Explosion on board a two mast clipper, Medemblik, 8 June 2006

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THE DUTCH SAFETY BOARD

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LIST OF ABBREVIATIONS

BBZ	-	Vereniging voor Beroeps Chartervaart (Professional Sailing Skippers Association)
ISO	-	International Organization for Standardization
IVW	-	Inspectie Verkeer en Waterstaat (Transport and Water Management Inspectorate)
NEN	-	Nederlands Normalisatie-instituut (Netherlands Standardization Institute)
NFI	-	Nederlands Forensisch Instituut (Netherlands Forensic Institute)
NBKB	-	Nederlands Bureau Keuringen Binnenvaart (Netherlands Bureau for the Certification of Inland Shipping)
PPS	-	Public Prosecutions Service (in Dutch: *Openbaar Ministerie*)
RI&E	-	Occupational Health and Safety Hazard Identification and Analysis
TNO	-	Netherlands Organisation for Applied Scientific Research

TERMS AND DEFINITIONS

Explosive limit
The explosive limit is the concentration of a gas or vapour in a liquid and/or solid state expressed as a percentage volume in air at which the vapour-air mixture can explode if ignited.
The lower explosive limit is the lowest concentration of an inflammable gas, vapour or dust-based solid material in air or in another gas that could cause an explosion.
The upper explosive limit is the highest concentration of an inflammable gas, vapour or dust-based solid material in air or in another gas that could cause an explosion.
Above the upper explosive limit and below the lower explosive limit there is no explosion risk. However, if there is an excess of volatile components present (above the upper explosive limit) then there is a chance of fire. The upper and lower values of the explosive limits are different for different volatile materials.
The range between the lower and upper explosive limits is known as the explosive range.

Gas well
A storage site for propane gas bottles.

Cabin
Sleeping living quarters

Bunk
Bed

Recreational vessel
Yachts and modified commercial vessels that are solely used for holidays and pleasure trips.

Septic tank
Tank used to separate and collect floating/solid materials and liquids. The waste water is removed by overflow. The solid materials sink and must be removed over time.

Dilution pump
A dilution pump dilutes the waste water and pumps it away.

Sewage tank
Collecting tank for waste water from toilets, kitchen and shower. The entire content of such a tank must be emptied at regular intervals.

CONSIDERATION

Facts and reason for investigation
HAVO (higher general secondary education) and VWO (pre-university education) pupils from Develstein College in Zwijndrecht were on a sailing trip that was due to last from Tuesday 6 June to Friday 9 June. They were sailing on the Friesian lakes and on the IJsselmeer under the watchful eye of their teachers. All in all, there were 26 pupils and 2 teachers on this trip on board a chartered two-mast clipper.

On 8 June 2006, an explosion occurred on board their ship at about 7.50 p.m. [NB. All times are local times.] At that time, the ship was moored in the harbour at Medemblik. At the time of this incident, there were eleven pupils on board the clipper. Some of them were preparing the evening meal, cooking on the gas rings on the four-ring cooker. Eight of the pupils on board were wounded, four of them seriously. At least three of the pupils have permanent injuries from the explosion.

The clipper is part of the so-called 'brown fleet'. The ship is used as a passenger (sailing) ship to make trips that last one or more days. The clipper is often hired out to schools and companies. During daytrips, it has room for up to 40 people. A total of 28 people can sleep on the ship. During such trips, the guests usually cook their own meals on board.
The Dutch Safety Board monitors passenger ships in particular, due to the composition and number of people that travel on board such vessels. People of all ages use such ships for recreational purposes. The Board felt that there were grounds for investigating the explosion, given the serious injuries sustained by a number of young people and the potential risks associated with using gas on board such ships.

Shortly after the incident, the damage assessment led the Dutch Safety Board to conclude that the explosion had to be ascribed to the ignition of a gas/air mixture under the floor. Further evidence that the explosion had occurred under the floor was the injuries sustained by the pupils, which were primarily complicated ankle fractures and burns to the legs.

Following on from these initial findings, the Dutch Safety Board found two possible causes for the gas accumulation:

i) a leak of propane gas from pipes and/or the cooker, and
ii) a leak/outflow of gases (hydrogen gas and/or methane gas) from the sewage tank.

A leak of propane gas was the most likely cause of the explosion. After all, the gas cooker was being used at the time of the explosion. Gas explosions have been known to occur - the Dutch Transport Safety Board and the Dutch Safety Board have published four other reports of investigations into gas explosions in residential environments, which found there were a range of causes for such incidents.
Investigations into incidents on board vessels have shown that the most common cause for gas explosions is poorly functioning gas equipment, sometimes caused by a defective connection or overdue maintenance.

Leak of propane gas
The investigation by the Dutch Forensic Institute (NFI) revealed that the explosion was almost certainly due to a poorly functioning gas cooker. The thermoelectric safety device on one of the cooker's control knobs was dirty with leftovers, which meant it wasn't functioning properly. This allowed unburnt gas to flow out of the cooker's oven compartment and spread via the oven door and ventilation openings under the oven to places both under and above the wooden floor of the living quarters. This created a propane-air mixture that ultimately exploded. The gas pipelines were not found to have any faults.
In order to test the hypothesis that the explosion was caused by a leak of propane gas, the Dutch Safety Board carried out experiments on board the clipper using a gas that behaves and smells like propane. These experiments showed that the gas diffused very quickly. At one of the measuring points under the floor, an explosive gas/air mixture was measured approximately five minutes after the start of the experiment. The results of the experiments support the conclusion that the explosion on board the clipper was very probably caused by a leak of propane gas.

The pupils who were on board the ship did not smell any gas prior to the explosion. For safety reasons, an artificial odour known as an 'odorant' is added to gas. The chosen odorant is designed to smell unpleasant and thus to warn of gas leaks. Previous investigation by the Dutch Safety Board into gas explosions has revealed that it can still be difficult to detect gas even if it has been odorised. Possible reasons for this could include:

- *People becoming used to the smell*: When choosing the odorant, the degree to which people get used to it is taken into account. Even so, if the concentration of gas in a room

only increases slowly then the gas will only be noticed at a much higher concentration.
- *Reduced sensitivity*: The ability of those in the room to smell the gas may be lower than the standard used to define 'smellability'. The standard is based on tests that involved trained odour observers, whose ability to smell odours may be better than that of the pupils on the ship. Temporary changes in the ability to smell odours can also be caused by colds and allergies. However, in the case of this incident, there are no indications that this was the case.
- *Problems with association*: The odorant may be present but not be associated with gas.

The experiment that the Dutch Safety Board performed on board the clipper showed that the build-up of the gas/air mixture under the floor up to the lower explosive limit must have happened quickly – more quickly in fact than the build-up of gas concentration in the galley (i.e. kitchen) that would have allowed it to be recognised by the people there. This eliminated the built-in safety margin for the gas odorant for such situations.
As a result, the Dutch Safety Board advocates that there should be a further investigation of ways of improving the detectability of propane gas. This must bear in mind that unlike natural gas, propane gas is heavier than air and always tries to find a way to the lowest point. On a ship, these are the enclosed areas where gas accumulation can quickly lead to problems.

The Dutch Safety Board feels that the above findings from the investigation are alarming, and not only because relatively large groups of people are on board such ships. On the clipper, the cooker was being used by various people, some of whom had hardly done any cooking before in their lives, and some of whom even had no experience at all of using gas cookers.
The cooking gas equipment on board the clipper where the explosion occurred was carefully installed, connected up and tested. Despite this, the contamination of a safety device that had completely escaped everyone's attention led to gas escaping unnoticed. This is clear evidence that gas leakage can occur not only from technical defects in equipment such as a faulty pipeline or coupling that comes loose, but also from problems that can occur whilst the equipment is being used. In this case, it was caused by a thermoelectric coupling that was no longer working properly as the result of encrusted leftovers, possibly resulting from liquid boiling over during the food preparation. This allowed an uncontrolled outflow of gas to take place, partly as a result of inexperience or careless use of the gas cooker. This problem is aggravated by the fact that various locations on board ships, including the area under the floor, are not or cannot be properly ventilated or indeed ventilated at all. In addition, it is often difficult to access them to inspect them. This increases the likelihood that a gas accumulation on board the ship may go unnoticed until it is too late.

It had already been noted in an investigatory report into an explosion on board a pusher tug published in 2000 by the Board's predecessor, that a gas mixture can accumulate under a floor for various reasons, including because it is difficult or impossible to visually inspect the area under the floor or to adequately ventilate it.[1] Here too, this led to an explosion.

The risks associated with the use of gas on board vessels are recognised by the industry. As a result, gas usage and the use of gas cooking equipment for so-called 'household use' (cooking etc.) are subject to laws and regulations. The equipment is also a permanent component of the Occupational Health and Safety Hazard Identification and Analysis (RI&E) process that ships' captains must carry out. Given the associated risks, it is no surprise that a European Directive[2] and the ROSR 1995 (Rhine Vessel Inspection Regulation) lay down that the use of gas on ships must be reduced. However, it will not be until the year 2045 that the use of gas for household uses on board passenger vessels will be prohibited.
Harmonisation of the relevant legislation makes it impossible for a Member State to bring forward the deadline for transition. The European Commission has laid down in the Directive that additional measures may only be taken in certain selected areas. However, these additional measures may only be demanded via the Commission. Although the Dutch Safety Board wanted to advocate bringing forward the deadline for transition, LPG equipment is excluded from this and from other additional measures.
Alternative forms of cooking fuel such as diesel fuel or electricity are already available.

The formation of gases in the sewage tank
A second point of concern felt by the Dutch Safety Board is a risk that the industry has not

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1 Dutch Transport Safety Board, "*Explosie aan boord van een duw-/sleepboot op 8 augustus 2000*" ('Explosion on board a pusher tug on 8 August 2000'), November 2002.

2 Council Directive 82/714/EEC laying down technical requirements for inland waterway vessels. This Directive was revised in 2006, which led to Directive 2006/87/EC. This will be implemented by December 2008 at the latest.

recognised yet. This risk relates to the leaking/outflowing of gases from the sewage tank[3] to the ship's interior. Given the damage assessment on board the clipper and the fact that the tank's ventilation was blocked, amongst other reasons, the Board felt that it was possible that the explosion was caused by gases that formed in the sewage tank and spread through the ship, due to leaks in the drainage system and/or overpressure, doing so via the ship's toilet drainage, showers' sink holes and draining board.

The waste water coming from the galley, washbasins, toilets and showers is carried away via PVC sewage pipes to the sewage tank. This tank then contains a mixture of liquids and floating materials. The floating materials sink and create sludge. This sludge undergoes fermentation that releases such biogases as hydrogen gas (H_2), methane gas (CH_4) and carbon dioxide (CO_2), along with very small quantities of (residual) gases such as hydrogen sulphide (H_2S) and ammonia (NH_3). Enough of these gases are usually conducted away via the ventilation fitted to the tank. However, if the tank's ventilation is blocked, these gases may flow out elsewhere in the ship. This is because each time the toilet is flushed, or each time the washbasins and sinks are used, there is a brief build-up of pressure in the sewage tank. The gases in the sewage tank will then flow out of the tank via a route other than through the tank ventilation. Such overpressure will lead to a welling up in the various discharge pipes. This possible outcome was established by the experiments performed on board the clipper. In addition, the outflow of gases in the ship can occur via a faulty connection of the waste pipes (which are usually located under the floor of the below-deck area). The gases can form a compound with oxygen under the floor, creating an explosive mixture. If these gases then come into contact with an ignition source, this may cause an explosion.

Based on the experiments performed on board, the Dutch Safety Board has concluded that the most likely cause of the explosion on board the clipper was the propane gas. However, this has not been established conclusively, so the Board believes it is necessary to carefully investigate the risks associated with the poor design or poor installation of sewage tanks on board vessels.

This problem is aggravated by the fact that these gases can accumulate unnoticed and over longer periods of time in the area between the floor of the below-deck area and the ship's bottom. It is also true that in ships these areas are not or cannot be properly ventilated. This increases the likelihood of gas accumulation.
There is no RI&E (Occupational Health and Safety Hazard Identification and Analysis) nor any laws and regulations that cover the risks of gas escaping on board vessels. Another point is that sewage tanks are not covered by inspections.

A feature of passenger sailing ships is that these vessels are usually operated by a captain/owner. About half these captains are members of the BBZ (the Professional Sailing Skippers Association). This association has developed an RI&E for the industry that captains can use to test and maintain safety levels on board their ships. They can also use it to draw up a plan of action to solve flagged problems. The above shows that in this case the RI&E failed to identify the risk.

Apart from this, the industry does not have a generally accessible system for recognising such risks that can be used to introduce preventive measures across the industry. There are various parties responsible for the implementation and maintenance of safety measures in the passenger transportation industry. It is not just the AI (Labour Inspectorate) and the IVW (Transport and Water Management Inspectorate) who are responsible here – the delegation of supervisory tasks means that market players are responsible too. The downside of using the free market system for certification and inspection in the shipping industry is that risks may not be (fully) recognised and that relevant knowledge is not shared fully (or at all) with other players. This means that (new) issues cannot be responded to. This is why the IVW has to build up a complete picture of the risks in the shipping industry. In addition, it is the captain's/owner's own responsibility to find out about recent developments and to apply these where necessary, in order to ensure the safe operation of his/her vessel(s).

The above observation by the Dutch Safety Board is a good example of how risks can be overlooked. Despite mandatory risk inventories, it is still possible that certain parts of the business are not regarded as being risky and thus are not recognised as such even after an incident. However, new developments can lead to a better understanding of potential hazards. The industry association, the captain/owner, as well as all other stakeholders, must continue to assess which aspects of their business operations are associated with risk. Cross-sectoral expertise too can be used to recognise risk, in order to prevent a unilateral approach that may overlook certain risks.

In view of the requirement that will come into force in 2009 to use a sewage tank in recreational

[3] Collecting tank for waste water from the toilets, galley and showers.

vessels, the number of vessels with onboard sewage tanks will rise in the future.[4] It is also likely that passenger transportation vessels on the inland waterways will have to use sewage tanks too. The Dutch Safety Board believes that the risks of using sewage tanks need to be recognised and that this knowledge must be disseminated throughout the industry. Problems in this field can be avoided by the proper installation and maintenance of such tanks.

4 The pleasure cruise sector with recreational vessels has really taken off since 1970, and this trend is still continuing. The number of vessels more than 6 metres long is estimated to be 275,000 and more than 150,000 of these are classified as recreational vessels. This includes vessels used for trips outside their own travel region that have sleeping accommodation. The forecast is that by the year 2030 the Netherlands will have 230,000 tourist vessels. Source: '*Beleidsnota provinciale vaarwegen*' ('Policy document on provincial waterways'), Province of South Holland, 2006, p. 115.

Final conclusions

1. The explosion on board the two-mast clipper took place at about 7.50 p.m. (local time) in the ship's living quarters. On board the ship at that time were eleven pupils, four of whom were seriously injured in the explosion.

2. The explosion's planes of fracture and direction of movement indicate that gas accumulated under the floor. The front of the explosion travelled below deck under the floor in a horizontal direction towards the sleeping living quarters at the front and rear, and from the floor in an upward direction towards the ceiling and dome light (the poop lantern).

3. The NFI concludes that the explosion was caused by a leak of propane gas. This leak could have been caused by a faulty thermoelectric coupling on the cooker that resulted from a failure to keep the cooker properly clean.

4. Experiments performed at the behest of the Dutch Safety Board on board the clipper in question revealed that the gas flowing out of the cooker can quickly accumulate under the floor.

5. The Dutch Safety Board concludes from its investigation that the explosion on board the clipper was in all probability caused by a leak of propane gas from the cooker. There were also found to be several potential ignition sources on the ship that could have ignited this gas.

6. In addition, the Dutch Safety Board has established that gases can be formed in sewage tanks, a fact that under certain circumstances can pose a significant risk to those on board. One of the critical circumstances was the blocked ventilation of the sewage tank, which meant that the gases could no longer be carried away to the outside air. This meant that gases could escape from the sewage tank via other routes (for example via sewage pipe joints or sink holes of showers, washbasins and toilets) and could accumulate unnoticed in an area on board the ship. If mixed with the necessary quantity of oxygen, an explosive gas mixture will result.

7. This investigation has revealed that in certain circumstances the odorisation of gas may not be enough to ensure that leaks will be identified in time. This is certainly true of ships, because propane gas is heavier than air and will quickly find its way to areas below deck that are not (properly) ventilated. The Dutch Safety Board believes that there should be an investigation into finding ways of improving the detection of propane gas, including by using a more detectable odour. There should also be an investigation into other forms of flagging gas on board ships.

8. Given the risk of using gas and the other alternatives already available, the Dutch Safety Board believes that the transitional deadline, which is currently set for the year 2045, needs to be reviewed.

9. The industry does not deploy a safety management system (or else only does so patchily). This is mainly because the vessels are usually in the hands of a single person, namely the captain/owner. There is a body that collects and shares knowledge, this being the coordinating (industry) organisation BBZ. However, only half of all captains have joined the BBZ so far.

Recommendations

Its investigation into the explosion on board the two-mast clipper has led the Dutch Safety Board to make the following recommendations:

1. Given the risks associated with the use of sewage tanks, the Dutch Safety Board recommends that the Transport and Water Management Inspectorate (IVW) make the checking of the installation and maintenance of these tanks part of the system of certification and inspection.

2. The Board recommends that as part of the planned organisation of the supervision of inland shipping the IVW should ensure that a total overview of safety levels in the passenger sailing industry is drawn up and kept up to date.

3. The Board recommends that the Minister of VROM (Housing, Spatial Planning and the Environment) has an investigation carried out into ways of improving the detection of propane gas, including improving the odorants used.

4. The Board recommends that the Professional Sailing Skippers Association (BBZ) bring to the attention of the industry the knowledge about the risks and prevention of gas accumulation under vessel floors. There should also be special attention paid to sewage tanks and possible flagging methods.

Pieter van Vollenhoven Chairman	M. Visser General Secretary

1 INTRODUCTION

1.1 GENERAL

On Thursday 8 June 2006, in the Medemblik harbour, there was an explosion on board a two-mast clipper. At that time, a group of pupils and two teachers were on board. The crew consisted of a captain and a mate. Eight pupils were wounded in the explosion, four of them seriously. At least three pupils suffered permanent injury.

The investigation by the Dutch Safety Board concentrated on two hypotheses regarding the possible cause of the explosion: hypothesis 1) a leak of propane gas from the gas pipes and/or the cooker on board the ship, and hypothesis 2) a leak/outflow of gases (hydrogen gas and/or methane gas) from the sewage tank[5].

One of the aims of the Dutch Safety Board's investigation was to determine the actual or probable cause of the explosion. The Board hopes that its investigation into this explosion will result in the drawing up of measures to avoid such incidents in the future and/or to limit the consequences of such incidents. The Board believes that the independent investigation into this incident can help to systematically improve safety on board passenger sailing vessels. The Board is also trying to use this investigation to raise awareness of the risks of using propane gas and installing sewage tanks.

1.2 NOTE TO READERS

This report consists of seven sections and is organised as follows: Section 2 contains the factual information on the incident and a description of the two-mast clipper[6]. It also looks at the facts and the two hypotheses (which are gone into in greater detail in two scenarios) about the cause of the explosion.

Section 3 sets out the assessment framework for the investigation. This framework consists of three sections: i) the relevant laws and regulations, ii) additional standards and guidelines, and iii) a description of the way in which the Dutch Safety Board believes that parties must assume responsibility themselves for safety.

Section 4 describes the stakeholders (i.e. the parties involved) and their responsibilities.

Section 5 looks at two possible scenarios regarding the possible cause of the explosion on board the ship, namely: i) a leak of propane gas from the gas pipes and/or the cooker and ii) the build-up of gases in the sewage tank that then escaped and accumulated in the area under the floor.

Section 6 sets out the conclusions from the investigation into the explosion on board the clipper. Section 7 contains the Board's recommendations that it has made as a result of the investigation into the explosion.

[5] Collecting tank for waste water from the toilets, galley and shower.
[6] Speedy sailing ship with acute bow and multiple masts.

2 FACTUAL INFORMATION ABOUT THE INCIDENT

2.1 INTRODUCTION

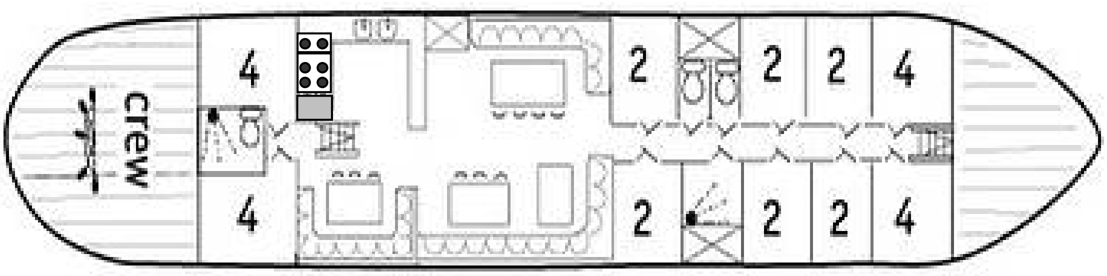
First, this section contains a description of the two-mast clipper. Then the events of Thursday 8 June 2006 will be described, based on interviews and details of the situation on board the ship after the explosion. This section also looks at two hypotheses about the cause of the explosion.

2.2 DESCRIPTION OF THE TWO-MAST CLIPPER

The clipper was built in 1905. Up to 1995, it was used for freight transport on various inland waterways. In 1995, the ship was re-built, since which time it has been used as a passenger sailing ship for trips lasting a day or longer. During daytrips, the ship has room for 40 people, with there being room for up to 28 passengers to sleep. The clipper is one of the more than four hundred vessels that are part of the so-called 'brown fleet'[7]. The size of this 'brown fleet' is such that each year more than 1 ½ million guest days[8] are spent on them.[9]

Stern | Fore

Port



Starboard

Figure 1: Layout of the two-mast clipper at the time of the explosion on 8 June 2006
- *The figures stand for the number of bunks per cabin.*
- *'Crew' stands for the ship section above the engine room that is reserved for the crew, which is separated from the rest of the ship by a steel bulkhead.*
- *A toilet and shower are located between the cabins in the stern.*
- *There are two toilets and a shower located between the cabins in the bow.*

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7 Traditional sailing fleet of early 20th century vessels that originally carried brown sails. They are usually old, restored fishing boats or freighters. The most common vessels in this fleet are fishing smacks, cutters, clippers and other Dutch sailing vessels including 'lemesteraken' and 'tjalks'. Source: www.waddenzee.nl.

8 A 'guest day' is each day that a paying person remains on board.

9 Figures from BBZ 2004-2005.

Figure 2: The two-mast clipper under full sail (photo from operator's website)

The ship is about 32 metres long and 6 metres wide. The stern provides above-deck access to the captain's living quarters (marked 'crew' in the figure) and the engine room (see figure 1). These areas are partly below the deck. The crew's cabin also contains a toilet. Immediately in front of the crew area and the engine room there are two cabins that can each accommodate four people. One of the rooms is on the starboard side, the other is to port. Between these living quarters there is a toilet and shower area. At the back of the ship there is also a small gangway and a storage area under the stairs. These stairs provide access from the above-deck area to the living quarters below deck.

In the middle of the ship there are living quarters that include a galley (i.e. kitchen/caboose). The galley is located on the port side of the ship and is equipped with such things as a gas cooker (with oven compartment) and a freestanding fridge. The living quarters have three sitting areas - two on the starboard side and one on the port side. The sitting areas consist of benches, chairs and tables. The ceiling in the living quarters is furnished with a dome light whose fitting extends to the above deck area. This dome light has a four-part plastic shade.

Figure 3: The galley (kitchen) on the port side of the ship prior to the explosion. On the left, the stairs that lead above deck (photo from operator's website)

At the front of the ship, on opposite sides of a straight gangway there are a total of eight cabins. Additionally, there are two toilets on the port side and a shower on the starboard side[10].

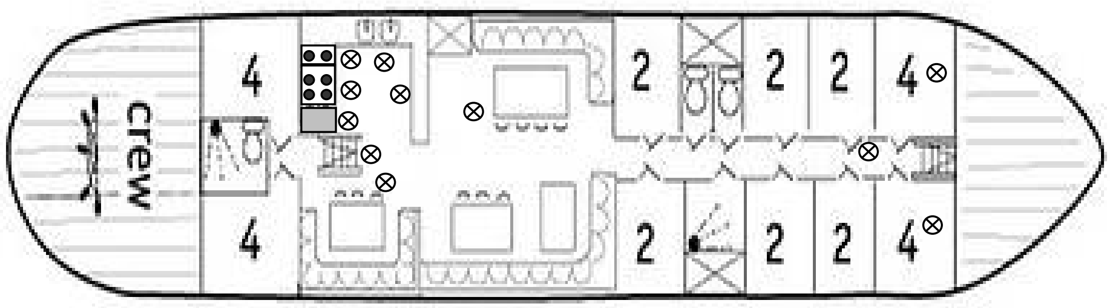
[10] At the time of the explosion, the ship had two showers. After the explosion, the ship was renovated and a third shower installed.

2.3 RECONSTRUCTION

During the time from Tuesday 6 June to Friday 9 June 2006, HAVO (higher general secondary education) and VWO (pre-university education) pupils from Develstein College in Zwijndrecht were sailing on the Friesian lakes and on the IJsselmeer under the watchful eye of some of their teachers. The 83 pupils and teachers were spread over four vessels from the 'brown fleet'. All in all, there were 26 pupils and 2 teachers on board the vessel where the explosion happened later. The ship had a two-man crew (i.e. captain/owner plus ship's mate).

On Thursday 8 June, the vessels moored in the Oosterhaven harbour at Medemblik at about 6.00 p.m. After this, the pupils prepared the evening meal themselves for the whole group in the ship's galley, cooking the meal on the four-ring gas cooker. Apart from the four-ring gas cooker there was also a two-ring cooker, which was not used to cook this meal.
The captain and the mate remained above deck on the ship alongside and were accompanied by some of the teachers and the crew from the other ships. All in all, eleven pupils were below deck (see figure 4). Apart from the exit off the ship, the ship was fully sealed off.

Port



X

Starboard

Figure 4: Top-down view, showing the position of the pupils
- *The circles with crosses in them indicate the positions of the pupils who were on board the ship when the explosion occurred.*

At about 7.50 p.m., there was an explosion below deck in the living quarters. Witnesses report hearing a 'very loud bang'. Immediately after the explosion, smoke or a cloud of dust could be seen outside the ship.
Eight of the eleven pupils who were below deck in the ship at the time were wounded, four of them seriously. These were all pupils who were in the living quarters when the explosion occurred. Immediately after the explosion, the pupils, teachers, captain and mate provided first aid and brought the wounded pupils outside. Eyewitnesses report that the emergency services were on the scene quickly. The wounded pupils were then taken by ambulance to hospitals in Hoorn and Alkmaar. Three of them sustained permanent injuries as a result of the explosion.

The pupils and teachers who were unhurt because they were in town or on board one of the other ships at the time of the explosion were taken to the hotel 'Het Wapen van Medemblik', from where they were taken at about 11.00 p.m. and bussed to Zwijndrecht. The school, working with the *Slachtofferhulp* victims' aid organisation, gave the pupils and teachers counselling and aftercare.[11]
The police contacted the captain and the mate of the clipper separately in respect of the provision of aftercare.

[11] The Dutch Safety Board did not investigate the relief effort and aftercare of the persons involved in the explosion, as the initial indications were that the responsible parties organised this relief effort and aftercare well. Both the Medemblik municipality, the regional emergency services and the KLPD (National Police Services Agency) said that the various parties had worked well together. On the evening of the explosion, the ship was moored in the Medemblik harbour. This meant that it was the Medemblik municipality who had the responsibility and duty to respond to the effects of the explosion. The school devoted a lot of time and effort to the aftercare of the pupils and organised various get-togethers jointly with the Slachtofferhulp victims' aid organisation.

2.4 POSSIBLE CAUSES OF THE EXPLOSION

On the basis of the damage assessment and other information, the police and the Dutch Safety Board established that the explosion was due to an accumulation of gas under the floor. On the basis of this observation, the Dutch Safety Board put forward two hypotheses about the cause of the gas accumulation. These hypotheses have been detailed in two scenarios that are described in the following sections.

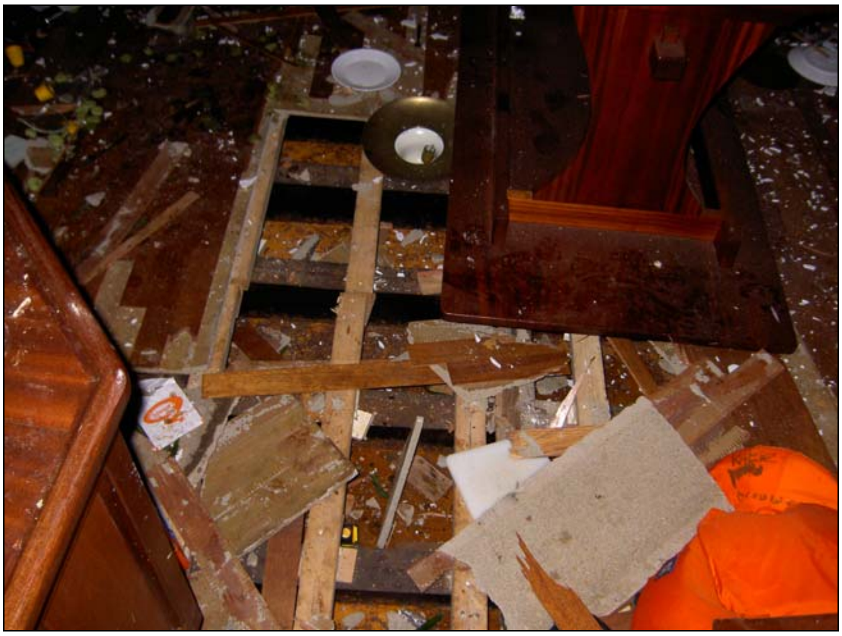


Figure 5: Damage after the explosion, floor of the living quarters (Photo: Dutch Safety Board).

2.4.1 Scenario 1: Explosion of propane gas

Propane gas explosions have been known to occur on board recreational vessels[12]. The cause of such explosions is often to be found in poor-quality connections and/or poorly functioning gas equipment, sometimes aggravated by overdue maintenance. With recreational vessels, these problems surface in particular when the sailing season starts, which is when the equipment is first used (again). An investigation by the Dutch Transport Safety Board, the predecessor to the current Dutch Safety Board, revealed that in some of the incidents investigated, gas had leaked out and accumulated in the ship. In most cases, witnesses said that they smelled gas prior to the explosion.

The scenario that the explosion on 8 June was caused by propane gas can be subdivided into two possible causes:

- a leaking of gas from the pipe; or
- a leaking of gas from the four-ring gas cooker.

The gas pipeline on board the clipper was connected to the gas well[13] on deck, consisted in part of a steel pipe (on deck) and a copper pipe (in the ship) and was fitted with 'bottleneck couplings' at various locations. A leak from one of these couplings, primarily from those in the ship, could have led to an accumulation of gas.

A possible alternative cause of the accumulation of gas was a gas leakage from the cooker. On the evening of the explosion, several pupils were present in the living quarters, in order to prepare the evening meal, which they did using the gas cooker. A lack of experience with the on-board gas cooker or with gas cookers in general could have led to gas escaping.

In both cases, the ship's construction and the physical properties of propane gas (which is heavier than air) meant that the gas could spread through the room <u>and</u> flow through seams, chinks or holes in the floor and via the adjoining kitchen cupboards and then accumulate. Note by the way that the gas supply pipes to the cooker were located above the floor.

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[12] Yachts and renovated commercial vessels that are solely used for holidays and pleasure trips.

[13] A gas well ('gasbun') is a mandatory storage site for propane gas bottles.

2.4.2 Scenario 2: Explosion of biogas

The explosion on board the clipper caused most damage on the side of the ship where the sewage tank was located, which means that another scenario is possible, namely one where there is an accumulation of, and then an ignition of, biogases from the sewage tank.

On passenger vessels, waste water from toilets, showers, galleys and washbasins is collected in a sewage tank. From here, the waste water is pumped out of the tank to the quay using specially designed connections, or else the waste water is pumped overboard fairly regularly. The sewage water system that uses a collecting tank is a simple example of a sewage system. The waste water from the showers, from the washbasins in the cabins, and from the toilets and the galley, is transported on the ship via PVC sewage pipes to the sewage tank.

The sewage tank contains a mixture of liquids and floating material (toilet flushings, washing-up water and shower water). This floating material sinks and forms sludge. The sludge in the tank undergoes fermentation processes that release such gases as methane, carbon dioxide, and hydrocarbons/hydrogen gas. Normally, these gases are carried away via the ventilation fitted to the tank. However, if the sewage tank is not (properly) ventilated then these gases can flow out, for example via the connection with the pipes. The gases may then mix with oxygen under the floor to create an explosive mixture.

If this scenario is the correct one then the sewage water system on board the clipper would have to contain defects that would demonstrate that the connection with the pipes could have provided an exit route for the fermentation gases. These defects could include blocked ventilation or a badly installed sewage system.

Biogases such as methane and hydrogen gas are 'lighter' than air. This makes it less likely that the explosion on board the clipper was caused by biogases. However, the ship's construction would have allowed the biogases to spread throughout the ship and accumulate under the floor.[14]

[14] These aspects will be looked at in Section 5.

3 ASSESSMENT FRAMEWORK

3.1 INTRODUCTION

The assessment framework is an essential part of the investigation, as we need to know the criteria that are going to be used to assess the incident. There are three parts to the framework, namely:

1. a description of the relevant applicable laws and regulations in the sector in which the incident took place;
2. a description of additional standards, guidelines and insights from the relevant industry itself;
3. a description of the general assessment framework used for safety management purposes.

The first two parts of the assessment framework are sector-specific, with their content depending very largely on the type of incident that took place. The third part of the assessment framework is a general section that details the way in which the Dutch Safety Board expects the relevant stakeholders to take responsibility for safety in practice. In this section, we will look at these three parts in more detail.

When deciding on the assessment framework, we have borne in mind the two scenarios mentioned above, namely: i) an explosion of propane gas and ii) an explosion of biogas.

3.2 LEGISLATION AND RULES

We list below the directives and laws that played an important role in our investigation. They include both European and national legislation.

International guidelines and rules
The European Union (EU) draws up directives for inland shipping. These guidelines must be implemented in the national legislation of the EU Member States. The same is true of the rules laid down by the CCR (the Central Commission for Navigation on the Rhine).

In October 1982, the European Commission drew up Directive no. 82/714/EEC laying down technical requirements for inland waterway vessels. This Directive was revised in March 2006 and led to the announcement of Directive 2006/87/EC, which relates to the technical specifications and equipment requirements for inland shipping vessels. The ROSR (Rhine Vessel Inspection Regulation) implemented by the CCR sets out rules for the construction design and crewing of ships that travel on the International Rhine. In the Netherlands, the European Directive and the ROSR have been implemented in the *Binnenschepenwet* (Inland Waterway Vessels Act), amongst others.

European Directive 2006/87/EC and the ROSR 1995 both prohibit the household use of liquid gas (propane gas) on passenger ships. Existing equipment must be phased out (after being modernised, converted or restored) by the year 2045 at the latest. This provision also applies to passenger sailing ships such as the two-mast clipper. This European Directive also stipulates whether Member States can lay down additional requirements, for instance those aimed at reducing the transitional period. No reduction of this period is permitted for LPG installations designed for household use on passenger ships.

There are no (generally) applicable laws or regulations that apply to sewage tanks, but passenger transportation on the Rhine is governed by a number of rules relating to the installation of waste water collecting tanks (namely ROSR 1995, Article 15.14, which looks at such factors as capacity, level measurement, pumps and pipes, and sewage treatment plants). These rules have been incorporated in full into European Directive 2006/87/EC.

National legislation: the Binnenschepenwet (Inland Waterway Vessels Act) and the Binnenschepenbesluit (Inland Waterway Vessels Decree)
The responsibility for these pieces of legislation lies with the Ministry of Transport, Public Works and Water Management. The *Binnenschepenwet* (BSW) regulates the following:

- the soundness, construction and equipment of a ship;
- the safety, health and well-being of those working on a ship; and
- the captain's know-how, competence and physical state.

The BSW is a framework Act. The specific rules are laid down using Orders in Council. In order to help implement the BSW, the constructional and equipment-related requirements are regulated in the *Binnenschepenbesluit* (BSB). The BSB had its roots in the old EU Directive 82/714/EEC

(October 1982) that laid down the national and international requirements regarding inland shipping. The BSB contains both the European requirements and the additional Dutch requirements.

The legislation directly relevant to this investigation into the explosion on board the clipper is the BSB, including Appendix 2 (constructional and equipment requirements for all vessels) and Appendix 7 (additional technical rules for passenger sailing ships). These appendices contain the regulations for propane gas installations.

Working Conditions Act
The Working Conditions Act (WCA/*Arbowet*) applies to all organisations that have employees in salaried employment. This Act also applies to passenger sailing ships. The WCA lays down rules for health, safety and welfare during the performance of work. The starting point is the prevention of risks. If the hazard cannot be removed entirely then the employer must search for other preventive solutions and the hazard must be 'screened off'. If this cannot be done then the employer must provide personal safety devices (the so-called 'occupational health' approach).
In order to understand the risks, the employer must draw up an RI&E (Occupational Health and Safety Hazard Identification and Analysis) and evaluate it annually.

3.3 ADDITIONAL STANDARDS AND GUIDELINES

Standards
Standards are issued by standardisation institutes such as the NEN (Netherlands Standardization Institute). The inland shipping industry is governed by a wide range of standards relating to the ship's design, its technical construction and to the various sections. Some of these standards can be found in the CE standard.[15]

A standard has been developed for sewage tanks on board sea-going vessels. This ISO 15749 standard came into force in December 2004 and deals with all aspects of the installation of sewage water systems. However, this standard does not apply to inland shipping.
The IBA standard for septic tanks[16] (Individual Treatment of Waste Water) was cited too, for the purposes of comparison. These tanks must comply with the CE standard as translated into the NEN-EN 12566-1 standard, which came into force in December 2005 but contains a transitional period that runs until July 2008.
The above standards in the field of sewage collection were developed in the wake of the discharge ban for waste water in surface water (International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and the 1973 Pollution of Surface Waters Act). These standards deal with the environmentally friendly use and maintenance of sewage tanks.

Industry guidelines
There are no specific industry guidelines that govern sewage tanks or propane gas installations.

3.4 ASSESSMENT FRAMEWORK FOR SAFETY MANAGEMENT

Past experience has shown that the structure of a safety management system and its implementation in practice by organisations and their employees play a crucial role in the demonstrable management and continual improvement of safety levels. The Dutch Safety Board recognises that the assessment of the way in which organisations implement their own responsibility for safety in practice depends on the organisation in question. Factors such as the nature and size of the organisation can play a role here, which is why they should be made part of the assessment process. The assessment of each incident may vary but the way of thinking is identical.

In principle, the way in which an organisation implements its own responsibility for safety can be tested and assessed in different ways. Accordingly, there is no universal guide that can be used in all situations.

The Dutch Safety Board has selected the following five action items that must be implemented in all cases:
1. Insights into risks as a basis for safety policy

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15 A product bearing a CE Marking complies with the requirements set in the applicable European standard.
16 A container that separates off and collects floating and solid material and liquids. The waste water is removed by overflow. The solid materials sink and after a while must be removed.

2. Demonstrable and realistic safety policy
3. Implementation and enforcement of safety policy
4. Tightening up safety policy
5. Management guidance, involvement and communication.

The Board believes that the above selection is justified, because these safety-related action items have been incorporated into numerous pieces of national and international legislation and regulations, as well as into a large number of broadly accepted and broadly implemented standards.

A more detailed description of these action items can be found in Appendix 3.

4 PARTIES INVOLVED AND THEIR RESPONSIBILITIES

The captain
The captain is responsible for the soundness of the ship and for the safety, health and the well-being of the crew and others on board. To support this process, certificates are issued after the inspection of those ship sections or equipment to which the certificate applies. Certificates do not give the captain a guarantee that his or her ship is seaworthy at all times, as the inspections merely represent a snapshot in time.
In the case of non-certified sections of the ship too, the captain/owner bears ultimate responsibility for their proper installation and maintenance. The captain can be expected to point out to the passengers and crew the risks and hazards during their stay on board and regularly checks whether they are complying with the safety measures.

The passengers
The passengers bear their own responsibility too. Instructions about how to behave on board are given at the start of the trip on board the clipper. Pupils and teachers are expected to obey these instructions and to inform the captain if people do not keep to them.

The BBZ
'Brown fleet' vessels are mainly run by businesspeople who are both owner and captain. Most of the fleet operates in the period from early April to the end of October. Some vessels also run in the winter or else during this time operate as a 'botel' (i.e. as a hotel ship). About 55% of these captains are members of the BBZ (the Professional Sailing Skippers Association), which represents the interests of the 'brown fleet'. The captain of the two-mast clipper was a BBZ member.
The BBZ's sphere of operations consists of:

- nature and the environment / spatial planning
- social / economic issues
- recreation and tourism
- nautical / technical matters.

The BBZ is the association that negotiates with the government on measures in the above-mentioned areas.

Collective arrangements can be made for those captains who are members. One of these measures is the RI&E (Occupational Health and Safety Hazard Identification and Analysis). The BBZ has agreed with the Labour Inspectorate as to the issues that should be covered by the RI&E, and has been given permission to use the RI&E across the whole industry.

Certifying bodies
Recognised expertise bureaus and classification societies that have been appointed by the IVW as certifying and supervisory bodies will use experts to carry out inspections of ship construction and equipment. A number of expertise bureaus have joined forces in the NBKB (the Netherlands Bureau for the Certification of Inland Shipping). However, not all expertise bureaus appointed by the IVW are affiliated with the NBKB. The classification societies recognised by the IVW are not members of the NBKB either. The expertise bureaus and classification societies must satisfy a number of requirements, including that they employ a standard quality assurance system. These agencies are monitored by the IVW.

Those 'brown fleet' vessels that sail with more than twelve passengers are covered by specific legislation. The direct supervision of the state of safety of these vessels is now performed by a number of parties appointed by the IVW, namely:

- Register Holland (specific classification society for the 'brown fleet');
- Verzekeringsmaatschappij efm expertise b.v (insurance company), part of efm onderlinge schepenverzekering u.a.[17] (The company is divided into two operating companies: insurance cover and inspection);
- The NKIP (Dutch Certification Institute) (NKIP, CE Markings, inspection).

The vessels in the 'brown fleet' are inspected every four years and if approved receive a general certificate of investigation ('*certificaat van onderzoek*'). The certificate of investigation is issued if all its sections, including one for life-saving appliances and equipment, are awarded a valid certificate.
Each of these sections has in turn its own certification regime. For example, fire extinguishers are inspected every two years by an IVW-approved certification institute. Gas installations have to be

[17] Excluding liability.

approved by recognised bodies too, but are only inspected every three years. Sewage tanks are not part of the official inspection and certification system.

Ministry of Transport, Public Works and Water Management
It is the Ministry of Transport, Public Works and Water Management who is responsible for the drafting of legislation relating to inland shipping. In addition, the European Commission can impose amendments to Acts.

The Transport and Water Management Inspectorate (IVW)
The IVW supervises compliance with legislation and regulations, one objective being to improve safety on the Dutch inland waterways. It supervises the inland shipping industry, the certified classification societies and expertise bureaus, and crew on ships. New forms of supervision are currently being developed,[18] with ultimate responsibility for this resting with the Ministry of Transport. One of the main reasons why the IVW wants new supervisory arrangements to be developed is that the government is becoming more 'hands-off' as there is now a greater focus on the citizen's own responsibility. The IVW is setting up supervisory arrangements that will be based on nine basic principles of good supervision.[19] These supervisory arrangements have already been drawn up and put in place for certain modes of transport[20]. Full implementation of such arrangements for the inland shipping industry is planned for 2008.

Under this new supervisory system for the inland shipping industry, the IVW will be handing over much of the certifying activity to market players. This means that vessels' construction and equipment will no longer be checked by the inspection institute itself. The IVW has drawn up a document called the '*Visiedocument Taakoverdracht*' ('Document regarding the planned transfer of duties') for this transfer of powers. This document states that the IVW will not only transfer the certification duties but also the task of issuing certificates. Those parties who take on the certifying duties for the charter fleet industry will have to be accredited themselves by the Board for Accreditation. They must comply with ISO/IEC standard 17020, this being the standard that sets out general criteria for those bodies that perform inspections. The IVW will continue to bear ultimate responsibility for supervising compliance with legislation and regulations, including in respect of sailing periods and rest periods, and manning levels.

18 *Nota Toezicht in Beweging*, Inspectie Verkeer and Waterstaat (Policy document 'Supervision on the move' by the IVW), May 2004. The development of new forms of supervision has its roots in the opinions issued by the Balkenende-II Cabinet (Other Government, 2003). One aspect of these opinions is that the primary supervision of various social sectors can be exercised within the context of the relationships that exist within society between companies, NGOs and citizens. In such a case, the government would increasingly be able to exercise so-called 'metasupervision', i.e. the supervising of supervision.

19 The nine principles of good supervision are: selective 'own responsibility', selective 'complete picture per domain', being decisive, collaborative, independent, transparent, professional, active in Europe, and digital supervision (Source: Letter from the Minister of Transport, Public Works and Water Management to the Speaker of the Dutch Lower House, 23 October 2006).

20 In 2004, new supervisory arrangement for Aviation, in 2005 for Rail, in 2006 for the Merchant Navy (supervision of classification societies).

5 ANALYSIS

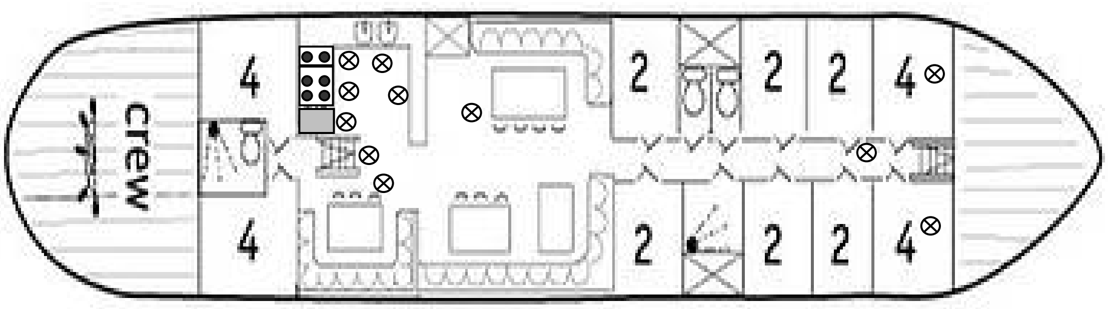
5.1 INTRODUCTION

Section 5.2 describes the pattern of damage found on board the clipper after the explosion. Section 5.3 describes and analyses two investigations into the cause of the explosion. This relates to the investigation that the Dutch PPS (Public Prosecutions Service) performed into a possible leak of propane gas and to the investigation that the Dutch Safety Board performed into the build-up of gases in sewage tanks. Finally, Section 5.4 looks at the issue of safety management.

5.2 POSITION OF PUPILS, INJURIES AND PATTERN OF DAMAGE

Witness statements were used to make a sketch of the positions of the pupils at the time of the explosion (figure 6). The four seriously wounded pupils who had to be taken to the hospital after the explosion were on the stairs and by the cooker. The injuries, mainly complicated fractures of the ankles, provide clear evidence that the explosion came from under the floor.

Port



Starboard

Figure 6: *Top-down view, showing position of pupils*
- *The circles containing crosses indicate the positions of the pupils that were on the ship at the time of the explosion.*
- *The four most seriously wounded pupils were in the galley and by the stairs to the rear of the ship, which is also the exit.*

The explosion on 8 June on board the clipper caused a lot of damage to property below deck. It wrecked the interior of the living quarters, as well as a number of cabins and the galley (see figures 7-11). Most of the floor in the living quarters had been burst open. In some places, pieces of laminated floor were found in the ceiling (see figure 9). The walls had cracked in several places and the dome light in the ceiling was blown out of its track by the force of the explosion.

The fixed benches in the living quarters had been detached from the wall by the explosion along most of their length. The dining tables screwed to the floor had become detached too. One of the tables had been forced through the partition wall of an adjacent cabin.

The door of the cooker's oven compartment was open and the left hinge was broken.[21] The cooker's control knob and one of the cooking rings were missing. These knobs were found on the floor of the galley section. The floor was also covered with other loose objects such as leftovers, glass, footwear and toiletries.

[21] (Dutch-language) report by Kiwa N.V. into the explosion on the ship "Bree Sant": An investigation into the cause of the explosion, 2006.

Figure 7: *Damage to the interior on the port side, view towards the bow of the ship (photo: Dutch Safety Board)*

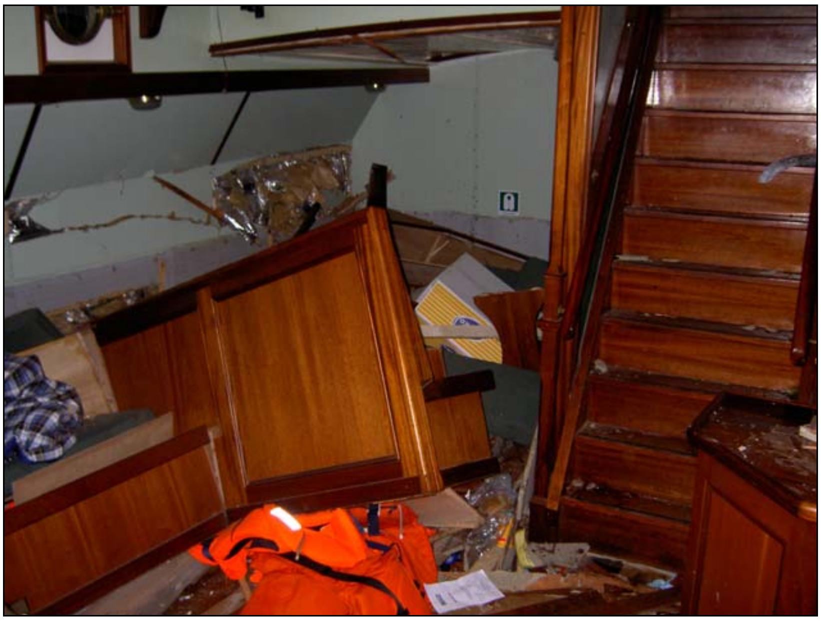


Figure 8: *View past the stairs on the starboard side towards the stern (photo: Dutch Safety Board)*

The floors in the below-deck areas of the ship were made of laminate strips that were glued to the subfloor.[22] The subfloor was secured to wooden beams on the floor structure in the ship's living quarters. Under the floor of the cabins at the rear of the ship there were cables and connections for electrical equipment, various pipelines for drinking water and shower water and for hot water for the convector heaters, and pipes for the drainage of sewage water from showers, toilets, washbasins and the galley. In the living quarters, although these cables and pipes were fitted above the floor they were concealed behind the benches and in kitchen cupboards. The shower and toilet areas had tiled subfloors.

[22] Viroc type (cement fibreboard). The laminated floor does not extend under benches, kitchen cupboards and similar, but the cement fibreboard does.

Figure 9: *Damage to the ceiling. Parts of the laminated floor have bored themselves into the ceiling (photo: TNO Construction and Service)*

The toilet to the rear between the two cabins was torn loose from its fittings by the force of the explosion and now had cracks in it (see figure 10). The floor and wall in that toilet also had cracks in them and some components that had come loose. The adjoining cabin on the starboard side had been greatly damaged. For instance, one of the double bunks had been ripped off the wall. The damage to the cabin on the starboard side turned out to be greater than the damage to the cabin on the port side that adjoined the living quarters.

Figure 10: *Toilet that had been fitted on top of the sewage tank. The way in which the floor has been forced upwards can clearly be seen. (photo: TNO Construction and Service)*

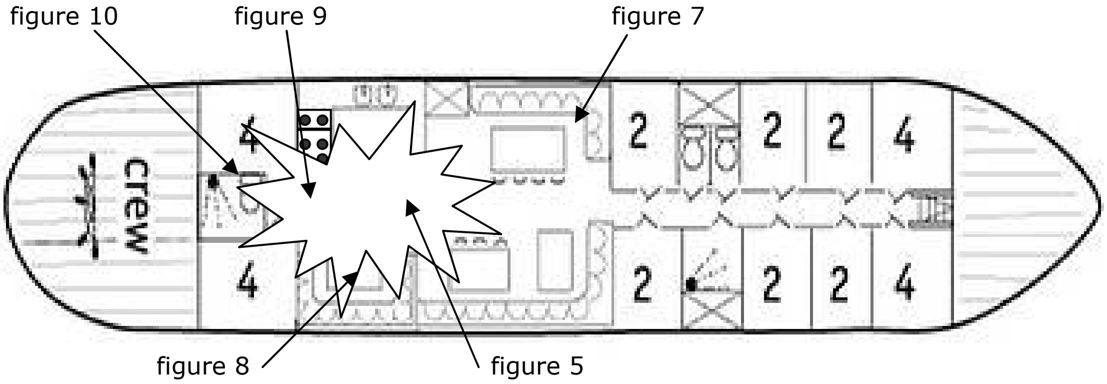


Figure 11: Top-down view of explosion, including viewpoint of photographs/figures

The pattern of damage provides sufficient evidence for assuming that the damage was caused by an accumulation of an explosive mixture under the floor. The greatest damage was found in the middle of the below-deck area under the stairs and on the starboard side. Given the damage assessment, the centre of the explosion was located near the cabinet under the stairs that lead off the ship. Note that the centre of the explosion is not necessarily the place where the gas mixture ignited.

The pupils with the most serious injuries were those who at the time of the explosion wanted to go up the stairs to the above-deck area or else were standing by the cooker. Two other pupils who were standing by the cooker escaped with less severe injuries. The draining board in the galley was partially buckled, but the total damage was considerably less than that on the other side of the ship.

5.3 Evaluation of the scenarios

5.3.1 Analysis of the propane gas explosion scenario

Introduction
On board the vessels in the 'brown fleet', people mainly use propane gas stored in bottles for household use (cooking etc.). The installation of propane gas systems must comply with strict statutory regulations and is certified every three years by a recognised certification institute. For instance, no pressure at all may be lost when the installation is tested (not even minimal loss is acceptable) - unlike the situation with gas installations in residences. In addition, an odorant (mercaptan[23]) is added to propane gas, just as it is with natural gas. In the event of a gas leak or gas escape into a room, this odorant warns people that unburnt gas is escaping. This smell is very distinctive, with most people associating it immediately with escaping gas.

Criminal investigation
The Public Prosecutions Service (PPS) carried out a criminal investigation into the cause of the explosion on board the clipper. The PPS impounded the ship, after which the NFI (Netherlands Forensics Institute), working with Kiwa Gastec (a certification agency) performed a technical investigation on it. This investigation covered the entire gas installation, the gas bottles, the gas pressure regulator, the pipes, the couplings, the cooker in the living quarters and the gas burner in the captain's living quarters.

This investigation found no evidence of defects in the gas equipment that could explain an accumulation of gas under the floor. The report by KIWA Gastec to the NFI only mentions a very slow leak from the pipe, which may have been caused by the explosion.

[23] Propane is odorised with about 20 ppm of mercapto ethane. This is a component unlike the one usually added to natural gas, which is tetrahydrothiophene.

Figure 12: Cooker ready to be taken away for further investigation, with those control knobs present having been turned to the off position (Note: The oven knob is the 3rd from left - a gas burner knob on the right is missing) (photo: TNO Construction and Service)

The cooker's performance was then examined a few weeks later in the laboratory. This investigation revealed that all the cooker knobs were working properly, apart from the oven knob. What was interesting about this knob was that when partially pushed in it could be turned without having to push the knob in all the way. When testing the knob, it turned out that the gas tap could remain open without the thermoelectric safety device taking effect (see below).

> *Thermoelectric safety device:*
> *To ignite the oven burner, the control knob has to be pressed in and turned anti-clockwise. The cooker user now has to press in the ignition knob until the oven burner ignites with an electric spark. While the flame safety device registers a flame, gas will continue to flow out, even if the control knob has been released. If the flame is extinguished when the control knob is in the 'ON' position, the flame safety device will shut off the gas supply. This prevents accidental outflow of (unburned) gas.*

KIWA Gastec concluded that the thermoelectric safety device did not work correctly because of contamination caused by a deposit of leftover food. This deposit was not found on the other knobs, because they were protected by a drip-tray.

When performing the tests, the cooker control knob was set in the position that it was photographed in by the technical investigation team on the evening of the explosion. In its conclusions, the NFI proceeded on the premise that the oven knob was in this position at the time of the explosion. In this state, 0.19 m³ of propane per hour can flow into the cooker. Propane's lower explosive limit is 2.2%.[24] This would mean that each hour a maximum of 8.63 m³ of

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[24] The explosive limit is the concentration of a gas or vapour in a liquid and/or solid state expressed as a percentage volume in air at which the vapour-air mixture can explode if ignited.
The lower explosive limit is the lowest concentration of an inflammable gas, vapour or dust-based solid material in air or in another gas that could cause an explosion.
The upper explosive limit is the highest concentration of an inflammable gas, vapour or dust-based solid material in air or in another gas that could cause an explosion.
Above the upper explosive limit and below the lower explosive limit there is no explosion risk. However, if there is an excess of volatile components present (above the upper explosive limit) then there is a chance of fire. The upper and lower values of the explosive limits are different for different volatile materials.
The range between the lower and upper explosive limits is known as the explosive range.

explosive mixture could be created. The total area under the floor is estimated at 6.25 m³.[25] If the proposed scenario of a leak of propane gas as the cause of the explosion on board the clipper is correct then - based on the estimated gas outflow - the lower explosive limit would be reached after about 43 minutes. However, this period could have been shorter if the gas accumulation only occurred under part of the floor. There is also the possibility that the gas had flowed out when previous meals were being prepared and had already been under the floor for some time.

As a result of the investigation by KIWA Gastec and other information, the NFI came to the following conclusions:

- The explosion was very probably caused by the explosion of a propane-air mixture that was present under the wooden floor and that exploded because propane gas above the wooden floor came into contact with an ignition source.
- This propane gas was able to flow through the ventilation openings in the oven base and thus end up under the oven. It may be that the gas could not get to the living area because a wooden plinth was mounted in front of the oven, which could be why the gas was not smelled.
- The failure of the combined thermoelectric safety and regulating device to work meant that unburnt propane could flow towards the oven burner for a long period of time. The combined thermoelectric safety and regulating device (the gas regulating unit) continued to stick because it became contaminated over a long period of time. The contamination occurred because the design did not include a protective plate, although these had been provided for the spark igniters next to the gas regulating unit.

The Dutch Safety Board's findings
Investigations have shown that the gas equipment on board the clipper was installed in the prescribed way, as set out in Appendix II Section 8 of the Inland Waterway Vessels Decree. Additionally, it was regularly certified by an accredited institute. An important part of this test involves a compression test of the pipes, whereby there must be no leak at all of any type. The certificate for the gas equipment on the clipper was valid until 1 March 2007.

In the Netherlands, gas explosions in rural areas caused by problems with the natural gas pipeline are reported fairly regularly. These explosions mainly occur in or near residences. The Dutch Safety Board and its predecessor, the Dutch Transport Safety Board, have issued four public reports on natural gas explosions. In two of these incidents, some of those living at or near the site of the explosion reported a smell of gas.

The quantity of gas calculated by KIWA Gastec needed to achieve the damage found on the clipper is such that it is surprising that none of those present smelled gas.

In its conclusions, the NFI mentioned that the gas was ignited by propane gas above the floor. The fridge or the gas cooker was deemed to be the source of the ignition. In both cases, there would have to have been a recognisable smell of gas as the result of air movement.

It has been calculated that even if just 0.4% of the necessary explosive quantity of gas flowed into the living quarters, those present would have been able to smell it. This smell of gas should have been noticed earlier, especially because it is assumed that the leak had already been going on for some time.

In order to test the possible spreading of the gases, the Dutch Safety Board carried out tests on board the clipper with gas whose behaviour is similar to that of propane and to which has been added the same odorant. As part of the test, the events leading up to the explosion were reconstructed. These tests showed that gas could be smelled in the living quarters after about five minutes.

In the case of the explosion on board the clipper, none of those present on board the ship smelled gas prior to the incident. Apart from the possibility that the pupils smelled no gas because it was masked by the smell of food, it may be that the pupils did not recognise the gas smell for what it was.

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25 Every hour, a maximum of $0.19m^3 / 0.022 = 8.63m^3$ of explosive mixture can be created. The volume of the area under the ship's floor where the explosion occurred was $6.25m^3$. At least 6.25 / 8.63 = 0.72 hours (approx. 43 minutes) would be needed to achieve the lower explosive limit.

The investigation by the Dutch Safety Board found that even in cases where the gas odorisation complies with the necessary standards, propane gas can still be difficult to smell. Here is a non-exhaustive list of reason for this:

- *People becoming used to the smell*: When choosing the odorant, the degree to which people get used to it is taken into account. However, if the concentration of gas in a room only increases slowly then a gas will only be noticed at a much higher concentration.
- *Reduced sensitivity*: The ability of those in the room to smell the gas may be lower than the standard used to define 'smellability'. The standard is based on tests that involved trained odour observers, whose ability to smell odours may have been better than that of the pupils on the ship. Temporary changes in the ability to smell odours can also be caused by colds and allergies. However, in the case of this accident, there are no indications that this was the case.
- *Masking effect*. The gas smell was masked by another penetrating smell.
- On 30 August 2003, there was a fire and explosion in a residence in Bergschenhoek. The resident stated that she noticed a 'strange' smell but did not associate this with natural gas.

The experiment that the Dutch Safety Board had performed on board the clipper revealed that it does not take long for the gas/air mixture accumulating under the floor to reach its explosive limit – quicker in fact than the increase in concentration in the galley would allow the gas to be recognised by those present. This eliminates the built-in safety margin achieved by using an odorant, whether or not intended for such situations.
This is why the Board advocates changing the odorisation. A few years ago, the gas industry started research into an alternative, more environmentally friendly way of achieving odorisation. These environmentally friendly odorants are available now but are scarcely used in practice.

The current requirements for propane gas are set down in the Hazardous Material Publication Series 20.26. In connection with this series of publications, the Hazardous Material Advisory Board, writing in its publication '*De publicatiereeks nader beschouwd*' ('A closer look at the publication series') (2006) advised the government that clear and specific target stipulations should be drawn up for those aspects of safety where in the Advisory Board's opinion the necessary regulation is lacking.

In the light of these developments, the Dutch Safety Board believes that an investigation into improving the range of available options for the detection of gas, including odorisation, could provide new insights into ways of promoting safer propane gas usage.

The results of the experiment support the conclusions reached by the PPS and indicates that it is very likely that a leak of propane gas was the cause of the explosion on board the clipper. The pattern of damage and the position of the four seriously wounded pupils at the time of the explosion also appear to indicate a propane gas explosion resulting from a gas accumulation under the floor.

5.3.2 Analysis of a biogas explosion scenario

Sewage tank
Biogases are gases created by the decomposition of waste such as food leftovers and/or excrement. The only place where biogases can be created on board a ship is in the sewage tank. This tank is usually emptied twice a day, by using a dilution pump[27] to discharge the contents of the tank onto the surface water. The steel water tank can hold about 1.5 m3 and covers the width of the ship (see Figure 13). The sewage tank was tailor-made for the clipper and installed in 1995. An aerator/de-aerator was fitted to the tank. This ensures that the resulting gases are discharged and that fresh air flows into the tank when the tank is emptied (see sewage tank diagrams in appendix 2).

[26] Hazardous Material Publication Series 20: Propane (5 m3). The storage of propane and butane in stationary overground reservoirs with a volume of more than 0.15 m3 but not exceeding 5 m3.
[27] A dilution pump dilutes the waste water and pumps it away.

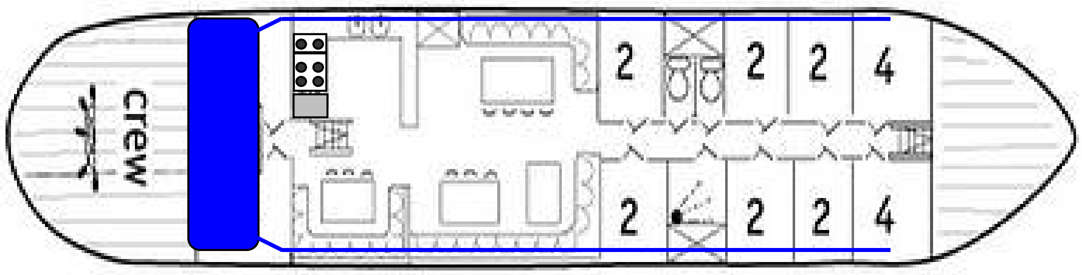

Figure 13: *Sewage pipe and sewage tank under the rearmost two cabins, shower and toilet*

Biogases hydrogen and methane
TNO's research of the relevant literature has shown that under anaerobic conditions hydrogen gas can be formed organically from diverse substrates. Carbohydrates are the most well-known of these, but this also applies to ethanol, formic acid, proteins and amino-acids. Their production is part and parcel of the anaerobic fermentation process, in which organic material is converted into acids, alcohols, hydrogen gas and carbon dioxide. There are four steps to the anaerobic fermentation process, namely:

- In hydrolysis, long carbon chains are split enzymatically into shorter chains.
- In the second step, the acidification, the short chains are broken down further into volatile fatty acids.
- In the acetogenous phase, the volatile fatty acids are converted further into acetic acid, hydrogen gas and carbon dioxide gas.
- The final phase is the methanogenous phase, which means that acetic acid as well as carbon dioxide and hydrogen gas are converted into biogas.

Biogas mainly consists of methane gas (CH4) and carbon dioxide (CO2), but also contains very small quantities of (residual) gases such as hydrogen sulphide (H2S) and ammonia (NH3).
In many fermentation processes, the above-mentioned acids and the hydrogen gas, carbon dioxide and acetic acid are converted into methane gas (methanogenous phase). However, if this methanogenous phase occurs, then hydrogen gas will accumulate. Hydrogen gas has a lower explosive limit of 4 % by volume and an upper explosive limit of 75.6 % by volume.

Methanogenous bacteria can produce methane gas in the final phase of the anaerobic fermentation process. The components acetic acid, hydrogen gas and carbon dioxide can be produced by other micro-organisms from a wide range of organic compounds. The list of usable compounds includes carbohydrates (sugar, starch and cellulose), proteins, amino-acids, animal fats, vegetable oil and soap. Methane can be produced at pH values of between 6 and 9 and at temperatures between 10 and 70 degrees Celsius. The group of mesophile methane producers (i.e. those that like moderate temperatures) are very temperature-sensitive: these will work increasingly quickly at temperatures of up to 40 degrees Celsius. Methane bacteria reproduce themselves very slowly, only doubling in number every 3 to 10 days. Methane production may fail to occur if insufficient numbers of methanogenous bacteria are present, because the discharge of sludge containing these bacteria is greater than the speed with which they reproduce. At room temperature and atmospheric pressure, methane is a gas. Methane's explosive range lies between 4.4 % by volume and 16 % by volume.

Explosions involving biogases are less frequent. Based on a quick scan of TNO's database, data was found on seven methane gas explosions that occurred between 1986 and 2006. Five of these explosions occurred in sewage water systems, one of which was in the Netherlands (1987), one in the UK, (1986), one in Canada (2005) and two in the United States (both in 2003). The other explosions occurred in pig sties in the Netherlands in 1986 and in 2005.

Dutch Safety Board findings
The sewage tank on board the clipper is located under the raised floor of the two cabins to the rear of the ship (see figure 13). Between these two cabins there is a toilet fitted directly on top of the tank. Two other toilets are connected to the sewage tank via a PVC sewage pipe. The toilet on the tank was torn off it by the explosion and even exhibits cracks (see figure 10).
The floor and wall in this toilet show cracks and detached components. The explosion caused a lot more damage in the cabin adjoining the toilet on the starboard side than it did in the cabin adjoining the toilet on the port side.

On board the ship, defects were found in the sewage water system even before the explosion, in addition to the damage resulting from the explosion itself. A section of the PVC sewage pipe fitted by the tank under the floor and that ran above the floor of the recreational area under the benches through to the bow of the ship was tied with tape and partly glued with PVC glue. This joint was not gasproof. No tape was found on the other PVC sewage pipe joints.

In addition, the aeration/deaeration of the sewage tank ran from the side of the tank to the above-deck area. However, the length of the flexible hose and a lack of support meant that it sagged (see diagrams of sewage tank appendix 2). The ship's movements and the level of fluid in the tank meant that the hose could fill up at its lowest point and silt up, and as a result could no longer function as an aeration/deaeration gap (see figure 14).

Figure 14: Blocked ventilation of the sewage tank (photo: TNO Construction and Service)

The dilution pump for the drainage of the waste water was fitted above the floor in the side of the tank. This made it impossible to fully empty the tank, leaving behind waste residues in it.[28] In the situation described above, it is possible that this residue could produce biogases in the tank and that the blocked ventilation could have meant that these gases looked for a way out via the sewage pipe joints. Each flushing of the toilet added liquid to the tank that expels the gases there.

The clipper's sewage tank was completely emptied twice a day, which should have meant that few hydrogen-forming and methane-forming bacteria could have been left behind there. However, some of the bacterial activity was produced by the excrement itself, as it contains small quantities of methane-producing and large quantities of hydrogen-producing bacteria. Another part of the activity could have developed in the (sludge) residue in inaccessible places in the sewage tank. These are zones where residues remain after the sucking-out process. Here, both hydrogen-producing bacteria and methane-producing bacteria can develop.

A possible indication that there was an explosion as the result of biogases present is that in interviews some of the pupils involved reported a noxious smell in the days leading up to the explosion. Methane and hydrogen gas are odourless gases, but the report of smells indicates that sewage gases were escaping.

Another factor indicating a potential problem with the sewage tank is that of the level of the outside temperature in the days preceding the explosion. In the first week of June 2006, it was fairly cold at night. On 6, 7 and 8 June, the minimum temperatures fluctuated between 4 and 6 °C. During the course of these days, the air temperature during the day rose to 18 °C. The temperature of the IJsselmeer on 8 June was about 16 °C. On the steel ship, the sun was clearly felt to be warming things up – according to witness statements, pupils could no longer run around barefoot on deck. It is likely that the bacterial fermentation process was started by the higher environmental temperature. The relatively warm IJsselmeer water and the warming-up of the ship by the sun in combination with the closed-off ventilation created the conditions for the build-up of biogases.

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28 The tank was fitted with a suction device that could be used to pump out waste located deeper down in the tank. However, the tank can never be pumped completely dry.

During the onboard investigation, the investigators also observed a high concentration of H_2S (hydrogen sulphide) around shower drainholes[29] closed off by plugs. This phenomenon is evidence of the production and accumulation of gas. As long as several months after the explosion, an explosive mixture of methane was measured in the clipper's sewage tank. Toxic hydrogen sulphide was also recorded again. The plugging of the shower drainholes and the blocked aeration/deaeration stimulates the anaerobic process, as evidenced by the noxious odour observed.

Investigation by other bodies has shown that explosive gas mixtures can form in sewage tanks. In order to find out more about the build-up of these gas mixtures, as part of this investigation the Dutch Safety Board looked at the development of gases in sewage tanks for household use in rural areas (i.e. those not connected to a sewage system). These septic tanks are a further development of the simple sewage tank on board this clipper.

Builders of septic tanks warn about the dangers of explosions caused by accumulated methane gas, as do independent research institutes such as universities. In order to prevent explosions, the tanks need to be equipped with ventilation that allows the gas to flow out. In sewage tanks, about 25% of the organic material present in sewage water is converted into methane-bearing biogas.

The sewage tank on the ship differed from modern septic tanks in which liquid is stored for long periods in that with the ship's tank, the sludge and waste water were drained off twice a day. This made the volume of throughflow much higher than in septic tanks. This can affect the quantities of hydrogen-producing and methane-producing bacteria that can survive such a throughflow regime. Another point is that normally the empty space in the top of the tank should be filled with fresh oxygen-bearing air when the tank is emptied. Given the situation described above, namely that the ventilation in the clipper's tank was blocked, oxygen-bearing air had to be drawn from the adjoining separate area under the floor or from the air traps in the showers and toilets.

In order to test this scenario, an additional investigation was performed on 14 February 2007, at the request of the Dutch Safety Board. This investigation showed that the conditions described were suitable for the initiation of anaerobic processes and the production of biogases. This, when combined with the blocked seal, allowed gas to accumulate in the tank.
In the experiment, a harmless gas was used to build up pressure in the tank. It turned out in the end that gas could get outside via the air trap in the shower drainholes. This is evidence that explosive gas mixtures from the sewage tank can escape and accumulate unnoticed within an area on board the ship. The gases can form an explosive mixture if they mix with the necessary quantity of oxygen. In this case, however, the experiment was unable to show that the explosive mixtures from the sewage tank had actually filled the area under the floor at the time the explosion occurred.
It should be noted here that the experiments were performed after the sewage pipes had either been repaired or replaced, so it is clear that the previously observed situation - whereby there was a defective coupling in the connection - no longer applied.

5.3.3 Summarised analysis of the scenarios
The damage found on board the clipper led to suspicions that one of two scenarios could have occurred. The Dutch Safety Board investigated both scenarios and tested them in practice using a similar gas that does not form an explosive mixture with oxygen. This experiment revealed that propane gas quickly finds its way to the floor of the ship. The gas was able to spread under the floor and within just a short period of time reach such a concentration that an explosive mixture was formed.
Accordingly, we conclude that in all probability the explosion on board the two-mast clipper was caused by a leak of propane gas.

However, the investigation by the Board also revealed that gases could develop in the sewage tanks. Under certain conditions, this gas production can also pose risks for the users of such tanks. The experiment performed at the behest of the Dutch Safety Board could not, however, confirm whether methane gas had actually filled the area under the floor and reached its explosive limit at the time of the explosion. This was because the original conditions could not be reproduced, one reason for this being that the PVC waste pipes had been repaired. However, the Board's investigation did uncover shortcomings in the clipper's sewage water system.

5.3.4 Ignition source for the explosion
There were a number of potential sources on board the clipper that could have ignited the gas mixture. However, the Board was unable to prove indisputably that any of the ignition sources

[29] The captain has stated that these plugs were fitted during the trip to prevent odour nuisance.

named below had actually ignited the gas. What can be stated based on the pattern of damage on board and the statements by pupils is that there was a burst of flame on the ship that came from below. This flame was seen in the area behind the stairs, which is also the access route to the two rearmost cabins.

The investigation has localised the following possible ignition sources.

- The gas cooker: At the time of the explosion, pupils were preparing the evening meal and all the gas rings on the four-ring gas cooker were in use.
- Under the floor in the two cabins at the rear of the ship there were cable connections connected via junction boxes; several of these boxes were missing their cover. This meant that there was an open electrical connection. This open connection makes a sparkover possible.
- In the toilet between the two rearmost cabins, a wad of toilet paper was found that contained residues that had been briefly exposed to a naked flame (traces of fire and soot). The investigation was unable to uncover the cause of the traces of fire and soot on this wad of toilet paper.
- Pupils who were cooking at the time of the explosion said that one of their fellow-pupils had opened the fridge door just before the explosion. The fridge has a switch for the interior light inside the fridge door at its top. The switching-on of the light when the fridge was opened could have caused a sparkover. Starting the fridge could have ignited the gas too.

5.4 Safety management

5.4.1 Introduction

A safety management system plays an important role in any drive to manage and improve safety. In practice, such a system is mainly found at large-scale organisations and not at all (or only to a limited degree) at smaller companies such as those that run passenger sailing ships.

These small companies were founded in the 1970s when a number of hobbyists started restoring old ships. In order to pay for the restoration, they started carrying passengers. When these ships were re-built, the main focus was on maintaining their classic exterior, although the provisions of the Inland Waterway Vessels Act did have to be complied with. This industry has now left its hobbyist roots behind: some owners have now 'scaled up' by running larger ships that can handle large numbers of passengers (150 and more). This scaling-up and professionalisation of the individual companies means that it is now more important than ever that the captain/owner assumes his responsibility for the safety of those on board.

5.4.2 Safety policy for passenger sailing ships

In general, the vessels in the 'brown fleet' are operated by a captain/owner. About 55% of the captains and/or owners in the Netherlands have joined the BBZ (Professional Sailing Skippers Association), which has drawn up an industry-specific RI&E (Occupational Health and Safety Hazard Identification and Analysis) exclusively for its members.

Owners/captains can use this RI&E to check whether appropriate safety levels are being maintained on board their ship. They can also use it to draw up a plan of action for solving any problems that have been identified.

The investigation has revealed that safety levels may no longer be adequate if attention is not paid to the fundamental aspects of the safety regime. In the end, the explosion on 8 June 2006 was mainly caused by inadequate design and inadequate maintenance. Both the gas cooker and the sewage tank were designed in such a way that eventually the system would no longer function properly over time, even if the rules laid down in standards, legislation and regulations were being complied with.

Discussions with the industry representative (i.e. the BBZ) have revealed that in the passenger sailing industry there are three major problems in relation to the above-mentioned risks:

1) The industry is not aware of the potential risks in the design of both cookers and sewage tanks.
2) The industry does not have a system in place that recognises such risks and that makes it possible to take appropriate preventive measures.
3) The lack of knowledge about potential risks with sewage tanks and gas cookers means that in practice the regular maintenance of these components is inadequate.

The BBZ plays an important role when it comes to sharing information within this sector. When it received the findings of the investigation that the PPS carried out into the explosion, it informed its members of the importance of the regular maintenance of gas cookers. Where possible, the BBZ plays an active role in the processes of regulation and enforcement, both nationally and internationally. However, the fact that the BBZ is only active on behalf of its members (and only half of all captains are BBZ members) means that it is not clear whether all captains active in the charter industry received the warning and will act accordingly.

Another point is that the industry organisation, in anticipation of possible requirements regarding the collection of sewage water in the charter industry, has initiated an experimental project for such tanks. However, this project focuses on the environmental requirements for such tanks, not on the risks associated with the use of sewage tanks such as the build-up of gases.[30]

5.4.3 Supervision and enforcement of the safety policy

Various parties are responsible for the implementation and enforcement of safety policy. In addition to the Labour Inspectorate and the IVW/TEB (IVW Supervisory Unit Inland Waterways), the delegation of inspection duties means that market players are responsible for this too. In principle, this system could lead to clashes, which is why the IVW/TEB should work with the Labour Inspectorate to ensure that there is a complete overview of the state of safety in the passenger sailing industry.

The IVW is moving towards a supervisory regime that is tailored towards the industry in question. This is based on the fact that captains, owners and the market players are responsible themselves for safety. In this specific sector, the market players are Register Holland, efm expertise b.v. and the agency NKIP. The IVW maintains a complete picture of the situation in the passenger sailing industry as a subsector of the inland shipping sector, using for this purpose the supervisory arrangements that are designed to create a system of metasupervision.

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30 From 2009, the pleasure cruising sector will no longer be permitted to discharge toilet water directly into the surface water. In future, this ban may apply to the charter industry too. In 2001, the BBZ initiated a project called 'Sewage water in the charter industry'. The project is a joint venture between RDIJ (Public Works Department of the Netherlands, Directorate IJsselmeer Region), the Province of Friesland, Riza (National Institute for Water Management and Waste Treatment) and the industry organisation BBZ. The aim of this project is to set up a disposal system for sewage water that originates from ships run by the Netherlands Charter Industry, with the additional aim of improving the quality of the surface water.
In 2006, as part of a pilot project, 16 vessels (according to BBZ) were able to dispose of their sewage tank waste water via a special sewage water installation (vacuum piston) located on a harbour quayside.

6 CONCLUSIONS

This section contains the summarised conclusions of the investigation into the explosion on board the two-mast clipper on Thursday 8 June 2006.

1. The explosion on board the two-mast clipper took place at about 7.50 p.m. (local time) in the ship's living quarters. On board the ship at that time were eleven pupils, four of whom were seriously injured in the explosion.

2. The explosion's planes of fracture and direction of movement indicate that gas accumulated under the floor. The front of the explosion travelled below deck under the floor in a horizontal direction towards the sleeping living quarters at the front and rear, and from the floor in an upward direction towards the ceiling and dome light.

3. The NFI concludes that the explosion was caused by a leak of propane gas. This leak could have been caused by a faulty thermoelectric coupling on the cooker that resulted from a failure to keep the cooker properly clean.

4. Experiments performed at the behest of the Dutch Safety Board on board the clipper in question revealed that the gas flowing out of the cooker can quickly accumulate under the floor.

5. The Dutch Safety Board concludes from its investigation that the explosion on board the clipper was in all probability caused by a leak of propane gas from the cooker. There were also found to be several potential ignition sources on the ship that could have ignited this gas.

6. In addition, the Board has established that gases can be formed in sewage tanks, a fact that under certain circumstances can pose a significant risk to those on board. One of the critical circumstances was the blocked ventilation of the sewage tank, which meant that the gases could no longer be carried away to the outside air. As a result, gases could escape from the sewage tank via other routes (for example via sewage pipe joints or sink holes of showers, washbasins and toilets) and could accumulate unnoticed in an area on board the ship. If mixed with the necessary quantity of oxygen, an explosive gas mixture will result.

7. This investigation has revealed that in certain circumstances the odorisation of gas may not be enough to ensure that leaks will be detected in time. This is certainly true of ships, because propane gas is heavier than air and will quickly find its way to areas below deck that are not (properly) ventilated. The Dutch Safety Board believes that there should be an investigation into finding ways of improving the detection of propane gas, including by using a more detectable odour. There should also be an investigation into other forms of flagging gas on board ships.

8. Given the risk of using gas and the other alternatives already available, the Dutch Safety Board holds the opinion that the transitional deadline, which is currently set for the year 2045, needs to be reviewed.

9. The industry does not deploy a safety management system (or else only does so patchily). This is mainly because the vessels are usually in the hands of a single person, namely the captain/owner. There is a body that collects and shares knowledge, this being the coordinating (industry) organisation BBZ. However, only half of all captains have joined the BBZ so far.

7 RECOMMENDATIONS

Based on its investigation into the explosion on board the two-mast clipper, the Dutch Safety Board makes the following recommendations:

1. Given the risks associated with the use of sewage tanks, the Board recommends that the Transport and Water Management Inspectorate (IVW) make the checking of the installation and maintenance of these tanks part of the system of certification and inspection.

2. The Board recommends that as part of the planned organisation of the supervision of the inland shipping the IVW should ensure that a total overview of safety levels in the passenger sailing industry is drawn up and kept up to date.

3. The Board recommends that the Minister of VROM (Housing, Spatial Planning and the Environment) has an investigation carried out into ways of improving the detection of propane gas, including improving the odorants used.

4. The Board recommends that the BBZ bring to the attention of the industry the knowledge about the risks and prevention of gas accumulation under vessel floors. There should also be special attention paid to sewage tanks and possible flagging methods.

APPENDIX 1: RESPONSIBILITY FOR THE INVESTIGATION

Notification of and investigation by the Dutch Safety Board
On Thursday 8 June 2006, there was an explosion on board a two-mast clipper that was reported to the Dutch Safety Board by the KLPD (National Police Services Agency). That same evening and in the week following, the Dutch Safety Board launched a preliminary investigation that ran simultaneously with an investigation by the Public Prosecutions Service (PPS). In the first few days there were intensive discussions with the PPS, mainly because of the impound of the ship. Once the PPS had reported that it did not believe that methane gas was a possible cause, the Dutch Safety Board continued that part of the investigation itself under its own responsibility. To this end, the Dutch Safety Board called on the expertise of TNO *Construction and Services* (in the form of a team of expert chemical analysts). A number of other parties were involved in other parts of the investigation as well.
On 14 August 2006 the Board agreed with the proposal to investigate.

Scope
The investigation by the Dutch Safety Board focused on the underlying factors that led to this incident. The report is based on the two most likely scenarios, both of which could have affected levels of safety on board the ship. The scenario involving propane gas is an important consideration, given the risks of having naked flames on board a ship. This is recognised by the government too, as evidenced by the imminent legislative amendments under which the use of propane gas for household use on board passenger ships will be prohibited.
The biogases scenario is an important consideration in connection with the development and use of sewage tanks on board vessels. The focus on this issue originated from an environmental quarter, but this report also looks at the potential safety risks posed by sewage tanks.

Other investigations
The incident was investigated by the KLPD in collaboration with the NFI in respect of a possible criminal prosecution.

Interviews and information
As part of the investigation, interviews were held with those directly involved, including with the captain and the pupils who were on board the clipper at the time of the explosion. In total, the Board held 19 interviews. The interviews were primarily designed to obtain insights into the cause of the explosion.
In addition, information was obtained from the IVW and from the ship's insurer (efm onderlinge schepenverzekering u.a.).

Analysis
The analysis focused on a reconstruction of the incident and on the immediate and underlying causes. To this end, various sections of the ship were inspected in order to uncover evidence of the cause of the explosion. In order to get a better idea of how the gas spread on board the clipper, the Dutch Safety Board performed experiments using a harmless gas with similar properties to that of propane gas. A TRIPOD analysis was used to look for potentially failing barriers and for latent factors that helped bring about the explosion.

Drafts
The draft final report (i.e. without the consideration and recommendations) was submitted to the stakeholders so that they could assess it for factual accuracy. Where relevant, the Dutch Safety Board has incorporated the responses received into the definitive final report.
The following responses by the BBZ to the draft report's conclusions have not been incorporated:

Conclusion 4: leak of propane gas from the cooker.

An examination of the entire gas installation on board revealed that it was the cooker that was the weakest link. This is also the item where the ship's owner has to put his faith in the quality of the appliance, and in the CE standard awarded to it. You have to assume that a manufacturer will take measures to prevent the contamination of the thermocoupling by leftovers. The manufacturer recognised this problem, as evidenced by the protection provided for the other thermocouplings. In other words, it may be argued that the cooker's particular construction led to a failure on the part of the thermoelectric coupling to work, leading in turn to gas leakage. This also shows that the current system of CE standardisation does not solve this problem, although it may be possible to improve the certification process.

Comment by the Dutch Safety Board

The operating instructions for the cooker explicitly refer to the maintenance and cleaning of the gas rings and gas taps.

Conclusion 5: development of explosive gases in sewage tanks

The board of the BBZ shares your concern that gases can form in sewage tanks that can create an explosive mixture if mixed with oxygen. This is why the BBZ board is urging the government to commission further investigation into the potential explosive risk for gases from sewage tanks. Between 2007 and 2011, many captains/owners will modify their ships to bring them into line with the Inland Waterway Vessels Act. This will often involve the installation of sewage tanks. This makes it essential to obtain a better understanding of the potential risks and of the measures needed to prevent them. The BBZ board asks you whether it is possible to include this comment in the investigation report, provided that this lies within the scope of your competence.

<u>Comment by the Dutch Safety Board</u>
The hazards have arisen due to inadequate or overdue maintenance and/or incorrect installation. This investigation has led to recommendations on supervision in this area.

Conclusion 6: The passenger sailing industry is insufficiently aware of the above risks.

The passenger sailing industry is indeed unaware of the potential risks posed by sewage tanks, but at the same time it is aware of the risks associated with the use of propane gas on board vessels. This is why these installations are installed by, and inspected every three years by, certified companies. For this reason, we would like to see conclusion 6 limited to the risk of the formation of an explosive mixture from the sewage tank.
Note too that it is not just passenger sailing ships but also the entire passenger-carrying shipping industry that is insufficiently aware of this risk - this accident could also have occurred on board a motorised passenger vessel.

<u>Comment by the Dutch Safety Board</u>
An inspection every three years by a certified company is not enough. The operating instructions for the cooker read [in Dutch] 'to be inspected at least twice a year by expert personnel'.

Conclusion 7: Safety management system

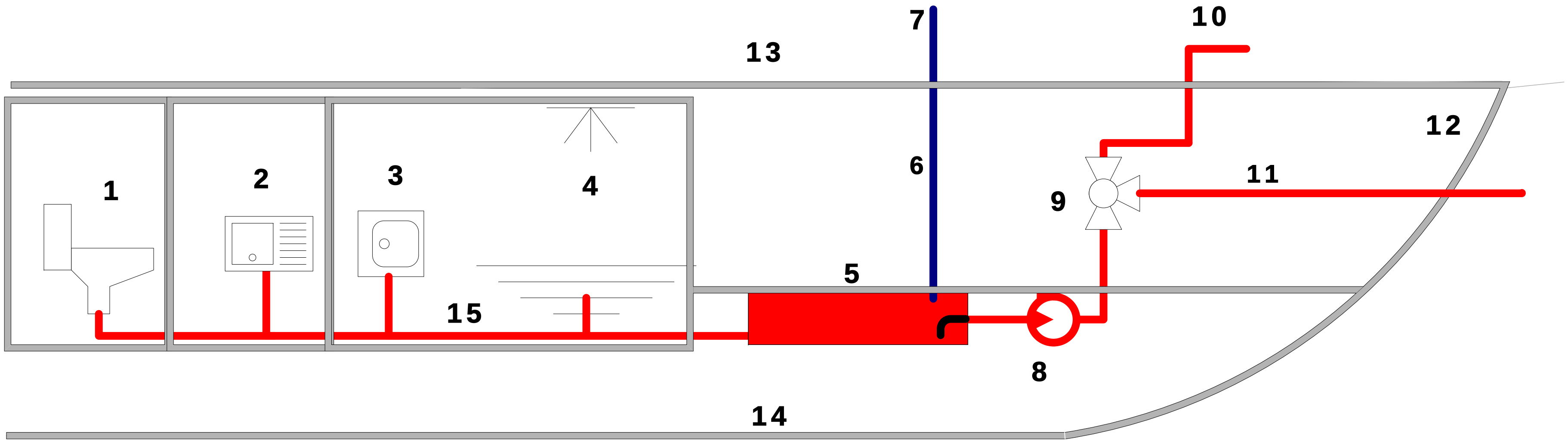
Within the ocean-sailing industry (i.e. for traditional sailing ships carrying passengers at sea), there is currently a pilot project that is testing a tailor-made safety management system developed by the BBZ in close collaboration with, and utilising a subsidy from, the DGTL (Directorate of General Transport and Aviation) of the Ministry of Transport, Public Works and Water Management. This did not come up in our discussion in November 2006 because the system was not yet under development at that time. It may be possible in the future to implement this safety management system throughout the inland waterway passenger shipping industry too. The question remains as to whether a safety management system would actually spot a construction fault in a cooker (see also our previous comment to conclusion 4).

<u>Comment by the Dutch Safety Board</u>
One aspect of the safety management system is the maintenance schedule for the (various sections of the) ship. The instruction about maintenance of the cooker should be included in it. See also the comments to conclusions 4 and 6.

Project team
The project team consists of the following persons:

G.Th. Koning MSHE	Project leader
S.H. Akbar	Investigator
W. Boutkan	Investigator
S.M.W. van Rossenberg	Investigator
E.M. de Croon	Analyst
S. Pijnse van der Aa-van Gelder	Secretary-safety specialist
H.J.A. Zieverink	Senior secretary-safety specialist

APPENDIX 2: DESIGN OF GENERIC SEWAGE TANK



1 = toilet
2 = sink
3 = washbasin
4 = shower
5 = sewage tank
6 = tank ventilation hose below deck
7 = tank ventilation hose above deck
8 = dilution pump

9 = distributing valve
10 = quayside connection for sewage water drainage
11 = overboard sewage water
12 = ship's side
13 = deck
14 = ship's bottom
15 = sewage water waste pipe

Figure 1: Simplified diagram of generic sewage tank for the delivery of sewage water from on board vessels in general

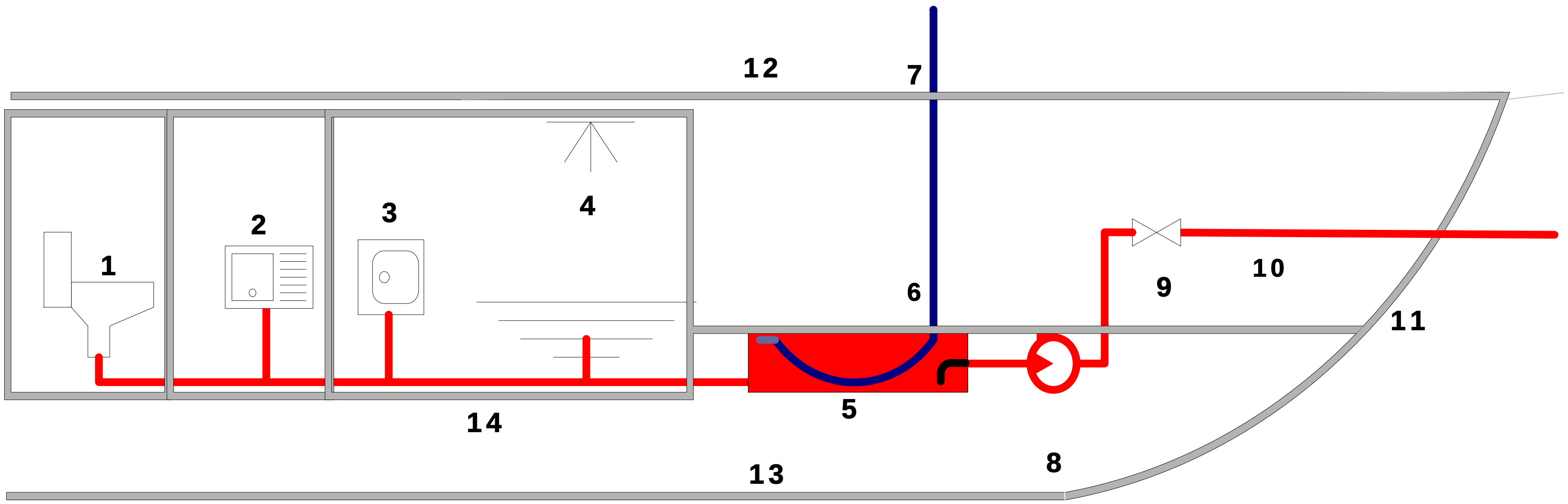


Figure 2: Simplified diagram of the sewage tank for the drainage of sewage water from the two-mast clipper in question

APPENDIX 3: ASSESSMENT FRAMEWORK FOR SAFETY MANAGEMENT

Past experience has shown that the structure and features of a safety management system play a crucial role in demonstrating that safety is being managed and continually improved. This is true of all organisations engaged in activities, either directly or indirectly, where there is a potential risk to citizens in the Netherlands. This relates to organisations of various types and sizes and with various roles and responsibilities such as ministries, provinces, municipalities and private sector companies. The necessary features of a safety management system in a particular investigatory field will directly depend on the context, which is determined by such factors as the nature, size and responsibilities of the stakeholders. The phases in the life cycle (focus on design, execution, management etc.) will play an important role in this respect too. On the basis of national and international laws and regulations and on numerous broadly accepted and broadly implemented standards, the Dutch Safety Board has defined a number of safety issues that will need to be specified in more detail in the safety management systems of the relevant organisations. This relates to the following action items:

Safety policy based on understanding risks
Starting-points for the attainment of the required level of safety are:
(i) an investigation of the system, followed by
(ii) an inventory of the associated risks. This is used to determine which hazards need to be managed and which preventive and repressive measures are needed in this context.

Demonstrable and realistic safety policy
In order to prevent and manage undesirable events, a realistic and practical safety policy, including the associated starting points, needs to be laid down. This safety policy must be established at managerial level and must be guided from that level too. The safety policy is based on:
(i) relevant current laws and regulations,
(ii) available standards, guidelines and 'best practices' from the industry, on own insights and experiences of the organisation in question, and on the specific safety goals for the organisation.

Implementing and enforcing safety policy
The implementation and enforcement of the safety policy and the management of the identified risks is achieved by:
(i) drawing up a description of the way in which the safety policy will be implemented, including specific objectives and plans and the resulting preventive and repressive measures.
(ii) drawing up a transparent, unambiguous and 'accessible to all' allocation of responsibilities on the workfloor for the implementation and enforcement of safety plans and measures.
(iii) a clear definition of the personnel deployment and expertise required for the various tasks.
(iv) a clear and active centralised system for the coordination of safety activities.

Tightening up the safety policy
The safety policy must be continually tightened up, based on:
(i) the periodical - including for each amendment of the starting points - performance of (risk and other) analyses, observations, inspections and audits (proactive approach).
(ii) a system of monitoring and investigation of incidents, near-accidents and accidents, along with an expert analysis of them (reactive approach). On this basis, evaluations will be performed and the safety policy may be modified by the management team, if necessary. Possible improvements will be revealed too and can be actively implemented.

Management guidance, involvement and communication
The management team of the stakeholders/organisation must:
(i) be responsible internally for setting clear and realistic expectations regarding the safety objectives, and for ensuring that there is a climate of continuous improvement in safety on the workfloor, by always setting a good example, and last but not least by providing sufficient people and resources.
(ii) communicate clearly externally regarding the general procedure, test methods, procedures for deviating etc., based on clear arrangements made with the external environment that are laid down in writing.

The Dutch Safety Board recognises that the assessment of the way in which organisations handle their own responsibility for safety in practice will largely depend on the organisation in question. Factors such as the nature and size of the organisation can play a role here, which is why they should be made part of the assessment process. The assessment of each incident may vary but the way of thinking is identical.