Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation
Bundesoberbehörde im Geschäftsbereich des Bundesministeriums
für Verkehr, Bau und Stadtentwicklung

Investigation Report 187/05

Serious Marine Casualty:

Explosion and Fire on board CMV PUNJAB SENATOR in Hold No. 6 on 30 May 2005 on the way to Sri Lanka

15 December 2006

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The investigation was conducted in conformity with the law to improve safety of shipping by investigating marine casualties and other incidents (Maritime Safety Investigation Law - SUG) of 16 June 2002.

According to this the sole objective of the investigation is to prevent future accidents and malfunctions. The investigation does not serve to ascertain fault, liability or claims.

The German text shall prevail in the interpretation of the Investigation Report.

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1 Summary of the marine casualty

The container vessel PUNJAB SENATOR left Singapore on 28 May 2005 at 05:18 h[1]. It was carrying a cargo of 31,604 mt in altogether 1050 x 20' and 1094 x 40' containers and was on its way to Colombo, Sri Lanka.
On 30 May 2005 at 07:23 h a container exploded. It was located at the forward edge in hold 6 by the partition wall to the engine room. The crew managed to bring the fire that finally extended over two containers holding standard commercial, small, rechargeable batteries under control with massive use of CO_2 and intensive cooling, and put the fire out.
No personal injuries were noted. The damage to the cargo and the vessel was substantial. No environmental damage was sustained.

[1] All times in this report refer to local time = UTC + 8h

2 Scene of the accident

Nature of the incident: Serious marine casualty: explosion and fire in the hold
Date/time: 30 May 2005, at 07:23 h
Location: Bay of Bengal
Latitude/longitude: φ 05°59' N λ 086°15' E

Excerpt from sea chart 2702, BSH

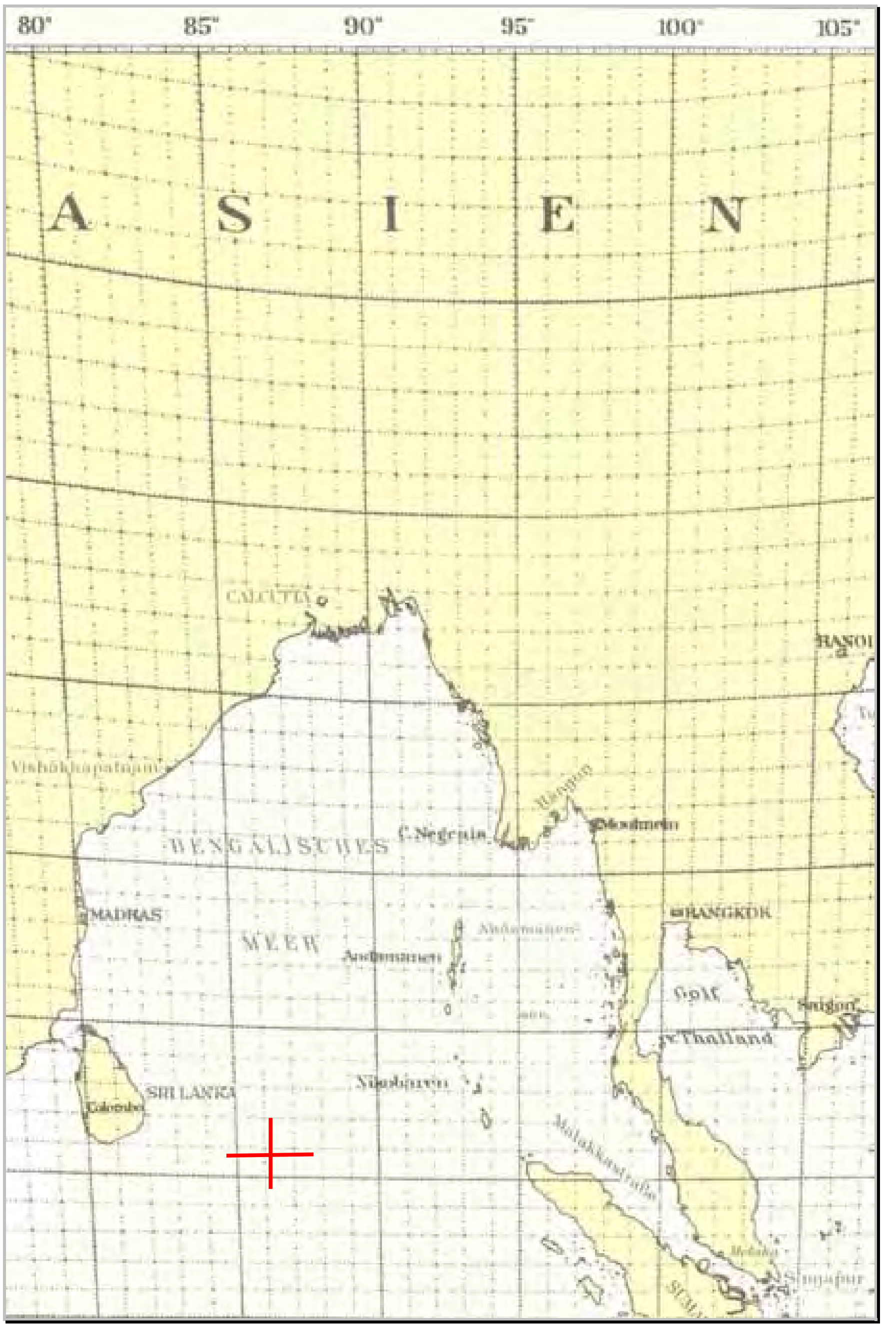

Figure 1: Scene of the accident

3 Vessel particulars

3.1 Photo of vessel

Figure 2: CMV PUNJAB SENATOR
(Photo: Reederei F. Laeisz GmbH)

3.2 Vessel particulars

Name of vessel:	PUNJAB SENATOR
Type of vessel:	Container vessel
Nationality/Flag	Germany
Port of registry:	Rostock
IMO number:	9141285
Call sign:	DQVK
Vessel operator (company in accordance with 3.1 ISM Code):	Reederei F. Laeisz GmbH Rostock
Year built:	1997
Building yard:	Ulsan, South Korea
Classification society:	Germanischer Lloyd
Length overall:	294.13 m
Width overall:	32.20 m
Gross tonnage:	53,324 gt
Deadweight:	55,515 t
Max. draft:	12.00 m
Service speed:	23.7 kn
Engine rating:	41,040 kW
Main engine:	Hyundai MAN B&W, Diesel Engine, 9K90MC-C
Crew and passengers:	22+2

4 Course of the accident

According to the "Statement of Facts" by the command of the container vessel PUNJAB SENATOR, the vessel had left Singapore at 05:18 h on 28 May 2005. The vessel was carrying a cargo of 31,604 mt in altogether 1050 x 20' and 1094 x 40' containers and was on its way to Colombo in Sri Lanka.

At 07:23 h on 30 May 2005 an explosion had been perceived that shook the vessel conspicuously. The speed had immediately been reduced to "slow ahead". A little later the smoke alarm system had indicated an alarm for Bay 58. A fire alarm had been triggered and the crew and passengers had been informed.
The following instructions had been issued: visual inspection of Bay 58 through the hatch entry, then closing and securing of the hatch entry, preparation of two breathing apparatus sets, mustering of the crew, setting all on standby and preparing to fight the fire, switching off of all fans, switching off of the electric current in hold 6 (Bay 58).

Instructions had then been issued already at 07:28 h to prepare the CO_2 system, to close all ventilator dampers, and to use three fire hoses for cooling. At this time it had been reported that two persons wearing breathing apparatus sets were ready and that the smoke from Bay 58 had become more intensive.
It had expressly been ascertained that there was nobody in the hold. Thereupon the CO_2 system had been used for the first fire fighting operation at 07:30 h.
At the same time the area had been cooled from the exterior with now altogether seven fire hoses.

In the course of the following hours temperatures had been measured repeatedly at various positions all round the hold.
When the temperatures had risen again at about 08:55 h, the vessel command had decided to use a further 40 cylinders of CO_2.
In the meantime the crew had cut a hole in a ventilator damper to which a fire hose coupling was welded.
At about 10:40 h exchanging of this special ventilator damper had been ordered so that firewater could then be pumped directly into the hold without allowing oxygen to enter through the hatch (**see also Figures 3 and 4**). The bilge pump had at all times been well able to pump the gathering water out of the hold again. About one hour later the temperatures measured had dropped distinctly.

Figure 3: Ventilator damper converted for cooling

Figure 4: Cooling of the hatch

The voyage to Colombo had been continued at 12:15 h and the fire had been under control at 15:00 h. A fire watch had been set up until the target port of Colombo was reached.
The vessel had reached the roads off Colombo the next morning at 08:54 h. The harbour master had banned the vessel from entering the port until fire experts from Colombo had examined the vessel.
At 11:30 h the Chief Engineer had reported that the temperatures were rising again. Instructions had thereupon been given to use a further 20 cylinders of CO_2 in the hold. Since the temperatures had risen further, work on intensive cooling had been started again. A drop in temperatures had only ascertained at about 14:30 h.

Since the harbour master's requirement that the vessel spend the night at some distance away had been received at 17:20 h, the vessel had weighed anchor at 18:36 h in order to change its anchorage accordingly.
During the night two sailors had been commissioned with cooling the cargo hold constantly and keeping a watch for pirates.

At 08:00 h on 1 June 2005 the anchor had been weighed again in order to shift to the previous anchorage. Then various inspectors had come on board, including some from the Colombo Fire Brigade.
At 10:40 h the Chief Engineer had reported that the temperatures were rising again. The Master had thereupon issued instructions to change the direction of the cooling water to the forward edge of the cargo hold and to use two additional hoses. At 11:30 h the temperature had dropped rapidly. Shortly after this the fire experts had left the vessel again. After they had handed over their approval for PUNJAB SENATOR to run into the port to the harbour master at about 13:25 h, the harbour master had issued a permit for entry at 15:00 h. The pilot had come on board at 16:30 h and one hour later the vessel had been made fast at the pier.
After the cargo intended for Colombo and the containers on the deck of Bay 58 had been discharged first for draft reasons, the vessel had shifted to another berth. There the entire Bay 58 had been unloaded in the course of 2 June 2005 under the supervision of the fire brigade.
During unloading of the two burned out containers it had been ascertained that the fire had been extinguished. The destroyed cargo had consisted exclusively of NiMH[2]-rechargeable batteries of standard size AA HR6.
In the course of 3 June the class had been confirmed so that after taking on further cargo PUNJAB SENATOR had been able to continue its sea voyage bound for Northern Europe at 07:06 h on 6 June 2005.

[2] NiMH: Nickel Metal Hydride

5 Investigations

The next port of call for CMV PUNJAB SENATOR was Hamburg. The Federal Bureau of Maritime Casualty Investigation (BSU) conducted an examination on board on 20 June 2005. During this it was ascertained among other factors that one head end of the heavy oil settling tank No. 2 bordered on the container that exploded and would thus have to be taken into consideration particularly in the subsequent investigations as a source of heat.
At the same time Germanischer Lloyd conducted temperature measurements on and in the heavy oil settling tank No. 2 on behalf of the vessel operator Reederei F. Laeisz GmbH. In addition the temperatures of the heavy oil settling tank No. 2 recorded electronically on board every day were read out.[3]

5.1 Laboratory experiments to clarify the origin of the fire [4]

The Federal Bureau of Maritime Casualty Investigation (BSU) commissioned an expert to draw up an expert opinion that is set out below.

5.1.1 Documents and information for the first series of experiments

The following documents and information were available for preparing the expert opinion:

a) Survey of MV PUNJAB SENATOR on 20.06.2005, from 16:00 to 18:00 h in Hamburg (Eurokai)
b) Interviewing of the Technical Inspector of Reederei F. Laeisz GmbH concerning the incident
c) Statement of Fact MV PUNJAB SENATOR; Reederei F. Laeisz GmbH
d) 12 photos – showing the condition immediately after the fire; Reederei F. Laeisz GmbH
e) Measuring Report No. ESE 2005.127 ;Germanischer Lloyd
f) Excerpts from the logs of MV PUNJAB SENATOR
g) Ship's drawings
h) Data sheets for nickel metal hydride (NiMH) rechargeable batteries; sector network batteries (COR)
i) Safety data sheets nickel metal hydride rechargeable batteries
j) NiMH rechargeable battery of the manufacturer concerned, Type AA – 2500mAh
k) NiMH rechargeable battery of the same size (AA) with differing capacities

[3] See Annex: Graph of the temperatures measured in settling tank No. 2 on board
[4] Note: The expert opinion is reproduced in abbreviated form (retaining the meaning), and partly verbatim.

5.1.2 Damage constellation / description of condition

The statements relate to the conditions recorded photographically directly after the fire. The photos were supplied by the vessel operator.

5.1.2.1 Hold

Hold 6 on the starboard side shows traces of fire and damage in the place where containers 1 and 2 [5] were stored. In the area of the corner (hold floor / forward edge / outer side) the paint coating on the wall sections is discoloured and partly burnt. In the area of the position of container 1 the paint coating is intact apart from the corner area. In the area of the lower hold corner there are clear traces of major heat influence that can be seen (**see also Figure 4: Hold 6 – storage place of container 1**). In the outer wall area the paint coating is burnt over an area of approx. 1 m. In the floor area there is discolouring, blister formation and peeling in the area of the outer edges of the container over a length of approx. 2 m. The paint coating on the outer wall is discoloured in the entire area of container 2 (**see also Figure 3**: **Hold 6 – starboard forward edge**). However it can be ascertained that the temperature in the forward edge area must have been higher.

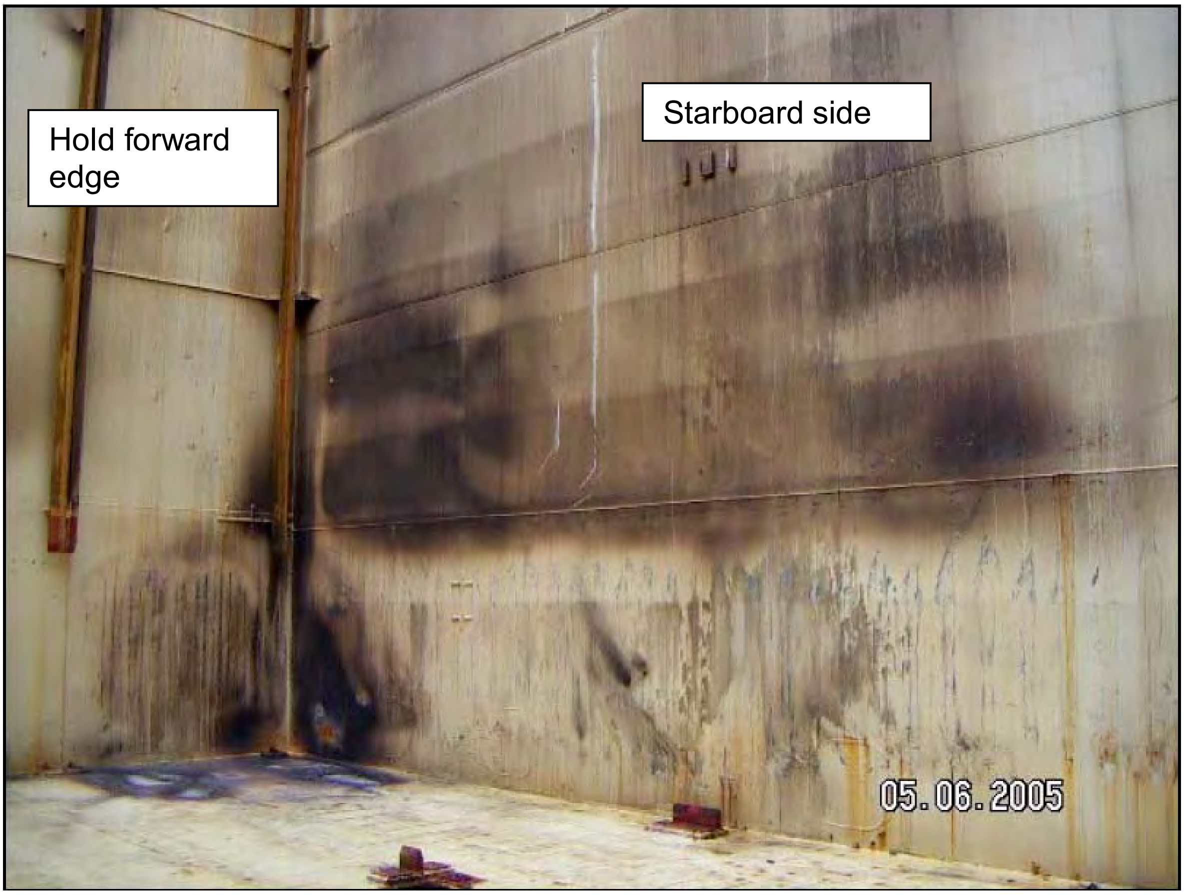

Figure 5: Hold 6 - forward edge stbd.

[5] Container No. 1 exploded and burned out,
Container No. 2 refers to the container that subsequently burned out without exploding

Figure 6: Hold 6 - Storage space of Container 1

Figure 7: Hold 6 Stbd. - view from above

5.1.2.2 Container 1 (exploded)

The evidently exploded container No. 1 in the bottom layer shows substantial signs of fire and damage. In addition it shows signs of mechanical damage over a large area. The container ceiling is closed and the whole area shows discolouring of the paint layer resulting from the influence of heat (**see also Figure 8: Container 1 – plan view**). The port sidewall is separated from the container ceiling at the top over the entire length and bulges outwards. The starboard sidewall is severed in the aft area. The mechanical destruction of container 1 can be explained by a fast and steep increase of pressure inside the container that could have only been caused by detonation or explosion, judging by the extent of the damage (**see also Figure 9: Container door of Container 1 wrapped round the frame).** The inside of the container shows no signs of fire in the aft area (**see also Figure 10: Container 1, partial view of interior**). The sidewall shows clear signs of fire and damage. In the forward area there are large areas of discolouring and burnt coatings of paint. There are further burnt coatings of paint and discolouring in parts of the bottom area of the container. The aft area is intact (**see also Figure 11: Container 1 side view**).

Figure 8: Container 1 – plan view

Figure 9: Container door of Container 1 wrapped round the frame

Figure 10: Container 1 partial view of interior

Figure 11: Container 1 side view

5.1.2.3 Container 2 (burnt out)

The evidently burnt out container No. 2 in the second layer shows substantial traces of fire and resulting damage. No major mechanical damage was noted. The container ceiling is closed and bulges up slightly, and the whole area shows signs of discolouring of the paint layer due to the effect of heat. The aft edge and forward edge of the container are less strongly affected (**see also Figure 12: Container 2 plan view in the hold).** The sidewall also bulges out. The starboard side was subjected to slight thermal stress, the paint coating is intact. In the front area burnt paint coatings and discolouring can be seen over approx. 1-2 m **(see also Figure 13: Container 2 side view).**

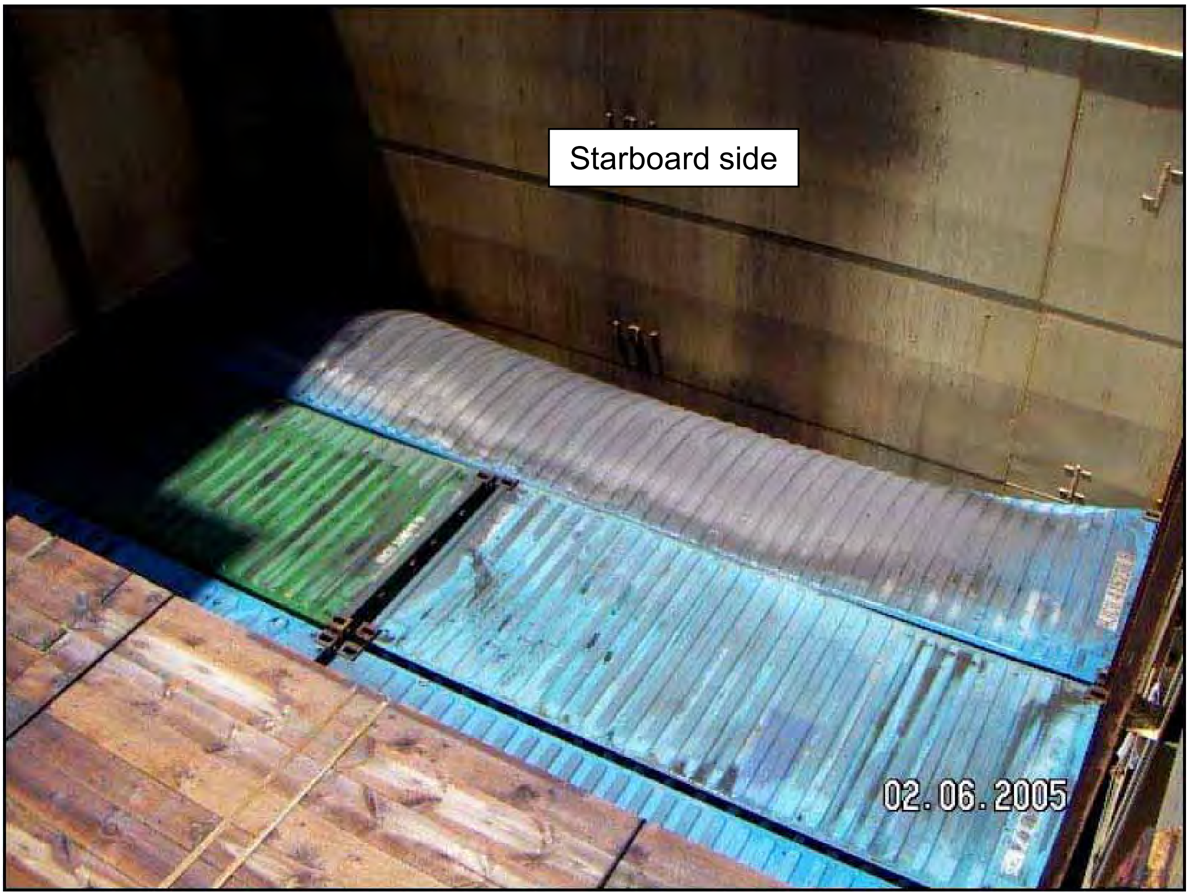

Figure 12: Container 2 plan view in the hold

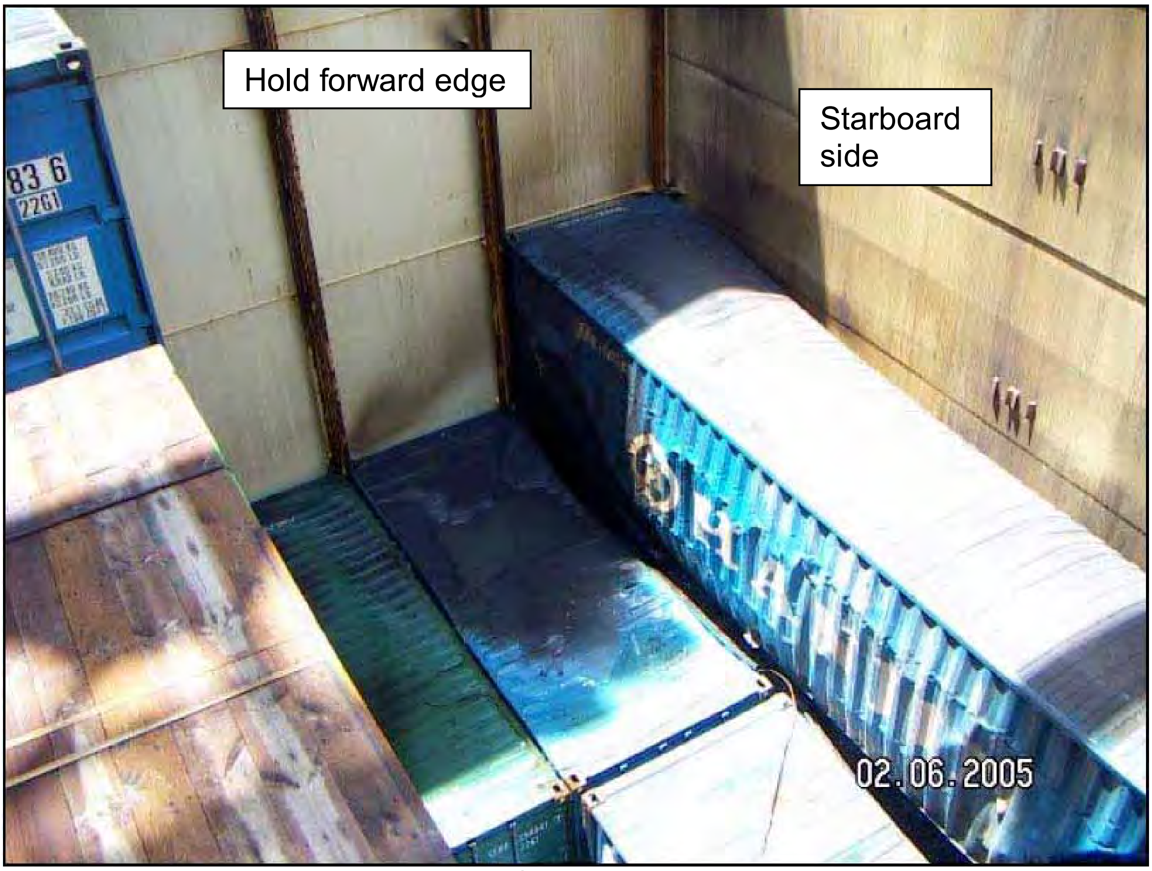

Figure 13: Container 2 side view

5.1.2.4 Cargo: NiMH rechargeable batteries

According to an analysis of the photos, nearly all the rechargeable batteries or rechargeable battery housings still exist after the fire. It is possible to ascertain that the outer packaging consisting of corrugated cardboard (cartons) and plastic film sheeting was largely burnt. The rechargeable batteries show clear differences in the degree of thermal stress. Some batches are only coated with soot, whereas the casing of others is burnt, and still others evidently burnt out. The almost complete lack of residues of the outer packaging is an indication of active embers over a relatively long period. Figure 14 shows the view from aft on both containers at the time of the lifting of the top container. The top of container 1 is visible and the rechargeable batteries from container 2, whose bottom was burnt away, lying on it. Apparently the bigger part of the cargo of container 2 lies on the top of container 1. Accordingly only few rechargeable batteries got in container 1.

Container 1 was stuffed with 21 pallets (16.255 t). It had a total weight of 20 t. Container 2 was stuffed with 15 pallets (11.079 t) and had a total weight of 14.8 t. The total cargo was thus made up of 36 pallets with altogether 1480 cartons, with approx. 40 cartons per pallet.

Figure 14: NiMH rechargeable batteries after the fire

Figure 15: NiMH rechargeable batteries after the fire

5.1.3 Investigations into the cause of the fire

In order to ascertain the cause of the fire the BSU commissioned an expert who conducted two comprehensive series of experiments with the assistance of a specialist fire laboratory. The first series of experiments was conducted with standard commercial rechargeable batteries in order to basically demonstrate the possibility of auto-ignition by the supply of heat from the exterior. A second series of experiments could be carried out subsequently with rechargeable batteries that corresponded to those in the cargo forming the subject of the accident (see here 5.2).

The BSU expert assessed the first series of experiments as follows.
It was possible to demonstrate the possibility of auto-ignition by supplying heat from the exterior using standard commercial rechargeable batteries. That is why the location of storage is considered causal for the development of the fire. The direct vicinity of the heated heavy oil settling tank No. 2 means that the stowage space in Hold 6 is maintained at a permanently high temperature level **(see also. Figures 16 and 17).** It is assumed that on average a wall temperature of settling tank No. 2 of 70 °C – 80°C prevails. With a closed hatch and inactive ventilation, it is further assumed that after a certain time the cargo in the container located there also has reached temperature levels of about 70°C. According to the information supplied by the manufacturer and by the trade associations, at higher temperatures on the one hand the rechargeable batteries become discharged more quickly and thus heat up independently, and on the other hand hydrogen is formed and released in an uncontrolled manner. Accordingly, in a non-cooled and non-ventilated container, the atmosphere is necessarily enriched with hydrogen. This process depends on time, since it is determined by the chemical reactions in the NiMH rechargeable batteries. Accordingly, heating of NiMH rechargeable batteries over a relatively long period creates an elevated danger of fire and explosion in the outer packaging and in the entire container. The presence of electrical charge carriers and the circumstance that a very low minimum ignition energy is required for hydrogen/air mixtures enhances the danger potential further.

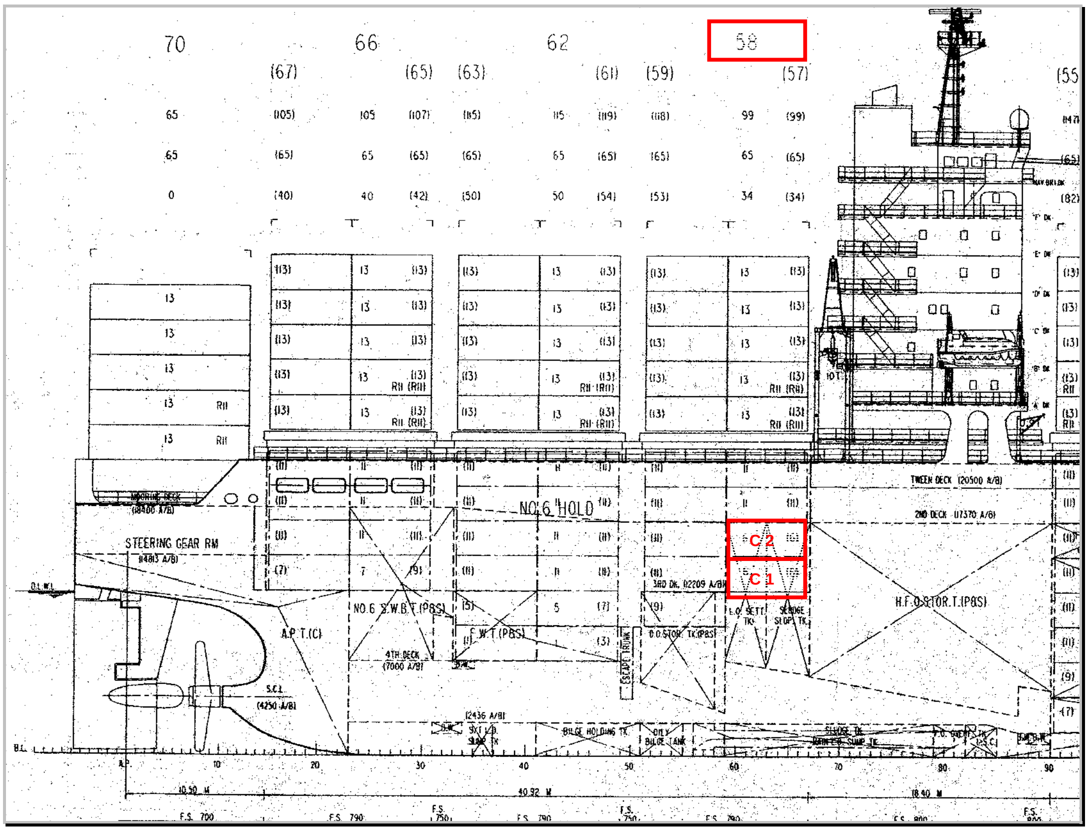

Figure 16: Excerpt from the general plan

5.1.4 Assessment of the first series of experiments on the origin and propagation of the fire

The fire probably started at the forward edge of container 1. The discolouring over large areas of the hold floor and the burnt coats of paint in the hold wall are an indication of the occurrence of high temperatures in this area. Moreover, the container was closed in this area after the fire too, indicating that the fire damage to the hold wall resulted from radiant heat from the container and not from direct flame action. The presence of this source of fire is confirmed by the coinciding traces of fire on the outer wall of the container. After evaluating the data available it can be assumed that the fire developed as a smouldering fire in the bottom container. It can also be assumed that this smouldering fire broke out before the explosion and could not be detected due to the lock and the spatial geometry. As a result of the smouldering fire, the cargo consisting of NiMH rechargeable batteries size AA, corrugated cardboard, plastic sheeting and paperboard in various thicknesses was further conditioned thermally. According to the information supplied by the manufacturer, it can be assumed that NiMH rechargeable batteries in particular give off the hydrogen resulting at higher temperatures and during the internal chemical reactions taking place at these temperatures, e.g. discharging operations, via the safety valve on the plus pole. The experiments conducted show that plastic film sheeting begins to melt already at approx. 60°C, and that in addition combustible gases occur when the paperboard is heated to temperatures above 140°C. Furthermore, the moisture present is given off by the outer packaging and condenses on the cooler rechargeable batteries and plastic sheeting. This leads to the possibility of short circuits connected with the over-heating of the rechargeable batteries and the occurrence of ignitable spark gaps. In the further course of events an atmosphere that is combustible and becomes explosive as a result of the increasing presence of hydrogen develops in the entire container. Hydrogen-air mixtures are ignitable in a very broad range of mixing ratios (4 – 75 % by volume H_2 in the air) and require very low ignition energy (~ 0.02mJ), so that already slight electrostatic discharging is sufficient as a source of ignition. In the mixture ratio of 18 to 59 % by volume, hydrogen-air mixtures can detonate. It can be assumed that these conditions were satisfied in container 1 and that the explosion occurred as a result.

The processes that took place in container 1 have the following impacts on container 2 standing above it: heat is transferred by radiation and conduction so that the container and the cargo become thermally conditioned. As a consequence the floor and the cargo ignite. The damage constellation confirms this process, whereby the fires in container 1 and container 2 can have run in a similar manner but offset in time up to the explosion. Evidently explosive mixtures did not occur and ignite in container 2. After flooding with CO_2, the naked flame fires in container 1 opened by the explosion were extinguished and smouldering fires developed in the outer packaging on the container floor (**see also Figure 11: Container 1 side view).**

In container 1 naked flames only occurred in the forward edge area where the fire originated. The inside paint in container 1 shows hardly any traces of fire (**see also Figure 10, Partial view of interior**).

In container 2 smouldering fires and naked flames developed subsequently, despite flooding with CO_2. The atmospheric oxygen in the packagings prevents self-inerting. As a result of the enrichment of the container atmosphere with smoke gases and the fact that it is not possible for sufficient oxygen to flow in due to the CO_2, there was no headlong igniting right through the container, but instead gradual burning off, above all of the container floor and the outer packaging due to ember fires. That is why the outer walls of the container were hardly discoloured (**see also Figure 13: Container 2 side view**). The fire damage to the hold wall in the position of container 2 is evidently attributable to the thermics of the burning container floor.

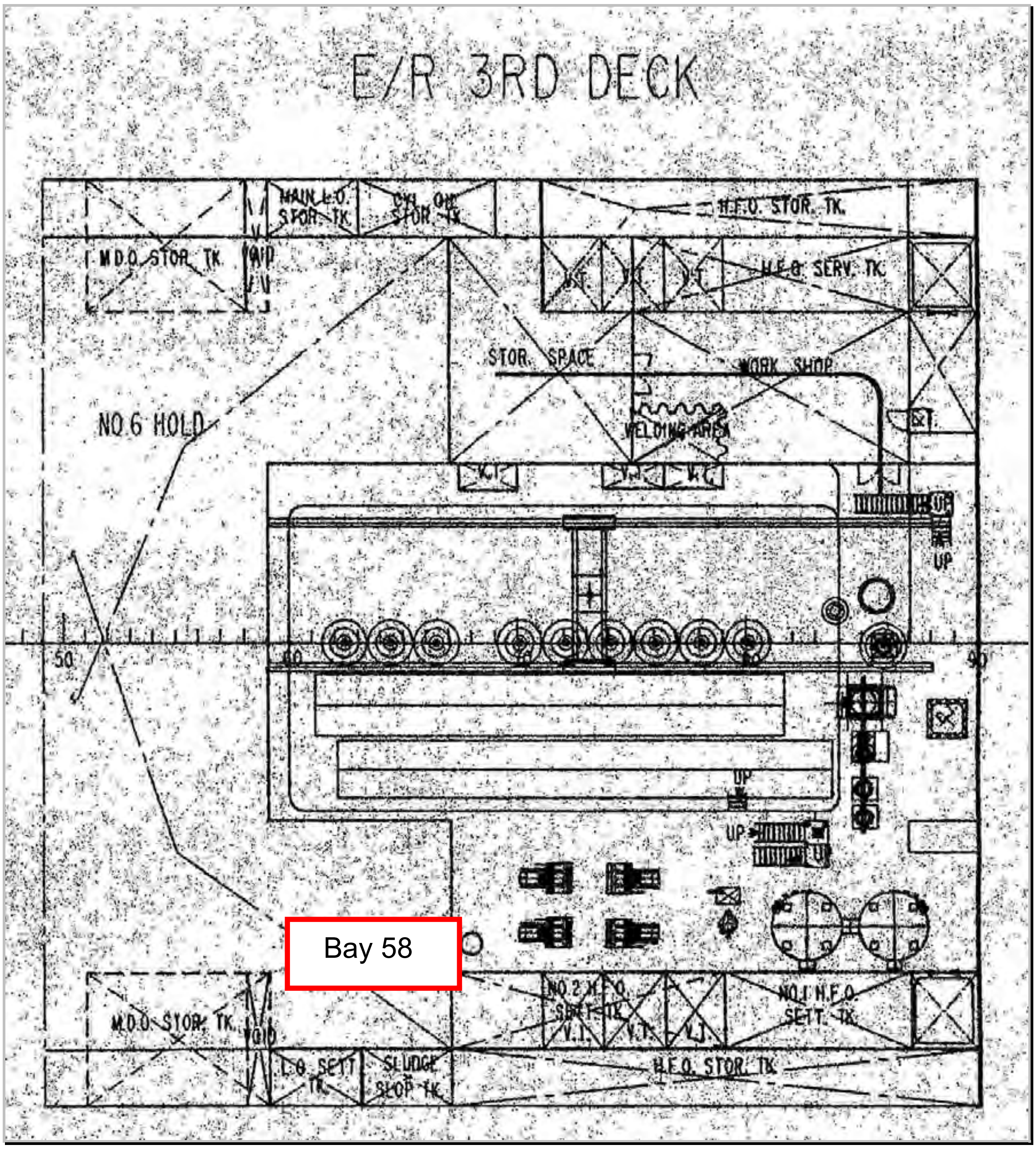

Figure 17: Detail plan deck 3

5.2 Second series of experiments

In order to back up the results of the first experiments, rechargeable batteries of the manufacturer (same type and packing as those involved in the accident) were used in a further series of experiments.

5.2.1 Documents, information and materials for the second series of experiments

The manufacturer provided 620 NiMH rechargeable batteries in their original packing as had been present at the time of the accident (620 NiMH rechargeable batteries 2500mAh size AA HR6; 1.2V).
In addition the loading circumstances of the containers affected were reported and further cargo documents were handed over.

5.2.2 Execution of the experiments

5.2.2.1 Basic notes on the execution of the experiments

Loading condition of the containers affected:

Container 1 (here lower container (exploded))
Total weight 20 t
Cargo weight 16.255 t
21 cargo units – pallets

Container 2 (here upper container (burned out))
Total weight 14.8 t
Cargo weight 11.079 t
15 cargo units – pallets

Total cargo – 36 pallets
1480 cartons (16.70 m^3) – approx. 40 cartons/pallet
Dimensions of individual cartons 41.5 x 34 x 8 cm

Subject container 1

40 ft, dimensions 12.2 x 2.4 x 2.6 m

Cubic capacity approx. 70 m^3

1 carton – 0.011288 m^3

21 pallets – 9.74 m^3

The following specifications were made to determine a realistic size of the experimental container:

- number of packing units actually in the container 21/number of cartons per packing unit 41
- basis of calculation: 20 packing units and 40 cartons per packing unit
- cargo consists of two rows of 10 pallets each standing centred in the container
- number of cartons per pallet base area: 4; stacking height: 10

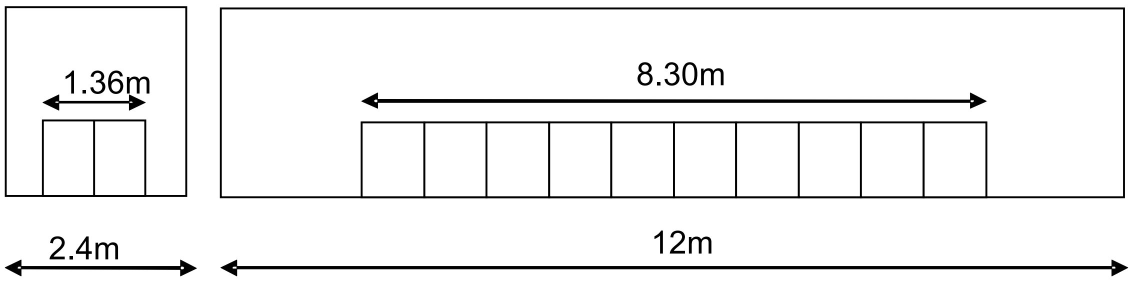

Figure 18: Reference situation in the real container

The volumetric calculation excluding the cardboard, without pallets, results in a cargo stack of 8.3 x 1.36 x 1 m.

Related to the dimensions of the individual packages, this results in the following container mock-up[6] dimensions: 60 x 60 x 20 cm

This ensures that on the one hand the empty spaces and on the other the relative distances between the cargo and the container walls in the mock-up coincide with the circumstances presupposed in the real container.

[6] Mock-up: Dummy, common term describing a model for safety investigations

5.2.2.2 Experimental set-up

The experimental set-up consists of a container mock-up made of 2 mm St 12, closed with a top made of 4 mm St 37.
The original carton with the 620 NiMH rechargeable batteries is placed in the centre and set down on a 10 mm strip of hard timber in order to prevent direct heat transmission from the housing bottom. This caters to the fact that in the real container the cargo was palletised.

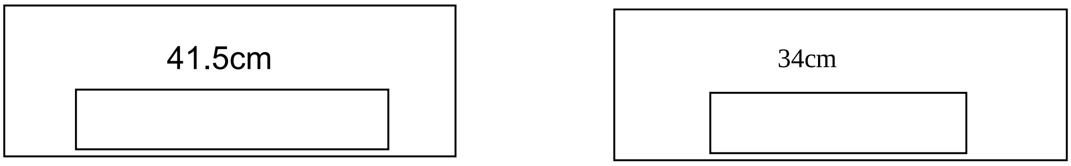

Figure 19: Side view, experimental set-up


Figure 20: Experimental set-up opened

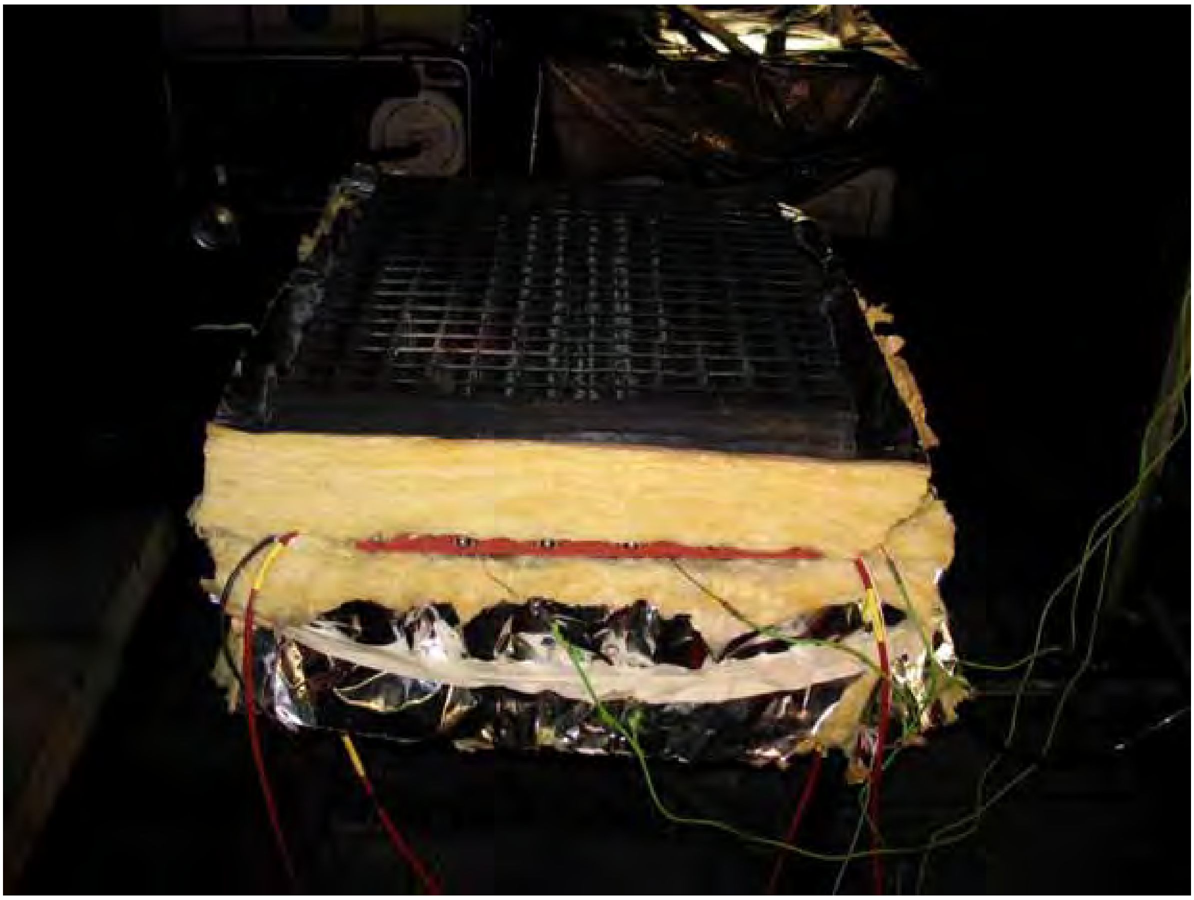

Figure 21: Experimental set-up closed

The container mock-up was warmed from the top and bottom with heating mats for the experiment in order to ensure uniform distribution of the heat in the interior.
The complete insulation of the container prevented temperature differences at the side walls.

5.2.2.3 Subject of the investigation

An original transport carton for 620 NiMH rechargeable batteries was selected as subject of the investigation. The packing consists of cover, carton, inner cover and pad. All the components are made of A-flute cardboard.

Figure 22: Carton exterior

Figure 23: Carton inner cover / pad

Figure 24: Carton, opened

Figure 25: Rechargeable batteries, stored upright

The 620 NiMH rechargeable batteries were stored standing upright. The packing density allows slight movement between the rechargeable batteries in relation to each other.

5.2.2.4 Measuring concept

The relevant temperatures* in the package and in the container mock-up were kept under observation. The gas was extracted from the upper part of the mock-up to keep the atmosphere under surveillance.

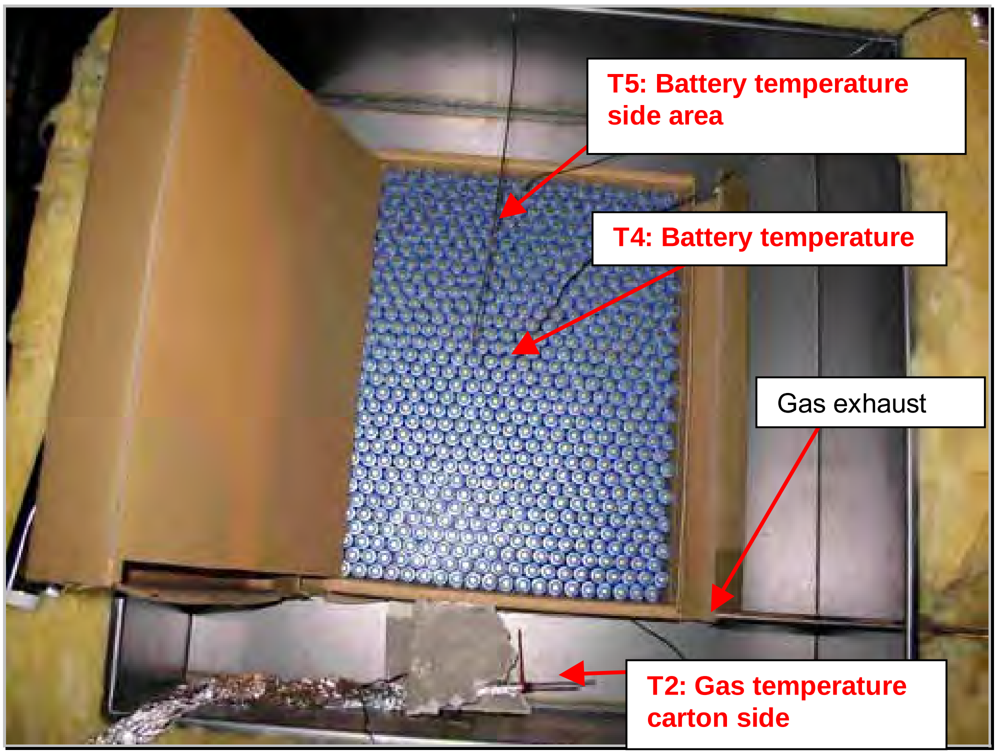

Figure 26: Measuring points

Temperature measuring points:

T1 bottom, interior	material temperature, container mock-up
T2 gas side carton*	relevant gas temperature in the mock-up/container temperature
T3 heating mat top	exterior temperature
T4 rechargeable battery centre*	material temperature rechargeable battery casing
T5 rechargeable battery side area*	material temperature rechargeable battery casing
T6 heating mat bottom	exterior temperature
T7 gas above carton	surveillance of occurrence of fire

*(relevant temperatures for assessing behaviour at higher storage temperatures)

The measurements were conducted with thermocouples of type K.

5.2.2.5 Gas measurement

The gas measurement was conducted using a mobile gas analysis device of type G750 Polytector II.

The following sensors were used:

CO_2	0 - 70 % by volume
O_2	0 - 25 % by volume
H_2	0 - 100 % UEG

Figure 27: Gas measuring device

5.2.2.6 Experimental concept

The concept consisted in exposing the rechargeable batteries in their original packing to the reproduced environmental conditions prevailing during sea transport and documenting the processes resulting from this.
Of the stresses occurring during transport, only the temperature conditions were simulated.

The following scenarios were followed for this:

Phase 1

- Warming of the room atmosphere (gas temperature) in the container from ambient temperature approx. 16 °C to 40 °C (normal temperature in corresponding cargo holds)
- Gradual increasing of the temperature to 60 °C within 3 hours
- Maintaining a temperature of 60 °C in the container mock-up over approx. 20 hours

Phase 2

- Gradual increasing of the temperature to 90 – 100 °C within approx. 3 hours
- Maintaining the temperature of 90 – 100 °C for approx. 21 hours

5.2.3 Experimental results

From the extensive data material available from the experiments, the temperature curves displaying the development of the rechargeable batteries' own temperature while the container space atmosphere temperature increased gradually until it was maintained constant at approx. 85 - 88 °C are shown here. Figure 29 also shows the curve of the hydrogen escaping.

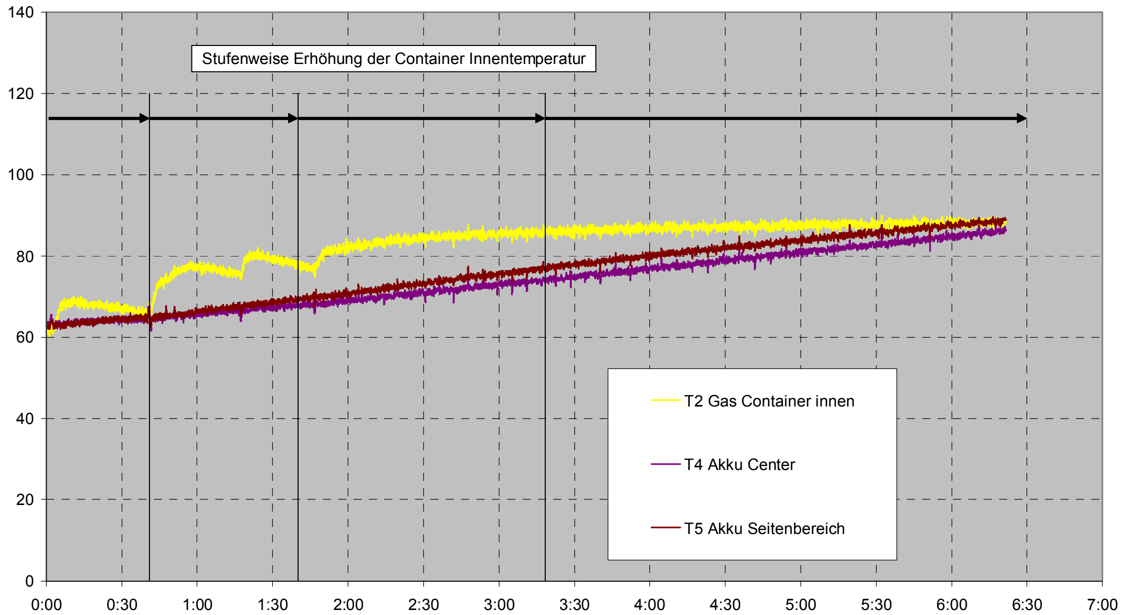

Figure 28: Temperature curves during warming

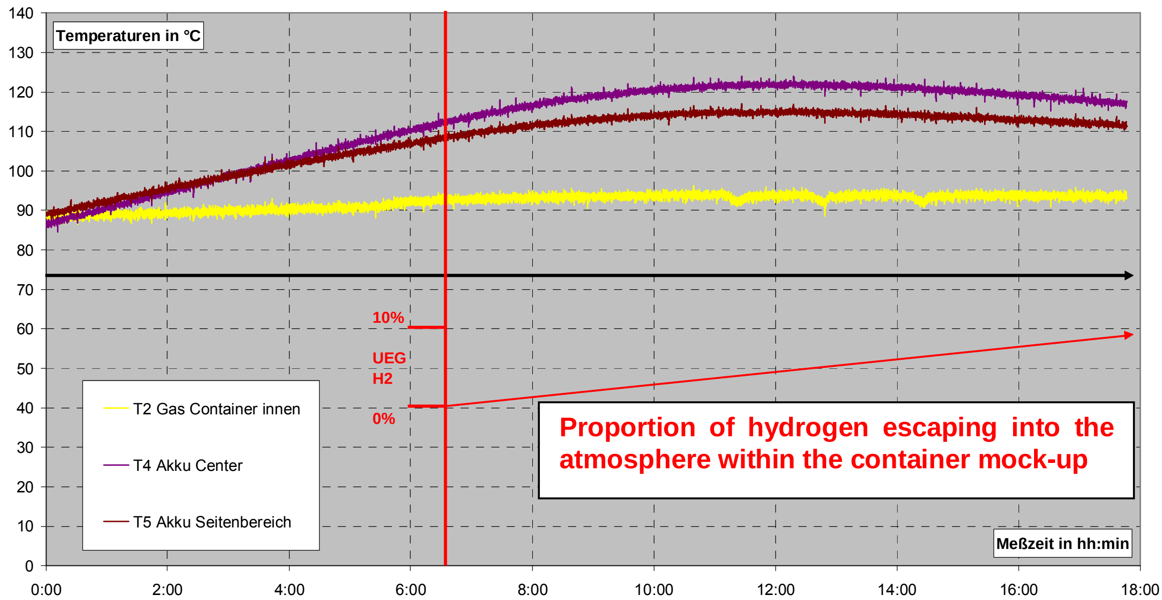

Figure 29: Temperature curves at constant temperature in the interior

5.2.4 Evaluation of the experiments

The evaluation of the second series of experiments shows clearly that up to a temperature range of approx. 60 °C no detectable reactions emanate from the rechargeable batteries even over a relatively long period (20 hours).
After approx. 20 hours the rechargeable battery temperature is equivalent to the gas temperature, in other words to the room atmosphere inside the container.
No changes can be detected in the atmosphere with regard to the gas levels measured, especially where hydrogen is concerned.

After the gas temperature has been increased to approx. 85 - 88 °C and then maintained constant, the rechargeable battery temperatures assimilate to the gas temperatures, especially in the side area, after approx. 6 hours.
In the further course of events the rechargeable battery temperatures exceed the interior space temperatures inside the container by up to 30 °C and even the temperatures of the heating mats by approx. 20 °C. They thus reach the evident activation temperature for inner process of approx. 120 °C that was already demonstrated in the preceding experiments.
In this experimental series hydrogen can be detected in the container atmosphere after approx. 10 hours (gas temperature level around 90 °C and a rechargeable battery temperature of approx. 110 °C). It is to be assumed that the hydrogen release was activated in the closed packing already at an earlier point in time and at correspondingly lower rechargeable battery temperatures. The hydrogen only made its way into the container atmosphere later.
It is furthermore to be assumed that the hydrogen concentration in the outer packing was substantially higher in order to generate the detected concentrations in the container atmosphere by emerging from the packing.
The voltage levels in the rechargeable batteries prior to the experiment were on average 1.227V, and after the experiment 1.1V. This means that discharge processes occurred.
During the experimental series relatively high moisture fall-out was ascertained in the extracted atmosphere.
There was no ignition or explosion in the container mock-up.
At the end of the second experimental series there was a hydrogen concentration of 9 %UEG in the container atmosphere, corresponding to approx. 0.4 % by volume.

The evaluation of the results shows that the statement produced by the first experimental series is confirmed by this second experimental series.
Warming of NiMH rechargeable batteries over a relatively long period creates an elevated danger of fire and explosion in the outer packaging and in the entire container. The presence of electrical charge carriers and the circumstance of the very low minimum ignition energy for hydrogen/air mixtures enhance the danger potential further.

6 Data supplied by the manufacturer

The manufacturer of the rechargeable batteries was listed as client for the transport of the containers concerned in the cargo papers of PUNJAB SENATOR. The Federal Bureau of Maritime Casualty Investigation (BSU) wrote to the company and requested answers to some questions. In reply it was stated that details of the manufacturer's storage conditions for such NiMH rechargeable batteries had not been made known to others. However, it is stressed that the cargo has always been designated properly as “NIMH RECHARGEABLE BATTERIES” to the shipper.

Reefer containers were not used for transport unless a customer requested this. They were then used and billed; generally the cargo was treated as common dry cargo, however. As long as the cause of the accident is not known, reefer containers will be used as an appropriate counter-measure.[7]
The manufacturer attends projects and measures within the framework of the responsible manufacturer associations and organisations as well as within the scope of his internal investigations in order to further improve the safe shipping of his products. He will be making sure that the warning notices “Never dispose of batteries in a fire or heat them” generally applying for the rechargeable batteries will be better known and that the contractual partners henceforth comply with the warning notices during the transport of the rechargeable batteries.

7 Data supplied by the charterer

BSU wrote to the charterer who had the opportunity to respond to questions similar to those posed to the manufacturer. In reply it was stated that the charterer was not informed about the precise transport and storage conditions for this type of battery. Apart from the data contained in the bill of lading, no precise information had been available from the manufacturer prior to occurrence of the incident. If the shipper declared that certain batteries were dangerous cargo, special measures would be taken for transport of the batteries. The shipper had not made any special conditions and accordingly none such had been satisfied.
Consequently this cargo was treated as normal dry cargo in the stevedore's software on board too.
No reefer containers are used for comparable transport operations as the charterer was not aware that any danger emanated from this cargo. The charterer does not require the use of reefer containers by shippers of similar cargo today either, as the charterer ensures that these special containers are stowed in cells in which there are no potential sources of heat.

[7] As a supplement to this it can be stated here that the manufacturer refrained from transporting the rechargeable batteries in reefer containers again as it appeared to be proven that a sustained, external source of heat was responsible for the incident.

The charterer's operating team has a general arrangement drawing of CMV PUNJAB SENATOR made available by the vessel operator. The arrangement of the tanks can be seen from this drawing.

After this incident on board CMV PUNJAB SENATOR, all batteries are stowed on deck, regardless of what type is involved and whether or not they are classified as dangerous cargo. .

8 Data supplied by the vessel operator

The responsible representative of the vessel operator informed us that the long-term charterer had received all the shipbuilding drawings and further official documents. However, no special shipbuilding information had been passed on.

9 Data supplied by Germanischer Lloyd (GL)

The classification society of PUNJAB SENATOR stated:

There are no classification regulations (applies for all IACS[8] societies) regarding maximum permissible temperatures in the cargo holds of container vessels.

In the event that a heated tank projects into a cargo hold of a container vessel or borders on a cargo hold (as in this case – vertical tank bulkhead), there are no special specifications that have to be fulfilled for the issue of the class certificate.

The classification society does not know of any comparable or similar incidents in the past.

[8] IACS: International Association of Classification Societies

10 The fuel system of CMV PUNJAB SENATOR

10.1 Fundamental principles

In heavy oil operation, by contrast with diesel operation, the holding tank, settling tank and day tank[9] must be heatable in order to keep the heavy oil pumpable and allow cleaning.
Before the fuel enters the injection facility it has to be separated in order to prevent malfunctions during injection.
In heavy oil operation the final fuel pre-heater must ensure the temperatures necessary for the specified injection viscosity. In modern installations this temperature is automatically regulated via a changeable steam supply to the final pre-heater following comparison of the target value with the respective actual value. Even under heavy load and speed changes and the associated changes in filling, it is possible to maintain a constant injection viscosity within a very narrow tolerance range in this way. This prevents overheating of the fuel and hence gas formation, as well as any insufficient atomisation due to excessively low or excessively high injection viscosity even for a brief period.[10]

10.2 On board CMV PUNJAB SENATOR

The engine system on board CMV PUNJAB SENATOR is designed in such a way that it can be operated with heavy oil as well as with diesel oil.
The heavy oil is stored in the double-bottom tanks at temperatures of approx. 40 °C. If it is to be used, it is pumped into one of the two settling tanks where the heavy oil is stored for approx. 12 hours to precipitate any impurities. Here it is heated to approx. 60 - 85 °C depending on the fuel class. The higher the temperature, the better the cleaning of the fuel. The settling tanks on board CMV PUNJAB SENATOR each have a capacity of half a day's journey, so that they have to be filled up approx. every 12 hours. This is done manually. The day tank is filled permanently via the separators. The separating temperature is approx. 90 -100 °C. This temperature is maintained in the day tank.
When little or no fuel is drawn from the day tank (e.g. during port operations), the heavy oil flows back into settling tank No. 2 of PUNJAB SENATOR via an overflow line. In this case the returned heavy oil heats the settling tank further, as the supply systems generally remain active even when the main engine is stopped.

[9] Today also known as service tank
[10] "Schiffsmaschinenbetrieb" 8 [ship engine operations] (team of authors) Page 160 f.

11 Analysis

The cause of the fire on board PUNJAB SENATOR was the fact that the NiMH rechargeable batteries were stored close to the vessel's own source of heat, settling tank No. 2. A contributory cause was the lack of any exchange of information about or ignorance of

- the special conditions of the storage spaces at the forward edge of hold 6 and
- the requirements made of safe transport of the NiMH rechargeable batteries.

The fact that the heavy oil settling tank No. 2 borders on cargo hold 6 and as a result of normal operations generates an above average high room temperature locally there may have been known to individual crew members. It was certainly possible for the charterer to obtain this information from the ship's drawings.
A further promoting factor was that the rechargeable batteries had already been exposed to these cargo hold conditions for 14 days and that the containers were located directly against the partition wall to the heavy oil settling tank.[11]
The thermal energy of the heated settling tank No. 2 was transmitted on the container and its cargo by thermal radiation and thermal conduction by the air layer as well as the hold construction. A thermal loss is to be neglected since an excess pressure developed in the complete cargo hold by a general warming which prevented a flowing in of colder air through the ventilation dampers.

In tropical latitudes, the waters where the accident occurred, a temperature level above the storage temperature of approx. 30 °C specified by the manufacturer of the rechargeable batteries generally prevails in the cargo holds. However, the stating of this storage temperature only serves to maintain the performance efficiency of the rechargeable batteries and does not represent any boundary level for endangerment caused by emergence of gases. That is why neither the influence of environmental temperatures in tropical latitudes nor the manufacturer's specified storage temperature are relevant for the cause of the accident.

The experimental series showed a boundary temperature of 85 - 88 °C. It was demonstrated that this is where the exothermic[12] reaction of the NiMH rechargeable batteries starts, in other words the supply of thermal energy from the exterior leads to a chemical reaction inside the rechargeable batteries. This causes a distinct increase in temperature of the rechargeable batteries and thus ultimately the gassing out of the rechargeable batteries, which leads to endangerment caused by the occurrence of an explosive hydrogen/air mixture. It is to be assumed that this exothermic reaction of the rechargeable batteries will also occur even at temperatures below 85 °C and correspondingly long period of action. Possibly additionally promoted by the particularly high capacity of these NiMH-rechargeable batteries.

[11] See Figures 16 and 17
[12] An exothermic reaction is a chemical reaction in which energy is released in the form of light or heat (etc.).

It is most improbable that these reactions occur everywhere in the cargo at the same time and with the same intensity. It is therefore to be assumed that first single fires developed where the biggest thermal stress occurred, further promoted by the outer packaging. Due to the self-locking of the outer packaging (see figure 22 to 25) a reaction through lack of oxygen arises in the cartons and thus smouldering fires develop. These smouldering fires led to thermal processing of adjoining cargo parts and thus to the enrichment of the complete container atmosphere with a combustible and explosive gas-air-mixture. This process inside a locked container is not detectable with the technique used in the cargo holds today. The damage constellation of container 1 confirms this process. The fire in container 1 was almost completely extinguished by the use of the CO_2 fire extinguishing system. This is due to the opening of the container by the explosion. Container 2 in contrast almost burnt out completely since it remained closed and the CO_2 could not get in.

The vessel command did not know concretely what was inside the affected containers because its attention had not been drawn specifically to these. The reason for this was the general designation in the loading list, the tool of the vessel's command, as "chemical materials" and the fact that this cargo is not contained in the IMDG Code. It is understandable practice that the vessel's command can no longer observe all details in comprehensive loading papers such as waybills or bills of lading for several hundred containers loaded per port. Instead, the cargo papers of containers that contain no dangerous cargo (according to the IMDG Code) or cargo that has to be refrigerated are generally sent to the target port for the cargo via another route.
For reasons of ship's safety and special cargo treatment, however, major staff effort is still expended on board in order to service containers with dangerous cargo or cargo that must be refrigerated properly. The vessel command also has all the necessary information (papers, electronic data) for this task at its disposal. In order to direct the attention of the vessel's command to a particularly temperature-dependent cargo such as NiMH rechargeable batteries too, these would have to be designated correspondingly as dangerous cargo or cargo to be cooled.

Finally, the excellent behaviour of the crew after the outbreak of the fire should be mentioned here. In addition the excellent co-operation with the vessel operator Reederei F. Laeisz GmbH and the manufacturer of the rechargeable batteries as well as the charterer during the investigation of the accident by the Federal Bureau of Maritime Casualty Investigation (BSU) also deserves mention.

12 Recommendations

1) The Federal Bureau of Maritime Casualty Investigation (BSU) recommends that the manufacturers of batteries and rechargeable batteries draw attention more strongly and specifically to the ambient parameters for safe storage and transport of their products and to danger potentials in the event of non-observation.

2) The Federal Bureau of Maritime Casualty Investigation (BSU) recommends that the firms responsible for shipping batteries and rechargeable batteries should ensure that not only "Chemical Materials" are declared in the cargo papers, but also that attention is drawn in appropriate form, for instance to "Batteries/Acc.", in the case of such cargoes. This helps the crew and the shore side to take appropriate measures, not only for storage but also and especially in the event of damage. Generally all-round concepts for marking cargo such as "Chemical Materials" appear very problematic, as they make it more difficult to tackle an accident.

3) The Federal Bureau of Maritime Casualty Investigation (BSU) recommends that the Federal Ministry of Transport, Building and Housing have the entry of NiMH rechargeable batteries in the IMDG Code as dangerous substances of class 8 reviewed in the appropriate committees.

4) The Federal Bureau of Maritime Casualty Investigation (BSU) recommends that all involved in sea transport should improve mutual sharing of information, especially about special structural features as was the case in this vessel, in order to enhance safety of shipping further.

5) The Federal Bureau of Maritime Casualty Investigation (BSU) recommends that classification societies should review adapting their shipbuilding regulations in order to insulate cargo from sources of heat due to vessel operations.

13 Sources

- Written and personal comments by the command of CMV PUNJAB SENATOR
- Investigation report by Messrs. MINTON, TREHARNE & DAVIES LIMITED on behalf of the vessel operator Reederei F. Laeisz GmbH and its insurers
- Survey report by Verein Hanseatischer Transportversicherer e.V.
- Expert opinion by the BSU expert Mr. Lars Tober
- Statement by the manufacturer
- IMDG Code
- Measuring Report No. ESE 2005.127; Germanischer Lloyd on behalf of the vessel operator Reederei F. Laeisz
- Excerpts from the journals of CMV PUNJAB SENATOR
- Vessel plans
- Datasheets nickel metal hydride rechargeable battery; Fachverband Batterien (ADR)
- Safety datasheets nickel metal hydride rechargeable battery
- Code of Practice (Reference: IEC 60086-1 2000 Annex B)
- Excerpt from sea chart 2702, Federal Maritime and Hydrographic Agency (BSH)
- "Schiffsmaschinenbetrieb" [Ship engine operations] – Verlag Technik GmbH Berlin, 5th. ed. 1990

14 Annex: Graph of the temperatures measured in settling tank No. 2 on board

The computer technology on board automatically records the internal temperature of settling tank No. 2 once a day. It was possible to read out these data and use them for the investigation. The measurements taken by GL for purposes of comparison confirmed that the recording system was free of errors.