in MSC.1/Circ.1320 (2009) and in the class rules. Another important factor in this regard is that the runoffs must be kept free from burnt material and cargo.

Spaces where hydrogen can escape must not be protected by a CO_2-based fire suppression system, as CO_2, when being discharged, may ignite hydrogen AGBF, 2008).

High pressure water mist systems seem to be particularly suitable because they disperse the fire-fighting agent very evenly throughout the room, also allowing it to reach covered areas. When applied locally, high pressure water mist has an inerting and cooling effect. High pressure water mist systems can take the form of mobile or fixed (MSC.1/Circ.1430) units. Mobile units have low hose diameters which, on the one hand, makes them lightweight and allows for long hose lengths. On the other hand, such hoses limit water throughput per unit time and may get stuck in narrow spots.

High energy fires might also be fought more successfully by adding additives to the extinguishing water. Additives are used to improve the properties of the extinguishing water. Compared with normal water, wetting agents and wetting water have a lower surface tension, and therefore the extinguishing agent can penetrate the burning material more thoroughly. Low-dose foaming agent is used as wetting agent. *Aqueous Film Forming Foam* (AFFF) is a synthetic foaming agent which helps to create a foam that forms a water film. AFFF is superior to water when it comes to forming an aqueous film between the burning material and the side on which the extinguishing takes place which prevents the supply of oxygen to the burning material, has good cooling properties and stops additional inflammable gases from outgassing into the combustion zone.

Additional proposed measure relate to demarcated areas specially reserved for transporting electric vehicles (BEV, HEV, FC):

- Equipment of these areas with pop-up nozzles which are also used for helicopter landing decks (cf. MSC.1/Circ. 1431 (2012)) or aircraft carrier landing decks. Advantages of these nozzles: fires are fought from below the vehicles, i. e., close to potential fire sources. Pop-up nozzles can also be used on open loading decks. However, due to its constructional complexity, this measure is more appropriate for new ships.

- These areas could be equipped with special detectors which are able to detect outgassings from batteries before a fire breaks out.

- It could make sense to have the fire extinguishing system (water spray system or high pressure water mist system) start automatically after detection by the fire detection system to contain fires already at a very early stage. Fire extinguishing systems which start automatically are allowed under MSC.1/Circ.1430 (2012).

- Areas with BEV, HEV and FC vehicles could also be sealed off from the remaining parts of the vehicle deck by means of a "water wall" activated in the case of a fire. Here, it would be important to make sure that the (additional) water can run off without any problems.

- If BEV, HEV and FC vehicles are transported on open loading decks, fixed swivelling monitors (water cannons) are a means of fighting fires effectively. Such monitors are also used on tankers (foam monitors) as well as on fireboats (water and/or foam monitors). Corresponding regulations can be found in the *International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk* (IBC Code), in Chapter 14 of the *International Code for Fire Safety Systems* and in the regulations concerning fireboats.

- For reasons of the increased risk of fire, rules could be imposed for BEV, HEV and FC vehicles that require them to be parked at greater distances to neighbouring vehicles in order to make it more difficult for a fire to spread from one vehicle to the next and to improve accessibility for emergency services.

- Also, special requirements regarding ventilation, explosion protection etc. in areas holding BEV, HEV and FC vehicles could be introduced.

5.3.4. Organisational measures

The workshop held in the framework of this study has shown that if BEV, HEV and FC vehicles are clearly marked and visible during transport on board this is beneficial information for emergency services with regard to self-protection, equipment, safety distances and the application of appropriate fire-fighting agents. So far, fuel cell-powered vehicles operated with compressed hydrogen, under Annex V of Regulation (EU) No. 406/2010, must only bear a small label. This label is not visible if the vehicle deck is fully loaded.

However, marking these vehicle (for example with a magnetic rooftop item) would require drivers concerned to specify their type of vehicle when booking the journey or prior to parking the vehicle on board. This information is also required if special parking spaces are provided for such vehicle groups. If electric vehicles are to be charged during the crossing, special parking spaces are required simply because not all parking spaces on the vehicle deck offer access to a socket.

Therefore, and in order to be able to assign the vehicles to their special areas on the loading deck, they must be separated from conventional vehicles in the terminal area. This could, for instance, be achieved by providing one or more specially marked separate waiting lanes.

In any event, the crew should know if and where BEV, HEV or FC vehicles are on board. This information is highly valuable for emergency services in the event of a fire.

Due the increased likelihood of fire, BEV, HEV and FC vehicles should, moreover, not be parked near dangerous goods vehicles.

The results of the workshop show that FC vehicles in closed loading decks pose special risks. Accordingly, it is proposed to transport such vehicles only on open loading decks. If they are transported on closed loading decks, it must be borne in mind that these decks must not be equipped with CO_2 fire extinguishing systems (AGBF, 2008). An increased air change rate (explosion-proof fans) is recommended. During the workshop, it

was proposed to connect the pressure-relief pipes of the hydrogen pressure tanks to an overboard discharge outlet when FC vehicles are transported on closed decks. However, this does not seem to be feasible in practice, as such a measure would also require alterations to the design of the vehicles.

Additional organizational measures concern the connection of electric vehicles or refrigeration units to the ship's power distribution system. It is recommended that only approved cables provided on board the ship be used and that they be inspected regularly. Furthermore, cables should be handled (i. e., laid, connected and disconnected) only by trained members of the crew.

5.3.5. Structural measures

Insulated fixed or mobile partitions (in accordance with SOLAS II-2/9.2 and 20), for example roller blinds, can be used to prevent a fire on the vehicle deck from spreading. Besides demanding structural requirements, this might also limit the usability of the deck; moreover, the requirements regarding ventilation etc. of the individual loading deck areas would have to be fulfilled.

5.4. Need for further investigation

- On the basis of the tests performed in the framework of the research project to improve the safety of passengers on ferryboats („*Verbesserung der Sicherheit von Personen in der Fährschifffahrt*“ (VESPER^{PLUS})), funded by the Federal Ministry of Education and Research, further investigations should be carried out to establish algorithms for the detection of gas mixtures that escape from defective lithium ion batteries or form as a result of cable fires. In particular, tests under realistic conditions (i. e. realistic stowage and ventilation conditions) need to be carried out on the loading deck.
- It is recommended to test the effectiveness of high pressure water mist for fighting fires resulting from lithium ion batteries and hydrogen jet flames (ignited hydrogen that escapes from pressure tanks of fuel cell-powered vehicles) as well as fires of cables used for alternating voltages of up to 400 V.
- Effectiveness tests are also recommended for the different combinations of fire detection, gas detection and fire-fighting installations in areas which might be used specially for the stowage of electric vehicles.
- Furthermore, parameters to test the effectiveness of fire and gas detection in conjunction with different means of fire fighting should be developed in order to define criteria for appropriate fire-fighting agents and systems.

- It is recommended to define a structure for effectiveness tests for fire and gas detection systems on ro-ro and ro-pax ships.

5.5. Recommendations for action

- While on the ferry, BEV, HEV and FC vehicles should be clearly marked (so that emergency services can act accordingly).
- BEV and HEV/FC vehicles must be clearly marked on the stowage plan (so that emergency services can act accordingly).
- FC vehicles with hydrogen pressure tanks should only be transported on open decks.
- BEV/HEV and FC vehicles should be transported in special areas (equipped with appropriate detectors, fire-extinguishing equipment and fire-extinguishing agents). In the case of a fire, possibly separation of such vehicles by means of a water wall or mobile partitions (roller blinds).
- Only tested cables provided on board the ship should be used to connect electric vehicles and refrigeration units, and these cables should only be handled by trained members of the crew.
- It should be possible to switch off the sockets (used to charge electric vehicles and to connect refrigeration units) from one central location if, due to a fire, the cable can no longer be detached locally.
- BEV/HEV and FC vehicles should be kept physically separate from vehicles carrying dangerous goods.
- The awareness of fire-fighting teams should be raised with regard to the dangers arising from BEV/HEV and FC vehicles and their training should be extended accordingly.

6. Literature

AGBF, 2008	Wasserstoff und dessen Gefahren - Ein Leitfaden für Feuerwehren Arbeitsgemeinschaft der Leiter der Berufsfeuerwehren in der Bundesrepublik Deutschland – Arbeitskreis Grundsatzfragen – Bearbeitungsstand: Oktober 2008
EU 406/2010	COMMISSION REGULATION (EU) No 406/2010 of 26 April 2010 implementing regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles
FSA, 2008	Formal Safety Assessment FSA – RoPax ships, Details of the Formal Safety Assessment International Maritime Organization (IMO) MSC 85/INF.3, 21 July 2008
IACS SC 43, 2007	IACS unified interpretations of the International Convention for the Safety of Life at Sea (SOLAS) and its Amendments, SC43: Precaution against ignition of explosive petrol and air mixture in closed vehicle spaces, closed Ro-Ro spaces and special category spaces, Rev. 2, Dec 2007
IMO, 2002	IMO Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-making process MSC/Circ.1023/MEPC/Circ.392, April 2002
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MSC.1/Circ.1272 (2008)	Guidelines for the approval of fixed water-based fire-fighting systems for Ro-Ro spaces and special category spaces equivalent to that referred to in resolution A.123(V) MSC.1/Circ.1272, 4 June 2008
MSC.1/Circ.1320 (2009)	Guidelines for the drainage of fire-fighting water from closed vehicle and Ro-Ro Spaces and special category spaces of passenger and cargo ships, MSC.1/Circ.1320, 11 June 2009
MSC.1/Circ.1430 (2012)	Revised guidelines for the design and approval of fixed water-based fire-fighting systems for Ro-Ro Spaces and special category spaces, MSC.1/Circ.1430, May 2012
MSC.338(91), 2012	Adoption of Amendments to the international convention for the safety of life at sea, 1974 Resolution MSC.338(91), adopted on 30 November 2012
MSC.339(91) (2012)	Adoption of Amendments to the international Code for fire Safety Systems (FSS Code), Resolution MSC.339(91), adopted on 30 November 2012
NPE; 2011	Second Report of the National Platform for Electromobility, Published by: Federal Government Joint Unit for Electric Mobility (GGEMO), Berlin 2011
Shell, 2009	Shell Pkw-Szenarien bis 2030, Fakten, Trends und Handlungsoptionen für nachhaltige Auto-Mobilität, herausgegeben von Shell Deutschland Oil GmbH, Hamburg, 2009
TAB, 2012	Konzepte der Elektromobilität und deren Bedeutung für Wirtschaft, Gesellschaft und Umwelt, Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Innovationsreport, Arbeitsbericht Nr. 153, Oktober 2012

7. Annex

Reference ship
Mecklenburg-Vorpommern

Length: 200 m

Width: 28 m

Year of construction: 1996

Crew: approx. 50

Passengers: max. 665

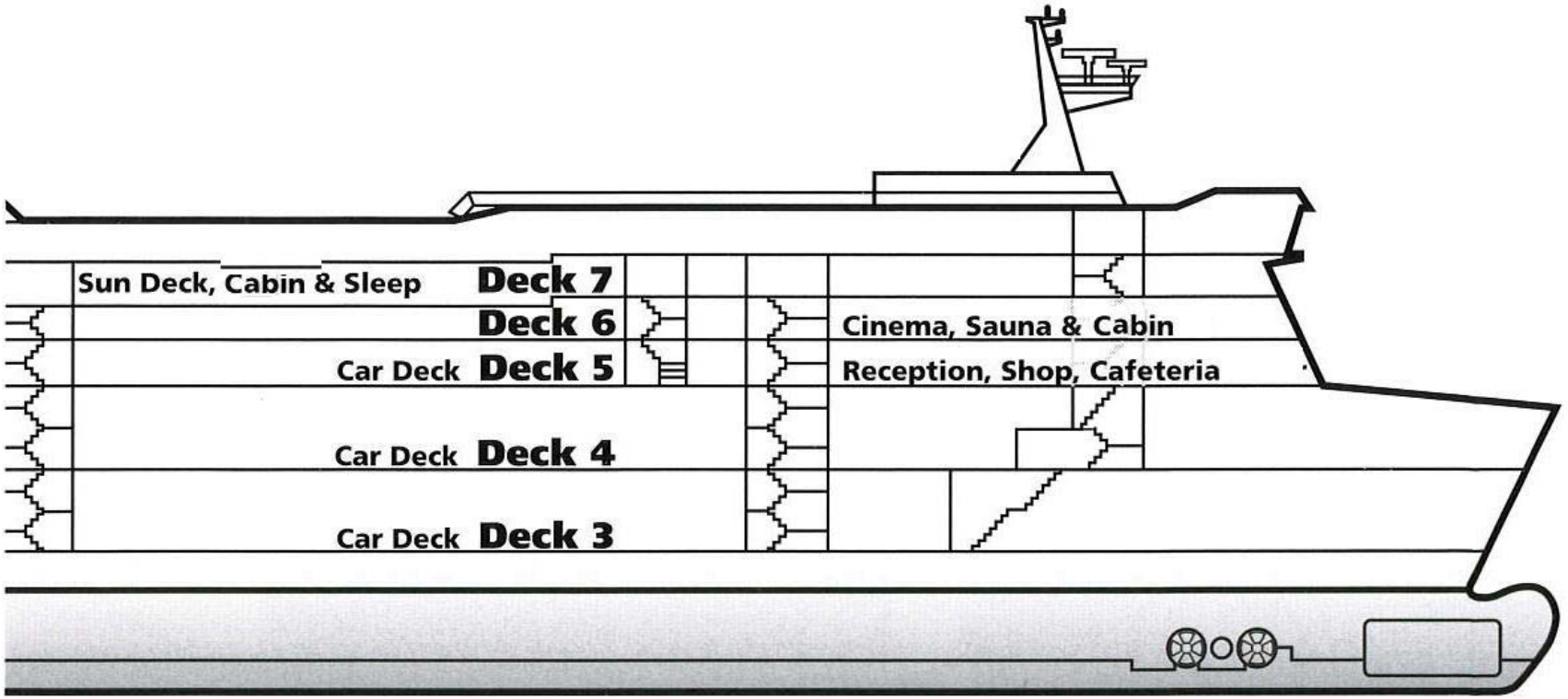
Loading capacity:

- cars: 445
- track length: 945 m

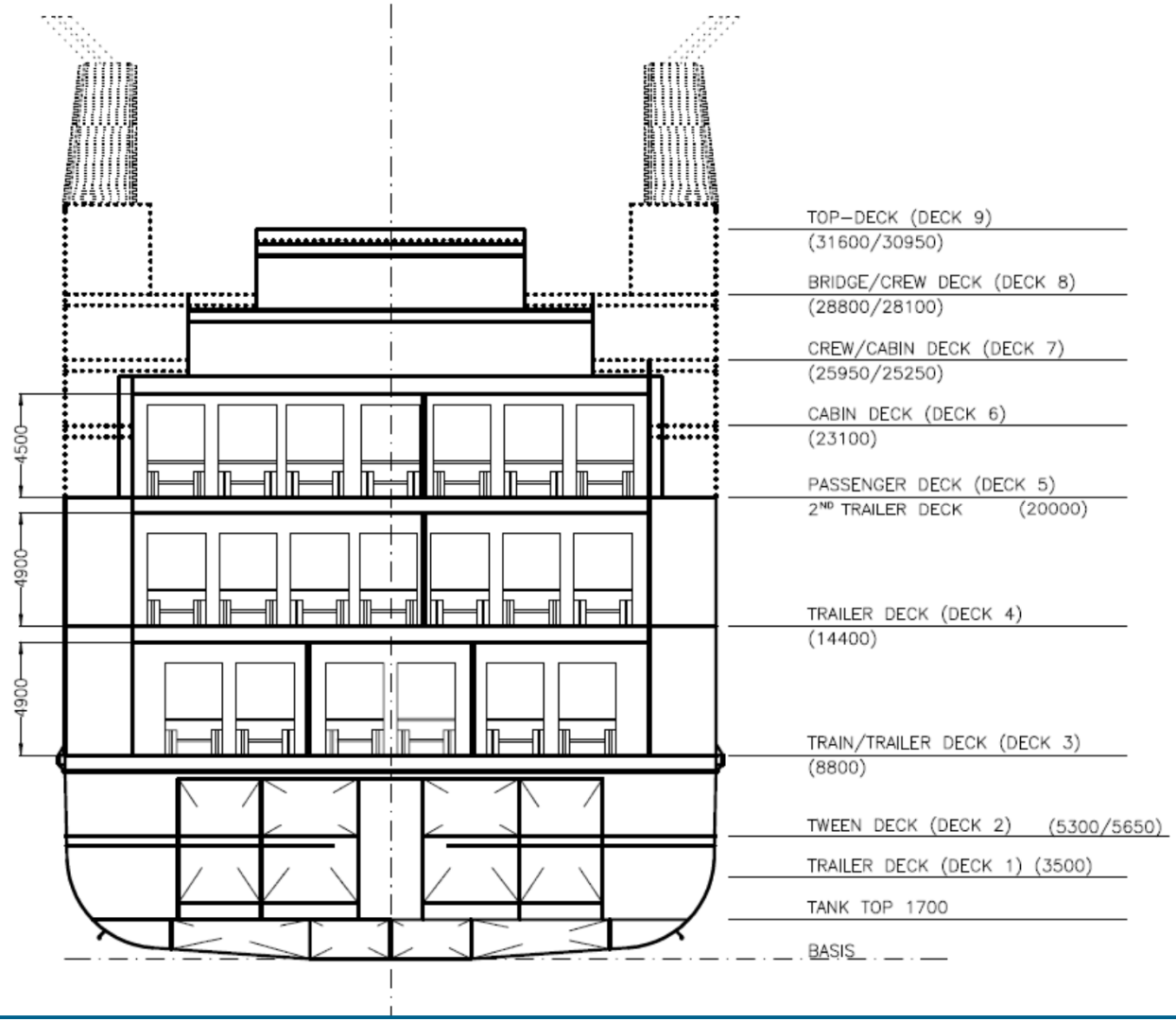
Route: Rostock – Trelleborg

Crossing time: approx. 6 hrs

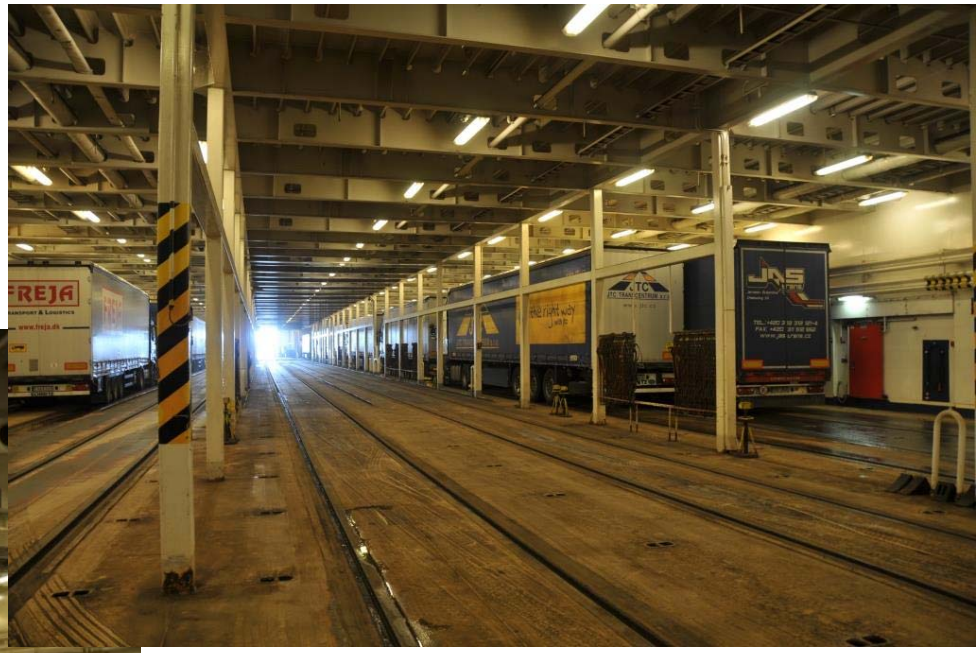
Decks 1

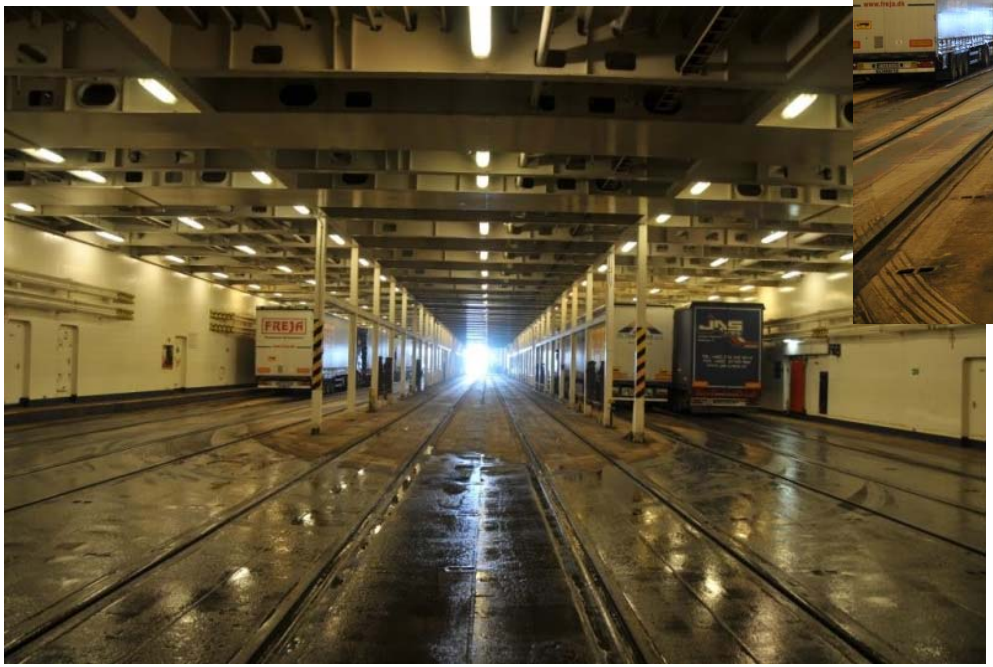

Sun Deck, Cabin & Sleep
Deck 7
Deck 6
Cinema, Sauna & Cabin
Car Deck
Deck 5
Reception, Shop, Cafeteria
Car Deck
Deck 4
Car Deck
Deck 3

Decks 2


TOP–DECK (DECK 9)
(31600/30950)
BRIDGE/CREW DECK (DECK 8)
(28800/28100)
CREW/CABIN DECK (DECK 7)
(25950/25250)
CABIN DECK (DECK 6)
(23100)
PASSENGER DECK (DECK 5)
2ND TRAILER DECK (20000)
TRAILER DECK (DECK 4)
(14400)
TRAIN/TRAILER DECK (DECK 3)
(8800)
TWEEN DECK (DECK 2) (5300/5650)
TRAILER DECK (DECK 1) (3500)
TANK TOP 1700
BASIS
4500
4900
4900

Deck 3 (train deck)





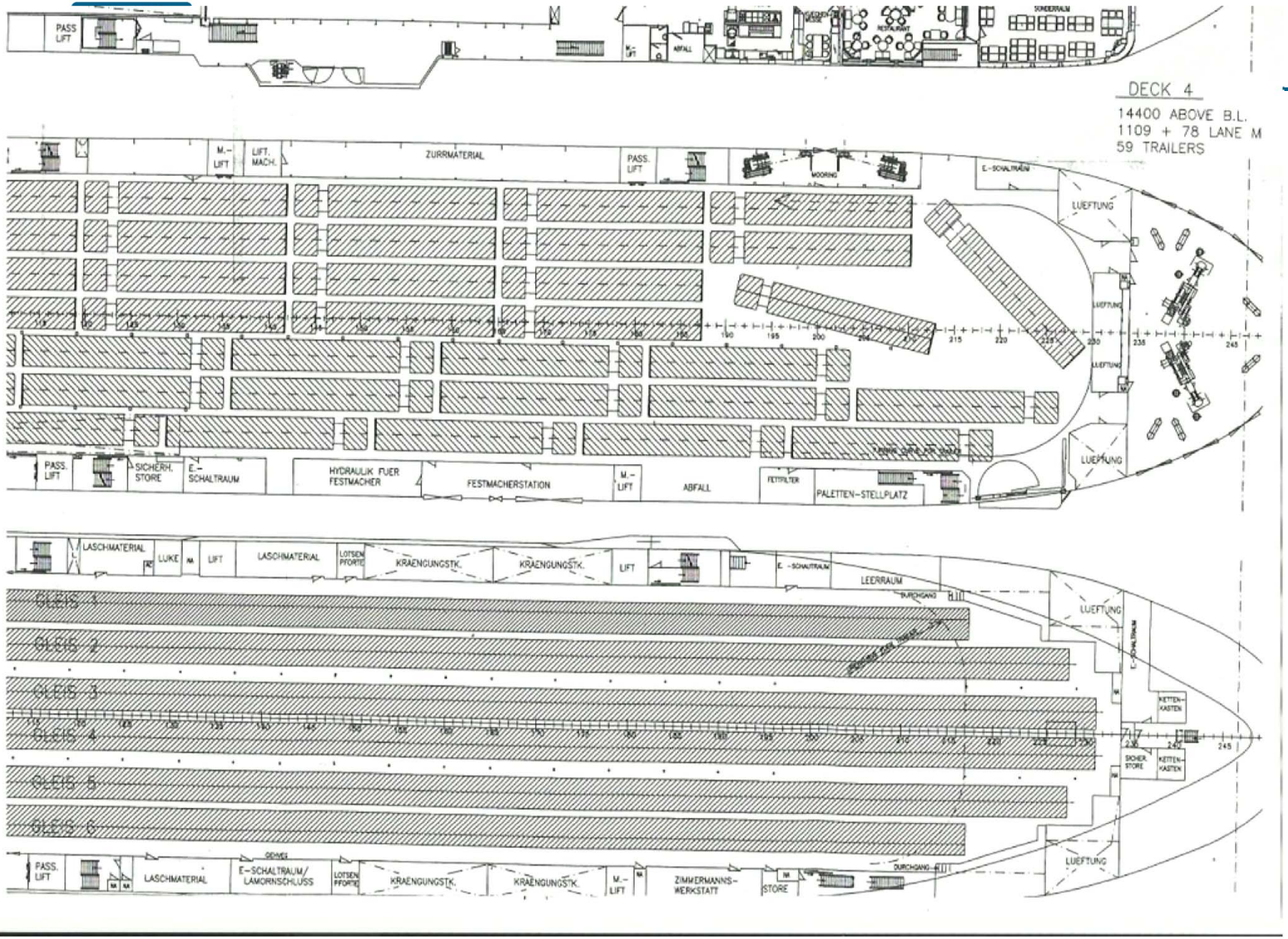
Deck 4

Deck 5

Videos

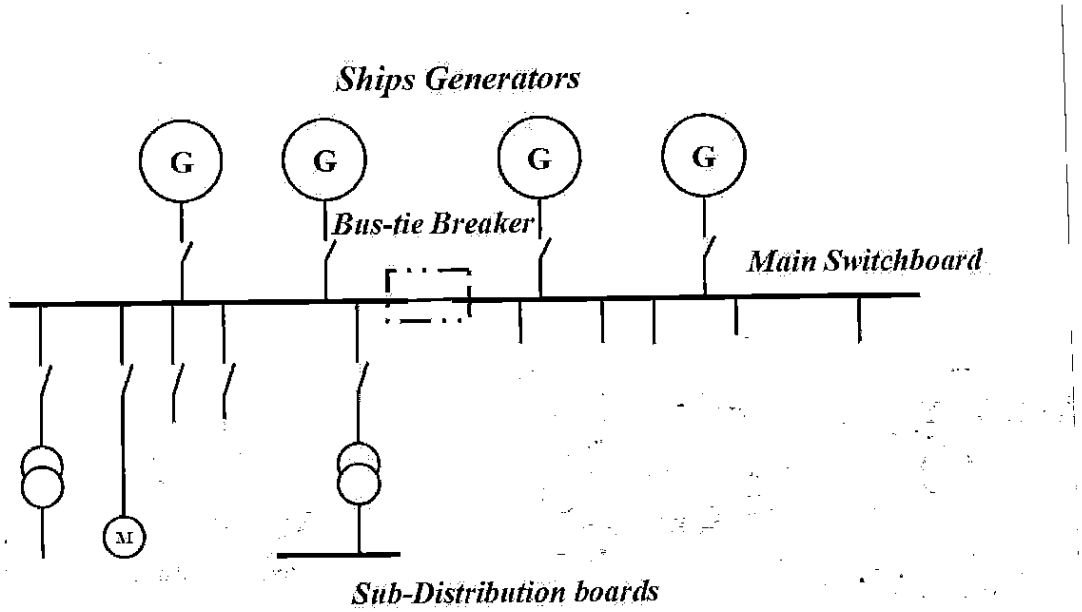
http://www.youtube.com/watch?v=SY2kMfoB8rE

http://www.youtube.com/watch?v=4ak7yJrLWOQ


DECK 4
14400 ABOVE B.L.
1109 + 78 LANE M
59 TRAILERS
PASS. LIFT
M.-LIFT
LIFT. MACH.
ZURRMATERIAL
MOORING
E.-SCHALTRAEN
LUEFTUNG
SICHERH. STORE
E.-SCHALTRAUM
HYDRAULIK FUER FESTMACHER
FESTMACHERSTATION
ABFALL
FETTFILTER
PALETTEN-STELLPLATZ
LASCHMATERIAL
LUKE
LIFT
LOTSEN PFORTE
KRAENGUNGSTK.
LEERRAUM
DURCHGANG
GLEIS 1
GLEIS 2
GLEIS 3
GLEIS 4
GLEIS 5
GLEIS 6
KETTEN-KASTEN
SICHER. STORE
GENIE
E-SCHALTRAUM/ LAMORNSCHLUSS
ZIMMERMANNS-WERKSTATT
STORE

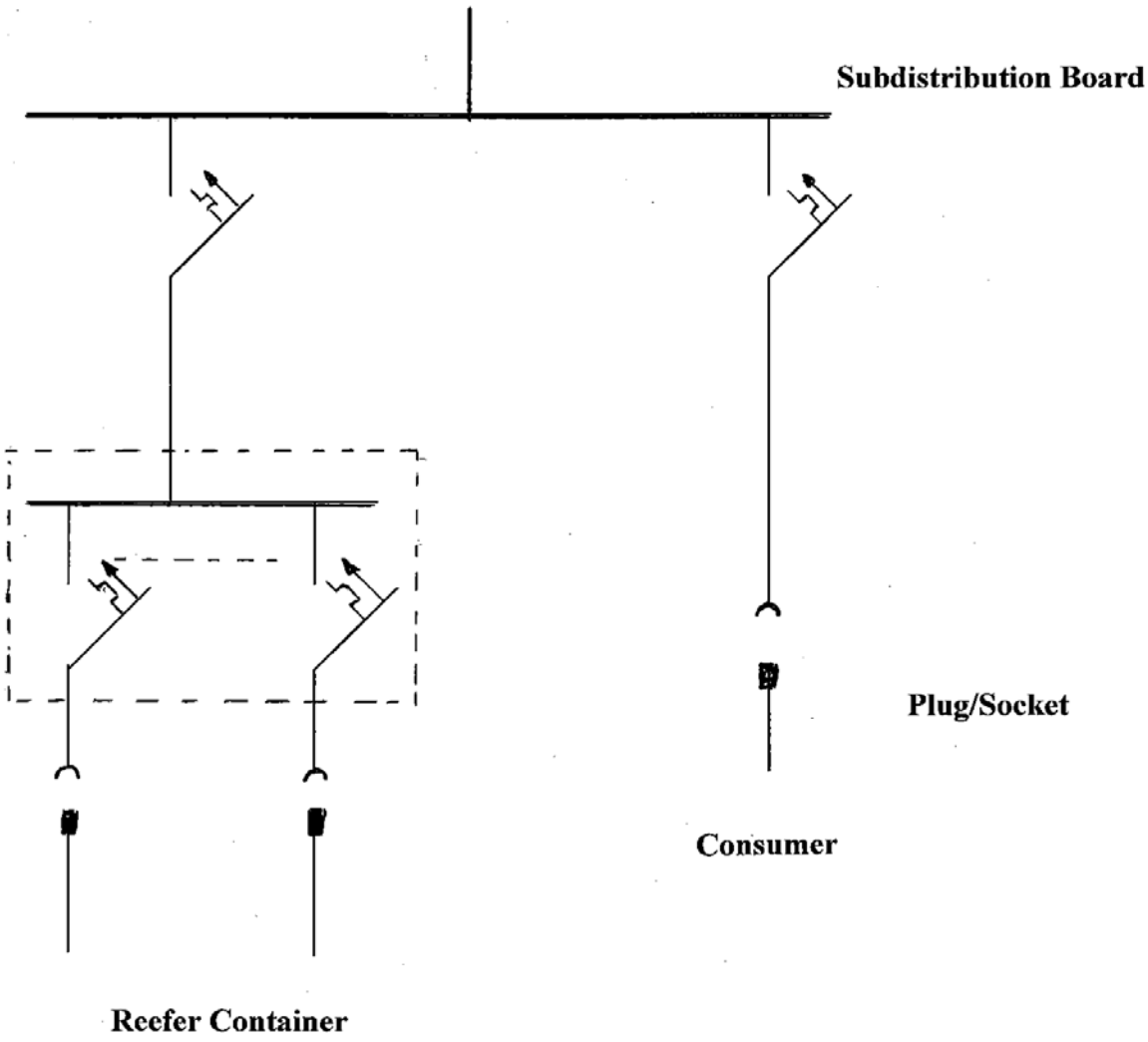
Typical energy supply on ships

Focus: supply of mobile consumers via plug connections



Typical power distribution system of a seagoing ship

- Consumers are supplied through sub-distribution boards or directly through the main switchboard.
- Distribution network voltage is 400 V/50 Hz or 440 V/60 Hz.
- The network is generally an IT network with insulation monitoring.
- If the insulation resistance drops below a set value, an alarm is raised, but the system is not switched off.
- With the exception of living areas, residual-current-operated protective devices (RCD) are not used in earthed networks either.
- Networks are protected selectively by means of power circuit breakers (where necessary, by way of a combination of power circuit breaker + fuse).
- Just as on land, sockets on board ships are protected against excessive loads or short circuits by means of upstream power circuit breakers or fuses.
- Appropriate sockets for supplying refrigerated containers are provided in the loading area. This makes it possible to selectively switch off the corresponding containers (connector, cable, container).
- Depending on the ship’s type and the requirements, additional sockets can be installed which are protected in the same manner as refrigerated container sockets.



High-voltage sockets on seagoing ships

For reefer containers (refrigerated containers), specific sockets are provided, in particular on container ships.

In addition, high-voltage sockets are installed in different areas of the ship, if necessary.

Sockets for refrigerated containers

- The requirements to be met by refrigerated containers (including power supply) are described in ISO 1496-2.
- High-voltage sockets are described in IEC 60309.
- (IEC60947-1 contains information on electrical engineering topics such as air and leakage paths).
- Power circuit breakers in the plug connections of refrigerated containers provide protection against overcurrent or short circuits.
- 32A plugs are a requirement under ISO 1496-2.
- Interlock mechanism: in order to remove the plug, a switch on the plug connection of the refrigerated container must be pressed. On-load removal of the plug is not possible.
- Under IEC 1496-2, containers must not require more than 18.75 kVA (15 kW). Typical: 400 V or 440 V; corresponding to 50 Hz, 360 V-460 V; 60 Hz 400 V-500 V

Normal high-voltage sockets

- Plug connection in accordance with IEC 60309 with relevant voltage levels: 16A, 32A, 63A
- Colour coding in accordance with IEC 60309:
  amber: 100 - 130 V
  blue: 200 - 250 V
  red: 380 - 480 V
- Confusion of plug connections is not possible
- Interlock mechanism not necessarily present, i. e. on-load removal might be possible
- Protection against short circuits and overcurrent in upstream distribution network

On-board operation

The ship’s power distribution system is built in such a way that failures resulting from overcurrent or short circuits are covered both **in the ship’s power distribution system** and **downstream from high-voltage sockets**. In the event of a failure, the system will be shut down by the shipboard protection systems. Failures in the ship’s power distribution system have no effect on the downstream consumers.

The electrical installations on ships are not only the responsibility of the shipping company, but are also subject to supervision by the classification societies. However, this does not apply to containers, vehicles and power cables which are ***outside the crew’s responsibility.***

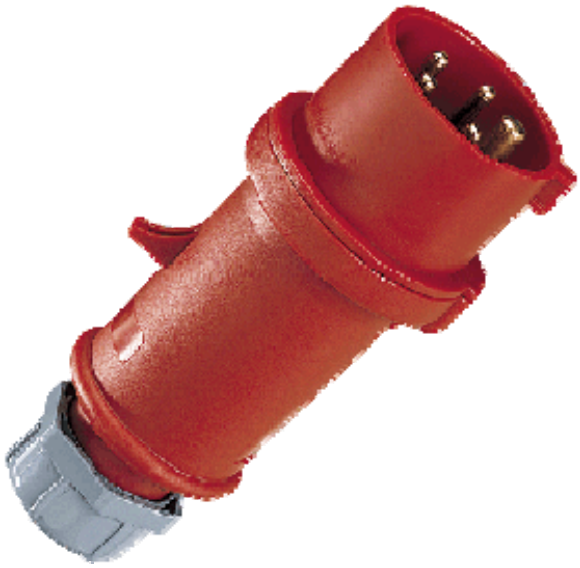
On **container ships**, containers are normally connected by the ship’s electricians. This ensures that the cables are laid and connected properly and that the correct type is used, irrespective of who provides them.

On **ro-ro ships**, the situation is a little different. Operators of HGVs with cargo containers connected to the ship’s power distribution system have stated that cables are provided on the ship. However, according to other information, power cables are carried in those vehicles.

Defective power cables are said to have already resulted in damage on numerous occasions. Currently, this issue is being discussed at IACS (International Association of Classification Societies) level.

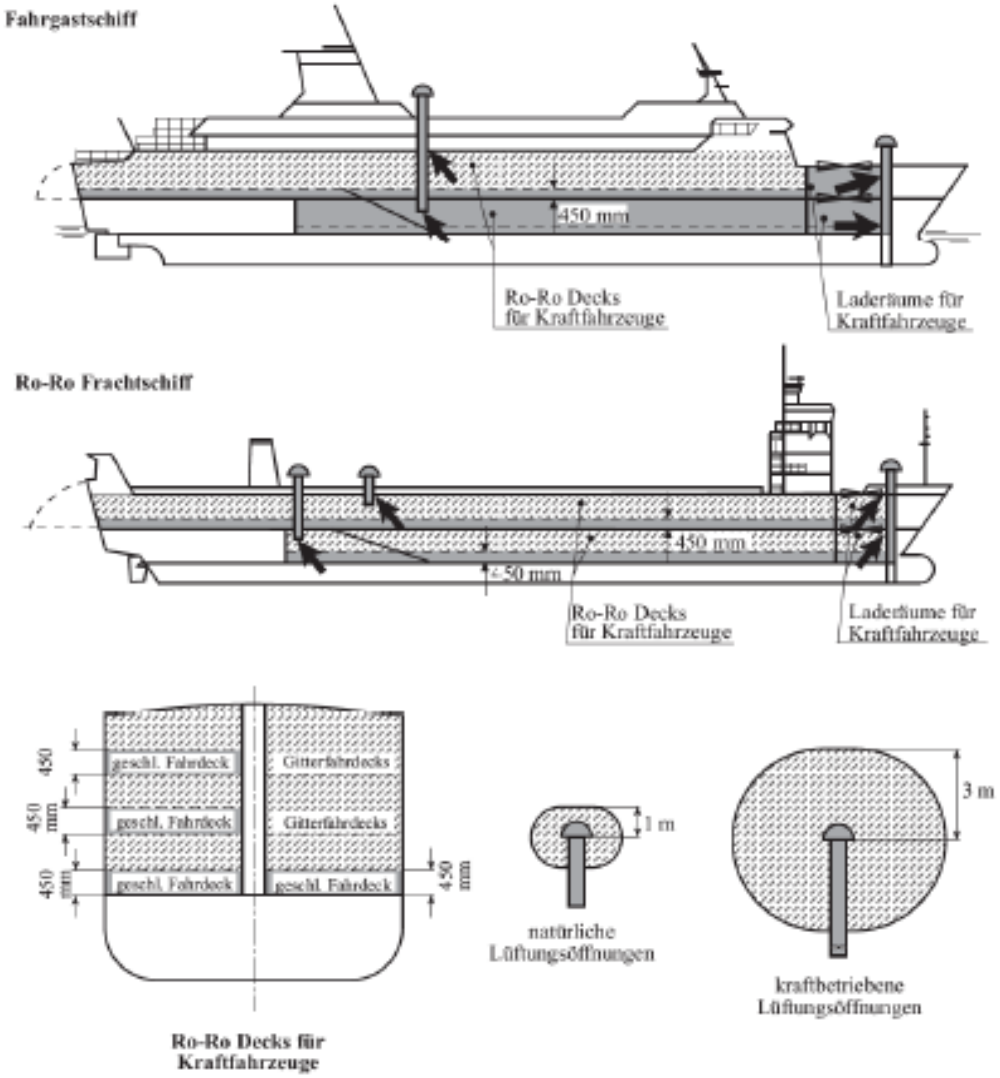
Reefer Container Socket, Type: Wiska Varitain Pushin

Source: Wiska



Industrial plug connection that can be found on “normal” seagoing ships

Source: Mennekes



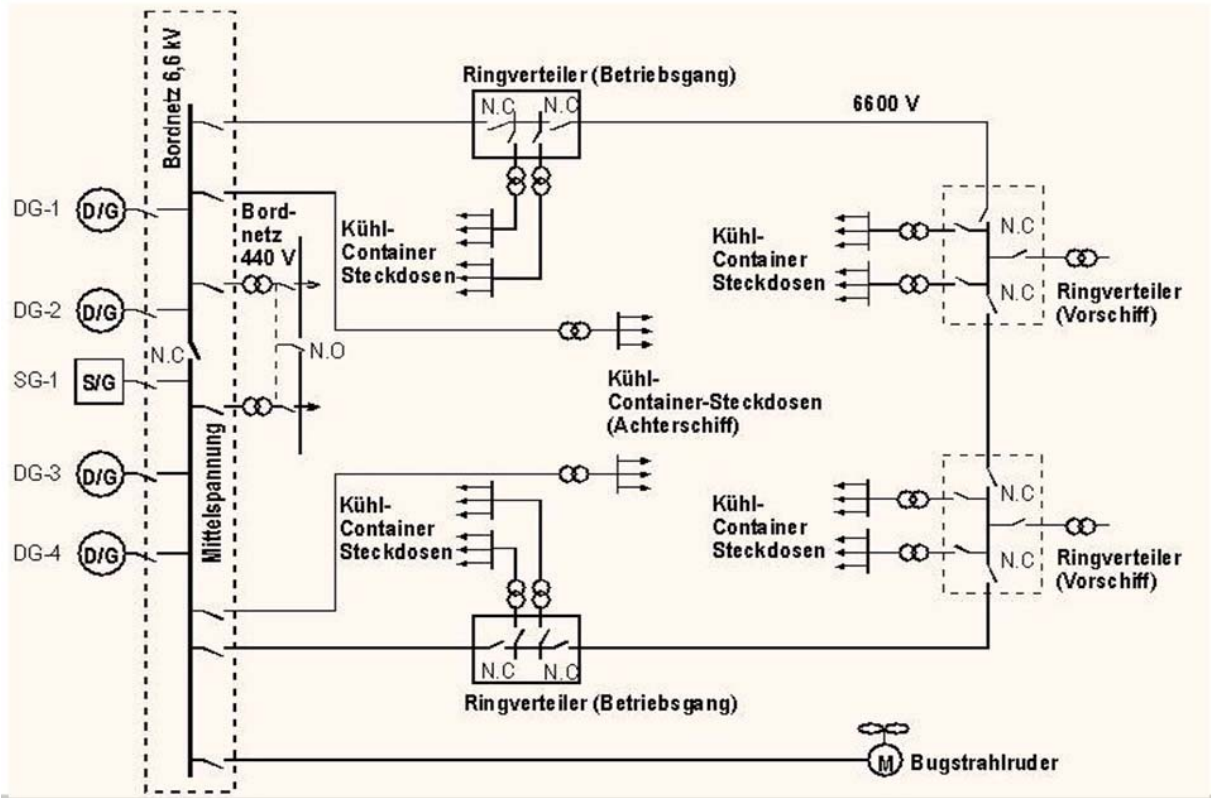
Bereiche	Ausführung der Geräte
oberhalb Schutzbereich (Zone 2)	≥ 10-fachem Luftwechsel/Stunde (siehe Abschnitt 1, K 3.4)
Schutzbereich (Zone 1)	explosionsgeschützte Betriebsmittel (siehe Abschnitt 1, K 3.3)

Abb. 16.1 Beispiele für Schutzbereiche in Kraftfahrzeugdecks und in Laderäumen zur Beförderung von Kraftfahrzeugen, die mit eigenem Antrieb an und von Bord gefahren werden und/oder die Kraftstoff in ihren Tanks haben

Installation requirements to be met on board are dependant on the potentially explosive atmospheres.

Annex

6 kV shipboard power distribution system



6.6 kV shipboard power distribution system

On ships with 6.6 kV power distribution systems, refrigerated containers and many of the ship’s consumers are supplied from the secondary 440 V network via a transformer.

Industrial wall socket with fuse protection

More commonly used in offshore applications or in land-based installations.

Source: Mennekes

Germanischer Lloyd

Short presentation of fires on ro-ro and ro-pax ships

www.gl-group.com

Contents

Overview of the fires

- Commodore Clipper
- Pearl of Scandinavia
- Mecklenburg-Vorpommern
- Lisco Gloria

Commodore Clipper - Facts

Type of ship	Ro-ro ferry
Entry into service	1999
Deadweight	4504 tdw
Load	HGVs (with trailers)
Persons on board	39 crew members
	62 passengers
Fire protection installations	Comprehensive fire detection system, CCTV, deluge system (drencher system, manual)
Nature of the marine casualty	Less serious marine casualty (fire)
Time and location	16 June 2010, 0242 hrs
of the marine casualty	English Channel, southwest of Portsmouth

Commodore Clipper - Development of the fire

Development of the fire

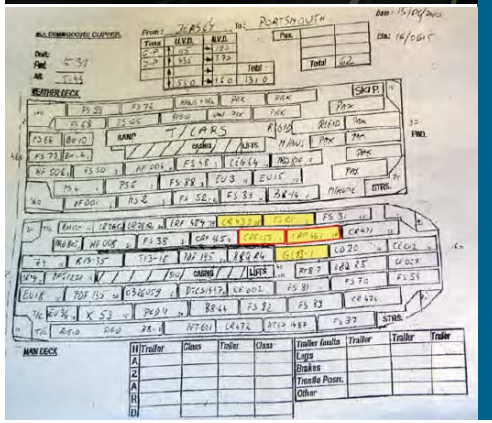
- An HGV trailer in the enclosed cargo area caught fire, and the fire spread to neighbouring vehicles (HGV trailers).

Fire-fighting efforts

- Deluge system (failed temporarily)
- Fire-fighting teams
  (crew and fire brigade)
- Manual cooling of the upper deck
- Extraction of smoke from the scene of fire (by natural and mechanical means)

Cause of the fire

Defective plug connection of the supply cable for a refrigerated trailer.



Commodore Clipper - Conclusions

Conclusions

- The control and power supply systems of the ship were damaged by the fire. This lead to an unexpected change of course, and the ventilation and mooring systems failed.
- As a result of mistakes in the installation of the fire detection system, it failed early on.
- The deluge system was damaged by the fire (while the system was in STOP mode).
- The stability of the ship was weakened due to the accumulation of extinguishing water (drainage facilities were blocked by cargo and burnt material.

Pearl of Scandinavia - Facts

Type of ship	Ro-ro ferry
Entry into service	1989
Deadweight	2800 tdw
Load	HGVs (with trailer), passenger cars
Persons on board	161 crew members
	490 passengers
Fire protection installations	Comprehensive fire detection system, CCTV, deluge system (drencher system, manual)
Nature of the marine casualty	Very serious marine casualty (fire)
Time and location	17 November 2010, 0558 hrs
of the marine casualty	6 nm northwest of Kullen, Sweden

Pearl of Scandinavia - Development of the fire

Development of the fire

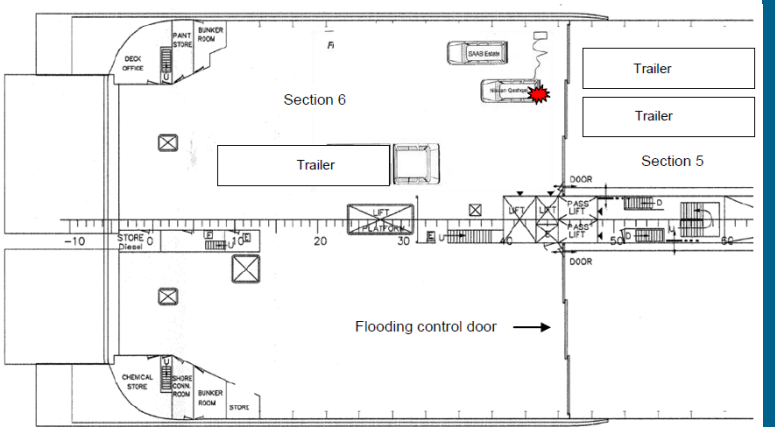
- A passenger car in the closed loading area caught fire, and the fire spread to neighbouring vehicles (HGV trailers).

Fire-fighting efforts

- Deluge system
- Fire-fighting teams
  (crew and on-shore fire brigades)

Cause of the fire

Could not be conclusively determined. Source of fire: battery unit of a hybrid electric passenger car (in charging mode)



Pearl of Scandinavia - Conclusions

Conclusions

- The fire spread fast.
- The fire was detected by smoke detectors early on.
- The incident was immediately investigated by the man on watch and using CCTV.
- The fire-fighting teams fought the fire effectively with manual means.
- The charging cable of the passenger car (property of the vehicle keeper) was ruled out as cause of the fire.

Mecklenburg-Vorpommern - Facts

Type of ship	Ro-ro ferry
Entry into service	1996
Deadweight	7205 tdw
Load	HGVs (with trailer), passenger cars
Persons on board	40 crew members
	136 passengers
Fire protection installations	Comprehensive fire detection system, CCTV, deluge system (drencher system, manual)
Nature of the marine casualty	Very serious marine casualty (fire)
Time and location	19 November 2010, 2035 hrs
of the marine casualty	Rostock port (Warnemünde)

Mecklenburg-Vorpommern - Development of the fire

Development of the fire

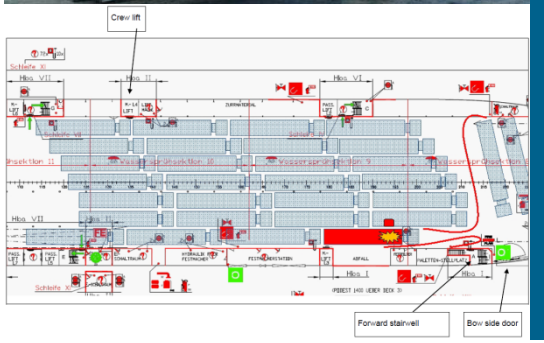
- A HGV trailer in the closed loading area caught fire, and the fire spread to neighbouring vehicles (HGV trailers).

Fire-fighting efforts

- Deluge system (failed temporarily)
- Fire-fighting teams
  (crew and Rostock fire brigade)
- Manual cooling of the upper deck
- Extraction of smoke from the scene of fire
- Deployment of an emergency towing vessel (Rostock port)
- Deployment of a fire-service vessel (Rostock fire brigade)

Cause of the fire

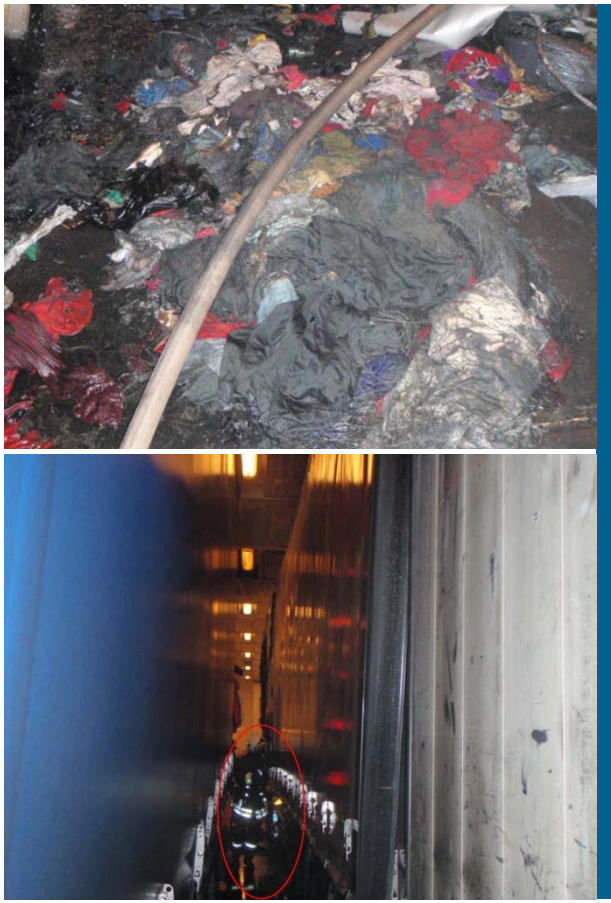
Battery of a VW mini bus (T3) on the load platform of an HGV trailer



Mecklenburg-Vorpommern - Conclusions

Conclusions

- The mini bus and the household items/clothing inside the vehicle represented a significant concentration of fire load and fire sources.
- Very tight stowing of vehicles hampered manual fire-fighting efforts and promoted rapid spread of the fire.
- The delayed activation of the deluge system (delay < 6 min) also contributed to this.
- Measures were delayed due to communication problems (no radiocommunication).
- Extinguishing water outlets became blocked which lead to stability issues.



Lisco Gloria - Facts

Type of ship	Ro-pax ferry
Entry into service	2002
Deadweight	7620 tdw
Load	HGVs (with trailer), passenger cars
Persons on board	32 crew members 203 passengers
Fire protection installations	Comprehensive fire detection system, CCTV, (automatic glass bulb type) sprinkler system Deluge system (drencher system, manual)
Nature of the marine casualty	Very serious marine casualty (fire)
Time and location	8 October 2010, 2358 hrs
of the marine casualty	Baltic Sea, about 7 sm northwest of Fehmarn

Lisco Gloria - Development of the fire

Development of the fire

- Uncontrolled fire of a refrigerated HGV in the open, roofed “garage area” of the stowage space.
- When the fire-fighting efforts (sprinkler, drencher, fire-fighting teams) failed, the ship was evacuated.

Fire-fighting efforts

- Deluge and sprinkler system (defective)
- Fire-fighting teams (unsuccessful)
- Cooling of the shell (by auxiliary vessels)

Cause of the fire

While a defect HGV refrigeration unit was suspected to be the cause of the fire, no final explanation was found.

Lisco Gloria - Conclusions

Conclusions

- The fire was very intense and spread rapidly.
- The fire was detected almost at the same time by the crew (officer on watch) and by smoke detectors.
- The A-60 fire protection insulation allowed for the safe evacuation of the ship.
- Successful fire fighting with the deluge system was only possible for a short time (malfunction due to technical failure).
- No attempt was made to bypass the technical defect of the sprinkler and deluge system.

Germanischer Lloyd

Thank you for your attention!

Fire protection arrangements in cargo spaces of ro-ro and ro-pax ships

- Overview of regulations
  - Keel laying after 1 July 2002 (2000 SOLAS amendments):

    a) SOLAS II-2, Regulation 9 (Containment of fire)

    b) SOLAS II-2, Regulation 20 (Protection of vehicle, special category and ro-ro spaces)

    => Ro-ro cargo ships and ro-ro passenger ships (ro-pax)

    c) SOLAS II-2, Regulation 10.2 (Fire pumps, fire main, hydrants, hoses & nozzles)
  - Keel laying before 1 July 2002 (e. g. SOLAS 74 as of 1 July 1986):

    a) SOLAS II-2, Regulation 37 (Protection of special category spaces), Regulation 38 (Protection of cargo spaces other than special category spaces intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion) and Regulation 38-1 (Protection of closed and open ro-ro spaces, other than special category spaces and ro-ro spaces intended for the carriage of motor vehicles with fuel in their tanks) => only for passenger ships (ro-pax)

    b) SOLAS II-2, Regulation 53 (Fire protection arrangements in cargo spaces) and Regulation 44 (Fire integrity of bulkheads and decks) => only for ro-ro cargo ships

    c) SOLAS II-2, Regulation 4 (Fire pumps, fire main, hydrants, hoses & nozzles)

Fire safety precautions in cargo spaces of ro-ro and ro-pax ships

- Fire protection insulation
  - Divisions from adjoining spaces are to be constructed in accordance with class “A-60” on all sides. Divisions from open decks, wet areas, tanks, void spaces and auxiliary machine rooms with no or a low risk of fire are to be constructed in accordance with class “A-0”.
  - Lower standards (“A-0”, “A-15” or “A-30”, depending on room combinations) apply for ships with up to 36 resp. 12 passengers.
  - From 1 July 2014, stricter insulation requirements will apply (cf. IMO MSC.338(91)) for the separations between cargo spaces and between the latter and escape routes as well as control stations.
- Electrical equipment and connections
  - Fitting with unprotected sources of ignition not permitted
  - Suitable for potentially explosive spaces in accordance with IEC 60079
  - With the exception of special category spaces from 450 mm above deck, protection by means of a flameproof enclosure is possible, provided the number of air changes in the cargo space is at least 10 per hour.
  - Scuppers must not lead to machinery rooms or other spaces with unprotected sources of ignition.

Fire protection arrangements in cargo spaces of ro-ro and ro-pax ships

- Ventilation

  Mechanical ventilation system with the following requirements:

  - at least 10 air changes (ro-ro cargo ships: 6)
  - independent of other ventilation systems
  - fans must be in continuous operation while vehicles are on board
  - fans and fire dampers must be operable from outside of the cargo space

  For the loading and unloading periods, 20 air changes are required in most cases.

Fire protection arrangements in cargo spaces of ro-ro and ro-pax ships

- Fire alarm

The fire detection and alarm system consists of fire detectors (smoke or heat detectors) as well as manually operated call points.

Requirements:

Max. monitoring space/max. monitor distance/max. distance from bulkheads:

Heat detectors = 37 m^2/9 m/4.5 m; smoke detectors = 74 m^2/11 m/5.5 m

Arrangement of call points: available within 20 m and present at every exit.

Alternatives:

- continuous fire watch (hardly relevant in practice)
- sample extraction smoke detection system in conjunction with CO_2 system (only in enclosed ro-ro cargo spaces on cargo ships)

Fire protection arrangements in cargo spaces of ro-ro and ro-pax ships

- Fire-fighting efforts
  - Water spraying system (deluge/drencher system) – standard application

    Manual activation, sprinkling with 5 l/m^2/min, open nozzles, division in sections; design in accordance with IMO Res. A.123(V) [1967]

    Alternatively: water mist system in accordance with MSC.1/Circ.1272 [2008] – less common

    Note: from 1 July 2014, water spray/water mist systems must be designed exclusively in accordance with the requirements of MSC.1/Circ.1430 [2012] (Res. MSC.339(91))
  - Alternative to water-based systems (only permissible in enclosed ro-ro cargo spaces on cargo ships): CO_2 fire extinguishing system
  - Fire hydrants

    Connection of hoses with multi-purpose spray nozzles; any part of the cargo space reachable with extinguishing water from two spray nozzles

    In ro-pax ships: hydrant extinguishing system is under pressure at all times
  - Portable fire extinguishers (available within 20 m)
  - Portable foam applicator and three L-shaped water mist pipes

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

AP 1.2

Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Basis

The description of fire detection systems on ro-ro/ro-pax ships is based on the consolidated 2009 edition of the regulations of the International Convention for the Safety of Life at Sea (SOLAS) and on the 2007 edition of the International Code for Fire Safety Systems (FSS-Code), amendments 01 and 07/2012.
As regards the tests, the 2012 amendments make reference, for the first time, to the standards EN 54:2001 and IEC 60092-505:2001.

DIN VDE 0833 and DIN 14675 are part of the above European standards. As mentioned before, these standards apply to tests and functional use.

Regarding the arrangement of the fire detection system's array elements, the following comments are made:
Any required fixed fire detection and fire alarm system with manually operated call points shall be capable of immediate operation at all times.
For the rest, the installation is carried out as demanded by the administration, i. e. the competent port state.

AP 1.2
Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Types of sensors

The ships in question are equipped with the following types of sensors to detect fires:

Light-scattering detectors – for detection of fire aerosols
Sensitivity in accordance with SOLAS/FSS-Code 2 up to 12.5 % obscuration/m

Heat detectors – for detection of temperatures exceeding pre-defined values.
Depending on the surrounding area, the temperatures at which an alarm is raised should be set to a range between 54 °C and 78 °C (130 °C to 140 °C for rooms subject to particularly high temperatures).

Differential heat detectors – for detection of temperature gradients (1 °/min).
Combination detectors (heat/light-scattering) with logic control (approved as light-scattering detectors).

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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Types of sensors

Flame detectors – for detection of flames resulting from organic incendiary substances. The infrared frequency detection, assumes CO_2 heated to approx. 800 °C (4.1 to 4.7 µm).

AP 1.2
Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Inspection in accordance with EN 54-10:2001 and ICE 60092-505:2001)

All aforementioned detectors follow physical principles to recognise dangers, and their parameters are geared to the different incendiary substances. ISO standard EN 54 takes these conditions into account with regard to the structural, air-, radiation- and convection-related ambient conditions which influence the inspection and hazard identification.

Test of effectiveness

While periodic performance testing is mandatory, testing the effectiveness is not.

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Generally, the following applies:

The danger signal must reach the sensor.

The fire detection systems installed on some ships deviate from the above requirements.

The effectiveness is in some cases limited by the local situation, or individual sensors or entire monitoring sections are ineffective.

This is not because of the sensors or systems, but due to where they are installed in.

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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Gas monitoring:

In some cases, the loading decks of ro-ro/ro-pax ships are equipped with electrochemical sensors for the four simplest alkanes (methane, ethane, propane and butane) and for carbon monoxide.

These gas sensors are only designed to detect the target gases and are very selective.

The carbon dioxide concentration in machinery spaces, too, is often monitored by means of highly selective electrochemical sensors.

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Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Statements

The installations for fire and gas detection present on board are largely unsuitable for the detection of gas mixtures potentially emitted by vehicles with alternative powertrains.

Such gas mixtures should already be detected at concentrations in the lower ppm range so as to leave sufficient time for intervention measures.

Gas mixtures originating, for example, from smouldering fires and presumably also from electrically powered vehicles, hybrid vehicles and fuel cell-powered vehicles as well as from flexibly-laid power cables for refrigerated containers cannot be detected by the above-mentioned electrochemical sensors.

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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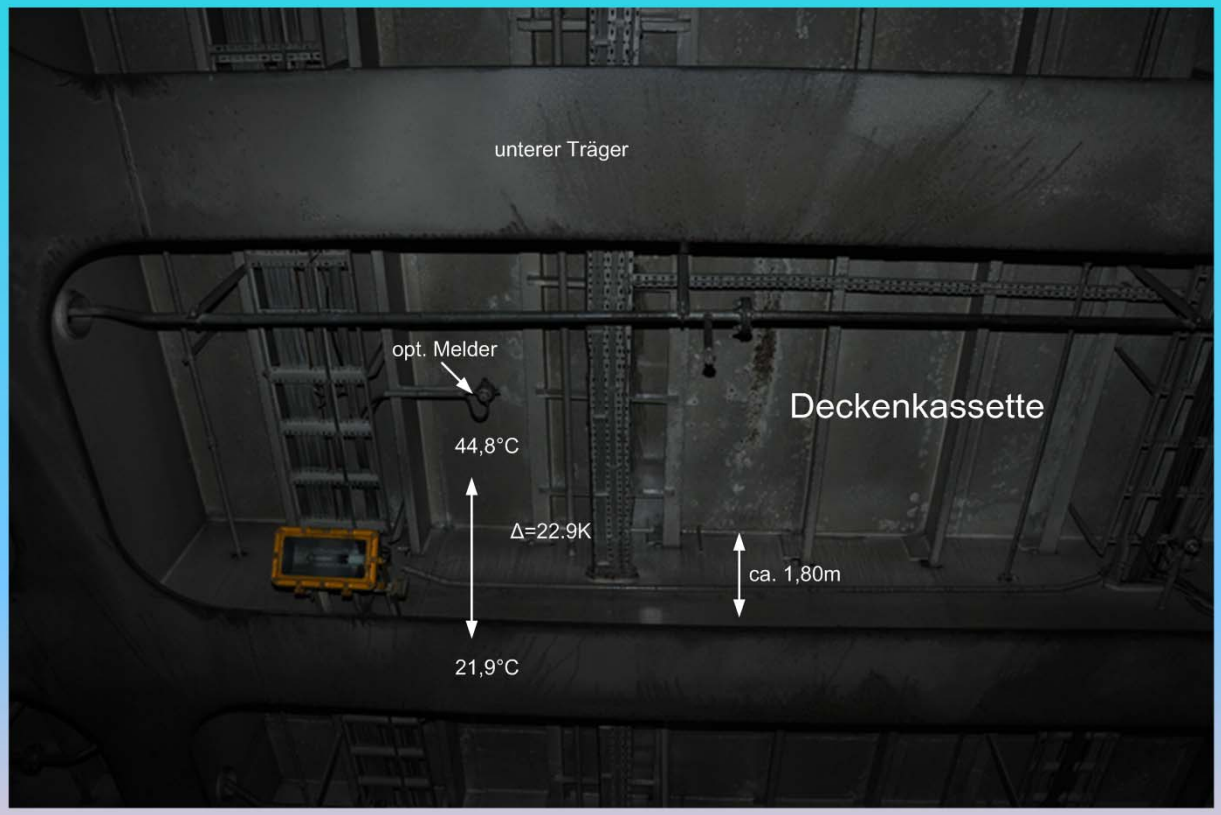
Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Negative installation example I



Explanation of the faulty installation

The ceiling of the vehicle deck is made up of panels whose dimensions are indicated in the figure.

Measurements revealed a Δ of up to 22.9 K between the lower beam and the actual ceiling.

This means that a **heat barrier forms** which prevents the fire signal from reaching the sensor.

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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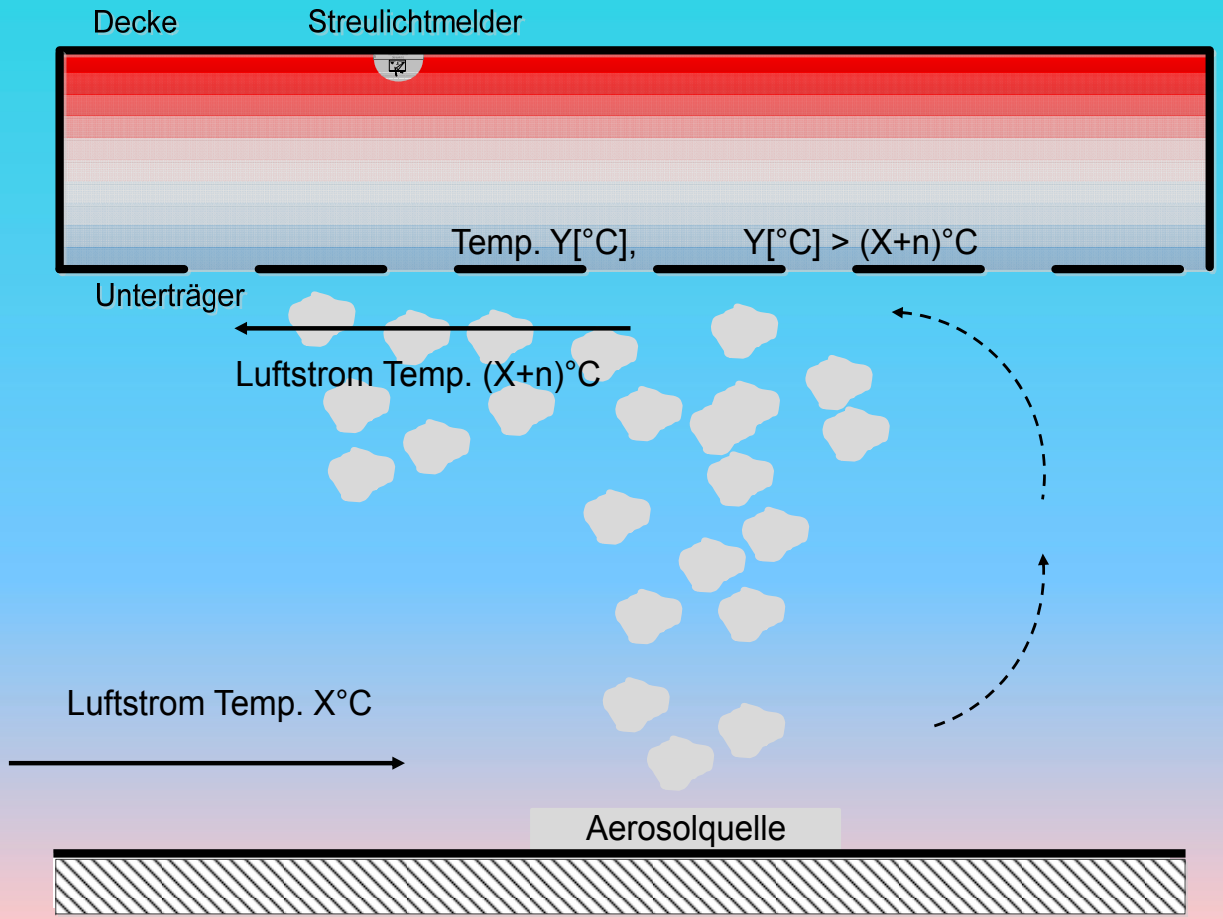
Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Negative installation example I



Reasons for the ineffectiveness

Here, it is almost impossible for the fire signal caused by the smouldering fire
to reach the sensor since, with the lack of convection, the heat barrier is not overcome.

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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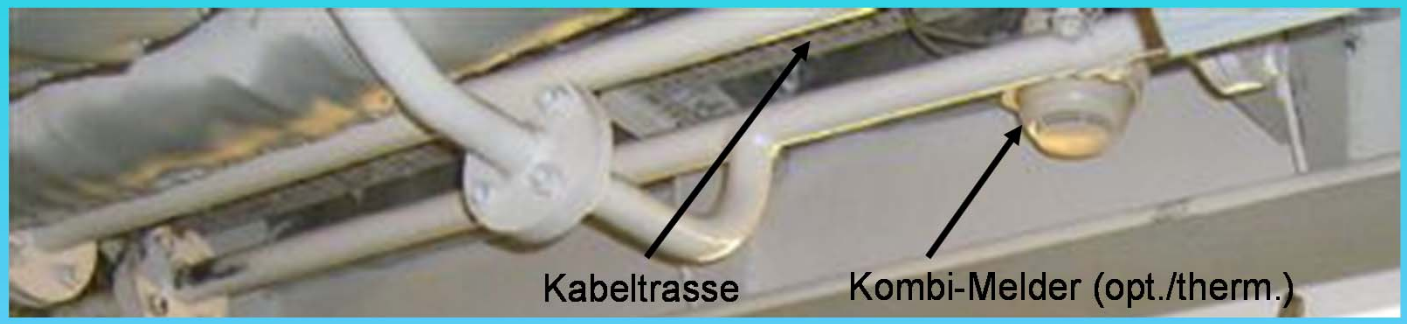
Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Negative installation example II



Explanation of the faulty installation

1.
The detector is located in a ceiling panel where heat can build up at any time, resulting in similar consequences as mentioned above.

2.
The sensor does not cover the whole assigned space, since a fire load in the form of a filled cable tray is located above it.

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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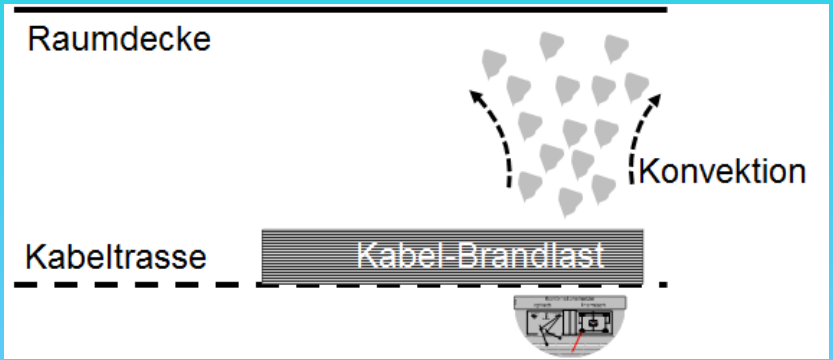
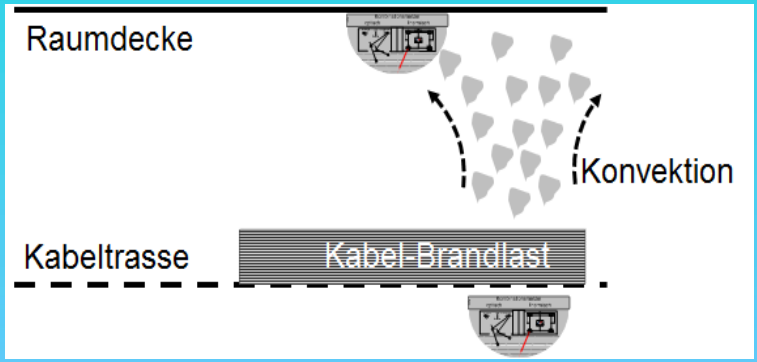
Negative installation example II



If installed like this (underneath the cable tray), the sensor does not have any effect in the event of a cable fire starts.
In addition, the sensor should at least be flush with the lower ceiling beam.

Corrected installation example II



In a correct installation, two sensors would need to be fitted: one to the ceiling and one underneath the cable tray to the lower ceiling beam.

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

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Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Samples of fire detection systems installed on ro-ro/ro-pax ships

Manufacturer	Year of built	Types of automatic sensors					
		Ionisation	Opt.	Opt./ Heat	Heat	Differential heat	Flame
Servoteknikk	1993		X			X	X
Autronica/ELNA	1982/2007 new central facility		X		X		X
Servotekknik	1996	X	X		X		X
Siemens	2002/06		X	X	X	X	X
Rauma	1995		X		X		X
Servotekknik	2001	X		X	X		X
Siemens	2002		X	X		X	X
Finnyard	1995		X		X		X
Siemens	1989		X	X		X	X
Consilium	2011		X	X		X	X

Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships

AP 1.2

Presentation of findings with regard to the fire protection situation based on past inspections of corresponding ship types

Summary

All hazard detection systems under investigation are permanently installed systems.

Fire detection systems

The installed fire detection systems are only able to detect

- aerosols,
- heat/temperature changes and
- flames.

Installation of the fire detection sensors

In some cases, the installations themselves do not take into account the

- structural,
- air- and
- temperature-related

requirements for their effectiveness.

Gas detectors

The installed gas detectors are highly selective electro-chemical sensors for one type of gas and are primarily located near the ground.

ISV INSTITUT FÜR SICHERHEITSTECHNIK SCHIFFSSICHERHEIT
ISO 9001 BUREAU VERITAS Certification

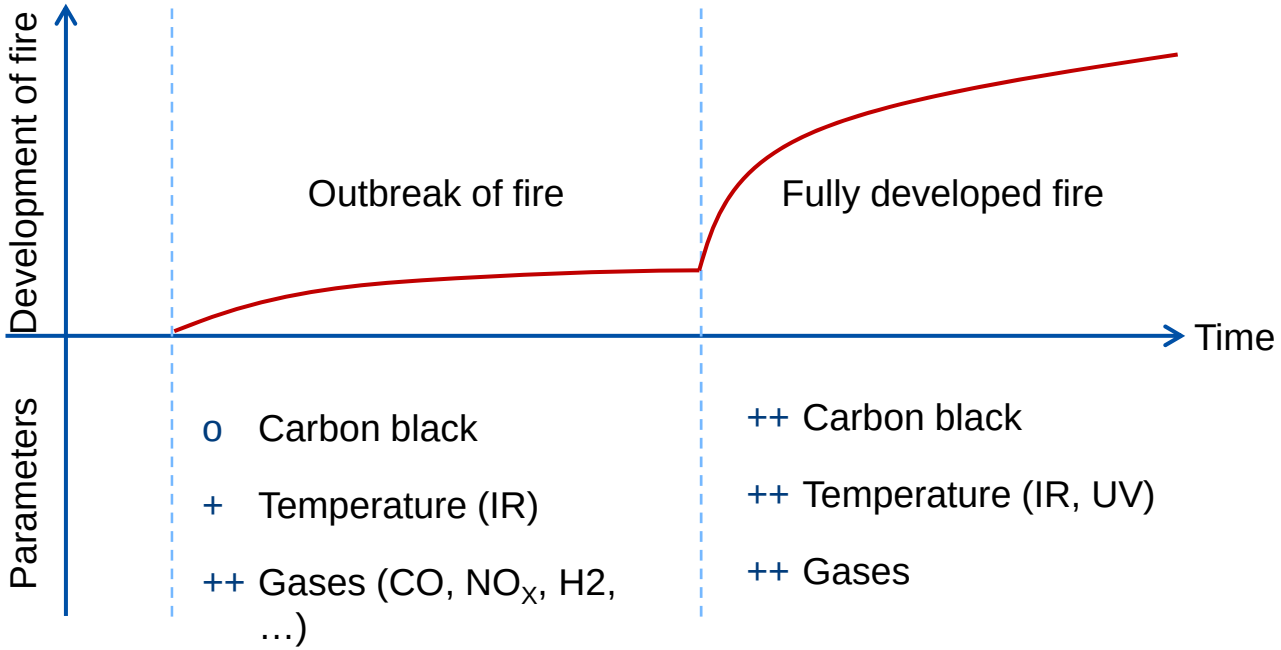
Thank you very much for your attention.

Dirk Sedlaček Ulrich Fielitz

Aspects of optimized fire detection on loading decks of ro-ro/ro-pax ferries

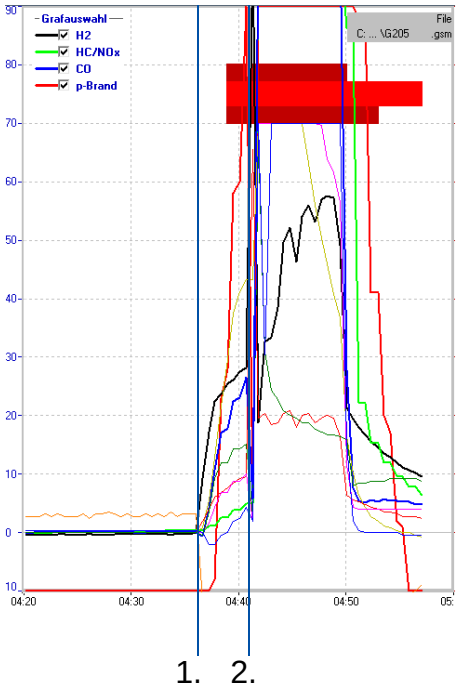
Simon Trippler, GTE Industrieelektronik GmbH

Fire development stages



> Different fire stages result in different parameters.

Fire test: Lithium ion battery



1. At the beginning of the test, the battery is overloaded with 20 A; as a result, gases are emitted, and the battery bloats up.

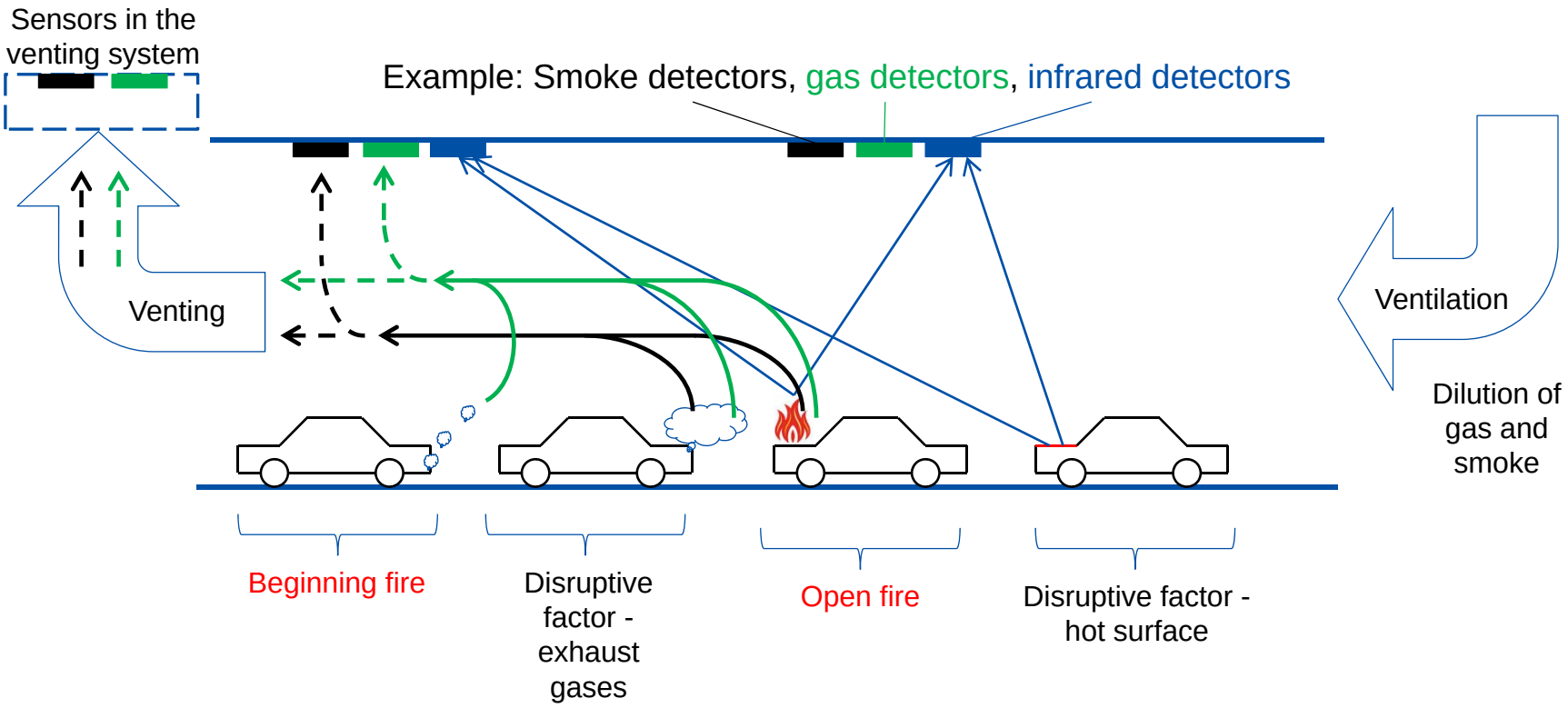
2. The battery shell bursts, and the battery starts to burn with a flame.

> In this test, the damage to the battery was detected several minutes before the ignition on the basis of gas emissions.

Risks resulting from electric vehicles and refrigerated containers

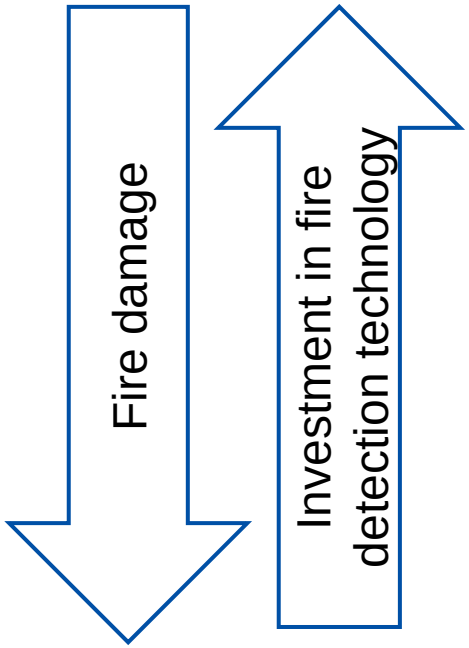
- Flammability of batteries, also without external ignition source (spontaneous ignition)
- Containment of the fire within the refrigerated containers during the outbreak of the fire. Detection only possible with delay.
- So far, only very limited experience in the planning of fire detection systems for battery fires.

Design of a fire detection system: Framework conditions on loading decks



Definition of fire protection objectives

> At which stage can or should a fire be detected?



Possibilities for optimizing existing fire detection systems:

- Increasing the level of coverage of existing alarm systems → higher costs
- Deployment of additional technologies → higher costs
- Adaptation of alarm levels → number of unwanted alarms will increase, may result in a desensitization towards alarms among the personnel

> Compromise required between feasibility, necessity and existing financial framework conditions (legal framework, insurance companies, operators)

Overview of the market

	Early detection	Disruptive factors	Costs per unit (approx.) excl. installation
Smoke detectors	+	Dust, water vapour	€ 200
Gas detectors	++	Emissions	€ 1,000
Flame detector	o	Sunshine	€ 2,000
Thermographic camera	++	Hot surfaces	€ 30,000
Fibre-optic sensors	o	Hot exhaust emissions	€50,000

> Normally, smoke detectors are already installed.

Development processes in fire detection engineering
Example: aircraft loading deck

Process

The steps of the process depend on disruptive factors, structural conditions, requirement with regard to detection capabilities and available financial framework

Existing technology

Development projects

Smoke detectors

Evolution

Heating against condensation (GTE)

Additional gas sensor (GTE)

Video-based smoke detection

Linear detectors (GTE)

Heat detectors

Battery systems in electric vehicles – risk potential

Workshop regarding the study of the Federal Ministry of Transport, Building and Urban Development

Hamburg, 28 October 2013

Dr Jochen Mähliß

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1. Electric vehicles

→ 2012 sales figures:

- 2,956 BEVs (battery electric vehicles)

- 21,438 HEVs (hybrid electric vehicles)

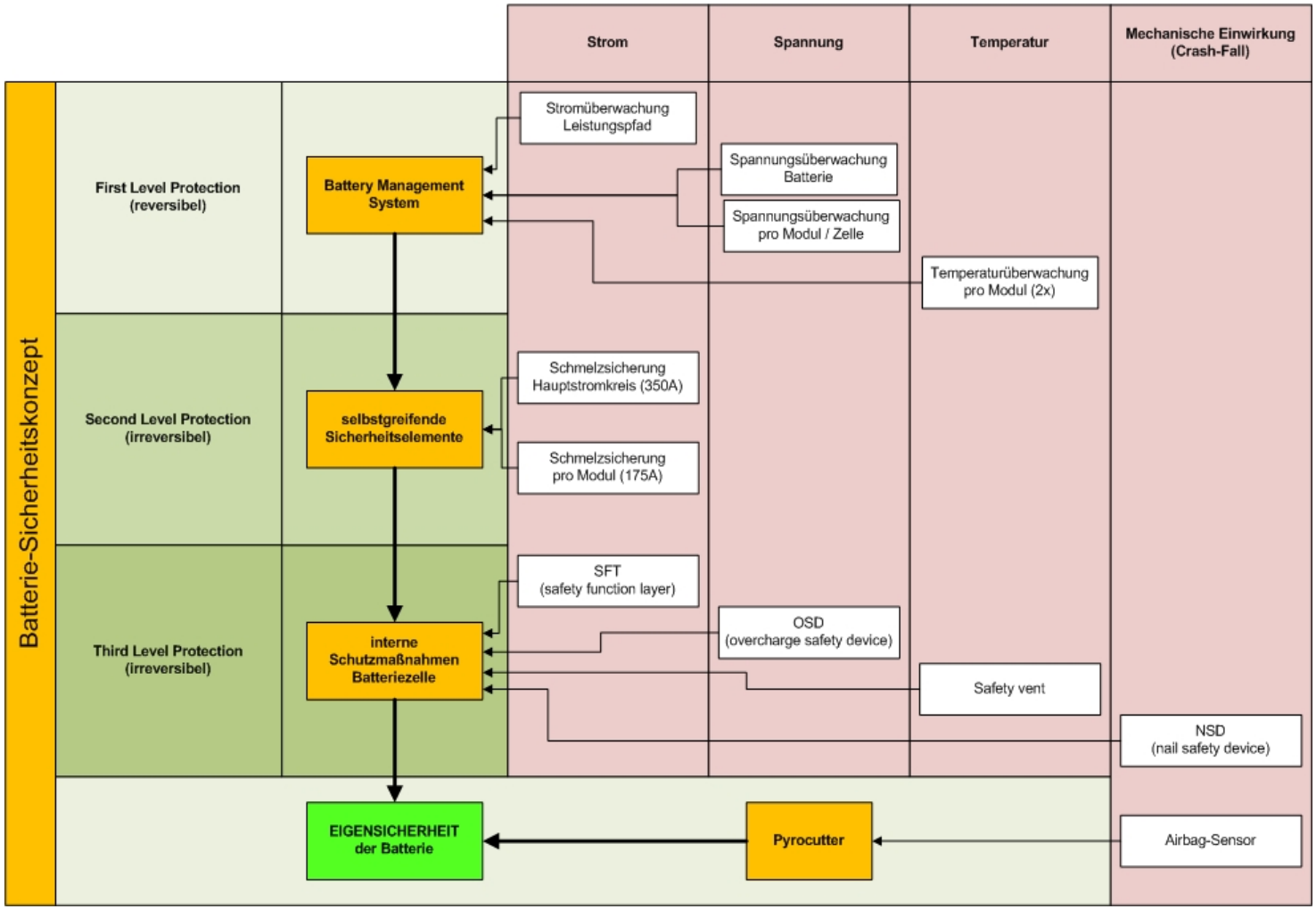
→ Aim of the "National Development Plan for Electric Mobility" of the Federal Government:
- by 2020: 1,000,000 electric vehicles (BEV and PHEV) in Germany
- by 2025: 2,000,000 electric vehicles

→ (Most) important component of electric and fuel cell-powered vehicles - the rechargeable battery

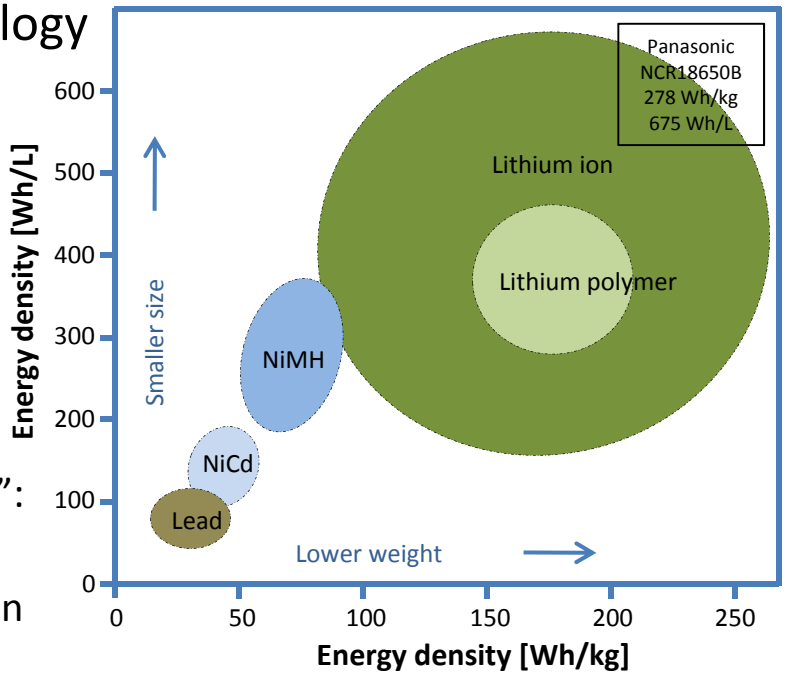
→ In rough terms: 30 kWh ≙ approx. range of 200 km

→ The battery consists of:
- cells (cylindrical, prismatic, pouch)
- battery management system (BMS)
- casing with insulation and cooling system

2. Battery management system (BMS)



3. Risk potential NiMH and Lithium ion technology



→ Greatest power and energy densities with lithium ions

→ NiMH similarly "good-natured" as lead acid (starter batteries):

- alkaline electrolyte
- when overloading, heat and hydrogen may be generated

→ Lithium ions react critically under "conditions of misuse":

- generation of heat
- discharge of inflammable and toxic gases or deflagration
- fire (with temperatures of over 1,000 °C)

Video "Internal short circuit – nail test"

Video „Tesla car on fire": http://www.youtube.com/watch?v=q0kjI08n4fg

→ Risks on ro-ro and ro-pax ships caused by the charging of damaged cells and batteries

→ Most effective fire-fighting agent: water mist (→ heat removal)

THANK YOU FOR LISTENING TO ME!

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FutureShip

A GL company

Note

Recipients	Workshop participants	Date	11 October 2013
Subject	Possible risks on board ferries associated with the transport of fuel cell-powered vehicles		
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1. Introduction

The Federal Government's Energy Strategy aims at a 10 % reduction in energy consumption in the transport sector by 2020 and a 40 % reduction by 2050, compared with 2005 levels. To achieve this, the Federal Government promotes the use of battery and fuel cell-powered systems in vehicles. Since 2008, numerous projects have been funded as part of the National Innovation Programme for Hydrogen and Fuel Cell Technologies (NIP).

In particular, hydrogen-powered fuel cell vehicles were tested and further developed within the framework of the Clean Energy Partnership (CEP). This partnership is due to expire in 2016, when hydrogen-powered production vehicles are introduced on the market.

Based on the requirements of the Energy Strategy and the funding programmes of the Federal Government, the National Organization for Hydrogen and Fuel Cell Technology (NOW) expects that there will be 50 hydrogen filling stations in Germany by 2015. By 2020, one million vehicles with alternative energy supply are to be in operation. [1; 2].

The increased use of alternative technologies makes it necessary to consider additional risks (other than those of conventional diesel or petrol engines) with regard to their use on the roads and also concerning the transport of vehicles using alternative drive systems with other means of transport.

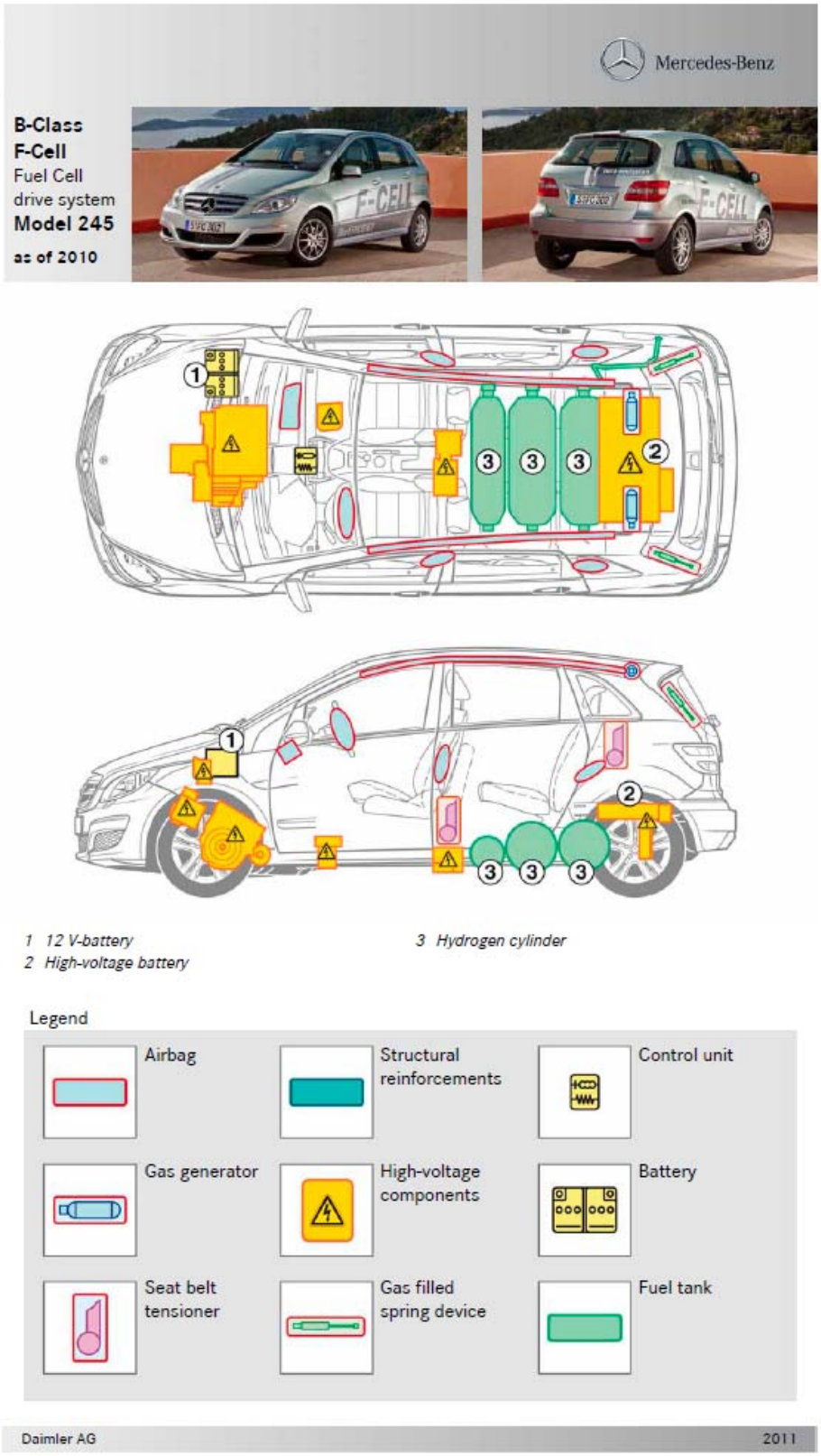
The aspects mentioned in this short report are meant to help prepare the risk analysis to be carried out within the framework of the Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships. The focus here is on fuel cell-powered vehicles.

2. Technology

So far, low temperature fuel cells (LTFC) with hydrogen have been used in fuel cell-powered passenger cars almost exclusively. These fuel cells operate at temperatures of around 80 °C and directly transform the hydrogen into electric power. The general safety systems include:

- pressure-resistant hydrogen tanks
- safety valves for a controlled discharge of the hydrogen in the case of fire
- gas sensors in the passenger compartment
- suitable positioning of the hydrogen tanks to reduce potential impacts of traffic accidents

On the following page, you will find an example of an assembly of a fuel cell-powered vehicle with a buffer battery and information on possible sources of risk as provided on the emergency services guide.


Mercedes-Benz
B-Class
F-Cell
Fuel Cell
drive system
Model 245
as of 2010
F-CELL
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3
1 12 V-battery
2 High-voltage battery
3 Hydrogen cylinder
Legend
Airbag
Structural reinforcements
Control unit
Gas generator
High-voltage components
Battery
Seat belt tensioner
Gas filled spring device
Fuel tank
Daimler AG
2011

3. Possible sources of risk

As compared with conventional systems, additional risks resulting from the use of fuel cell systems in road vehicles may arise from the use of gaseous fuels and their storage in pressure tanks. Further risks may result from the use of battery systems with a comparatively higher voltage level and from the use of lithium batteries. These risks are, for the most part, known due to the successful use of compressed natural gas (CNG) vehicles, the use of liquefied petroleum gas (LPG) and the use of hybrid electric vehicles. The additional risks of fuel cell-powered vehicles compared with such systems depend on the alternative fuels (such as hydrogen and methanol) used. [3; 4]

Generally, a distinction is made between

- a fuel cell engine powered by flammable liquid (e.g. methanol) and
- a fuel cell engine powered by flammable gas (e.g. hydrogen).

The considerations within the framework of the risk analysis are based on the use of both fuels.

It must be noted that where lithium batteries are used, their transport is, for safety reasons and to avoid risks of fire and explosion, subject to the provisions and requirements of the legally binding international and European agreements concerning the international carriage of dangerous goods. The same applies to fuel cells, metal hydride storage systems, capacitors and vehicles. Fuel cell-powered vehicles belong to UN No. 3166.

4. Outlook

As part of the risk analysis, possible additional risks for the ship's systems, the crew and the passengers that result from fuel cell-powered vehicles with different fuel types (hydrogen and methanol) are examined. More specifically, these are:

- external leakage of hydrogen/methanol into the vehicle parking space (vehicle deck)
- possible formation of explosive gas clouds (taking ventilation conditions and possible sources of ignition into consideration)
- battery system failures (fire, explosion, high voltage)

Within the framework of the risk analysis, possible further safety measures for the transport of fuel cell-powered vehicles on board ferries are identified.

5. References

[1] Federal Government's Energy Strategy, November 2010
[2] NOW Annual Report 2012
[3] DWV Hydrogen Safety Compendium, November 2011
[4] National Platform for Electric Mobility, AG4 - Standardization and Certification - Legislation in the Fields of Automotive Engineering and Transport of Dangerous Goods, November 2010

Project:	Ministry of Transport,	Electric vehicles on board ro-ro/ro-pax ships											
Date:	28 + 29 October 2013												
Revision:	10												

No.	Failure/Risk	Cause	Effect	Available means of detection	Available corrective measures	Frequency	FI	SI h	SI p	RI h	RI p	Improvement measures	Note
Hybrid Vehicles (HEV) - fire on board													
HEV15	battery fire (lithium ion)	increase in temperature due to fire in the immediate surroundings	- from 150 °C - outgassing - ignition very likely - in addition to original fire, further inextinguishable fires	fire in the surroundings is detected by smoke detectors etc.	- fire-fighting team - deluge system - cooling of the surrounding structure	0.16/year	1,8	1,7	1,7	3,5	3,5	separate parking spaces; high pressure water mist system	
HEV16	NiMH battery	increase in temperature due to fire in the immediate surroundings	none, NiMH batteries do not catch fire										
Fully electric vehicles (BEV) - fire on board													
BEV11	battery fire (lithium ion)	see HEV15	see HEV15	see HEV15	see HEV15	0.16/year	1,8	1,7	1,7	3,5	3,5		see HEV15
BEV12	NiMH battery	increase in temperature due to fire in the immediate surroundings	none, NiMH batteries do not catch fire										
Vehicles with fuel cell (FC) and hydrogen pressure tank - fire on board													
FC11	escape of hydrogen from the pressure tank	- increase of pressure due to high temperatures in the surrounding area (e.g. fire on the deck below the vehicle deck)	- significant amount of hydrogen escapes - inflammable mixture forms - ignition by non-explosion proof parts (zone 2 in the upper section Tmax 200 °C) cannot be ruled out (e.g. lamps) or fans (explosion-proof?) - explosion - might result in fire - more serious effects on closed deck than on open deck due to strong shock wave	no detection of hydrogen possible fire detection by smoke detectors etc.	ventilation	0.72/year	2,4	3,0	3,0	5,4	5,4	see FC6	tank content passenger car approx. 4 kg, busses approx. 30 kg; in passengers cars, the tanks are located under the passenger cell; in busses under the roof
FC12	escape of hydrogen from the pressure tank	temperature increase due to fire in the surrounding area (same deck)	- temperature and pressure increase in the hydrogen tank - discharge of tank contents through safety valve (duration?) - hydrogen ignites instantly (fire on deck) - potentially small explosions - jet fire until tank is empty	fire detection by smoke detectors	fire-fighting team, deluge system	0.167/year	1,8	1,7	3	3,5	4,8	see FC6+ fire monitor for the open deck	assumption: 0.1 % of veh. on board are FC vehicles; with 500 vehicles, this means that one FC vehicle is on board on every second journey; with three decks, there will be one FC veh. on the lower deck on every sixth journey. The SI for this scenario is assessed to be lower than for FC11, since, in the latter, the triggering fire does not occur on the same deck. Thus, rescue services present on this deck for cooling purposes might not anticipate the risks posed by the hydrogen.
FC13	escape of hydrogen from the pressure tank	temperature increase due to fire in the surrounding area (same deck)	see FC12 with the following escalation: - directed flame heats (and due to its high temperature burns through) ceiling - fire spreads to deck above - fire cannot be controlled - evacuation of the ship with the risk of several fatalities - loss of ship	fire detection by smoke detectors	- fire-fighting team - deluge system - cooling of the deck above (water)	0.055/year	1,3	4,00	5,0	5,3	6,3		image see "Brennstoffzellenfahrzeuge-und-Wasserstofftankstellen.pdf" (p. 9) (Fuel cell powered vehicles and hydrogen filling stations); assumption: 1/3 of the fires described in FC12 escalate in such a manner; SI taken from HEV3
Vehicles with fuel cell (FC), methanol - fire on board													
FC14	leakage of methanol	tank damaged by fire:	no increased danger identified as compared to gasoline vehicles (due to ignition temperature and explosion range), therefore no further examination										
Vehicles, semi-trailers and containers with refrigeration unit (RU) - fire on board													
RU9	high temperatures or fire in the surrounding area	refrigerated vehicles do not present other dangers than conventional vehicles											