DMAIB
DANISH MARITIME ACCIDENT INVESTIGATION BOARD

NORD MAGIC

Marine accident report on occupational accident

17 JUNE 2022

MARINE ACCIDENT REPORT ON OCCUPATIONAL ACCIDENT
ON NORD MAGIC ON 17 JUNE 2022

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Photo: Hatch no. 2 COT (S) on NORD MAGIC
Source: Norden Synergy Ship Management A/S

The investigations are carried out separately from the criminal investigation, without having used legal evidence procedures and with no other basic aim than learning about accidents with the purpose of gaining and promoting an understanding of safety. Consequently, any use of this report for other purposes may lead to erroneous or misleading interpretations.

Content

Introduction

Start of the investigation

On 17 June 2022, the Danish Maritime Authority informed DMAIB that two technicians had succumbed due to exposure to a toxic gas during inspection of a cargo tank on the Danish chemical/product tanker NORD MAGIC, while the ship was at anchor off Chittagong, Bangladesh. The next day, DMAIB was informed that both technicians had perished.

In view of the very serious consequences, DMAIB immediately started an investigation. It was, however, not possible to gain access to the ship to investigate and document the accident site until 9 July when the ship was alongside in Haldia, India.

The purpose of the investigation was to establish the circumstances that led to the death of the technicians.

Narrative

RECONSTRUCTION OF COURSE OF EVENTS

The reconstruction of the course of events is based on data from the ship's AIS, VDR, logbooks and testimonies from a selected group of crewmembers.

The course of events covers the period from when work on the ship began on June 17 2022, at 0342, until the technicians were evacuated from the ship later the same day.

Background

NORD MAGIC (Figure 1 and appendix) was a product tanker in worldwide tramp service carrying a variety of chemical and oil products. At the time of the accident, the ship carried soybean oil loaded in San Lorenzo, Argentina, some of which had already been discharged in ports in Madagascar and Mozambique, with the remainder to be discharged in India and Bangladesh.

The ship's crew comprised 23 persons of various nationalities. English was the official working language on board, but in practice the working language was mainly Hindi. English was spoken when the Indian crew communicated directly with crewmembers of other nationalities.

Figure 1: NORD MAGIC
Source: Norden Synergy Ship Management A/S

On 10 June 2022, NORD MAGIC arrived in Chennai, India. In the afternoon, two Indian technicians embarked, along with a classification society surveyor and a company superintendent. They met with the master and chief engineer to discuss ultrasonic measurements of bulkheads and plating ahead of a forthcoming classification society survey with regard to their scope and timeframe. Thickness measurements were to be taken in fourteen ballast tanks, two cargo tanks and on selected deck plating. The inspections were expected to be completed soon after the ship had discharged the final cargo of soybean oil in Haldia, India, 10 days later.

On 11 June 2022, the technicians reembarked, were familiarised with the ship, introduced to the safety management system, and commenced their inspections. The following day, NORD MAGIC departed Chennai for passage to Chittagong Anchorage, Bangladesh, where soybean oil was scheduled to be discharged into barges.

Course of events

The accident

On 17 June, NORD MAGIC was at anchor off Chittagong, Bangladesh, and at 0354, a cargo barge arrived alongside to receive a parcel of soybean oil. After the meeting between the ship's crew and the cargo surveyors, and when the sounding of the tanks was completed, the discharge operation from three cargo oil tanks (COT): no.6 COT port (P), no. 6 COT starboard (S) and no. 3 COT (S) began (Figure 2). The cargo discharge operation was planned to be completed at noontime.

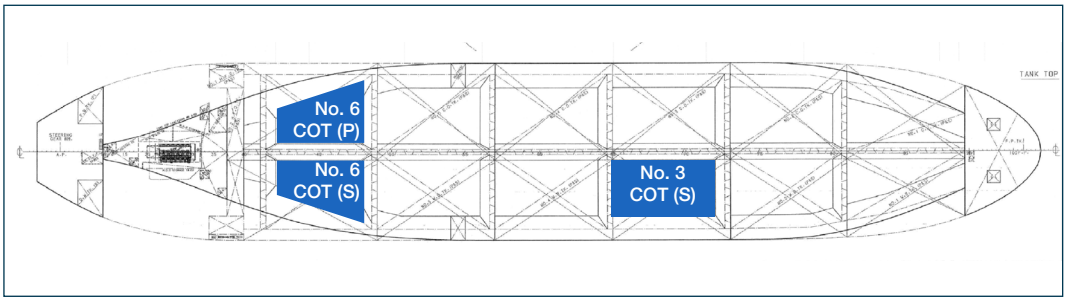


Figure 2: Overview of cargo oil tanks.
Source: Norden Synergy Ship Management A/S / modified by DMAIB

While the cargo operation was ongoing, the no. 6 COTs were ventilated as their cargo was discharged in preparation for entering the tanks for squeezing[1]. The deckhands and the chief officer also completed the work permits and obtained the authorisation from the master to enter the tanks. Between 0625-0930, the ratings entered no. 6 COT (S) for squeezing the remaining cargo, and continued the process on no. 6 COT (P).

At about 0830, the chief officer met with the two technicians to discuss the tank inspections to be carried out that day. They planned how to prepare and inspect the forepeak ballast tank and perhaps later in the day inspect no. 2 COT (S) (Figure 3).

1 Squeezing: Stage in discharge process for vegetable oils where crewmembers enter the cargo tank to sweep the remaining cargo on the bottom of the tank towards the suction pipe.

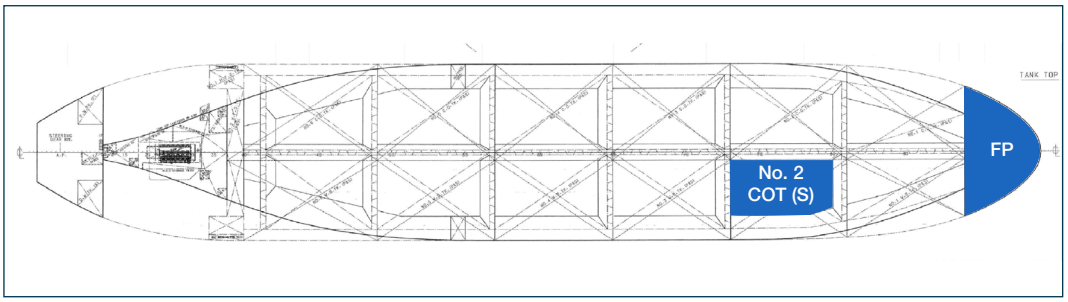


Figure 3: Overview of forepeak ballast tank and no. 2 COT (S)
Source: Norden Synergy Ship Management A/S / modified by DMAIB

During this meeting, a work permit for entry into the forepeak tank was prepared. The work permit was issued by the master and was valid from 0955. The technicians postponed the inspection of the forepeak ballast tank until after lunch, due to heavy rain as the manhole cover to the forepeak tank was located on the open main deck.

At 1018, the discharge operation was concluded and at noon, as soon as the cargo barge had been cast of, the chief officer went to his cabin to rest. He felt tired because he had worked about 0300, and he only had a few hours of sleep the night before.

After lunch, the rain stopped, so the technicians went on deck to inspect the forepeak tank. The tank had been ventilated, and gas checks had been performed by the chief officer and deckhands earlier in the morning. At 1404, the able seaman (AB) called the bridge and notified the 2nd officer that the technicians were entering the forepeak tank and that they intended to enter no. 2 COT (S) afterwards. The officer made a note of the time. At 1453, the AB called the 2nd officer and notified him that the technicians were entering no. 2 COT (S), and the 2nd officer again recorded it. The hatch to no. 2 COT (S) was already partly open by about 10cm, and the AB opened it completely for the technicians to access the tank. He observed the technicians enter the tank and descend a vertical ladder to a platform and then down stairs onto a second stairway landing where they started to use their ultrasonic measurement tool (Figure 4).

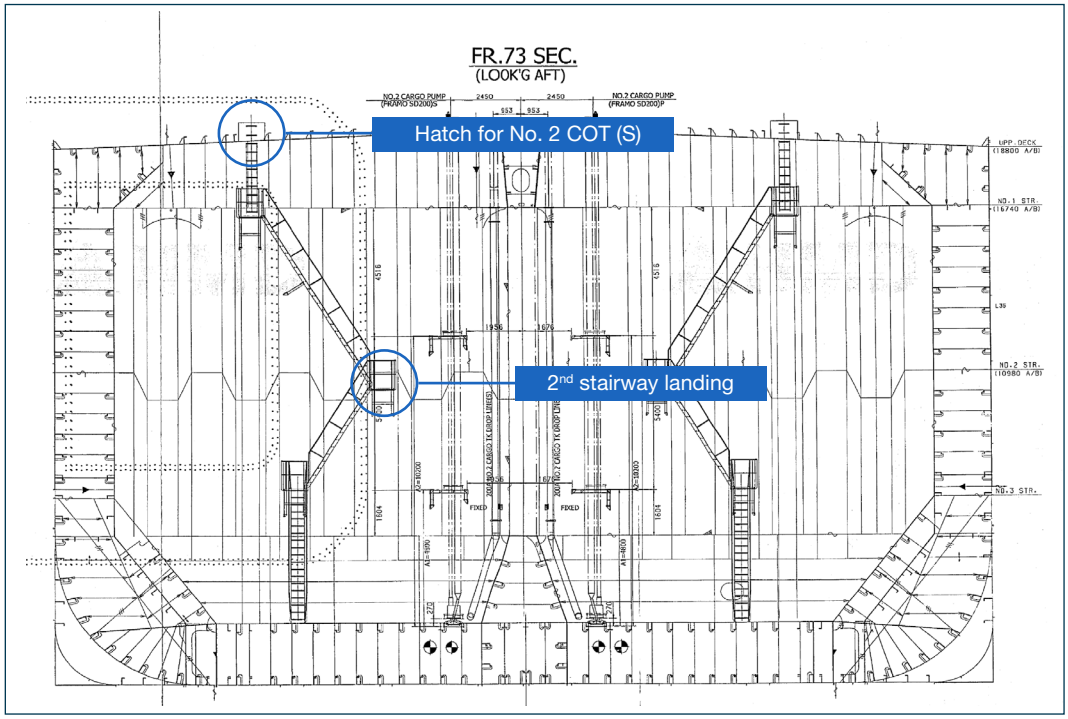


Figure 4: Platform in no. 2 COT(S)
Source: Norden Synergy Ship Management A/S / modified by DMAIB

At 1512, as the AB kept watch at the tank hatch, he noticed that a second cargo barge was approaching the ship. He was contacted by the 2nd officer by radio who asked the AB to assist the ordinary seaman (OS) and the dayman to secure the cargo barge on the starboard side. It would not take him farther than 10 meters from the tank's hatch, so he considered it unproblematic (Figure 5).

Figure 5: NORD MAGIC
Source: DMAIB

At 1543, the cargo barge was secured and the 2nd officer asked the AB about the whereabouts of the technicians. The AB replied that they were still in the tank. Soon after, the AB returned to the tank hatch. He looked inside the tank and saw the technicians lying on the second stairway landing. He immediately alerted the 2nd officer by radio. He also shouted aloud that the technicians were lying unconscious in the tank.

The AB's radio message was heard by the master, who was also on the bridge, and he ordered the 2nd officer to inform the engineers in the engine room. He then hurried to the cargo deck because he was concerned was that someone might enter the tank to assist the technicians without wearing a breathing apparatus. After having called the engineers and the chief officer, the 2nd officer made an announcement on the public address system at 1550 stating that the technicians were unconscious in no. 2 COT (S), and the crew was to muster on deck. By then, the technicians had been in the tank for about one hour.

The evacuation

On deck, as the crew assembled, they smelled the distinct odour of rotten eggs from the hatch opening to no. 2 COT (S). The crew sampled the atmosphere in the tank with a gas detector which indicated the concentration hydrogen sulfide to be over 100ppm (the maximum value the gas detector could measure). The oxygen concentration indicated was about 20%.

The crew gathered the equipment for evacuating the technicians from the tank and began ventilating the tank. The fitter and bosun donned breathing apparatuses and went into the tank. Once in the tank, they quickly realised that they would be unable to lift the technicians up the stairwell to the ladder below the hatch. The fitter exited the tank and the engine cadet and motorman donned breathing apparatuses and climbed into the tank to assist the bosun.

Within minutes, the whistle on the bosun's breathing apparatus sounded a warning that the air supply was low, and he immediately climbed out of the tank. The engine cadet, realising that he and the motorman had to manage the situation by themselves, resolutely took hold of one of the technicians and, assisted by the motorman, dragged him up the stairwell from the second platform. They then tied a lifting belt attached to a rope onto the technician, who was lifted out of the tank. On completion, they evacuated the second technician.

The evacuation of the technicians from the cargo tank took about 25 minutes from when they were seen to be unconscious. Once on deck, the crew placed them on stretchers, provided first aid assistance and administered medical grade oxygen. The technicians were breathing and were in a stable condition. At 1612, the master went back to the bridge and informed Chittagong Port Control about the situation and asked one of the cargo surveyors to call the ship's agent to arrange for a boat to transport the technicians ashore, so they could be taken to hospital.

At approximately 1730, a patrol boat arrived alongside, and the technicians were transferred on board using the deck crane and were then transferred ashore accompanied by a motorman and the 2nd engineer. Upon arrival at the hospital in Chittagong, one of the technicians was pronounced dead. The next day the other technician died. Subsequent autopsies identified that one technician died as a result of a haemorrhage caused by a head injury, and that the other died from asphyxia caused by inhalation of irrespirable gases.

Investigation

SCOPE OF THE INVESTIGATION

The course of events indicated that the technicians succumbed after exposure to a hazardous concentration of hydrogen sulfide in no. 2 COT (S). After the morning meeting, a work permit was issued for the technicians' entry into the forepeak tank, but no. 2 COT (S) had not been prepared, and a work permit had not been issued.

The investigation thus aimed at explaining why the technicians entered the cargo tank which had not been prepared for entry, and why the ship's crew did not intervene.

To answer these questions, the following topics will be examined:

- Design and content of no. 2 COT (S).
- Proporties of hydrogen sulfide.
- Technicians' qualifications and experience of marine tank inspections.
- Ship's procedures for entry into enclosed spaces.
- On board practices for enclosed space entries.

Starboard cargo oil tank no. 2

In this section the access and content of no. 2 COT (S) is described to determine the origin of hydrogen sulfide in the tank and to establish the circumstances which rendered the technicians unconscious.

Tank access

No. 2 COT (S) was accessed through a hatch on the aft part of the tank. The hatch was secured with dog clips and a handwheel mechanism. When the dog clips were released and the handwheel loosened, the hatch could be slid open (Figure 6).

Inside the tank, a vertical ladder led to a platform from which a sloped stainless steel ladder reached the bottom of the tank via two platforms. The vertical distance from the hatch to the bottom of the tank was 17 meters, and the distance from the hatch to the second (and middle) platform, where the technicians were found, was about 10 meters (Figure 7).

Tank content

No. 2 COT (S) was loaded with degummed crude soybean oil in San Lorenzo, Argentina, which was partly discharged in Maputo, Mozambique, with the remaining cargo being discharged on 29 May in Toamasina, Madagascar. The properties of the cargo were stated in the Material Safety Data Sheet (MSDS) which chemical tankers are required to carry[2].

2 International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) para. 16.2 and IMO Circulars: MSC/Circ. 100 and MEPC/Circ. 407.

Figure 6: Hatch no. 2 COT (S)
Source: Norden Synergy Ship Management A/S

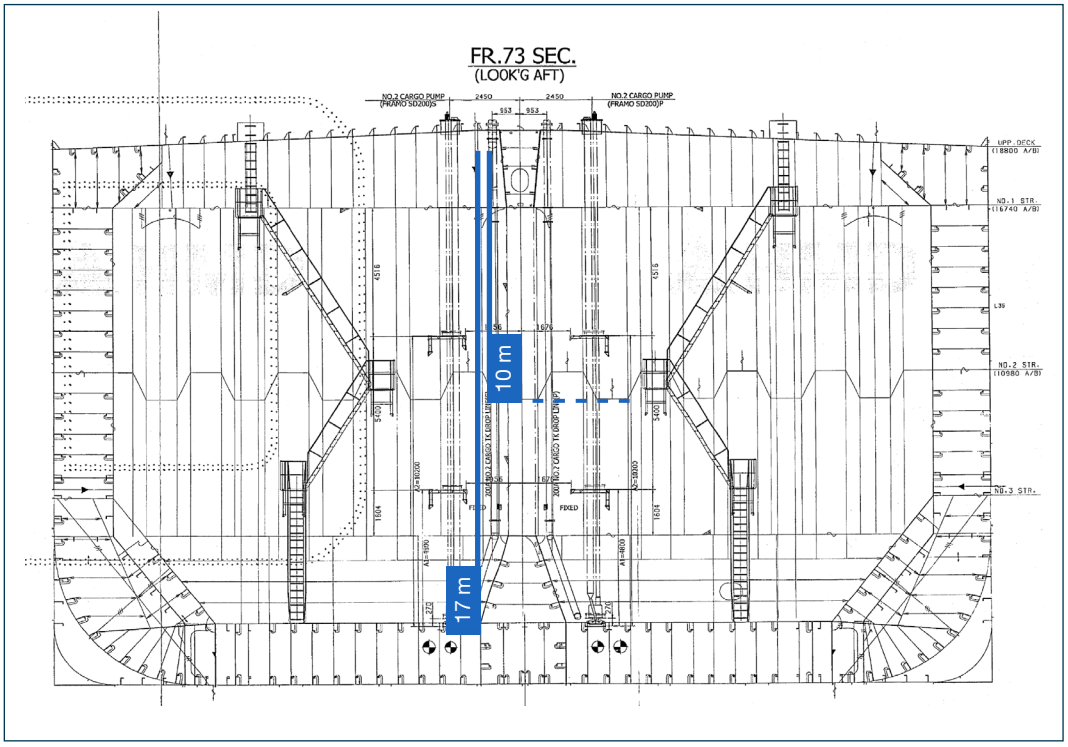


Figure 7: No. 2 COT (S) looking aft
Source: Norden Synergy Ship Management A/S / modified by DMAIB

The data sheets contain information to anyone involved in the handling and/or carriage of products that may be hazardous. They also provide information to workers who may be exposed to the product. The information is presented in a structured, concise and consistent manner based on information compiled by the manufacturer which is then provided to the ship via the shipper.

The data sheet for the soybean oil was divided into 16 sections. No hazards were identified in Section 2, 'Hazard Identification', and the wording of the controls listed in Section 8, 'Exposure Controls and Personal Protection', suggested that the hazards were related to direct contact with the product in liquid form or as an oil mist and not related to the product releasing volatile components (off-gassing). The controls stated that normal ventilation for standard manufacturing operations was adequate and low or confined areas should be provided with mechanical ventilation. The properties of the soybean oil described in the MSDS coincided with views of the deck crew on NORD MAGIC who considered soybean oil easy to handle and did not express any concerns related to hazardous properties of the cargo. Consequently, the crew on NORD MAGIC were surprised that no. 2 COT (S) contained a lethal concentration of hydrogen sulfide.

While the ship was on passage to Chennai from Toamasina, the charterer notified the crew that no. 2 COT (S) was to be pre-washed while the ship was underway. To achieve this about 10 m^3 of seawater at ambient temperature was pumped into the tank using the main seawater fire fighting arrangement. The tank was then cleaned by circulating the seawater in the tank using a fixed tank cleaning machine mounted on the tank's butterworth hatch. After half an hour of washing, the hatch was opened, and the tank was inspected from deck to ensure that the bulkheads had been cleaned and were wet, otherwise residues from the cargo could harden and make it difficult to finalise the cleaning later. The seawater from the tank cleaning was left in the tank to prevent the tank bulkheads from drying out.

The access hatch to no. 2 COT (S) was either not fully closed on completion of the pre-wash or was cracked open by about 10 cm at some point later in preparation for the future cleaning and inspection of the tank. By 17 June 2022, the mixture of soybean oil residue and seawater had been in the tank for about 19 days.

Following the accident, a wash water sample from no. 2 COT (S) was sent to a chemical laboratory ashore for testing. The resulting test report concluded that the sample contained over 2,000 ppm of hydrogen sulfide in vapour form, even after 14 days in storage. As the MSDS did not identify hazards related to toxic gasses, it remained to be determined how the hydrogen sulfide had developed in no. 2 COT (S) containing residues of soybean oil and seawater.

Findings: Starboard cargo tank no. 2

- No. 2 COT (S) was partially open prior to the technicians entering the tank and contained remains of soybean oil mixed with seawater.
- The MSDS did not identify hazards related to toxic gasses.
- The tank's atmosphere was rich in hydrogen sulfide.
- The technicians were not immediately affected by the presence of hydrogen sulfide.

Hydrogen sulfide

Emergence of hydrogen sulfide

Hydrogen sulfide occurs naturally through the anaerobic decay of organic matter in low oxygen environments where microbial reduction of the sulphate ion is the dominant mechanism for sulfide formation. Thereby, the presence of bacteria, sulphur and a low oxygen environment was necessary for the development of hydrogen sulfide.

In this respect, no. 2 COT (S) was not sterile, and bacteria were inevitably present in the tank before it was loaded with soybean oil. The amount of bacteria would also have certainly been increased when seawater was added. In addition, although after the mechanical extraction of soybean oil from soybeans, the sulphur content in the oil is normally diminished, it still might contain sulphur residues which can also be found in the settling soybean oil gum.

The mixture of soybean oil, gum and seawater was in the tank for 19 days, which was ample time for bacteria in the mixture to have an anaerobic affect. Furthermore, a layer of soybean oil likely covered the mixture, thereby creating a low oxygen environment and completing the conditions required for the creation of hydrogen sulfide.

Physiological effects of hydrogen sulfide

Hydrogen sulfide is heavier than air, and high concentrations may appear wherever protein decomposes without complete oxidation and is often generated in the same way in sewers, septic tanks, storage containers and in other enclosed spaces containing organic material. Its smell is thus recognisable to most people.

Acute symptoms of exposure to hydrogen sulfide are reactions in the respiratory tract, including hoarseness, coughing, nasal secretion and pulmonary edema. The latter is not rare and may develop as long as three days after an accidental exposure which did initially not appear to be severe. In concentrations as low as 0.005% (50 ppm), hydrogen sulfide may produce an irritation of the eyes. Concentrations as low as 0.02% (200 ppm) in inspired air depress, whereas higher concentrations stimulate the nervous system, and concentrations of about 0.1 % (1,000 ppm) paralyse the nervous system. Death from acute poisoning usually results from failure of respiration and the resultant asphyxia. The autopsy report issued for one of the technicians stated the latter as the cause of death. The other technician perished as a result of an injury to the head, likely as a result of a fall from height. Even though DMAIB has not been able to establish the concentration of hydrogen sulfide in the tank at the time of the accident, it is a possible scenario that he fell when overcome or when trying to evacuate the tank stairs leading to the first platform.

In concentrations as low as 0.000015% (0.15 ppm) in air, hydrogen sulfide has an odour resembling that of rotten eggs. At higher concentrations, its odour is perceived as sweet, and concentrations exceeding 0.015 % (150 ppm) in air can have a paralysing effect on the sense of smell, making the gas undetectable by smell alone. Hence it is dangerous to depend on the sense of smell to detect the presence of the gas[3].

3 Acute hydrogen sulfide intoxication; an unusual source of exposure. Industrial Medicine & Surgery 1964;33:656-60

The hatch to no. 2 COT (S) was partially open, but as hydrogen sulfide is heavier than air there would have been no smell of rotten eggs on deck before the technicians entered the cargo tank. This was confirmed by DMAIB's interviews with the crew working on deck during the morning of the accident and by the fact that the AB who opened the tank hatch fully, did not notice any odour. When the technicians approached the hatch, they might have smelled hydrogen sulfide, but their sense of smell was paralysed soon after as they entered the tank, giving them no cause for concern when climbing into the tank. Once they were in the tank, the hydrogen sulfide was not present in such a concentration that acute symptoms were felt. Once the effects of the gas set in, it was too late to climb the stairs and ladder and evacuate the tank.

Findings: Hydrogen sulfide

- The hydrogen sulfide developed as a result of the anaerobic decay of the mixture of soybean oil residues and saltwater which had been in the tank for about 19 days.
- When the technicians climbed into no. 2 COT (S), they might not have detected an odour of hydrogen sulfide as a high concentration of hydrogen sulfide has a numbing effect on the sense of smell.
- One of the technicians perished as a result of asphyxia caused by hydrogen sulfide poisoning. The other technician perished as a result of a fatal injury to the head from a fall likely caused by the effects of hydrogen sulfide poisoning.

The technicians

In this section, the technicians' background, training and work practice on NORD MAGIC are described with the aim of establishing what skills and experience they had in working in enclosed spaces.

Background

The technicians worked for a company based in Kochi, India. It was a marine and engineering company employing about 120 persons specialised in carrying out ultrasonic gauging in the marine industry and was approved to perform thickness measurements on behalf of classification societies.

Training and experience

The two technicians had been with the company for 6 years and 4.5 years, respectively, carrying out inspections weekly in different kinds of tanks on a variety of ship types. The company thus considered them to be experienced and familiar with the hazardous environment they worked in.

The technicians had an educational background as mechanical engineers. They were recruited directly from college and provided with inhouse training for 6 months in Kochi. During training, the technicians received practical training on ships in shipyards, where they gained experience using the ultrasonic equipment and were acquainted with working on board ships, including the precautions to take when working in enclosed spaces. It was also emphasised that on board ships they worked under the supervision of the shipboard crew and thus had to follow instructions from the officers and adapt and adhere to the work practices on board. These practices could vary, but the technicians were specifically instructed by the company to always have valid work permits issued and have the atmosphere in the tanks tested before entry. The training in general aimed at enabling the technicians to assess the quality of the safety measures on board and act accordingly.

At the company's office, the pool of technicians regularly participated in meetings where their various experiences were shared, e.g. relations with classification societies, safety related matters, cooperating with ship's crews, etc. The company informed DMAIB that they had not experienced any enclosed space accidents in the last 25 years.

Normally, the technicians worked as a team, but depending on the complexity of the work site and the availability of the tanks, they occasionally split up and worked in separate tanks. Besides the ultrasonic equipment, they brought personal protective equipment such as boiler suits, safety shoes and helmets. They always relied on ships to provide personal gas detectors and fall arresting equipment, if needed.

On NORD MAGIC, the technicians worked as a team during all the tank inspections. Each tank inspection was thereby completed within 40 minutes. DMAIB's interview with the ship's crew indicated that the technicians were conscious of the hazards of enclosed space entries and which safety precautions to take prior to making the tank inspections, including the importance of having valid work permits prior to entry into enclosed spaces.

Findings: The technicians

- The technicians were experienced inspectors who were knowledgeable about the hazards of enclosed space entries.
- The technicians were instructed to adapt to the ship specific procedures and work practices. They thus relied on the ship's crew's ability to involve them in the onboard procedures and work practices, including the use of the ship's safety equipment.
- Observations made by the ship's crew indicated that the technicians were aware of the dangers when entering enclosed spaces and which safety precautions to take.

Procedures for entry into enclosed spaces

In this section the procedure and work permit for enclosed space entry are described and analysed with the aim of establishing their purpose, design and functioning as barriers to prevent accidents. DMAIB thus reviewed the relevant sections in NORD MAGIC's procedure and permit to work for entry into enclosed space. The purpose was to determine how the documents were related, and how they governed and supported the crewmembers' work practices when entering an enclosed space.

Permit to work system

A permit to work system can have different designs and specified purposes, but is basically a documented system for controlling activities that expose the ship, the terminal, personnel or the environment to hazard. The system will use risk assessment techniques and apply them to the varying levels of risk that may be experienced. The system should conform to a recognised industry guideline[4]. In practice, a work permit system for enclosed spaces usually comprises a procedure, a risk assessment and a permit to work authorising the work to be carried out.

A procedure is typically a message from the managers to the employees about 'how work is to be carried out in this organisation'. The procedures are most often directed to the person responsible for a given task. It typically describes how a work task is to be carried out and by whom. This is generally achieved by specifying a sequence of work tasks, subtasks and actions to take.

A permit to work is a document issued by a responsible person on completion of all required actions regarding preparation and testing, which allows or authorises work to be performed in compliance with the ship's safety management system. In general, it includes confirming that means of ensuring and documenting that essential precautions have been taken and, where necessary, that physical safeguards have been put in place according to the risk assessment and industry guidelines.

Safety management on NORD MAGIC

In 2020, NORD MAGIC's owner DS NORDEN A/S and Synergy Marine Group established the company Norden Synergy Ship Management A/S in a joint venture to handle the technical management of the company's tanker vessels. At the time of the accident, this joint venture managed all the owner's oil and chemical tankers from its Copenhagen headquarters with technical support from a subsidiary in India.

After the transition of management there was a continuous update in close association with the standards of Synergy Marine Group's database of procedures and review processes. Thereby it was ensured that the documents in the safety management system were standardised and compliant with industry standards and international regulation and guidance. Traces of this change could be observed on NORD MAGIC in the presence of the obsolete safety management system concerning enclosed space entry, e.g. message boards used in the previous safety management system (Figure 8).

4 ICS, OCIMF and IAPH (2020): International Safety Guide for Oil Tankers and Terminals (ISGOTT 6), 6th Edition.

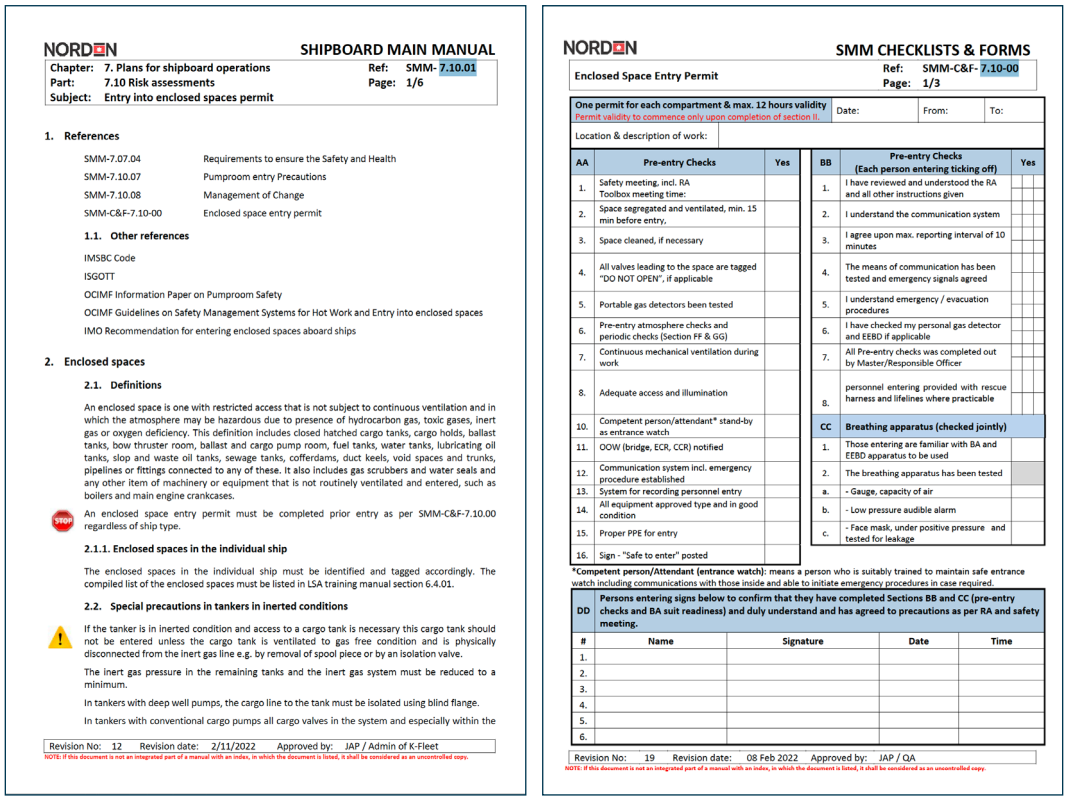
Figure 8: Obsolete message board on NORD MAGIC
Source: NORD MAGIC

The safety management review process was continuous and was coordinated by an appointed quality, health, security and environmental officer who was responsible for changing and updating the documents in the safety management system. Changes to the documents were made on the basis on the master's annual review, suggestions from crewmembers and changes suggested by Synergy Marine Group. Smaller updates were immediately implemented and larger changes were subject to an internal validation process before implementation. The validation process was followed by an instruction to the crew that the change was to be included in the following safety meeting and discussed with the crew. Typically, there were 1-2 changes made every month.

The management company's safety management system was accessible via online software on various computers on the ship. Typically, checklists, permits and other forms were printed out and filed in a binder after use. On NORD MAGIC, some officers had saved copies of the documents on the computers, so the documents could be accessed, if the ship server or the safety management software broke down.

New employees were familiarised with the software and the structure of the safety management system during a 2-3 hour online briefing before signing on the ships. If possible, the senior officers were briefed in the company's office in Kochi, India, or in the head office in Copenhagen. Before departure from Chennai, the technicians were introduced to the risk assessment system and work permits during a familiarisation process.

In the safety management system's section titled Shipboard Main Manual, chapter 7, there were two documents specifically related to entry into enclosed spaces: Entry into Enclosed Space Permit (doc. no. 7.10.01) and Enclosed Space Entry Permit (doc. no. 7.10-00) (Figure 9).



NORDEN SHIPBOARD MAIN MANUAL

Chapter: 7. Plans for shipboard operations Ref: SMM- 7.10.01
Part: 7.10 Risk assessments Page: 1/6
Subject: Entry into enclosed spaces permit

1. References

SMM-7.07.04 Requirements to ensure the Safety and Health
SMM-7.10.07 Pumproom entry Precautions
SMM-7.10.08 Management of Change
SMM-C&F-7.10-00 Enclosed space entry permit

1.1. Other references

IMSBC Code
ISGOTT
OCIMF Information Paper on Pumproom Safety
OCIMF Guidelines on Safety Management Systems for Hot Work and Entry into enclosed spaces
IMO Recommendation for entering enclosed spaces aboard ships

2. Enclosed spaces

2.1. Definitions

An enclosed space is one with restricted access that is not subject to continuous ventilation and in which the atmosphere may be hazardous due to presence of hydrocarbon gas, toxic gases, inert gas or oxygen deficiency. This definition includes closed hatched cargo tanks, cargo holds, ballast tanks, bow thruster room, ballast and cargo pump room, fuel tanks, water tanks, lubricating oil tanks, slop and waste oil tanks, sewage tanks, cofferdams, duct keels, void spaces and trunks, pipelines or fittings connected to any of these. It also includes gas scrubbers and water seals and any other item of machinery or equipment that is not routinely ventilated and entered, such as boilers and main engine crankcases.

An enclosed space entry permit must be completed prior entry as per SMM-C&F-7.10.00 regardless of ship type.

2.1.1. Enclosed spaces in the individual ship

The enclosed spaces in the individual ship must be identified and tagged accordingly. The compiled list of the enclosed spaces must be listed in LSA training manual section 6.4.01.

2.2. Special precautions in tankers in inerted conditions

If the tanker is in inerted condition and access to a cargo tank is necessary this cargo tank should not be entered unless the cargo tank is ventilated to gas free condition and is physically disconnected from the inert gas line e.g. by removal of spool piece or by an isolation valve.

The inert gas pressure in the remaining tanks and the inert gas system must be reduced to a minimum.

In tankers with deep well pumps, the cargo line to the tank must be isolated using blind flange.

In tankers with conventional cargo pumps all cargo valves in the system and especially within the

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NOTE: If this document is not an integrated part of a manual with an index, in which the document is listed, it shall be considered as an uncontrolled copy.

NORDEN SMM CHECKLISTS & FORMS

Enclosed Space Entry Permit Ref: SMM-C&F- 7.10-00
Page: 1/3

One permit for each compartment & max. 12 hours validity
Permit validity to commence only upon completion of section II. Date: From: To:

Location & description of work:

AA	Pre-entry Checks	Yes
1.	Safety meeting, incl. RA Toolbox meeting time:	
2.	Space segregated and ventilated, min. 15 min before entry,	
3.	Space cleaned, if necessary	
4.	All valves leading to the space are tagged "DO NOT OPEN", if applicable	
5.	Portable gas detectors been tested	
6.	Pre-entry atmosphere checks and periodic checks (Section FF & GG)	
7.	Continuous mechanical ventilation during work	
8.	Adequate access and illumination	
10.	Competent person/attendant* stand-by as entrance watch	
11.	OOW (bridge, ECR, CCR) notified	
12.	Communication system incl. emergency procedure established	
13.	System for recording personnel entry	
14.	All equipment approved type and in good condition	
15.	Proper PPE for entry	
16.	Sign - "Safe to enter" posted	

BB	Pre-entry Checks (Each person entering ticking off)	Yes
1.	I have reviewed and understood the RA and all other instructions given	
2.	I understand the communication system	
3.	I agree upon max. reporting interval of 10 minutes	
4.	The means of communication has been tested and emergency signals agreed	
5.	I understand emergency / evacuation procedures	
6.	I have checked my personal gas detector and EEBD if applicable	
7.	All Pre-entry checks was completed out by Master/Responsible Officer	
8.	personnel entering provided with rescue harness and lifelines where practicable	

CC	Breathing apparatus (checked jointly)	
1.	Those entering are familiar with BA and EEBD apparatus to be used	
2.	The breathing apparatus has been tested	
a.	- Gauge, capacity of air	
b.	- Low pressure audible alarm	
c.	- Face mask, under positive pressure and tested for leakage	

*Competent person/Attendant (entrance watch): means a person who is suitably trained to maintain safe entrance watch including communications with those inside and able to initiate emergency procedures in case required.

DD Persons entering signs below to confirm that they have completed Sections BB and CC (pre-entry checks and BA suit readiness) and duly understand and has agreed to precautions as per RA and safety meeting.

#	Name	Signature	Date	Time
1.				
2.				
3.				
4.				
5.				
6.				

Revision No: 19 Revision date: 08 Feb 2022 Approved by: JAP / QA

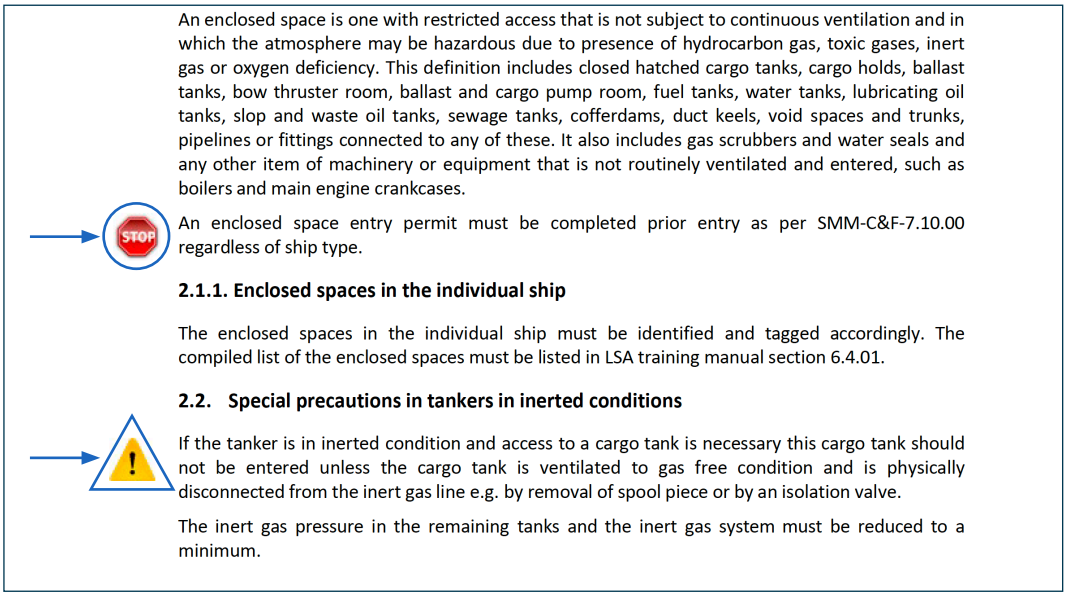
NOTE: If this document is not an integrated part of a manual with an index, in which the document is listed, it shall be considered as an uncontrolled copy.

Figure 9: Documents 7.10.01 and 7.10.00 related to entry into enclosed spaces.
Source: NORD MAGIC

The two documents had nearly similar titles but were apparently different types of documents. Document 7.10.01 (last edited 11 February 2022) was the main procedural document, and document 7.10.00 (last edited 8 February 2022) was part of a larger collection of checklists and forms. In the following analysis, document 7.10.01 is referred to as 'procedure for enclosed space entry' and document 7.10.00 is referred to as ´work permit´.

Procedure for enclosed space entry

The procedure for enclosed space entry was divided into eight sections with symbols highlighting selected paragraphs which were of particular importance (Figure 10).



An enclosed space is one with restricted access that is not subject to continuous ventilation and in which the atmosphere may be hazardous due to presence of hydrocarbon gas, toxic gases, inert gas or oxygen deficiency. This definition includes closed hatched cargo tanks, cargo holds, ballast tanks, bow thruster room, ballast and cargo pump room, fuel tanks, water tanks, lubricating oil tanks, slop and waste oil tanks, sewage tanks, cofferdams, duct keels, void spaces and trunks, pipelines or fittings connected to any of these. It also includes gas scrubbers and water seals and any other item of machinery or equipment that is not routinely ventilated and entered, such as boilers and main engine crankcases.

An enclosed space entry permit must be completed prior entry as per SMM-C&F-7.10.00 regardless of ship type.

2.1.1. Enclosed spaces in the individual ship

The enclosed spaces in the individual ship must be identified and tagged accordingly. The compiled list of the enclosed spaces must be listed in LSA training manual section 6.4.01.

2.2. Special precautions in tankers in inerted conditions

If the tanker is in inerted condition and access to a cargo tank is necessary this cargo tank should not be entered unless the cargo tank is ventilated to gas free condition and is physically disconnected from the inert gas line e.g. by removal of spool piece or by an isolation valve.

The inert gas pressure in the remaining tanks and the inert gas system must be reduced to a minimum.

Figure 10: Extract from document 7.10.01 concerning entry into enclosed spaces.
Source: NORD MAGIC

1. References

The first section of the procedure referred to other procedural documents in the Shipboard Main Manual and to authoritative publications such as OCIMF industry Guidelines, an IMO recommendation on entry into enclosed spaces[5] and the IMSBC[6].

These references were meant to inform the user about which authoritative sources the procedure was based on. Throughout the procedure, the same terminology and phrases used in the IMO recommendation were identified which indicated that these sources influenced the authors. Users of the procedure were also reminded about other applicable procedures in the safety management system which contained relevant information, e.g. high-level documents such as Management of Change and low-level documents such as the work permit.

Reference was notably made to a OCIMF information paper and a safety management procedure about pump room entry. A pump room which NORD MAGIC did not have, demonstrating that the procedure was generic and meant for fleet wide use across different ship types. Consequently, the crew was expected to adapt the procedure when using it on NORD MAGIC, and the crew had to be knowledgeable about the referenced documents to fully understand the procedure. It was not clear how these documents were accessed and who should read them. Although packed with an abundance of good information relevant to entry into enclosed spaces, the referenced documents were too extensive and non-specific for a crewmember to use in practice.

2. Enclosed spaces

Section 2 was divided into four subsections covering three overall topics: definition of an enclosed space, introduction to the work permit and a description of responsible personnel.

An enclosed space was defined as *"… one with restricted access that is not subject to continuous ventilation and in which the atmosphere may be hazardous due to presence of hydrocarbon gas, toxic gases, inert gas or oxygen deficiency*". It was further stated that it was the master's responsibility to identify which spaces were considered to be enclosed and covered by the procedure. The shipboard procedure was thus to be supplemented by a list of enclosed spaces which were not part of the shipboard main manual. No. 2 COT (S) was included in that list. The master was thus responsible for completing the procedure by making it ship specific. It was unclear whether that task was assigned to each master signing on the ship, or if it would suffice to have it made once.

The crewmembers were required to consult the responsible officer to determine if an entry was permitted. It was the duty of the master or the appointed responsible officer to check the atmosphere in the compartment, ventilate the space, ensure the appropriate procedures were followed, ensure the safety of the personnel concerned and issue an entry permit using SMM-C&F-7.10-00. Personnel entering the enclosed space as well as personnel involved with watch keeping, log keeping, recording etc. had to verify that they had full knowledge of the operation by signing the entry permit form. It was thus the duty of the master or appointed officer to ensure that the described precautions were taken before entry and to issue a work permit. The nature of that work permit was not described, so the procedure's user was required to have prior knowledge about how to use the work permit. Or the permit needed to be self-explanatory and/or include a guideline for its use.

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5 The reference to the IMO recommendation did not mention the document number. Presumably the reference was to IMO Resolution A.1050(27).

6 International Maritime Solid Bulk Cargoes (IMSBC) Code

When the personnel signed the work permit, they took responsibility for having full knowledge about the particulars of the enclosed space operation.

3. Check of atmosphere

Section 3 described how ventilation and atmosphere testing was to be performed and which precautions to take when encountering different types of gasses. Emphasis was put on continuous ventilation and the frequent testing of the atmosphere while working in enclosed spaces. The MSDS was to be consulted to determine which gasses to test for. It was highlighted that although a compartment had contained sour cargoes, which may contain hydrogen sulfide, general practice and experience indicated that if the tank was thoroughly washed, the hydrogen sulfide would be eliminated. However, even if the measurements did not indicate any toxic gasses, then the use of personal detectors capable of continuously monitoring the oxygen content of the atmosphere *"should always be considered"*. I.e., the procedure suggested that the use of personal gas detectors was discretionary.

4. Gas detection and evacuation equipment

The importance of testing the atmosphere was repeated in section 4 adding that the testing equipment had to be checked for proper functioning. It was also prescribed that a breathing apparatus had to be placed at the enclosed space entrance and an emergency escape breathing device (EEBD) should be carried into the space if the layout made it difficult to check the atmosphere.

When and where to use the EEBD was not described, which meant it was to be available at the discretion of the user. The procedure did not clearly elaborate what the purpose of the breathing apparatus was. Given that the title of the procedure was evacuation equipment, it may be presumed that it was meant for evacuating a person from the tank. Additionally, it was not described how to evacuate a person by only using a breathing apparatus and no other types of equipment, e.g. stretcher, lifting equipment, etc.

5. Entry into enclosed spaces

Section 5 was divided into five subsections describing precautions to be taken prior to entering an enclosed space: Instruction of personnel; keeping watch at the entrance; tagging entrance with signs stating whether entry was safe or unsafe; communication; and, keeping a log of entries.

Prior to entering an enclosed space, a work instruction, risk assessment and toolbox meeting had to be completed in accordance with a generic procedure about requirements to ensure safety and health (SMM 7.07.04). A competent person was to keep watch at the entrance while persons were inside, and the entrance was to be tagged with signs indicating when it was safe or unsafe to enter the space. Communication was to be established between the entrance watch, persons in the tank and the officer of the watch, and a log of the events in connection with the enclosed space entry was to be kept.

Basically, it was a workflow of which safety precautions to take, but only in part, because the other precautions such as atmosphere testing, use of breathing apparatus and EEBD were listed elsewhere in the procedure. Additionally, it was omitted who was to perform the various tasks, e.g. who filled in the log and who tagged the entrance. To understand how to meet the requirements to the risk assessment and toolbox meetings, it required reading the referenced procedure SMM 7.07.04.

6. Entry of enclosed spaces emergencies
Section 6 began with a verbatim repetition of what was stated in section 5: *"Prior to commencement of any work covered by this procedure, a risk assessment, work instruction and toolbox meeting must be completed in accordance with SMM-7.07.04 (Requirements to ensure the Safety and Health)"*.

From the wording, it is unclear if the risk assessment, work instruction and toolbox meeting was to be completed prior to entry into an enclosed space or before the emergency response to an accident in a tank. There was no mentioning of how to go about responding to the emergency, but the equipment to be used was listed: *"Rescue and resuscitation, such as breathing apparatus, lifelines, tripod, etc."*. An et cetera is added to the list of equipment, but it was unclear what that other equipment that might be. Hence, the procedure did not provide clear guidance on how to provide emergency response or what equipment to use.

7. Pumproom entry precautions
This section was not applicable for NORD MAGIC.

8. Entry of other spaces with potential unsafe atmosphere
This section was not relevant for the entry into no. 2 (COT (S).

Findings: Procedure for enclosed space entry

- The procedure did not explicitly communicate what its purpose was and who it was aimed at. From the content, it could be inferred that it served to govern safe work practices and thereby act as a safety barrier.
- The procedure's method for governing safe practices was standardisation, compliance with industry standards and regulation and assigning responsibility.
- If the crew or the technicians were to understand the content and context of the procedure, they were required to read all of the referenced documents.
- The procedure was incomplete concerning assigning critical tasks to persons, providing guidelines about safety critical work processes related to emergency reponses and what equipment to use.
- The procedure did not make reference to dedicated training or offer advice related to using the work permit.
- Remains of an obsolete safety managements system were found on the bulkhead outside the cargo control room.

Work permit

The work permit was a checklist comprising 11 tables that split the enclosed space entry procedure into groups of tasks and subtasks to help ensure that the tasks were carried out.

1. Pre-entry checks

The pre-entry checklist (Figure xx) comprised three tables: actions to be taken (AA); confirmations that the actions listed had been taken (BB); and, the testing the breathing apparatus (CC) (Figure 11).

NORDEN **SMM CHECKLISTS & FORMS**

Enclosed Space Entry Permit — **Ref:** SMM-C&F-7.10-00 **Page:** 1/3

One permit for each compartment & max. 12 hours validity Permit validity to commence only upon completion of section II.	Date:	From:	To:
Location & description of work:			

AA	Pre-entry Checks	Yes
1.	Safety meeting, incl. RA Toolbox meeting time:	
2.	Space segregated and ventilated, min. 15 min before entry,	
3.	Space cleaned, if necessary	
4.	All valves leading to the space are tagged "DO NOT OPEN", if applicable	
5.	Portable gas detectors been tested	
6.	Pre-entry atmosphere checks and periodic checks (Section FF & GG)	
7.	Continuous mechanical ventilation during work	
8.	Adequate access and illumination	
10.	Competent person/attendant* stand-by as entrance watch	
11.	OOW (bridge, ECR, CCR) notified	
12.	Communication system incl. emergency procedure established	
13.	System for recording personnel entry	
14.	All equipment approved type and in good condition	
15.	Proper PPE for entry	
16.	Sign - "Safe to enter" posted	

BB	Pre-entry Checks (Each person entering ticking off)	Yes
1.	I have reviewed and understood the RA and all other instructions given	
2.	I understand the communication system	
3.	I agree upon max. reporting interval of 10 minutes	
4.	The means of communication has been tested and emergency signals agreed	
5.	I understand emergency / evacuation procedures	
6.	I have checked my personal gas detector and EEBD if applicable	
7.	All Pre-entry checks was completed out by Master/Responsible Officer	
8.	personnel entering provided with rescue harness and lifelines where practicable	
CC	**Breathing apparatus (checked jointly)**	
1.	Those entering are familiar with BA and EEBD apparatus to be used	
2.	The breathing apparatus has been tested	
a.	- Gauge, capacity of air	
b.	- Low pressure audible alarm	
c.	- Face mask, under positive pressure and tested for leakage	

Figure 11: Pre-entry checklist and checklist for breathing apparatus.
Source: NORD MAGIC

Table AA listed 16 actions to be taken, some of which were included in the procedure whereas others were not. From the phrasings, it could be inferred most actions were discretionary (e.g., *"adequate"*, *"if applicable"*, *"if necessary"*, *"proper"*). In addition, it was seemingly mandatory to post the sign 'safe to enter' (AA no. 16) but the posting of the sign 'unsafe to enter', briefly mentioned in the procedure, was not included among the actions. The schema did not describe a sequential workflow as the actions were not listed in the order the user would take action.

E.g. it would not be expedient to ventilate a cargo tank before cleaning it with the butterworth system. It was likely that the checklist was intended to remind the responsible officer and master issuing the permit which actions to take prior to entry into an enclosed space. On NORD MAGIC it was the senior officers who were responsible for signing off that the actions had been taken.

In table BB, each person entering the enclosed space ticked off that the listed actions had been completed. There were six boxes available for six persons to tick off. During the investigation of the work permits issued in the period 12-17 June, it was found that between five and six of the boxes had been ticked off on most of the permits, even though fewer persons been in the enclosed spaces. This indicated that it was not always the individual person entering the enclosed space who ticked the boxes. It was unclear who actually ticked off the boxes.

It was noticeable that a person entering an enclosed space was required to tick the completion of the master/responsible officer pre-entry checks (BB no. 7). How that could be materially verified was not described which was problematic considering that the crewmembers, according to the procedure, were required to have full knowledge of the operation.

In action BB no. 8 it was stated that personnel entering the space were provided with a rescue harness and lifeline, where practicable. This equipment was not mentioned in the procedure or elsewhere in the work permit. It can thereby be inferred that some of the safety equipment was not mandatory but subject to practical considerations.

In table DD (Figure 12), the person entering the enclosed space signed and thereby confirmed that the previous sections (BB and CC) were completed.

DD	Persons entering signs below to confirm that they have completed Sections BB and CC (pre-entry checks and BA suit readiness) and duly understand and has agreed to precautions as per RA and safety meeting.			
#	Name	Signature	Date	Time
1.				
2.				
3.				
4.				
5.				
6.				

Figure 12: Work permit table DD
Source: NORD MAGIC

It was thereby apparent that the work permit did not only serve to remind the involved persons about essential actions, but was also meant to make the persons accountable for having taken the required actions. There was a similar table (II) for the master, responsible person, officer of the watch and team leader signing that the required actions had been taken (Figure 13).

II	Permit validity section (to be completed upon completing up to and including section FF)			
Function	**Rank/Name**	**Signature**	**Date**	**Time**
Responsible officer (or Master) Authorising /validating the entry permit				
Master (For being aware of planned entry)				
Enclosed space entering team leader				
OOW (Bridge/ CCR / Engine room)				

Figure 13: Work permit table II
Source: NORD MAGIC

Once the work had been completed, the responsible officer, team leader and officer of the watch signed table LL (Figure 14) indicating that the 'safe to enter' sign had been removed.

LL	Completion of Job - Space secured against entry and the sign "Safe to enter" is removed - OOW notified			
Function	**Rank/Name**	**Signature**	**Date**	**Time**
Enclosed space entering team leader				
Responsible officer				
OOW				

Figure 14: Work permit table LL
Source: NORD MAGIC

Other tables within the permit contained logs for recording times for keeping watch at the entrance, pre-entry gas check, periodic gas check, periods of ventilation and a record of entry. It was not stated in the checklist who was to fill in the logs. The company was of the opinion that the work permit was meant to be on-site with the responsible person in charge, i.e. the responsible person had to stay in touch with the entrance watch and continuously fill in the logs. In practice, the workflow among the deck crew was different (see chapter: The Enclosed Space Entries).

The last table presented a summary of the process of issuing the work permit (Figure 15) which was meant to be used as an aide-memoire for the responsible officer issuing the work permit rather than as a workflow description.

	Permit entry issuance process – Summary
1.	Morning/daily work plan schedule to include the work related to enclosed space entry.
2	Assigned work force to be guided to prepare the enclosed space for entry (ventilation, emergency equipment, tools and guarding of openings)
3.	Toolbox meeting with persons involved in the job where discussion of - RA, safety, section AA, BB, CC and DD completion.
4.	Pre-entry gas checks to be performed by the competent person.
5.	Permit validated by responsible or master
6.	Periodic gas checks and maintaining log of personnel's entering the space.
7.	Job completion

Figure 15: Work permit table LL
Source: NORD MAGIC

Findings: Work permit

- The work permit was not only meant for securing a standardised work flow or specific guidance. It was also an authorisation to carry out an enclosed space entry and assigned responsibility.
- Inconsistencies were found between the work permit and the procedure related to safety equipment and workflow.
- Some checks were prescriptive and others were discretionary which necessitated some adaptation of the checklist.
- The work permit did not describe how it was to be used practically in terms of where it was to be located, in which sequence the tasks were to be carried out, and who was to fill in the tables.

The enclosed space entries

The technicians' inspections were contingent on coordination between the technicians, master, deck officers and deck ratings. That coordination could be influenced by other work activities on deck, and the work permit's workflow. The following contextualises the enclosed spaces entries made by the technicians with other work tasks performed on deck and the work permits' approval process.

Work activities on deck

During the three-day sea voyage (12-14 June) from Chennai to the outer anchorage off Chittagong, Bangladesh, the deck officers kept the bridge watch, and the ratings were doing regular maintenance work on deck. Meanwhile, the technicians inspected 12 ballast tanks, four each day.

On 15 June, NORD MAGIC shifted from the outer to the inner anchorage off Chittagong. During that morning, the crew was busy with navigation, anchor operations and preparing for the following day's cargo operation. They were thus not able to assist the technicians with preparing the tanks and keeping watch by the entrance. Consequently, the technicians only made one tank inspection on that day. While at anchor, the junior deck officers kept the watch on the bridge. The chief officer was thus the only officer on deck to assist the technicians while planning and performing the cargo operations.
In the morning on 16 June, the meetings were held with the cargo surveyors and the cargo discharge was planned. In the early afternoon, the technicians inspected starboard cargo slop tank. No other tank was inspected on that day. Discharge operations commenced later in the afternoon and continued until the barge was cast off at 2112.

On 17 June, the cargo barge was made fast alongside in the early morning at 0354. Discharge operations began about an hour later. Throughout the morning until midday, the crew was busy discharging soybean oil from various tanks.

Between 0700-0930, all six deck ratings were involved in entering no. 6 COT (P&S) for squeezing. The atmosphere in the tanks was tested and found to be safe to enter without prolonged ventilation.

While some of the ratings were busy with squeezing the cargo tanks, the chief officer held the morning meeting with the technicians about entering the forepeak tank for inspection. But the tank inspection had to be delayed, because it started to rain heavily. By noon time, the discharge operation was concluded, and the chief officer went to his cabin to rest until later in the afternoon when the next barge was expected to arrive. After lunch, there were no other work activities on deck, and the weather conditions had improved, so the technicians and one AB began the inspection of the forepeak tank.

When the technicians had completed the inspection of the forepeak tank, they went directly to the empty and already partially open no. 2 COT (S). The tank was not marked with an “Unsafe to enter“ sign. It is unknown, whether the forepeak tank had been marked with a “Safe to enter” sign.

At the same time, the cargo barge arrived, and the ratings on deck were instructed by the watchkeeping officer on bridge to make it fast. At this time, all the deck crewmembers were unavailable to supervise or assist the technicians in the tank: the chief officer was resting, the junior officer was keeping watch on the bridge, and the ratings were making the cargo barge fast.

Work permit approval process

DMAIB’s investigation on the ship found that work permits had been issued for all 15 tank inspections the technicians made in the period from 12-17 June, except for the entry into no. 2 COT (S). Permits had also been issued for the ratings’ entries into the cargo tanks in the morning on the day of the accident. All the work permits had been filled out and signed.

During interviews with the involved crewmembers, DMAIB focused on the use of the entry into enclosed space procedure and the work permit’s workflow in the period 12-17 June 2022. All the interviewed ratings and officers were aware that there was a procedure for entry into enclosed spaces and made reference to the need for checking the atmosphere and having equipment at the entrance. None of the crewmembers had read the procedure recently and could thus not recall how it was structured or how an enclosed space was defined, resulting in diverging opinions on what an enclosed space was. But there was no doubt among the crewmembers that ballast tanks and cargo tanks were considered enclosed spaces. All the interviewed crewmembers were cognisant of the requirement of having a work permit issued prior to commencing work in an enclosed space.

The work permit workflow was governed by the chief officer, because he was responsible for planning and supervising work on deck, including entries into enclosed spaces. Normally, the chief officer printed the work permit from the computer in the cargo control room. He filled in the relevant sections and presented it to the nominated crewmembers and technicians at a toolbox meeting in the ship’s cargo control room. The procedure for enclosed space entry was usually not printed and discussed, because the crew did not have an understanding of the meaning of the document in relation to their specific work task.

At the meeting, the various tasks were assigned to the crewmembers, and they had a brief talk about which hazards to pay attention to. These meetings were held frequently, and new hazards were rarely identified, so the meetings were concluded in about 10 minutes. The ratings and junior officers on watch did not know the content of the work permit in detail but knew that signing the applicable boxes was required once the assigned tasks had been completed, thereby making the crew accountable for the tasks being completed. On the day of the accident, the ratings and technicians did not actively participate in filling out the work permits but merely signed them during the morning as the work progressed, or later in the day after the chief officer had filled in the relevant values and times. It was thus possible that the crewmembers did not have an overview of which work permits had been issued.

The work permit issued for the technicians' entry into the forepeak tank on 17 June was signed by the dayman, but it was the AB on duty after noontime who actually kept the watch. The same AB had signed the work permits for the tank entries made during the morning by the other ratings, even though he was not on duty. Arguably, he had signed the work permits later on the same day, and his name was noted in the work permits by mistake. It is thus possible that the involved persons did not have an overview of which permits were in the process of being filled out.

The master's involvement was limited to signing the permit. He did not have any knowledge about the details of the work but relied on the document having been filled in correctly, and the appropriate measures having been taken.

The chief officer showed the crew and technicians where to sign, and he kept the work permit in the cargo control room, until the job was done. He was of the opinion that the technicians dutifully took interest in the work permits.

It was found inexpedient to bring the printout on deck for recording times and values in the entry and atmosphere log, because rain and dirt made it difficult to keep it readable. The practise was to call the watchkeeping officer on the bridge and notify them when persons entered or exited the tank.

On the bridge, the officer wrote all times down on a piece of paper which was later handed over to the chief officer. He then filled in the work permit before filing it. It was thus only the chief officer who had handled the printout of the work permit. Overall, the deck officers and ratings viewed the work permit as an authorisation from the senior officers to enter a specified tank and as a formal record of tasks performed.

Findings: The enclosed space entries

- The frequent entry into cargo tanks which had contained soybean oil, resulted in the general notion that cargo tanks with soybean oil did not develop a hazardous atmosphere.
- The deck ratings and officer on the bridge were preoccupied with other work than keeping track of the technicians' work.
- The chief officer's work schedule made it necessary for him to rest during the afternoon. He was thus not able to monitor the technicians' work and the fulfilment of the enclosed space procedure and work permit.

- The technicians normally took an interest in having work permits issued.
- The work permits were not filled out and signed continuously as the entry into enclosed spaces were made, but were normally filled in later during the day. It is thereby possible that the involved persons did not have an overview of which permits were in the process of being filled out.
- The deck officers and ratings viewed the work permit as an authorisation from the senior officers to enter a specified tank and as a formal record of tasks performed. It was not viewed as a prescribed way of preparing and entering enclosed spaces.

Analysis

Conditions for the accident

The course of events showed that the technicians succumbed after exposure to a hazardous concentration of hydrogen sulfide after entering no. 2 COT (S). They did not regain consciousness and could thus not provide information about the events which unfolded prior to and during the accident. Consequently, the technicians' understanding of the situation is unknown.

The investigation therefore focused on the crewmembers' and technicians' work practices related to enclosed space entry. The aim was to shed light on the circumstances in which the technicians entered the COT, and why the ship's crew did not intervene.

The tank inspection

The technicians were motivated to enter the no. 2 COT (S), because it was necessary for completing their inspections, and they evidently believed it to be safe to do so. After completing the inspection of the forepeak tank, only two cargo tank inspections remained, which left ample time to complete the work en route, before the ship arrived in Haldia several days later. Consequently, nothing indicates that time pressure affected their usual work practice. However, other coinciding factors emerged during the investigation that might have influenced the technicians to consider no. 2 COT (S) safe to enter, even though no "Safe to enter" sign was posted by the entrance:

- During the morning meeting in the cargo control room on 17 June, when the technicians' inspection of the forepeak tank was considered, the intention of inspecting no. 2 COT (S) was mentioned. Although the details of that conversation are not known, that no. 2 COT (S) was mentioned indicated that it might be next to be inspected.

- On the same morning, four ratings entered two cargo tanks, and the work permits were in the cargo control room ready to be completed. The ratings and technicians did not actively participate in filling out the work permits. Instead, they signed them as necessary throughout the morning as the work progressed, or later in the day after the chief officer had filled in the relevant values and times. It is thus likely that the involved persons did not have an overview of which permits were in process of being filled out, except the chief officer who was responsible for keeping the document and filling in the relevant information. The absence of a work permit for no. 2 COT (S) thus went unnoticed by the crewmembers, except the chief officer.

- While the technicians inspected the forepeak tank, no equipment was ready by the tank's entrance. It is unknown, whether a sign was posted indicating that the tank was safe to enter. After the completion of the inspection of the forepeak tank, the absence of a breathing apparatus, EEBD or other types of equipment outside no. 2 COT (S) would not have alerted the technicians to an abnormal situation. On the contrary, no. 2 COT (S) hatch was partially open, and the tank would have seemed to be empty when looking into it. It can therefore be inferred that the absence of equipment outside the tank had by this time been normalised.

- The AB, who kept watch at the tank's entrance, was on duty from noon and did not participate in the morning meeting where the tank entries were planned. He thus had no reason to think that the technicians were not meant to enter no. 2 COT (S). On the bridge, the watch had also changed at noon, and the relieving officer was not made aware which tanks were to be inspected. The bridge officer's task was only to record the times of entry on a piece of paper, not to verify the existence of valid work permits. On deck, the chief officer managed the work permits, and when his work schedule made it necessary for him to rest during the afternoon, he was not able to monitor the technicians' work. The involved crewmembers thus had no reason to intervene, when the technicians entered the tank.

When the technicians climbed into no. 2 COT (S), the concentration of hydrogen sulfide had a paralysing effect on their sense of smell. They thus had no cause to suspect that the atmosphere contained a lethal concentration of hydrogen sulfide. Additionally, hydrogen sulfide is heavier than air and would not escape the tank, if the hatch was only partly open. This could be the reason why the smell was not detected by the technicians when by the hatch before entering and by other crewmembers on deck. The smell detected by the crew during the evacuation could be caused by the crew starting to ventilate the tank.

When mapping the circumstances in which the technicians entered the tank, it could be determined that several interwoven factors influenced the technicians to believe that the tank was safe to enter and why neither the AB, the officer of the watch nor the chief officer intervened.

Generally, a procedure and work permit aim to create safety by identification of hazards, standardisation of work processes and assigning responsibilities. But on NORD MAGIC they did not serve their intended purpose. The investigation thus aimed to find why the procedure and work permit failed to be effective.

Proceduralisation of the entry into enclosed spaces

The procedure

Different types of procedure can have different purposes or even several purposes at the same time. It is crucial to be aware of these differences when using procedures as a tool for managing safety. From the content in NORD MAGIC's procedure for entry into an enclosed space, it could be inferred that it served to govern safe work practices by standardisation, compliance with industry standards and regulation and assigning responsibility.

On NORD MAGIC, the crewmembers and technicians were found to be familiar with the existence of the procedure for entry into enclosed spaces, but they did not demonstrate detailed knowledge about its structure and content. In fact, DMAIB's analysis of the procedure found several issues which made the procedure difficult to understand and apply in practice: For the crewmembers to understand and correctly apply the procedure, they had to be knowledgeable about why the procedure was designed the way it was. On NORD MAGIC, the crew did not receive dedicated training in the enclosed space permit to work system and were not expected to read all the referenced documents in the procedure to fully appreciate the procedure's content. The crew thus had to rely on their experience from other ships to fill in the gap of information between the procedure and the work situation they were in. The technicians' knowledge about the procedure was based on an introduction from the onboard familiarisation. Thus, they did not have the prerequisite knowledge to fully understand the company's procedure and work permit.

The procedure did not communicate who it was aimed at, what its purpose was and was inconsistent with the content in the work permit. Further, it did not offer structured guidelines on critical work processes and emergency responses and what equipment to be utilised. It was thus not to be viewed as a series of prescribed actions conducted in a certain order or manner, but instead was a combination of different types of information, some of which was irrelevant and inconsistent. The content of the procedure was inconsistent with the work permit in terms of the description of the workflow and which equipment to prepare. That inconsistency was amplified by other prescriptive information provided by the ship's safety posters from industry organisations and safety boards from an obsolete safety management system. An individual interpretation of what a safe working practice was would thus be necessary for work to be done.

These issues resulted in the procedure not being viewed as an authoritative document when preparing entry into enclosed spaces. It was thus not customary to print the entire procedure and review it when preparing for entry into enclosed spaces and was consequently not read on a regular basis. On the contrary, it was considered cumbersome and time-consuming to go through the procedure several times each day when frequently and routinely preparing for entry into enclosed spaces.

The work permit

The investigation of the work permits from 12-17 June showed that work permits had been issued for all the tank entries apart from no. 2 COT (S). Interviews indicated that the crew was knowledgeable about the permit's structure and content, and the technicians were mindful about having work permits issued.

The DMAIB analysis of the work permit showed that it was not entirely prescriptive but also used discretionary phrases as 'where practicable' or 'if necessary'. The purpose of these phrases was to give the crewmembers a discretionary space where they were expected to apply their own judgement. Thereby, the phrases directed the crewmembers to analyse a given work situation and to act accordingly. Whether or not the crewmembers' analysis of the situation was adequate would likely be judged on the basis of the outcome. That the work permit was not viewed as a prescriptive document to govern the entry into enclosed spaces was compounded by its inconsistency with the procedure.

When mapping the work permit's workflow, it became evident that there was no mechanism in the work permit to ensure a handover between different ratings and officers. It was the chief officer who was solely responsible for managing it and making sure that all the tables had been filled in. It was not a document which was to be actively used by other crewmembers guiding them in their work.

The crewmembers consequently viewed the work permit as an authorisation to enter an enclosed space, and the crewmembers' effort to get the authorisation superceded its use as a prescribed way of work. The focus on getting the right signatures in the right tables indicates that the responsibility aspect of the work permit dominated its use.

The chief officer managed the authorisation process by collecting the right signatures and filling in the right tables with signatures, times and atmosphere test values. That process took considerable coordination, because as many as 5-10 persons in different places on the ship could be involved, some were actively participating in the work and others were only briefed about the work activity. The crewmembers thereby came to understand the work permit as a bureaucratic ritual that the chief officer managed, because he was responsible for work activities on deck. That a work permit was not issued for the technicians' entry into no. 2 COT (S) was thus not noted by the crewmembers because the chief officer was absent.

Conclusion

Instrumental factors of the accident

The course of events showed that the technicians succumbed after exposure to a hazardous concentration of hydrogen sulfide after entering no. 2 COT (S). The crew managed to evacuate the unconscious technicians, but they were pronounced dead after arriving at the hospital.

They entered the tank, even though the tank had not been ventilated, the atmosphere had not been tested, and no work permit had been issued. The AB and officer of the watch were aware of the technicians' intentions to enter the tank, but did not intervene. DMAIB's investigation aimed to explain why the technicians entered no. 2 COT (S) which had not been prepared for entry, and why the crewmembers did not intervene.

There were several interwoven factors that led the technicians to believe that the tank was safe to enter, e.g. the hatch was partially open, the tank was empty, the tank entry was previously discussed, and the ratings had squeezed other cargo tanks earlier in the morning without experiencing problems with the atmosphere. In addition, there was nothing that alerted them about the hazard. They had just completed inspection of the forepeak tank where no safety equipment was available by the entrance, because it was normal to make discretionary judgements about what equipment to make ready. The technicians were thus not alerted by the absence of equipment by no 2 COT (S) entrance.

It was not expected that no. 2 COT (S) contained hydrogen sulfide, because the MSDS did not mention a risk of toxic gas being produced by the product, and the crew had not detected hydrogen sulfide when entering the other tanks with soybean oil. It was not considered that residues of soybean oil mixed with seawater, which had been in the tank for 19 days, could develop hydrogen sulfide. The characteristic odour from the gas was not noticed by the AB keeping watch because the gas is heavier than air and was thus trapped in the tank. Once in the tank, the technicians did not smell the gas because the high concentration of hydrogen sulfide paralysed their sense of smell.

The crew, who was made aware of their intention to enter no. 2 COT (S), had not participated in the morning meeting about the tank entries and were thus not aware which tanks the technicians had planned to enter. The change of watch handover on the bridge did not include the ongoing work on deck, because they were only responsible for recording time and atmosphere values which were later filled into the work permit. The only person who had an overview of which tanks were prepared was the chief officer who was resting after a long day's work.

It remained to be explained why the work permit system was not adhered to. DMAIB thus investigated the design and functioning of the procedure and work permit.

The procedure was inconsistent with the work permit and did not offer structured guidelines on critical work processes, emergency responses and what equipment to utilise. The procedure was thus not to be viewed as a series of prescribed actions conducted in a certain order or manner, but was a combination of various types of information, some of which were irrelevant and inconsistent.

These shortcomings resulted in the procedure not being viewed as an authoritative guiding document when preparing entry into enclosed spaces. It was thus not customary to print the entire procedure and review it when preparing for entry into enclosed spaces and was consequently not read on a regular basis. It was considered cumbersome and time-consuming to go through the procedure several times each day when frequently and routinely preparing for entry into enclosed spaces.

The investigation of the work permit showed that it was not entirely prescriptive but also used discretionary phrases. These phrases encouraged the crewmembers to analyse a given work situation and to make discretionary judgements about, e.g. which equipment to prepare.

The work permit was thus not meant for prescribing a standardised work process or specific guidance but was an authorisation to carry out an enclosed space entry and to assign responsibility. The work permit's ability to manage the hazards associated with enclosed space entry was diminished, because it was managed by one person and focused on assigning responsibility rather than governing how work was carried out, and the workflow of the work permit made it possible for misunderstandings to arise about whether a permit had been issued or not.

Overall, it can be concluded that on NORD MAGIC enclosed space entries were frequent, necessary and did not supersede other work activities on board, e.g. cargo surveyor meetings, discharging cargo, making barges fast, squeezing cargo tanks, keeping anchor watch, etc. The chief officer was pivotal in managing competing demands when several tasks were to be performed simultaneously. In addition, he was the person responsible for managing the work permits authorising enclosed space entries. When he, as the responsible officer, was absent, the functioning of the work permit system failed to meet its intended purpose. The disadvantages of a hierarchy, where only one officer is responsible, were thus manifested. These disadvantages were compounded by a work permit system which was not effective in governing the crewmembers' and technicians' work practises related to entry into enclosed spaces.

DMAIB has in recent years investigated safety management systems from different ship management companies. Many of the same issues with structure, inconsistencies and focus on compliance and responsibility were found which made it difficult to put the procedural documents into practical use. This investigation's findings regarding the procedures on NORD MAGIC were thus not unique.

Safety learning

"The accident happened because procedure was not followed." DMAIB has frequently observed this reasoning in ship management reports in the aftermath of an accident. Furthermore, DMAIB has observed that, in the wake of an accident, the initiative taken to counter future accidents often involves adding procedures to an already large safety management system[7].

When deviation from procedure is stated as the cause of an accident, and future accidents are countered by new or more procedures, it pertains to the idea of procedures functioning as barriers between accident and normal operation. Thinking of a procedure as a safety barrier is based on a belief that safety is imbedded in the procedures and formalisation of the operations on board ships. It is rarely questioned why crewmembers deviate from procedures.

Procedures often include several purposes simultaneously, and in these cases it tends to be unclear to the user what these purposes are and to whom they are directed. When the procedures encompass multiple purposes that are not compatible, the procedure tends to become opaque, either over or underspecified and unclear in communicating their purpose. Procedures thereby become difficult to put into practical use.

It is habitual that procedures are implemented as barriers to solve a specific safety problem. For safety procedures to be effective, it is necessary to take a new and critical look at how they are created and for what purpose and to be aware of the functional limits of procedures.

Procedures and work permits at times fail to consider that entry into an enclosed space is not a linear sequential work process, something that is indicated by the procedure's and work permit's inability to define a consistent sequential work description. In changing circumstances, it becomes necessary for the crewmembers to negotiate the content of the procedure with the situational context, which brings crewmembers to be non-compliant with the procedure. Whether or not non-compliance is an acceptable part of the everyday work depends on the outcome of the work.

Rather than pointing to the crewmembers' abilities and will to follow procedures, the DMAIB suggests taking a critical look at the performance of the procedures as a tool for supporting work in a dynamic environment. I.e. having more attention on the quality of the procedures' ability to bridge the gap between how work is prescribed and how work can be done in a dynamic work environment.

7 Proceduralizing Marine Safety (DMAIB, 2016): https://dmaib.com/reports/2015/proceduralizing-marine-safety/

Preventive measures

Actions taken by Norden Synergy Ship Management A/S

Following the conclusion of the investigation, DMAIB has received the following information regarding actions from Norden Synergy Ship Management A/S:

"Norden Synergy, the managers of Nord Magic have carried out a thorough investigation of this incident. We recognize the gaps which led to the Incident and have taken measures to ensure a similar incident does not reoccur. The investigation has given us insights on the practical use and conduct of the safety management system onboard.

The learnings from this unfortunate incident have been analysed at all levels within our organisation. The senior management has taken a proactive role to look deeper into the safety philosophy of the company in order to address the main concerns, as to why procedures were not followed and how to improve compliance with enclosed space entry procedures.

A fleet and group wide sharing of the incidents, along with the learnings have been completed and discussed during the officers' seminar and the pre-joining briefing of personnel.

We have taken the following actions and preventive measures to help close out the investigation,

Immediate actions

- *A safety flash was sent to all vessels soon after, to keep them informed of the incident. An update to the safety flash was sent suspending enclosed space entry in all vessels, in the fleet. A follow-up to the update was later sent, which allowed entry only with office approval. The approval procedure is still in practice and will continue for twelve months from the day of the incident when it will be reviewed for subsequent action.*
- *The QHSE superintendent sailed with the vessel on the next voyage to carry out an internal audit and training. The understanding and the use of the permit-to- work (PTW) system were focused upon.*
- *A safety stand down was conducted on fleet vessels and offices. The incident was discussed with all office staff on the importance of having a safety philosophy in the organization. On board the vessel, an extraordinary safety meeting was conducted to discuss the incident. Further, all the vessels were individually called by office superintendents to re-emphasize on the importance of following safe work practices on board.*
- *Psychological support onboard with our in-house counselor was arranged to help the crew onboard deal with this incident. The seafarer well-being call center is in place for further support as required.*

Preventive measures

Prior to an enclosed space entry, all vessels have to carry out an extraordinary safety meeting where the enclosed space entry plan and risk assessment are discussed. This will then be sent to the office for approval. On completion of the job, close-out information is sent to the office.

- Learnings from incident will be shared with all vessels, group offices and presented at seminars.
- Safety campaigns on enclosed space entry and stop work authority was introduced in the monthly safety newsletter to build awareness and understanding of the procedures and risks involved. Addressing risk normalization was one of the primary objectives of these campaigns.
- Various procedures on enclosed space entry, third-party contractor management, simultaneous operations, toolbox meeting and training forms were thoroughly reviewed. The procedures were amended to bridge the gap between requirements and compliance, so as to ensure safe enclosed entries.
- During the pre-Joining familiarization/briefing of officers and crew, the incident is described and the seriousness of the lapses that led to the incident is discussed.
- New training modules were introduced and matrix was updated with a reduction in training interval for relevant modules. In-house training center has included incident learnings and the hazard of putrefaction in chemical tanker courses and various training modules.
- All vessels in the fleet have been attended by a superintendent/ port captain to carry out training and drills onboard. The vessel permit-to-work systems, updated procedures, leadership, emergency communication, stop-work authority and shell partners in safety were among the sections covered.
- A Safety Recognition Program to increase awareness and encourage the effective use of the stop-work authority was introduced. Recognition is given where the stop work authority has been used effectively and discussed in the safety committee meeting.
- Feedback on Chittagong port for not having adequate evacuation facilities has been taken up with the authorities through the local agent and information updated in the company port repository.
- The just culture approach was effectively utilized when carrying out the investigation of the personnel involved. This method places responsibility on the management to provide support, training and resources required to undertake a task.

To Norden Synergy safety is of paramount importance and endeavours to achieve the same by focusing on high safety awareness onboard.

Every employee, vendor or contracted worker at Norden Synergy has a right to work in an environment that is safe and free of hazards. We believe that every job can be done safely without injuries or damages.

We understand that safety performance excels when policies, procedures & practices, equipment & technology, Human behaviours, cognition & beliefs, the external physical environment, and their interactions synchronize harmoniously. Our policies, procedures and practices consider the performance variabilities of people performing the task.

Workplaces onboard should never be considered as inherently safe, however, it is our duty to create a safe workplace."

Norden Synergy Ship Management A/S

Appendix

SHIP'S DATA

Name:	NORD MAGIC
Ship type:	Chemical/Products Tanker
Nationality:	Denmark
Port of registry:	Hellerup
Call sign:	OYFP2
IMO number:	9392793
Year built:	2009
Shipyard/shipyard number:	Hyundai Mipo Dockyard Co Ltd/KRS086
Classification Society:	Lloyd's Register
Length overall:	183.21 m
Breadth overall:	32.2 m
Maximum draught:	12.768 m
Gross tonnage:	29,266
Deadweight:	49,999 t
Propulsion power:	9,480 kW
Hull material:	Steel

VOYAGE DATA

Port of departure:	Chennai, India
Port of arrival:	Chattogram Anchorage, Bangladesh
Voyage type:	International
Information about the cargo:	Degummed soybean oil
Manning:	23
Number of passengers:	None

WEATHER

Wind:	Unknown
Current:	3 knots - 355°
Wave height:	0.5 m
Visibility:	Good
Weather conditions:	Overcast
Light/dark:	Light

INFORMATION ABOUT THE ACCIDENT

Type of marine casualty:	Occupational accident
IMO Classification:	Very serious
Location:	Chattogram Anchorage
Position:	22°10.2093 N-91° 47.5787 E
Ship operation:	At anchor
Place on board:	Starboard cargo tank no. 2
Human factors:	Yes
Consequences:	Two technicians perished.

ASSISTANCE FROM AUTHORITIES ON LAND AND EMERGENCY SERVICES

Parties involved:	Bangladesh Coastguard
Resources Used:	Patrol boat
Speed of response:	70 minutes
Actions taken:	Two technicians brought ashore and to the hospital.

RELEVANT CREW MEMBERS

Master:	43 years old Indian national. Had been employed by the company for 12 years and served 1 month on NORD MAGIC.
Chief officer:	51 years old Lithuanian national. Had been employed by the company for 8 months and served 8 months on NORD MAGIC.
Able seaman by entrance:	27 years old Indian national. Had been employed by the company for 1.5 years and served 5 months on NORD MAGIC.
Technician 1:	23 years old Indian national. Had been an inspector for the company for 4.5 years.
Technician 2:	26 years old Indian national. Had been an inspector for the company for 6 years.