Bundesstelle für Seeunfalluntersuchung
Federal Bureau of Maritime Casualty Investigation

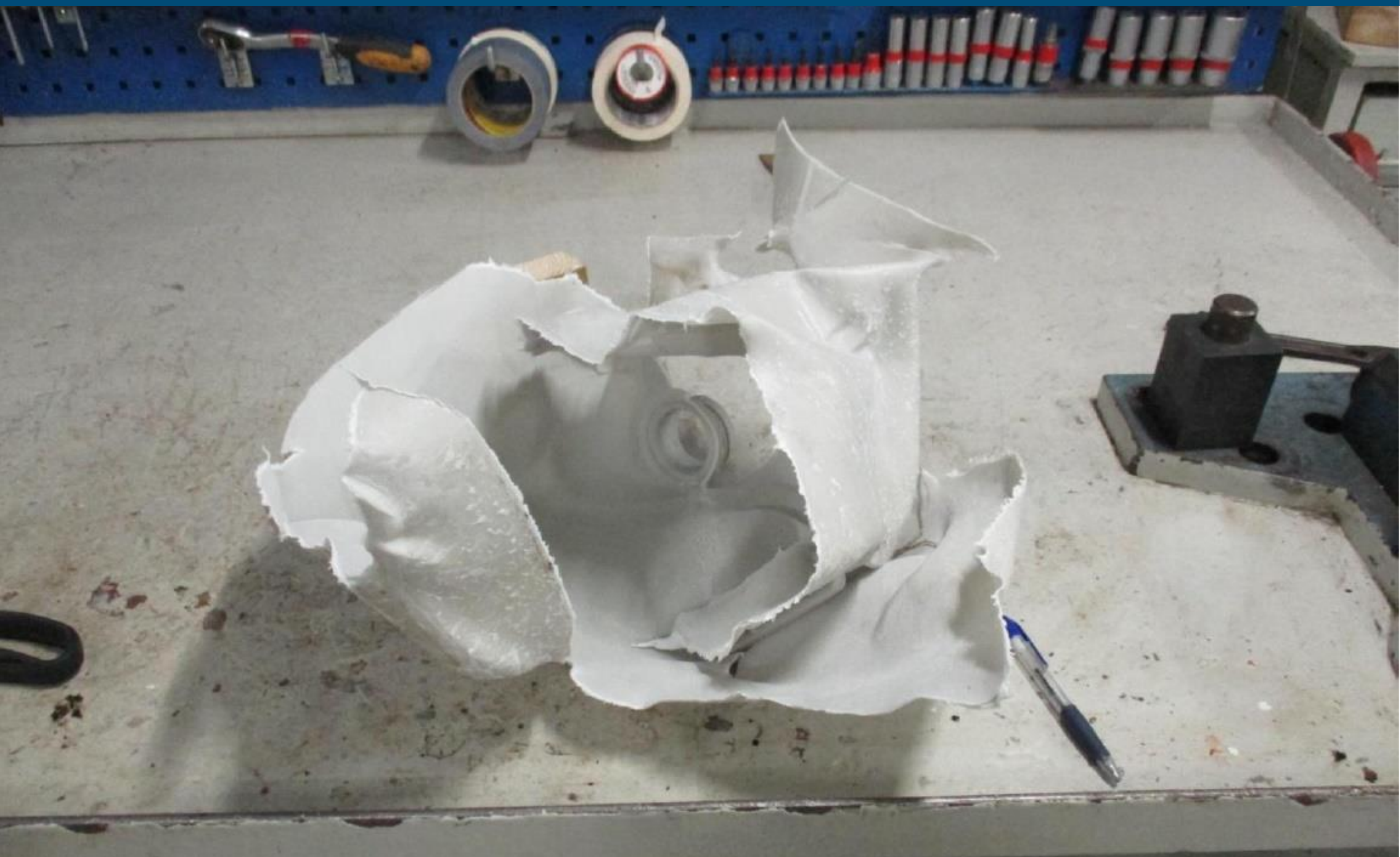
BSU

Less Serious Marine Casualty

Occupational Accident Involving Chemicals on Board the LNG Tanker CORALIUS in the Port of Travemünde on 5 August 2024

Investigation Report 385/24

13/08/2026



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Cover picture: Maritime Police S-H

Amendments

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Abbreviations

1/E	First Engineer
2/O	Second Officer
3/E	Third Engineer
3/O	Third Officer
AB	Able seafarer
BG Verkehr	German Social Accident Insurance Institution for Commercial Transport, Postal Logistics and Telecommunication
BSH	Federal Maritime and Hydrographic Agency, Bundesamt für Seeschifffahrt und Hydrographie
BSU	Federal Bureau of Maritime Casualty Investigation, Bundesstelle für Seeunfalluntersuchung
C/E	Chief Engineer
CEST	Central European Summer Time (UTC + 2 h)
CLP	Classification, Labelling and Packaging Regulation; Regulation (EC) No 1272/2008 in conjunction with Commission Delegated Regulation (EU) 2023/707 and Regulation (EU) 2024/2865
ECR	Engine control room
EMCIP	European Marine Casualty Information Platform
EMSA	European Maritime Safety Agency
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GUI	Graphic user interface
ICSC	International Chemical Safety Card
ILO	International Labour Organization
JRCC	Joint Rescue Co-Ordination Centre
LNG	Liquefied natural gas
LSC	Less serious marine casualty
MARPOL	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978, as amended in 2021 and 2022
MSDS	Material safety data sheet
NOK	Kiel Canal, Nord-Ostsee-Kanal
OEM	Original equipment manufacturer
PPE	Personal protective equipment
PSC	Port state control
RAS	Returned activated sludge
S-H	Schleswig-Holstein
SEG	SafeSeaNet Ecosystem GUI by EMSA
SMM	Biennial Shipbuilding, Machinery & Marine Technology trade fair in Hamburg

SMS	Safety management system
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended
STP	Sewage treatment plant
STP-manual	Installation, Commissioning, Operating and Maintenance Manual by manufacturer of CORALIUS' STP
TMAS	Tele Medical Assistance Service
UTC	Coordinated Universal Time
UV	Ultraviolet radiation
VDR	Voyage data recorder
VTS	Vessel traffic service
WHO	World Health Organization

Chemicals:

Cl^-	Chloride ion
Cl_2	Chlorine
CO_2	Carbon dioxide
H^+	Proton
HCl	Hydrogen chloride or hydrochloric acid (aqueous solution)
HSO_3^-	Bisulphite ion
$NaHSO_3$	Sodium bisulphite, also sodium hydrogen sulphite
NaOCl	Sodium hypochlorite
OCl^-	Hypochlorite ion
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphate ion

1 SUMMARY

In the late morning of 5 August 2024 in the port of Travemünde, the Motorman on board the LNG tanker CORALIUS noticed a low fill level of the sewage treatment plant's (STP) sodium hypochlorite (NaOCl) dosing tank. He intended to refill the tank but inadvertently and unknowingly obtained a different chemical, namely a 38–40% sodium bisulphite ($NaHSO_3$) solution, from the chemical store. When the remaining NaOCl solution in the dosing tank mixed with the poured-in $NaHSO_3$ solution, an exothermal chemical reaction occurred, releasing toxic gases and leading to the rupture of the plastic dosing tank. The chosen personal protective equipment (PPE) did not protect the Motorman's body from coming into contact with the chemical mixture, leading to minor injuries due to chemical burns and the forceful impact of the bursting container. The Motorman was given first aid. Because the ship was leaving the port, he was disembarked using the pilot boat and then transferred to hospital by ambulance.

The bursting of the NaOCl dosing tank occurred due to an attention-based unsafe action (slip) that went unnoticed until both chemicals mixed in the NaOCl dosing tank and reacted violently. This led to its bursting, as it was made of plastic. The safety investigation focussed on the underlying conditions that (may have) contributed to this accident. Several aspects, including personal and organisational factors, task features, and ergonomic conditions, were identified as contributory to the accident.

Various safety issues were identified – mainly with regard to the STP's design and installation, as well as safety information and risk management. Safety recommendations were addressed to the STP's manufacturer as well as the consortium of scientists preparing and peer-reviewing International Chemical Safety Cards (ICSCs) as common undertaking between the International Labour Organization (ILO), World Health Organization (WHO) and European Commission.

2 FACTUAL INFORMATION

2.1 Photograph of the ship

Figure 1: Photograph of CORALIUS[1]

2.2 Ship particulars

Name of ship:	CORALIUS
Type of ship:	LNG tanker (type 2G)
Flag:	Sweden
Port of registry:	Donsö
IMO number:	9769128
Call sign:	SCDL
Owner:	Sirius Veder Gas AB
Company as per SMC[2]:	Sirius Shipping AB
Year built:	2017
Shipyard:	Bodewes International Shipbuilding BV, The Netherlands
Classification society:	Bureau Veritas
Length overall:	99.60 m
Breadth overall:	17.94 m
Draught (max):	5.9 m
Gross tonnage:	5,921
Deadweight:	3,077 t
Engine rating:	3,000 kW

[1] Source: Company/operator.
[2] Safety Management Certificate: Certificate confirming to the ship that the company and its personnel on board operate the ship concerned in accordance with the approved system for the organisation of safety measures (Safety Management System, SMS).

Main engine:	Wärtsilä W6L34DF B
(Service) speed:	11 kts
Hull material:	Steel
Hull construction:	Double hull
Minimum safe manning:	11
Authorized cargo:	LNG

2.3 Voyage particulars

Port of departure:	Travemünde, Germany
Port of destination:	Tananger, Norway
Type of voyage:	Merchant shipping, international
Cargo information:	No liquid cargo
Manning:	13
Draught at time of accident:	d_f = 4.60 m, d_a = 5.30 m
Pilot on board:	Yes
Number of passengers:	1

2.4 Marine casualty information

Type of marine casualty:	Less serious marine casualty (LSC): Occupational accident[3] – bursting of a plastic dosing tank for chemicals
Date/Time:	05/08/2024, 1047[4]
Location:	Travemünde, Skandinavienkai, berth No. 5
Latitude/Longitude:	φ = 53°56.66′N, λ = 010°51.62′E
Voyage segment:	In port, still alongside a previously bunkered ship, during preparations for departure
Place on board:	Engine room
Human factors:	Yes
Consequences:	Bursting of a plastic chemical container; various injuries (right side of body and eyes) to a crew member due to proximity to the burst container; other crew members feeling unwell due to inhalation of toxic gases; contamination of the surroundings in the engine room by a chemical mixture

[3] See Annex 5 Table 4 MSC-MEPC.3/Circ.4/Rev.1.
[4] Local time = CEST = UTC + 2 h.

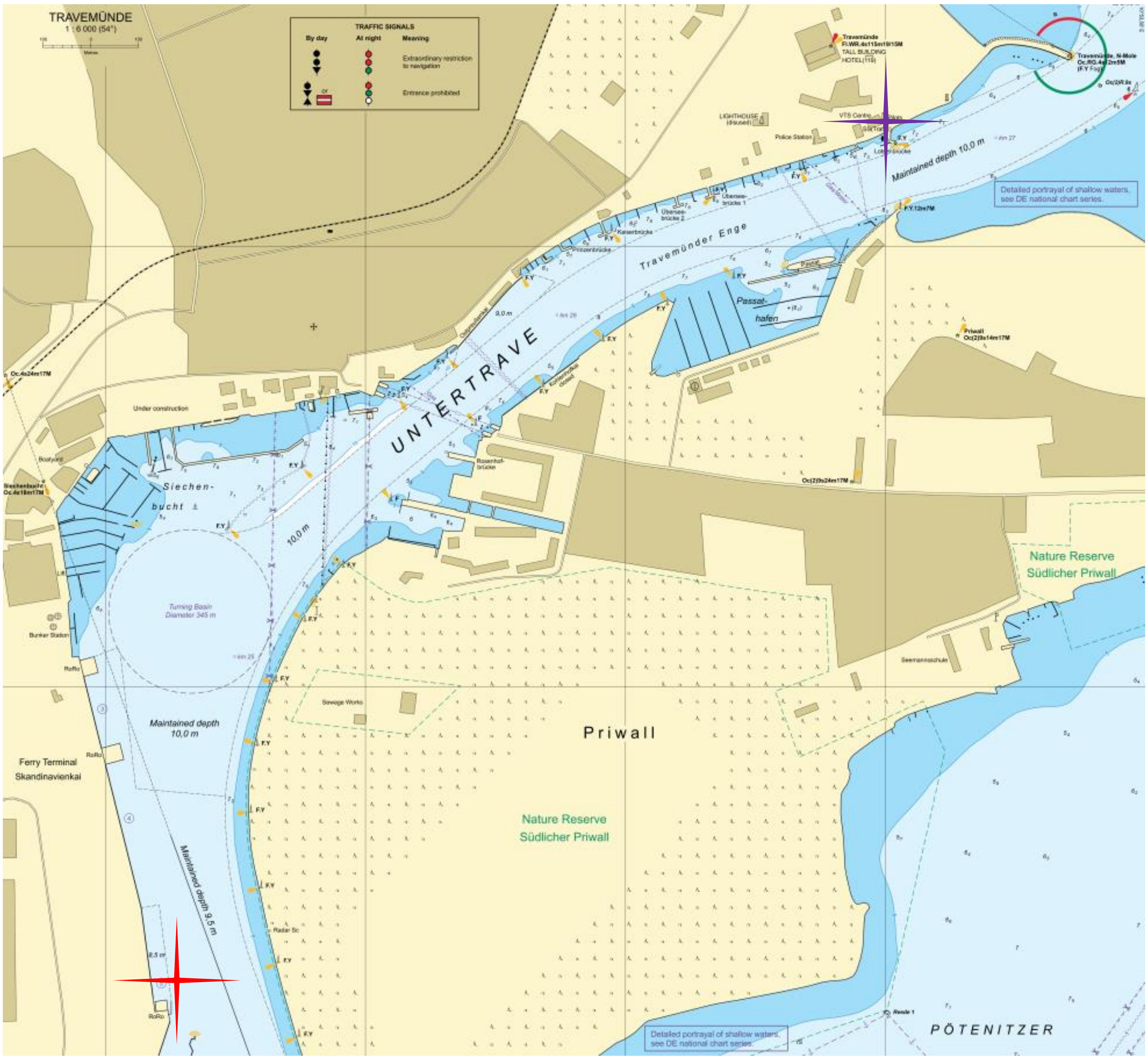

Figure 2: Excerpt from navigational chart DE51 / INT 1362 "Travemünde and Approaches" [5]

✦ location of the accident, ✦ pick-up by ambulance after disembarkation

2.5 Shore authority involvement and emergency response

Agencies involved:	Swedish Joint Rescue Co-Ordination Centre (JRCC Sweden, Sweden Rescue)
	Swedish Tele Medical Assistance Service (TMAS) by the University Hospital in Gothenburg
	Pilot Association NOK II, Kiel, Lübeck, Flensburg
	Shoreside emergency services and hospital (UKSH – Universitätsklinikum Schleswig-Holstein)

[5] Source: Federal Maritime and Hydrographic Agency (BSH), 1st edition 22.09.2022.

Means used:	Pilot boat SCHILKSEE Ambulance and emergency doctor
Speed of response:	Immediate onboard response (initial medical care) Time between accident and consultation with TMAS: 20 min Time between accident and disembarkation: 53 min
Actions taken:	Rinsing the eyes with an eye-wash bottle, removing and later replacing contaminated clothing, showering the whole body, consultation with TMAS, securing the injured person with a rope and harness during disembarkation via pilot ladder, transfer to hospital
Results achieved:	Casualty successfully given initial medical care, disembarked and treated without further injury to the casualty or other crew members; casualty not suffering from any lasting impairment except scarring/discolouring of the skin

3 COURSE OF THE ACCIDENT AND INVESTIGATION

3.1 Course of the accident

3.1.1 Events leading up to the accident

On the morning of Monday, 5 August 2024, the LNG tanker CORALIUS entered the port of Travemünde after a night at anchor. The pilot came on board at around 0700, and about an hour later CORALIUS was fast with her port side alongside the ro-ro cargo ship BALTIC ENABLER, which was to be bunkered at berth 5 of the Skandinavienkai.

For the Motorman on board CORALIUS, the working day began at 0600 with the daily morning inspection round of the engine room. After breakfast and the subsequent work meeting, different tasks on the sea chest were scheduled for the morning. After completing this work, the Motorman noticed that one of the chemical dosing tanks (removable plastic canisters) on the sewage treatment plant (STP) had a low fill level.

The CORALIUS is equipped with an STP that utilizes two chemicals in liquid form: Sodium hypochlorite (NaOCl) for chlorination/disinfection and sodium bisulphite ($NaHSO_3$, also sodium hydrogen bisulphite) for dechlorination. (cf. 3.2.3.1)

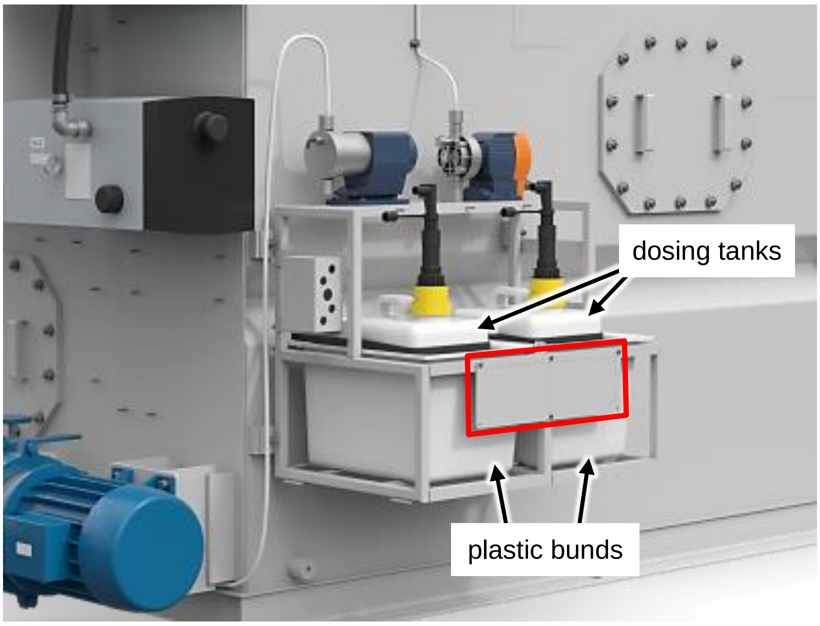

Figure 3: Dosing tanks for $NaHSO_3$ (left) and NaOCl (right)[6]

On board CORALIUS, the righthand plastic bund in which the NaOCl dosing tank is located was black instead of white, as shown in the model above. Additionally, signs were mounted on the blank plate (indicated in red above), as shown in Figure 11. (cf. 3.2.3.1.1)

[6] Source: WÄRTSILÄ: Home – Waste treatment – Sewage treatment plants for ships (08/10/2024); annotations and highlighting by BSU.

The Motorman wanted to refill the righthand dosing tank for NaOCl and went up one deck to the chemical store. The NaOCl and $NaHSO_3$ solutions are stored there on a shelf together with other chemicals that are needed on board. In addition to his usual work clothes for machinery spaces, the Motorman equipped himself with short rubber gloves and a face shield (plastic visor). This personal protective equipment (PPE) was kept in the chemical store. He then filled about five litres from a storage canister into a smaller transfer container. Inadvertently, he did not obtain the NaOCl solution as planned, but the $NaHSO_3$ solution.

Back at the STP, the Motorman removed the ten-litre dosing tank to be refilled from its holder, which is mounted on the plant. Initially, when he filled the chemical from the transfer container into the dosing tank, nothing unusual happened. However, just as he was putting the dosing tank back into its holder, the tank burst with a loud bang. A violent reaction had occurred and the Motorman was injured in multiple locations on the right side of his body from being sprayed with the mixture of chemicals as well as from the impact of the bursting container. The chemicals soaked his coverall and part of the spray reached beneath his face shield and came into contact with both of his eyes. Additionally, he suffered second-degree chemical burns to approximately 5% of his body.

Figure 4: Burst dosing tank as found after the accident[7]

[7] Source: Company/operator.

3.1.2 Emergency response

At 1047, a loud bang was heard in the engine room, engine control room (ECR), and on the bridge, alerting the crew. Initially, the bridge team suspected the sound to have come from a ballast water valve, but no ballasting operation was ongoing. In the ECR, alarms from the valve remote control system for ballast and bunker valves briefly triggered. As the bunker operation with the BALTIC ENABLER had been completed at 1023, the Chief Engineer (C/E) was preparing for departure. He heard the bang and assumed it might have been a “pressure bump” in the ballast system or related to mooring operations. When he contacted the bridge, he received no additional information.

The C/E attempted to investigate the engine room but was overwhelmed by a strong irritation to his eyes and airways on the top of the stairway from the ECR deck to the platform deck below. He saw the First Engineer (1/E)[8] two decks below, as well as a vague mist or fog on the platform deck in between. The 1/E also experienced an intense chemical smell, irritation to his eyes, and nausea, but managed to escape upwards to the ECR deck.

After the dosing tank burst, the injured Motorman ran up one deck to the workshop, where the C/E found him washing off a substance and removing his clothes. The C/E assisted him with eyewash bottles. The Motorman's injuries weren't immediately obvious, but the C/E, also concerned about the 1/E, contacted the bridge for further assistance and more eyewash bottles.

The C/E again tried to reach the platform deck but had to turn back due to the intense and irritating smell. He later found the Motorman in the shower of the gym, located close to the workshop on the same deck (cf. Figure 5), with the 1/E present. The Master also came down to inquire about the situation, but the C/E could not provide details at that time.

The pilot had remained on board all morning. At 1052 he informed both Lübeck Pilot and vessel traffic service (VTS, Trave Traffic) via radio that CORALIUS’ departure would be delayed by about ten minutes. At that point, he had not yet been given detailed information about what exactly had caused the delay, as the crew was still in the process of gathering information. Lübeck Pilot replied that the ten-minute delay was not a problem.

After proceeding to the platform deck using a breathing apparatus, the C/E was able to confirm to the Master that the ship was fit to sail. Departure preparation continued

[8] He was formerly a Second Engineer and was promoted. Because he was not mustered as Chief Engineer on this vessel, he was given the rank of “First Engineer”.

and CORALIUS started to cast off at 1100. VTS informed the pilot upon his departure report that there was no conflicting traffic.

After contacting the Swedish TMAS via the Swedish JRCC at 1107, the officer designated to carry out the communication was connected to a doctor. After an initial misunderstanding concerning the chemicals involved in the accident, they proposed using the pilot boat for disembarking the injured Motorman. Two doctors supported his disembarkation for treatment ashore. A discussion about whether using the pilot boat for this would be possible arose on board. While the JRCC suggested a helicopter, the doctor recommended using a boat. The injured person's ability to climb down the pilot ladder was also discussed to some degree by CORALIUS and the JRCC.

At 1127 the pilot was informed about the situation in more detail and the decision was made to disembark the Motorman via the pilot boat. This seemed to be the quickest solution and a viable option. The Master had assured the pilot that the injured crew member was fit to climb down the pilot ladder. VTS was informed immediately and an ambulance ordered to the pilots' pier. Additionally, the pilot informed VTS that, with their consent, he would disembark earlier than usual, before reaching the Trave buoy, together with the injured crew member. Shortly after passing the fairway buoys 1/2, the pilot left the bridge at 1131.

After retrieving the most important items from his cabin and changing his clothes, the Motorman disembarked CORALIUS at 1140 via the approximately 20-step pilot ladder. During the climb, he was secured against falling in case his condition worsened. After about 15 min, the pilot handed over the Motorman to the emergency medical service. While still onboard, the pilot had taken pictures of the material safety data sheets (MSDS) of both chemicals involved and was therefore able to provide this information to the rescue service.

About half an hour after the injured crew member had disembarked, maritime police officers boarded the vessel about 1.6 nm northeast of the Trave buoy for an initial investigation at the BSU's request. At 1330, CORALIUS continued her voyage bound for Tananger, Norway.

In response to the accident, a decision was made to temporarily suspend the STP's operation and collect sewage in a holding tank. On 8 August, CORALIUS' classification society verified the proper function of the STP in an occasional survey without issuing any recommendations. In the days following the accident, no machinery malfunctions were observed. After treatment in the hospital and follow-up, the Motorman was found fit to travel home on 13 August 2024 with the prognosis of a full recovery.

3.2 Investigation

The BSU was informed about the accident on the same day, 5 August 2024, by the maritime police in Lübeck (Travemünde), who were requested to carry out an initial investigation (cf. 3.1.2). Following an onboard visit by a BSU investigation team on 19 August during CORALIUS' next port call to Travemünde, the BSU decided to conduct a full investigation into the case on 22 August.

3.2.1 LNG tanker CORALIUS

3.2.1.1 Basic information and operation

The 100 m LNG tanker CORALIUS was built for its current operator *Sirius Shipping* in the Netherlands in 2017. Since then, no deficiencies were detected during any of the six port state control (PSC) inspections (as of 12/06/2026). The CORALIUS' trading area was mainly Northern Europe (Sweden, Norway, Denmark, Germany) and occasionally Western Europe (The Netherlands, Belgium).[9] [10]

The engine room of CORALIUS spans three decks: the engine room tanktop, the platform deck and the deck where the ECR is located. Above this deck lie the main deck and a five-deck accommodation superstructure including the bridge. The ship was in exemplary condition, demonstrating remarkable tidiness and cleanliness during the onboard visit by BSU on 19 August 2024.

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9 Electronic Quality Shipping Information System (equasis).

10 SafeSeaNet Ecosystem GUI by the European Maritime Safety Agency (EMSA).

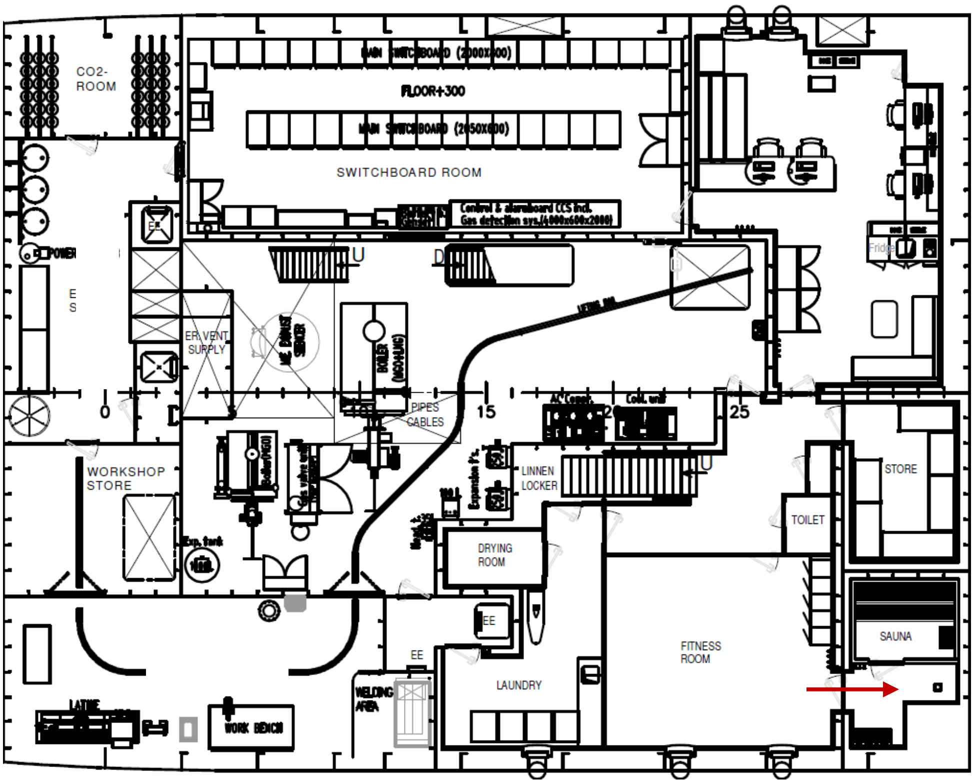

Figure 5: ECR deck[11]

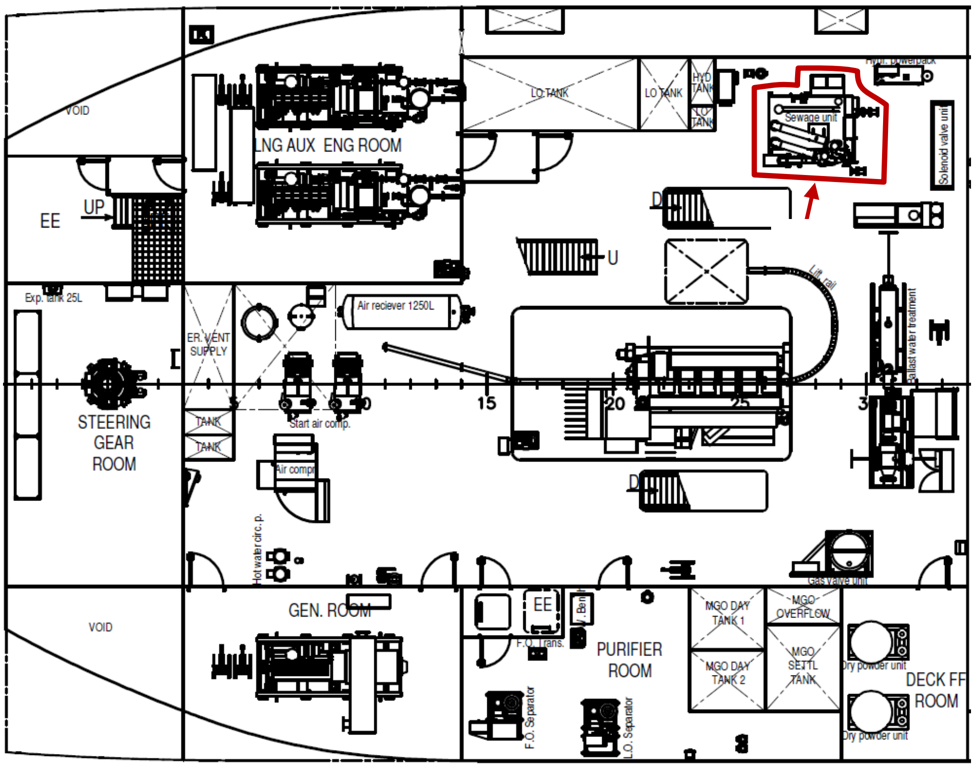

Figure 6: Platform deck[11]

11 Source: Company/operator, annotations by BSU.

3.2.1.2 Crew

According to her Minimum Safe Manning Document, CORALIUS had to be manned by at least eleven persons.

POSITION	NOS	COMPETENCY		SPECIAL COMPETENCY / REMARKS
		National code	STCW -78 as amended	
Master	1	K	II/2	GOC/GMDSS and Certificate of Proficiency in advanced training for liquefied gas tanker cargo operations Medical care (See Annex 1.)
Chief Officer	1	FB II	II/2	GOC/GMDSS and Certificate of Proficiency in advanced training for liquefied gas tanker cargo operations
2:nd Officer	1	FB V	II/1	GOC/GMDSS
3:rd Officer	1	FB V	II/1	GOC/GMDSS
Chief Engineer	1	I	III/2	Certificate of Proficiency in advanced training for liquefied gas tanker cargo operations
2:nd Engineer Off.	1	MB II	III/2	Certificate of Proficiency in advanced training for liquefied gas tanker cargo operations
Able Seafarer deck	2	MTR	II/5	
Watch keeping deck rating	1	LMTR	II/4	
Watch keeping engine room rating	1	VM	III/4	
Cook/Galley-Steward	1	-	-	Certificate of proficiency for ship´s cook (MLC 3.2.3)

Figure 7: Extract Minimum Safe Manning Document CORALIUS 2017[12]

The vessel was actually manned with 13 people on the day of the accident. Contrary to the prescribed minimum safe manning, there were two Second Officers (2/O) (instead of one 2/O and one Third Officer (3/O)). Additionally, the ship was manned with three ABs, an Apprentice Deck and a “Deckboy” (acc. to crew list) instead of two ABs and one watch keeping deck rating. In 2025, a new Minimum Safe Manning Document was issued by the flag state which requires a manning of twelve but also grants more flexibility. *Inter alia*, it makes it possible to dispense with the 3/O and a newly introduced Third Engineer Officer (3/E) (“provided that the schedule of the ship makes it possible for the remaining crew members to perform duties within the framework of current rest period legislation”[13]), reducing minimum safe manning to ten. The company/operator however did not make any changes to the crew’s composition or size as the operational manning of the vessel is decided according to the workload on board depending on the vessel’s trade.

[12] Source: Company/operator.

[13] Minimum Safe Manning Document for CORALIUS issued by the Swedish Transport Agency (STA) on 14/02/2025.

3.2.1.2.1 Motorman

The injured Motorman was 62 years old and had been a seafarer for many years. He had worked for *Sirius Shipping* for 15 years and joined CORALIUS for the first time two months prior to the accident. Before, he had worked with different agencies and sailed on other tankers for different operators. He held a certificate of proficiency as Able Seafarer Engine (STCW[14] Regulation III/5).

On board CORALIUS his work day started at 0600 and usually ended at 1700, with breaks for breakfast and lunch. In the month of August 2024, he had 10 h of rest or more during any 24-hour period, and 15 h of rest before starting work on the day of the accident. During the interview with BSU investigators on 15 August, he remembered feeling very well (9/10)[15] and not tired (2/10)[16] on that day.

The Motorman was familiar with different kinds of STPs using chlorination, sometimes with a defoaming agent or UV-radiation (cf. 3.2.1), but had not yet come across one using both NaOCl and $NaHSO_3$. He was not very familiar with $NaHSO_3$ for dechlorination and had not familiarized himself with the MSDSs. On the day of the accident, he carried out the job of refilling the chemicals for the first time. He had witnessed the procedure a couple of weeks before when accompanying the 1/E. That time, the 1/E had refilled the $NaHSO_3$ dosing tank.

3.2.1.2.2 First Engineer

The 1/E was 37 years old and had worked at sea for 15–16 years. He had joined *Sirius Shipping* almost six years ago and worked in his position for eight years. CORALIUS had been his regular vessel since 2019 and for the present assignment he had joined the ship on 7 June, two days after the Motorman.

The 1/E is responsible for the maintenance of the STP. When instructing the Motorman on this plant, he had reportedly explained which chemicals to use, where to pour them, as well as their basic function within the STP. During the demonstration of the refilling of $NaHSO_3$ solution, goggles and gloves were worn as PPE.

A couple of days before the accident happened, the Motorman had approached the 1/E and told him about a slightly low level of the NaOCl dosing tank. After checking, the 1/E had told him to keep it as it was for the moment. It was suspected that on the day of the accident the level had been even lower, prompting him to refill the chemical himself.

[14] International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended.
[15] 1 – really bad, 10 – really good.
[16] 1 – not tired at all, 10 – almost falling asleep.

3.2.1.2.3 Chief Engineer

On the day of accident, the 39-year-old C/E had been on board for almost three weeks. He had been with *Sirius Shipping* for around six years, with CORALIUS being his regular vessel in the past two years. Before his employment with *Sirius Shipping*, he worked on product and bitumen tankers for another operator.

The C/E is responsible for overseeing all machinery, including the STP. He orders the needed chemicals as well as spare parts, but is not directly involved in the maintenance of this plant. Apart from his usual working hours between 0800 and 1700, the C/E is stand-by for handling possible machinery faults every other night between 1700 and 0800, sharing this duty with the 1/E.

3.2.2 Shipboard sewage treatment

3.2.2.1 General process

All shipboard STPs follow the same steps of wastewater treatment, regardless of their specific design. Many STPs combine some of the described processes, some steps may be so effective as to make the next obsolete, and the order of the steps can vary.

<u>Separation:</u>

Before any treatment can take place, the incoming sewage is separated from any solid matter and debris it contains.

<u>Primary separation:</u>

Usually, this is achieved by pumping the sewage through a basket or screen. If large sewage quantities have to be managed, like on cruise vessels, then this step can be sped up by maceration[17].

Some plants make use of chemical coagulants or flocculants that cluster the solids, which are then moved to the surface using a carpet of air bubbles (“precipitation” and “flotation”), and finally skimmed off (“chemical separation”).

<u>Secondary separation:</u>

If necessary, heavier materials and liquids are further separated using physical methods (“physical separation”). This is often a settling process in a sedimentation tank or compartment. Spinning gravity separators are another possibility, as are fine membrane filters (“filtration” or “ultra-filtration”).

There are plants with primary separation so effective that it makes a second separation step unnecessary, such as those using chemical separation.

[17] Reducing solids within the sewage to smaller pieces using a grinding or blending mechanism creating a pumpable slurry.

Biological treatment:

This step breaks down organic matter (remaining small solid particles) through an aerobic microbial process, i. e., organic pollutants are degraded biologically by bacterial matter and air. The injection of ozone, a powerful oxidising agent, can speed up this step.

If the separation of solids and water has already been highly effective, like when chemical separation is followed by ultrafiltration, the biological treatment stage can be skipped. Conversely, biological treatment minimises the use of chemicals.

Disinfection:

Any remaining pathogens are killed in this last treatment stage. Ozone (either as part of the biological treatment stage or as a stand-alone disinfecting agent), UV radiation, electric currents, or chemical disinfection (usually chlorine-based) are commonly employed for this.

If disinfection is carried out by chlorination, then the excess chlorine can either be neutralised with a dechlorination agent during discharge, or it is pumped outboard with the highly diluted effluent. Some ultra-filtration plants can be effective enough to render even the disinfection stage unnecessary.

Sludge Handling:

The sludge separated from the water in early steps is either disposed overboard on high seas (more than 12 nm from the nearest land at a moderate, approved discharge rate while the ship is *en route* and proceeding at no less than 4 kts, never near a coast or in protected sea areas)[18], or moved into a holding tank for disposal to a designated facility ashore. Chemically separated sludge can never be pumped overboard, only biologically treated residue, which is similar to compost.

Prevalence:

The most frequently installed STPs on commercial vessels are biological treatment plants, membrane bioreactors (combining biological treatment with ultrafiltration), and physical-chemical treatment systems (combining coagulants / flocculants with a physical separation method, most commonly filtration).

The most widely used disinfection methods are chlorination and UV radiation. STPs requiring chemicals for their operation are supplied with these chemicals either in liquid or tablet form, depending on the design.

[18] International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978, as amended in 2021 and 2022 (MARPOL) Annex IV, Regulation 11.

3.2.2.2 Market research

In order to establish how common the kind of STP installed on CORALIUS is and whether potential safety issues also affect a larger number of other ships, market research was carried out. To this end, the BSU investigation team visited the biennial trade fair for maritime technology "SMM" in Hamburg (Germany), conducted online research and contacted the manufacturer of CORALIUS' STP.

Prior to visiting the SMM 2024, the investigation team reviewed the official exhibitor directory in order to identify manufacturers of sewage treatment systems. A keyword search under "sewage" revealed eleven relevant entries. A supplementary search under "water" yielded one further sewage treatment plant manufacturer, plus a number of manufacturers of potable water generating plants. While not equivalent systems, these were also noted, as their process often also concludes with a disinfection stage. All manufacturers of STPs that were identified through this process were subsequently visited during the fair, as well as a few manufacturers of potable water generators.

About 15 manufacturers of water treatment systems were approached at the SMM, and twelve of these offered biological treatment plants comparable to the one installed on CORALIUS. No plant with a chlorination/dechlorination step had a distinctive colour scheme or visual differentiation for the two canisters or filling inlets, although this measure could reduce the risk of operational errors. When the issue was raised, most representatives acknowledged its relevance but did not consider it to warrant immediate corrective action, attributing potential incidents to operating errors rather than system design.

The inquiry did not extend to a quantification of the distribution of system types across vessel classes. According to *MarineInsight*[19], however, the type of STP installed on CORALIUS is the most commonly used system on merchant vessels. Alternative systems are typically installed only where significantly larger wastewater volumes occur, e. g. on passenger vessels.

Wärtsilä Water & Waste, the manufacturer of the STP on board COLARIUS, informed BSU that 930 comparable plants have been sold since 2013 (information as of 07/10/2025). This kind of plant is typically installed on commercial vessels with up to 40 persons on board. No other accidents similar to what occurred on board CORALIUS with this kind of STP have been brought to the manufacturer's attention.[20]

[19] MARINEINSIGHT (RAUNEK): Marine Technology – Sewage Treatment Plant on Ships Explained, 29/03/2024; Maritime Law – MARPOL ANNEX 4 Explained – How to Prevent Pollution from Sewage at Sea, 16/03/2024 (07/10/2025).

[20] Statement by Wärtsilä Water Systems on 07/10/2025.

3.2.3 Sewage treatment on board CORALIUS

3.2.3.1 Wärtsilä Hamworthy Super-Trident STC03-13

The sewage treatment plant (STP) installed on board the CORALIUS is a “Wärtsilä Hamworthy Super-Trident STC03-13”, a compact biological treatment plant, built in 2016. These plants make use of the so-called “activated sludge process” described below. The effluent is disinfected by chlorination and dechlorination.

Sewage collection:

The raw sewage is collected via a vacuum-fed inlet (see No. 1, Figure 8), which is designed to handle both “black water” (from toilets) and “grey water” (from showers, sinks etc.). The vacuum system ensures efficient transfer even in moving shipboard environments.

Screening:

The incoming wastewater passes through a filter basket, or “screen”, (No. 2) to break down larger particles.

Biological treatment:

The wastewater then enters an aeration compartment (No. 3) where the biological treatment takes place (“aeration process”). A compressor (No. 4) injects air in fine bubbles into the aeration chamber via a rotating diffuser (No. 5). This promotes the activity of aerobic microorganisms. These microorganisms metabolise and break down the organic compounds in the sewage, thriving and multiplying, resulting in inorganic waste, water, and CO_2. The (odour-free) gas is released via vents (No. 6).

A large part of the sludge that settles in a later process is returned to the aeration compartment as so-called “returned activated sludge” (RAS, No. 7). This RAS contains highly concentrated microorganisms, re-seeding the incoming sewage and significantly boosting biological activity. The process of returning active bacteria means that the plant only needs to be inoculated with active bacterial matter a single time when it is being commissioned, keeping microbial activity at a high level throughout the plant’s life. This step is therefore a crucial part of the process, maintaining the population of active bacteria, which in turn keep the biological process stable even in fluctuating load conditions.

Settling:

The aerated liquid is displaced into a hopper-shaped[21] settling compartment (No. 8), where gravity-driven sedimentation and settling of denser components takes place ("settling process"). Here, the sludge (No. 9), which contains concentrated biomass and unprocessed solids, is separated from the biologically treated water (No. 10). The separation allows the clear liquid to move forward, while the denser sludge settles at the bottom of the hopper. Finally, most of the settled sludge is returned to the aeration tank as RAS (see above).

Chemical disinfection:

The clear, supernatant[22] liquid (No. 10) at the top of the settling compartment – the biologically treated water – is displaced into the contact compartment (No. 11). There it undergoes chemical disinfection with a chlorine-based agent, sodium hypochlorite (NaOCl, cf. 3.2.3.2.1), which removes any remaining pathogens and harmful microorganisms ("disinfection process") (No. 12). This step is essential for achieving the required health and safety standards for discharge.

Discharge:

Finally, the treated and disinfected effluent is discharged overboard (No. 13) after the contact compartment has reached a certain filling level.

Dechlorination:

During discharge, a dechlorination step (No. 14) takes place, neutralising any remaining chlorine with sodium bisulphite ($NaHSO_3$, cf. 3.2.3.2.2). This measure prevents chlorine pollution in marine environments.

The result is clear as water, clean, and safe for marine discharge (No. 15).

Sludge processing:

Periodically, as the separated sludge reaches a certain density, it is removed from the settling tank to a holding tank for disposal, e. g. to a shore reception facility, or directly overboard.

[21] A "hopper-shaped" tank has sloping sides converging downwards. This shape allows gravity to direct the flow towards a discharge outlet at the very bottom, minimising residues, facilitating the collection and discharge of contents, and optimising the emptying process.

[22] The "supernatant" element of a settling process is the liquid above a precipitate or sediment.

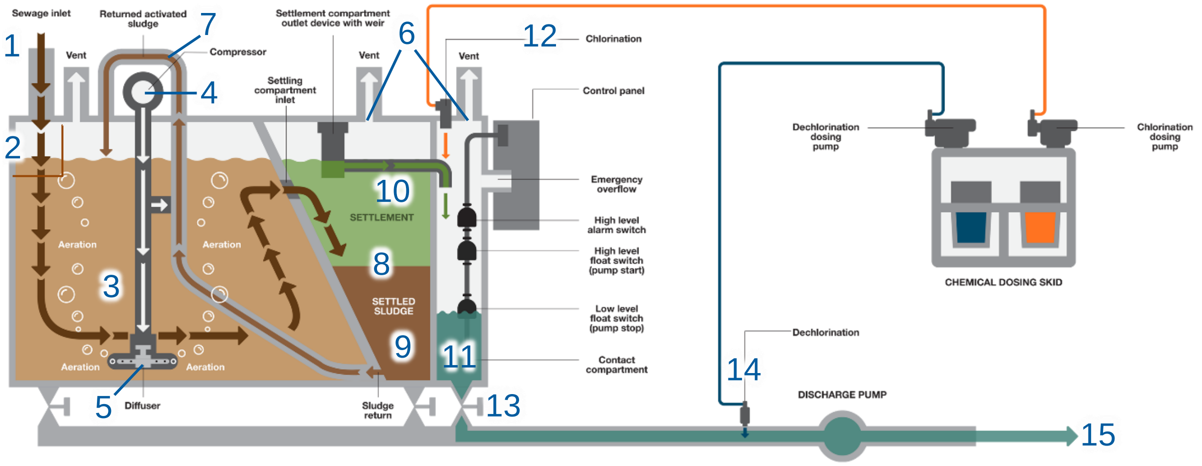

Figure 8: STC03-13 process flow[23]

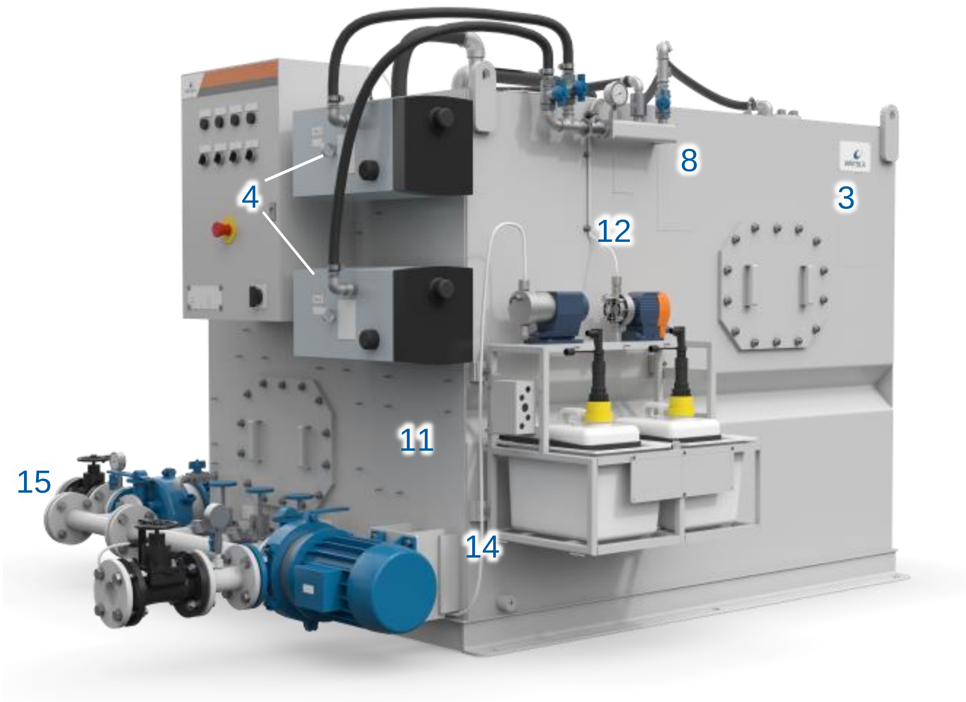

Figure 9: STC03-13 plant[24]

CORALIUS was the only vessel in its company's fleet using this type of STP which requires the use of both NaOCl and $NaHSO_3$ solutions.

[23] Source: WÄRTSILÄ: Home – Waste treatment – Sewage treatment plants for ships (08/10/2024); additions by BSU.
[24] Source: WÄRTSILÄ: Home – Waste treatment – Sewage treatment plants for ships (08/10/2024); additions by BSU.

3.2.3.1.1 Signage and colour-coding

On the STP, there were different safety signs and warnings. These included the mandatory action symbols for wearing ear, hand and eye protection.

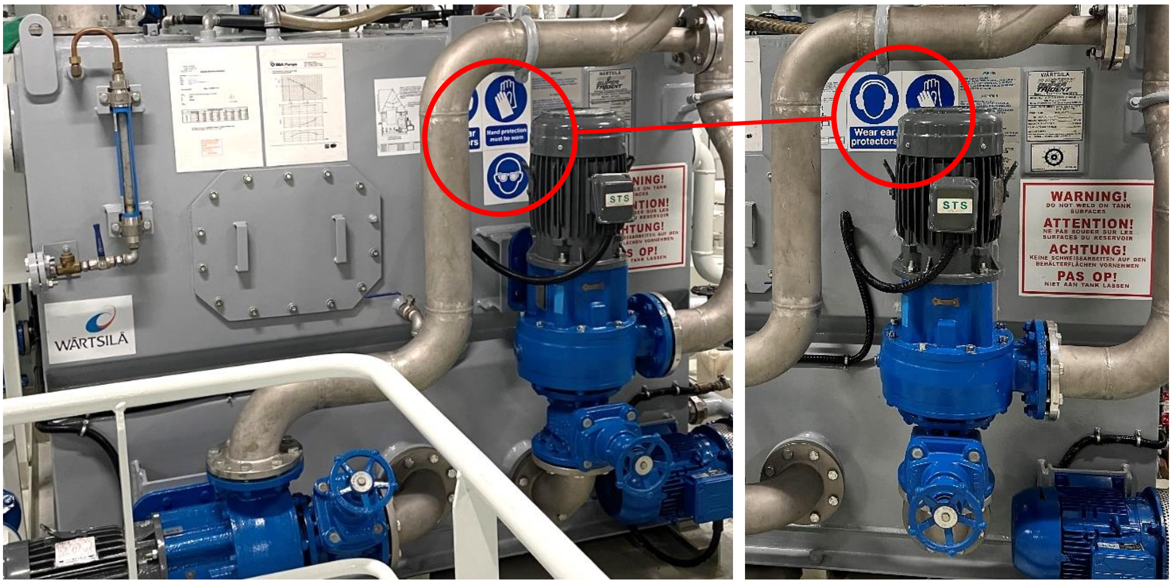

Figure 10: Mandatory action symbols on STP[25]

The symbols for eye and hand protection were repeated on signs attached to the front of the dosing tanks' holder (cf. Figure 3 and Figure 11). These also show

- which chemical goes in which dosing tank (arrows left/right),
- the chemicals' desired concentration (NaOCl: 14-15%, $NaHSO_3$: 12%),
- hazard symbols for each chemical (NaOCl: Corrosive, $NaHSO_3$: Harmful), as well as
- the warnings "Contact with acids liberates toxic gas" (NaOCl & $NaHSO_3$), "Causes burns" (NaOCl) and "Harmful if swallowed" ($NaHSO_3$).

[25] Sources: Left side: *Sirius Shipping AB*, right side: BSU.

Figure 11: Signs at dosing tanks on CORALIUS[26]

At the time of the accident, the signs depicted in Figure 11 were the only written indication of which chemical is designated for which dosing tank. There were no additional signs or labels. However, the plastic bunds underneath the dosing tanks as well as the arrows shown on the signs were colour-coded in black (NaOCl) and white ($NaHSO_3$). The colour code originally also included the containers in which the OEM (original equipment manufacturer) chemicals were supplied. On board CORALIUS, the OEM container for NaOCl was dark grey and the container for $NaHSO_3$ from a different supplier was green. Therefore, the colour-coding on board CORALIUS did not include any items or signs beyond the plastic bunds and arrows.

During the investigation, the STP's manufacturer supplied an updated version of the signs at the dosing tanks as shown in Figure 12. Compared to the signs on board CORALIUS, the following changes had been made:

- colour-coded arrows no longer included;
- pictograms updated to current GHS[27] versions;
- more details included on classification and hazard statements including GHS codes;
- mandatory action symbols for hand and eye protection changed to written directions including relevant GHS codes for precautionary actions; (A decision was made in January 2020 to remove the symbols in order to mimic the CLP[28]-labels on the chemical containers in order to supply more information.)

[26] Source: *Sirius Shipping AB*; picture taken after the accident and before clean-up.
[27] **G**lobally **H**armonized **S**ystem of Classification and Labelling of Chemicals.
[28] **C**lassification, **L**abelling and **P**ackaging Regulation; Regulation (EC) No 1272/2008 in conjunction with Commission Delegated Regulation (EU) 2023/707 and Regulation (EU) 2024/2865.

- increased PPE-requirements: protective gloves, protective clothing, eye protection, face protection; (This was changed due to new requirements by the chemical manufacturer in the respective MSDSs around 2015.)
- the warning "Contact with acids liberates toxic gas" was removed.

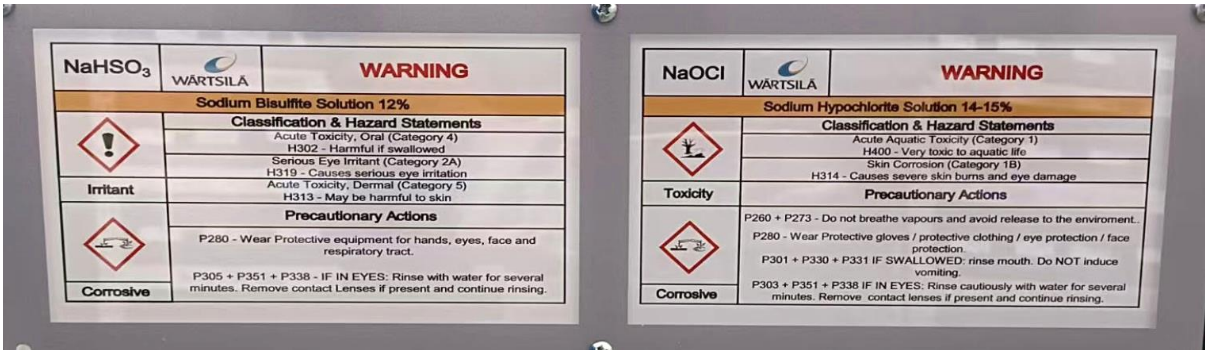

Figure 12: Updated signs at STP dosing tanks[29]

The company/operator of CORALIUS did not update the signs on board as no added value was identified.

3.2.3.1.2 Refilling the dosing tanks and installation position of the STP

Checking the fill level of the dosing tanks was part of the Motorman's routine checks in the engine room each morning. Either an engineer or a rating usually refilled the dosing tanks. Reportedly, the Motorman was not explicitly expected to carry out the refilling alone, as he had little experience with the plant. Neither, however, was it considered inappropriate for him, as an experienced rating, to take on this task by himself without first informing a superior.

On board CORALIUS, the average consumption of the chemicals used was estimated to be 5 l every two months for each substance. Therefore, the dosing tanks with a total capacity of 10 l did not have to be refilled very often. As the 25-litre storage canisters in which both chemicals were delivered on board did not directly fit into the plastic bunds in the holder at the STP, each chemical had to be manually transferred from its storage container into the correct dosing tank.

It was common practice to use a smaller transfer container (e. g. a large plastic jug) to avoid carrying the much heavier storage canister from the chemical store (ECR deck) to the STP (platform deck) and back. The 25-litre storage canisters are difficult to handle, especially when full. At the STP, it was customary to remove the dosing tank from its holder before pouring the chemical inside. This was not strictly necessary but made refilling easier, as the space next to the dosing tanks was very limited with < 30 cm between piping along the wall and the tanks' holder. The dosing tanks were

[29] Source: STP manufacturer.

therefore refilled next to the plant instead, where there is more open space (cf. Figure 6 and Figure 13). According to the STP manufacturer's installation instructions, access to the chlorination and dechlorination dosing tanks must be arranged when installing the plant on board.[30] "No need for modification of these tanks and their placement had previously been identified."[31]

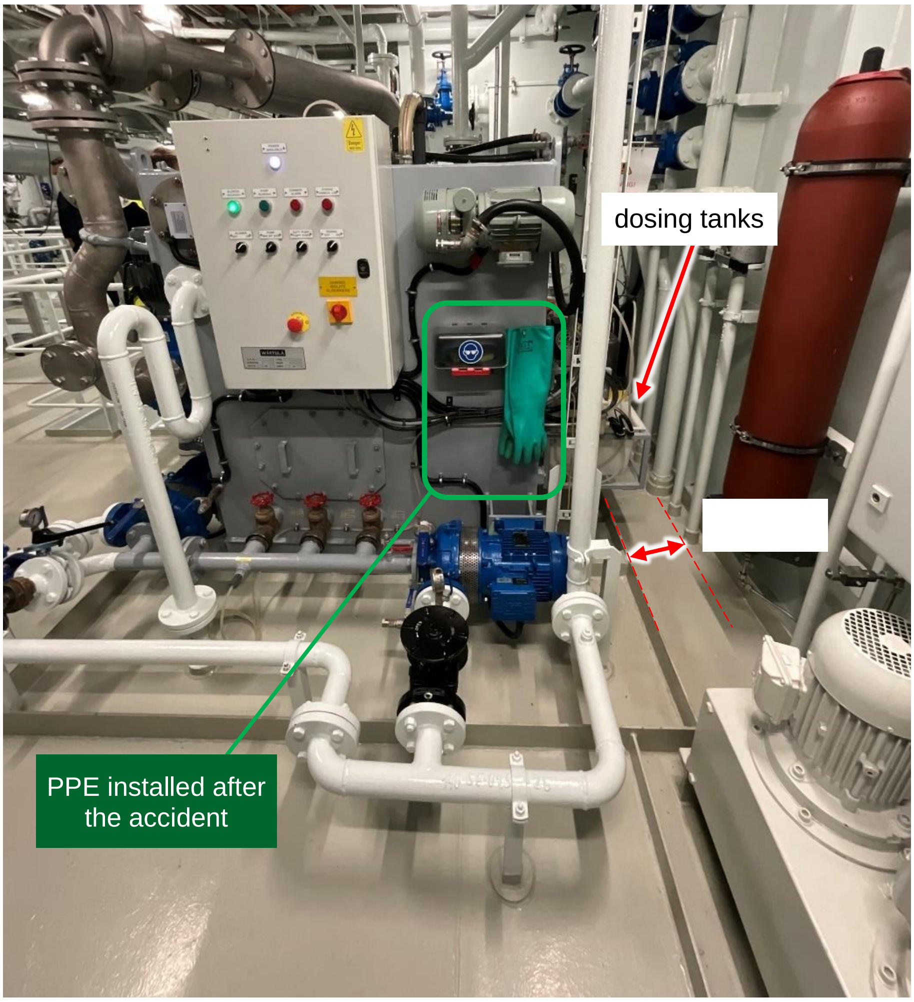

Figure 13: STP on board CORALIUS[32]

In the above picture, the restricted access to the dosing tanks' holder due to pipes, other machinery and dip trays welded to the floor is clearly visible.

[30] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 3-8.
[31] SIRIUS SHIPPING AB: *Investigation Report – Incident report Coralius personal injury due to chemical reaction 05-Aug-2024*.
[32] Source: BSU, picture taken on 19 August 2024.

3.2.3.2 Substances involved

3.2.3.2.1 Sodium hypochlorite (NaOCl) solution

NaOCl (sodium hypochlorite) solution is a yellowish-green alkaline solution (pH > 11) and a very reactive oxidant. It can react with many inorganic as well as organic compounds and smells slightly of chlorine. At a concentration of 14–15%, as supplied on board CORALIUS, it poses the hazard of severe skin burns and eye damage since it is corrosive and very toxic to aquatic life. It may also cause respiratory irritation and be corrosive to metals. Vapours or mist are not to be inhaled and a release to the environment is to be avoided. Protective gloves (complying with EN 374[33]) and clothing as well as tightly fitting eye protection (conforming to EN 166[34]) are to be worn when handling this chemical. However, the eye protection requirements also give the option of wearing a face shield. ("Eye protection: Chemical goggles or face shield. Safety glasses"[35]; "Wear face shield or eye protection in combination with breathing protection."[36]) According to its MSDS, the contact with acids liberates toxic gas (chlorine). Hazardous decomposition products include

- hydrogen chloride gas (HCl) – colourless and pungent smelling gas dissolving easily in water forming hydrochloric acid, e. g. leading to severe burns inside the lungs when HCl is inhaled,
- chlorine gas (Cl_2) – pale yellow-green gas, extremely reactive element and oxidising agent attacking the respiratory system, eyes and skin,
- chlorine oxides – tend to explode in the presence of oxidizable matter; unstable compounds that are very reactive to strong oxidising agents.

NaOCl solution should be stored in its original container in a cool, dark and well-ventilated space separated from strong bases and strong acids as well as combustible materials, ammonia and food.[37] [38]

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33 European Norm 374 on protective gloves against dangerous chemicals and micro-organisms.
34 European Norm 166 on specifications for personal eye-protection.
35 WÄRTSILÄ: *B18013, Sodium Hypochlorite 14 - 15% – Safety Data Sheet*, Version 1.5, revision date: 01/11/2022.
36 ILO ; WHO: *ICSC 1119 – SODIUM HYPOCHLORITE (SOLUTION, ACTIVE CHLORINE >10%)*, 2017 (24/01/2025).
37 WÄRTSILÄ: *B18013, Sodium Hypochlorite 14 - 15% – Safety Data Sheet*, Version 1.5, revision date: 01/11/2022.
38 ILO ; WHO: *ICSC 1119 – SODIUM HYPOCHLORITE (SOLUTION, ACTIVE CHLORINE >10%)*, 2017 (24/01/2025).

3.2.3.2.2 Sodium bisulphite ($NaHSO_3$) solution

$NaHSO_3$ (sodium bisulphite or sodium hydrogen sulphite) solution is a colourless-to-yellow, weak acidic solution (pH 4–5) with a characteristic odour of SO_2 (reminiscent of matchstick smoke) which reacts as a reducing agent. It poses a risk of fire and explosion upon contact with acids or oxidants and also decomposes when heated, producing sulphur oxides. At a concentration of 38–40%, as supplied on board CORALIUS (cf. 3.2.3.3), it poses the hazard of irritation to the skin and eyes (redness) as well as the respiratory tract (coughing). It is corrosive to metals and may be hazardous to the environment. It is recommended to wear protective gloves and safety spectacles as PPE when handling this chemical. $NaHSO_3$ solution should be stored in tightly closed containers and separated from acids, strong oxidants and food.[39]

3.2.3.2.3 Chemical reaction between NaOCl and $NaHSO_3$ solutions

An exothermic redox reaction will take place when combining NaOCl and $NaHSO_3$ solutions, meaning that if cold concentrated solutions of both chemicals are combined, the resulting mixture will have a significantly increased temperature. The more water is present during this reaction, the lower the temperature increase will be. The bisulphite ion (HSO_3^-) reduces the hypochlorite ion (OCl^-) to a chloride ion (Cl^-) while being oxidized to a sulphate ion (SO_4^{2-}) itself. Additionally, protons (H^+) are generated, acidifying the resulting solution:

$$HSO_3^- + OCl^- \rightarrow SO_4^{2-} + H^+ + Cl^-$$

Adding an acid to a NaOCl solution "will reverse the chemical reactions associated with its production from chlorine gas."[40] The hypochlorite anions (OCl^-) react with acids to form chlorine gas.

[39] ILO; WHO: *ICSC 1134 – SODIUM BISULPHITE 38-40% AQUEOUS SOLUTION*, 2021 (24/01/2025).
[40] FOREMAN, M. R.StJ.: *On mixing sodium hypochlorite and sodium bisulfite solutions*, 27.08.2024.

3.2.3.3 Storage and ordering of chemicals

On board CORALIUS, chemicals were ordered by the C/E and stored on designated shelves inside the chemical and lubricant store on the ECR deck.

Figure 14: Chemical and lubricant store on board CORALIUS[41]

[41] Source: BSU, taken on 19 August 2024.

Figure 15: Chemical shelves inside the chemical and lubricant store[42]

As can be seen in the pictures above, the chemicals were not separated or marked by their properties (e. g. pH-value) on the shelves. A folder with all MSDSs was available as well as different kinds of PPE, such as rubber gloves, goggles and a face shield/visor. On the left side of the shelves, different funnels and transfer containers were mounted, some marked for specific uses.

In the past, both the NaOCl and $NaHSO_3$ solutions were ordered directly from the manufacturer of the STP and received at the needed concentration for the plant's operation. However, in the months before the accident, the $NaHSO_3$ solution was sourced from another local supplier and delivered at the higher concentration of 38–40% instead of 12%. The reason for this were difficulties in the supply chain as the STP's manufacturer ships the chemicals from outside the European Union, which led to longer delivery times and higher transportation costs. Since $NaHSO_3$ solution has a limited shelf life, while only small amounts are regularly needed for the STP (cf. 3.2.3.1.2), long delivery times were unfavourable.[43]

[42] Source: BSU, taken on 19 August 2024; securing plank removed only for the purpose of this picture.
[43] SIRIUS SHIPPING AB: *Investigation Report – Incident report Coralius personal injury due to chemical reaction 05-Aug-2024*.

3.2.3.4 Safety management

3.2.3.4.1 Familiarization and instructions

When the Motorman joined CORALIUS at the beginning of June 2024 for the first time, he received the obligatory safety induction and ship familiarization from the 2/O. According to the corresponding safety management system (SMS) checklist, this included the use, location and handling of PPE. Additionally, there was an engine room familiarization on general safety, emergency routines and escape ways. It also included the operation and maintenance as well as routines and safety precautions for selected systems, the STP not being one of them.

As described in 3.2.1.2.2 the Motorman received an initial demonstration on refilling the STP's dosing tanks on board CORALIUS by the 1/E. After this demonstration, the Motorman was neither expected nor explicitly asked to carry out this job by himself.

During the investigation, it was found that the $NaHSO_3$ solution on board was of a higher concentration than needed for the operation of the STP (cf. 3.2.3.3). Reportedly, the operator's technical department had instructed the vessel to dilute the supplied 38–40% $NaHSO_3$ solution to the desired concentration. On the day of the accident, the Motorman inadvertently took the undiluted $NaHSO_3$ solution out of the chemical store instead of the desired NaOCl solution. Based on a paper[44] provided by a chemistry expert, the company's internal investigation report concluded that the bursting of the dosing tank would also have occurred with the usual concentration of 12%.

3.2.3.4.2 Safety information provided

The investigation found that the crew on board CORALIUS was not aware of the danger of mixing both chemicals. Safety information was provided in the form of

- material safety data sheets (MSDSs) in the chemical store,
- mandatory action symbols and warning signs on the STP (cf. 3.2.3.1.1) and
- warning notices inside the manufacturer's "Installation, Commissioning, Operating and Maintenance Manual" (STP-manual).

The MSDSs for the NaOCl solution (OEM chemical) comprised ten pages, the one for $NaHSO_3$ (OEM chemical) had seven pages. The 38–40% $NaHSO_3$ solution MSDS was 15 pages long. The company's internal investigation report cited a different 17-page extract of a 41-page MSDS for NaOCl, and a ten-page MSDS for $NaHSO_3$. These stem from the manufacturer's manual for the STP. It should be mentioned that this 41-page MSDS for NaOCl is not complete, as pages 15–29 and 33–41 are not included in the

[44] FOREMAN, Mark R.StJ.: *On mixing sodium hypochlorite and sodium bisulphite solutions*, 27 August 2024.

manual. The layout of all abovementioned MSDSs is different for each manufacturer or supplier.

The STP-manual provides the following warnings from the manufacturer regarding the handling of the respective chemicals:

- “Manual Handling Warning; possible crushed limb or serious injury from tripping over. The Sodium Hypochlorite [/Sodium Bisulphite] chemical tank weighs 25kg. Care must be taken when attempting to manoeuvre the tanks into position. Ships staff to perform a risk assessment and produce a method statement prior to installing the chemical tanks. Correct PPE to be worn.”[45]
- “All chemical handling should be carried out in accordance with the Materials Safety Data Sheets under Section 9.1 “Health and Safety” […].”[46]
- “Chemical Warning; possible injury from chemical contact or ingestion, ensure the safety data sheet for the Sodium Hypochlorite [/Sodium Bisulphite] chemical is read and followed. Care must be taken when attempting to manoeuvre the tanks into position [/when attempting to clean the dosing injectors]. Refer to the relevant Safety Data Sheet […]. [Eye wash stations are recommended and] Correct PPE to be worn.”[47]
- “Danger from hazardous substances! Possible consequence: Fatal or very serious injuries. Please ensure when handling hazardous substances that you have read the latest safety data sheets provided by the manufacturer of the hazardous substance. The actions required are described in the safety data sheet. Check the safety data sheet regularly and replace, if necessary, as the hazard potential of a substance can be re-evaluated at any time based on new findings. The system operator is responsible for ensuring that these safety data sheets are available and that they are kept up to date, as well as for producing associated hazard assessments for the workstations affected.”[48]
- Different warnings concerning the leakage or forceful ejection of feed chemicals under various circumstances, such as worn seals, ruptured or loose pipes, damaged hydraulic parts, etc.[49]

[45] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 4-1, 5-6.
[46] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 4-2.
[47] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 4-4, 4-5, 5-5, 5-6, 5-8.
[48] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 8-9.
[49] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 8-9, 8-10, 8-12.

- MSDS for $NaHSO_3$ (excerpt, STP-manual section 9.1.2):[50]
  → acidic; contact with acids liberates toxic gas; incompatible materials: strong oxidizing agents, acids, nitrites; vapours may be invisible, heavier than air and form explosive mixtures with air; hazardous decomposition products: heating may cause toxic fumes, sulphur oxides; no information available on possibility of hazardous reactions; in case of insufficient ventilation, wear suitable respiratory equipment; wear suitable gloves (PVC, rubber), safety goggles and protective work clothing.
- MSDS for NaOCl (excerpt, STP-manual section 9.1.3):[51]
  → corrosive; causes severe skin burns and eye damage, very toxic to aquatic life; contact with acids liberates toxic gas; no information about oxidizing properties provided by supplier; incompatible materials: acids, ammonium compounds, acetic anhydride, organic materials, hydrogen peroxide, metal salts, copper, nickel, iron; may develop chlorine if mixed with acidic solutions; hazardous decomposition products: hydrogen chloride gas, chlorine, chlorine oxides; do not breathe vapours, wear protective gloves (butyl-rubber, polyvinylchloride, polychloroprene), alkali resistant protective clothing, eye protection (safety glasses with side shields / tightly fitting safety goggles) and face protection, use respirator with appropriate filter if vapours or aerosol are released.

While there is a procedure on what to do in case of a ruptured chemical dosing tank, warnings about the hazards of mixing both chemicals are not included in the STP-manual.

[50] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 9-2 – 9-11.
[51] WÄRTSILÄ: *Installation, Commissioning, Operating and Maintenance Manual*, Document ID: PCH 1602 STC03-13 2P1C, Issue 4, September 2015, p. 9-12 – 9-28.

3.2.3.4.3 Personal protective equipment

The company's SMS included a "Policy for Safety of Health and Work Environment Onboard" comprised of a matrix on what PPE to use for different tasks on board as well as further instructions and explanations. This matrix shows the minimum safety requirements. The following table was reproduced from this matrix.

Table 1: Extract of PPE matrix[52]

	Boiler suit	Safety shoes	Helmet	Ear protection	Harness	Goggles[1]	Gloves	Chemical suit	Visor	Fall arrestor	Floating aid	Breathing protection	Warning signs	Isolate/check	Drain/Vent	Work permit	Gas detector
Machinery space work	at all times	at all times	as required	at all times		as required	as required										
Chemical store handling	at all times	at all times	at all times			at all times	as required	as required	as required			as required	as required				
Pressurized syst. work **	at all times	at all times	as required	as required		at all times	at all times		as required				at all times	at all times	as required	as required **	

■ at all times protective equipment/precaution to be used at area/task

■ as required protective equipment/precaution to be used at area/task as required

** The work permit to be used for work on systems with compressed gas with a pressure of at least 7 bar.

[1] Goggles used onboard shall [at a] minimum comply with [the] following marking of the frame: 3 = liquids and 4 = coarse dust particles.

A one-page copy of the PPE matrix was framed and prominently posted on a wall in the ECR. However, only the explanation of the table's colour-coding was included at the bottom of the page but not the other additional instructions referenced by numbers or asterisks, as these were on the next page of the procedure.

The general PPE required, according to the matrix as well as the chemicals' MSDSs, was available in the chemical store (cf. Figure 14 and 3.2.3.3). However, it was not investigated if the provided gloves were of a material suitable for working with the STP-chemicals, because the material characteristics of the gloves were not considered to be contributory to the accident or its consequences.

[52] Source: Company/operator.

3.2.4 Meteorological conditions

When the Motorman disembarked, it was partly cloudy without precipitation, and air and water temperatures were at 21 °C. In the Bay of Lübeck, a light westerly breeze (2 Bft) with gusts of 3–4 Bft prevailed. The significant wave height[53] in the area did not exceed 0.4 m. Surrounding weather stations reported good visibility of more than 17 nm.[54] The following picture was taken about one hour after the Motorman had disembarked.

Figure 16: Weather conditions in the Bay of Lübeck after the accident[55]

[53] Mean height of the upper third of all waves developing across a wider area over an extended period of time (e.g. 20 minutes).
[54] Kachelmann GmbH: Messwerte & Klimadaten Ostholstein, 05/08/2024 1000 UTC (29/08/2025); ship's logbook; pictures taken shortly after disembarkation.
[55] Source: Maritime Police Schleswig-Holstein.

3.2.5 Onboard accidents with chemicals

According to the Prevention Department of BG Verkehr (German Social Accident Insurance Institution for Commercial Transport, Postal Logistics and Telecommunication), accidents involving chemicals play virtually no role on board German ships. In the five years preceding the accident on board CORALIUS, no accident with hazardous substances had resulted in an unfitness for work of more than three days. On average there are two to three accidents with hazardous substances per year, representing less than 0.5% of the total number of accident reports received. In most cases, cleaning agents or disinfectants are involved. No specific accident hotspots have been identified. The most common causes of accidents include failure to use PPE or the use of unsuitable PPE and carelessness when handling cleaning agents and disinfectants. No incidents were recorded with regard to the storage of hazardous substances or unintended reactions of hazardous substances.[56]

A search in the European Marine Casualty Information Platform (EMCIP) produced similar results. The period between January 2020 and August 2024 was considered and entries were filtered for two types of deviation:

- “Breakage, bursting, splitting, slipping, fall, collapse of Material Agent” (387 cases), including *inter alia*:
  - Breakage of material – at joint, at seams;
  - Breakage, bursting – causing splinters (wood, glass, metal, stone, plastic, others);
- “Deviation by overflow, overturn, leak, flow, vaporisation, emission” (152 cases), including *inter alia*:
  - Liquid state – leaking, oozing, flowing, splashing, spraying.

17 accidents were found in conjunction with chemicals that were not the vessel’s cargo. The accidents happened at different locations and with different kinds of equipment and machinery on board. Five cases involved cleaning agents for various jobs. The accident on board CORALIUS was the only one involving a STP or the inadvertent mixture of two chemicals causing a reaction.

[56] Statement by BG Verkehr on 27/08/2024.

4 ANALYSIS

4.1 Overview

Upon noticing a low fill level of the STP's NaOCl dosing tank, the Motorman felt confident to refill the tank by himself. This was an unplanned job – the decision to do this was made spontaneously and none of his superiors were informed. Inadvertently and unknowingly, the Motorman obtained a different chemical, namely a 38–40% $NaHSO_3$ solution, from the chemical store. When the remaining NaOCl solution in the dosing tank mixed with the added $NaHSO_3$ solution, an exothermal chemical reaction occurred, releasing toxic gases and leading to the rupture of the plastic dosing tank. The chosen PPE did not protect the Motorman's body from coming into contact with the chemical mixture, leading to minor injuries due to chemical burns and the forceful impact of the bursting container.

This section of the report identifies and analyses factors that contributed to the accident. The emergency preparedness and actions taken by the crew are also discussed.

4.2 Non-contributing factors

After examining all available evidence and conducting further investigations and research, the following factors can be ruled out as having possibly caused, contributed to or worsened the accident and/or its consequences:

- fatigue, insufficient manning → The Motorman was well-rested at the time of the accident and in general, the vessel's manning with engine personnel allowed for sufficient rest;
- influence of alcohol, drugs or addictive substances → Based on the information available, there is no reason to assume influences of this nature;
- lack of available PPE → The PPE required for the job was available in the chemical store;
- (time) pressure → The Motorman was neither in a hurry nor otherwise under pressure to complete the job. It was neither asked nor expected of him to refill the chemicals independently;
- 38–40% $NaHSO_3$ solution on board → The higher concentration of the $NaHSO_3$ solution was not the decisive factor that led to the bursting of the dosing tank. Even the original concentration (12%) would have been sufficient for creating the same outcome.

4.3 Contributing factors

In particular, the investigation identified the following factors that (may) have contributed to the accident's occurrence or its consequences. Some of these are explained in more detail in the chapters below:

- Plant installed close to a wall and piping, not according to the manufacturer's recommendation → The dosing tanks were difficult to access and therefore had to be moved to a different location for refilling. On the one hand, the insufficient space made it more difficult to exchange the chemical containers and therefore less safe, as it was more likely for someone to bump into something and suffer bruises or abrasions. On the other, the installation made it more difficult to see the (warning) signs at the dosing tanks' holder, low above the floor;
- Necessity to pour chemicals → The design of the STP on board CORALIUS and the shape/size of its chemical storage canisters required highly reactive chemicals to be poured manually, increasing the risk of coming into contact with them;
- Insufficient awareness and lack of caution → The Motorman had not familiarised himself with the MSDSs for the STP-chemicals, the 1/E did not instruct him about the chemicals' properties or hazards, and the Motorman had not received any company training in the handling of chemicals;
- MSDSs provided not user-friendly → The multi-page MSDSs did not display relevant safety information in a clear manner and were not read by the crew, leading to unawareness of the dangers of combining both chemicals;
- Danger of mixing NaOCl and $NaHSO_3$ not identified → There was limited information/warnings in the manufacturer's manuals and at the STP dosing tanks. No problems regarding the operation of the plant or the handling of both chemicals had occurred prior to the accident;
- Colour-coding not attracting attention → The distinction of the plastic bunds underneath the dosing tanks in black and white did not catch the eye. Both dosing tanks/containers were of the same colour (white) and not colour coded correspondingly;
- Colour-coding interrupted by the use of a transfer container → By using a transfer container, the label on the chemical storage canister as well as its colour could not be compared to the signs at the dosing tanks' holder or the colour of the plastic bunds;
- PPE insufficient → When the dosing tank burst, the chosen PPE did not protect the Motorman's body from coming into contact with the chemical mixture.

4.3.1 Necessity to pour chemicals

Pouring chemicals from one container into another poses different risks of chemical exposure, such as skin/eye contact due to spilling and splashing or inhalation of released vapours and fumes. Due to several different circumstances, the STP-chemicals on CORALIUS needed to be poured from the larger container in which they were delivered into a smaller transfer container and then into the respective dosing tank:

- Other than STPs from other manufacturers, which work with chemicals in solid form, e. g. as tablets, the installed STP only works with liquid chemicals;
- The 25-litre OEM NaOCl container was too big to fit into the black plastic bund at the STP's dosing tanks' holder. Therefore, it could not act as dosing tank and the solution had to be transferred to the white plastic dosing tank delivered with the STP;
- The third-party $NaHSO_3$ solution had to be diluted manually before use at the STP, and the dimensions of its 25-litre container were not compatible with the white pastic bund at the plant, either.

In order to prevent accidents while carrying the heavy 25-litre storage canisters between two engine room decks (chemical store ↔ STP), a smaller transfer container was used instead. While this was supposed to reduce the risk of injury from loosing balance whilst carrying a heavy load, this led to new operational risks:

- The chemicals had to be poured twice, once from the storage canister to the transfer container, and again from there into the dosing tank, thereby increasing the risk of chemical exposure;
- Carrying an open transfer container through the engine room and on stairs causes an increased likelihood of spills due to stumbling or falling, and therefore an increased risk of chemical exposure;
- Using funnels and transfer containers for different chemicals presents the risk of reactions between transferred chemicals and chemical residues from previous uses if the transfer containers are not cleaned properly (This was not the case and did not influence the chain of events on board CORALIUS when the accident happened.);
- The use of a transfer container interrupted the black-and-white colour-coding scheme used on OEM chemical containers as well as the plastic bunds and signs (arrows) on the STP. This increased the risk of inadvertently mistaking one chemical for the other. Neither the labels on the storage containers nor their colours could be directly compared with the dosing tank's plastic bund and signage in order to make sure that the correct chemical had been chosen from the store. (cf. 4.3.2.4)

4.3.2 Insufficient awareness of existing risks

4.3.2.1 Low familiarity with the STP-chemicals

While the Motorman was a very experienced seafarer and generally able to carry out tasks such as refilling the STP dosing tanks, he was not very familiar with STP's working with two chemicals in their liquid form. He had received an instruction on the plant, which chemicals to use and how to refill the dosing tanks. He had witnessed this task being carried out by the 1/E but had never performed it himself. As the chemicals had not needed refilling since, he did not have the chance to gain further hands-on experience. Therefore, he was not familiar with the chemical's properties, such as colour or smell. Since the storage container's label and colour could not be directly compared to the signage and colour-coding at the STP (cf. 4.3.1 and 4.3.2.4), only recognizing the chemical itself by its properties could have alerted the Motorman to his slip. While they have different odours, both NaOCl and $NaHSO_3$ solutions have a similar colour. This could possibly have further contributed to the Motorman's mix-up.

4.3.2.2 Unknown hazards of combining the STP-chemicals

The STP-manual warns plant users to perform a risk assessment and produce a method statement prior to installing the chemical tanks. (cf. 3.2.3.4.2) This was not carried out, however. According to the company/operator, it is not normal for equipment manufacturers to dictate what to include in the SMS. Neither crew nor company/operator were aware of the manufacturer's recommendation.

Neither the Motorman nor the engineers on board were aware of the hazards involved in mixing the NaOCl and $NaHSO_3$ solutions. This led to an insufficient awareness of the existing risks and the importance of making sure that the correct chemical is used for refilling a dosing tank. There were limited information/warnings in the STP-manual. On site, the warning phrase "contact with acids liberates toxic gas" was posted for both substances. To process this warning and its implications, knowledge about the pH-value of each chemical would have been required. Therefore, reading the MSDSs would have been necessary, as chemicals were not marked or separated according to pH-value or other properties in the chemical store. From the MSDSs, a user might have concluded that mixing both chemicals would lead to the formation of gas, since the $NaHSO_3$ solution is slightly acidic. However, neither the intensity of the reaction, nor the resulting amount of gas, nor the subsequent bursting of the dosing tank could have been anticipated from the provided information. Additionally, support-level crew cannot be expected to have this kind of knowledge or be able to make conclusions of this nature with the given chemical information. The same is true for anybody in an inattentive mindset.

A warning of the hazards of mixing both chemicals should have been brought to the crew's attention through the STP-manual or signs at the plant. This may have prompted the crew to be more cautious when handling either chemical. Furthermore, safety information should be provided in a user-friendly format. Long MSDSs with different layouts discourage users from consulting them.

4.3.2.3 Insufficient PPE

The Motorman was not aware of the required PPE to be worn when handling the STP-chemicals. He could have obtained this information from the

- company PPE matrix (cf. Table 1) in the ECR,
- MSDSs from both chemicals located in a folder in the chemical store and
- mandatory action symbols on the STP and the signs on the dosing tanks' holder.

All these sources were accessible and known to him.

Table 2: Comparison of PPE requirements

	Boiler suit	Safety shoes	Helmet	Ear protection	Goggles	Gloves	Chemical suit	Visor / face shield	Breathing protection	Warning signs
Company PPE matrix										
MSDS NaOCl solution					1	*		2	1 **	
MSDS $NaHSO_3$ solution						*			**	
Mandatory action symbols										

protective equipment to be used at area/task: at all times / as required / either 1 or 2

* PVC or rubber gloves are suitable; ** in case of insufficient ventilation.

Table 2 lists combined PPE requirements from different sources for handling the STP-chemicals in a well-ventilated environment. These are protective work clothing (boiler suit, safety shoes, helmet), ear protection, tightly fitting goggles and/or face shield and PVC or rubber gloves.

The company PPE matrix did not give clear instructions for handling corrosive chemicals. The most relevant items on the list for the job of refilling an STP dosing tank were “chemical store handling” and “machinery space work”. It was left to the person performing the job to decide whether additional PPE such as gloves, a chemical suit or a visor were necessary. This information could be obtained in each chemical’s MSDS.

Information on PPE contained in Section 8 of the MSDSs was not easily accessible and unclear. While the documents were available in a folder in the chemical store, they were very comprehensive with many pages of small text and information on other topics besides PPE requirements. Furthermore, in the OEM chemical MSDS for the NaOCl solution, it is ambiguous if safety glasses or goggles can be substituted with a face shield.

Eye protection:

Chemical goggles or face shield. Safety glasses

Type	Use	Characteristics	Standard
Safety glasses	If there is a risk of liquid being splashed : To protect against splashes from pouring	With side shields	EN 166
Safety goggles	If there is a risk of liquid being splashed : To protect against splashes from pouring	tightly fitting safety goggles	EN 166

Figure 17: Eye protection requirements for NaOCl solution in OEM chemical MSDS[57]

Additionally, the above PPE requirements differed slightly from the information given in the International Chemical Safety Card (ICSC) (cf. 3.2.3.2.1). The ICSC gives the option to either wear goggles in combination with breathing protection or a face shield if breathing protection is not necessary.[58]

The mandatory action symbols on the STP were clearly visible, but on the opposite side of the plant from the dosing tanks. The symbols on the signs at the dosing tanks were not clearly visible due to their location near the floor and close to a wall/piping. Neither signage included a mandatory action symbol for wearing a visor.

[57] Source: WÄRTSILÄ: *B18013, Sodium Hypochlorite 14 - 15% – Safety Data Sheet*, Version 1.5, revision date: 01/11/2022. p. 5.

[58] ILO ; WHO: *ICSC 1119 – SODIUM HYPOCHLORITE (SOLUTION, ACTIVE CHLORINE >10%)*, 2017 (24/01/2025).

The Motorman had chosen to use a visor instead of googles in order to protect a larger area of his face. Since the face shield was open to the sides, chemicals were still able to reach his eyes and face when he was standing laterally to the bursting canister as the reaction occurred. While the gloves chosen were not penetrated by the spilled chemical mixture, they were too short to protect the skin on the Motorman's lower forearm. Due to the amount of liquid spilled when the dosing tank burst, his boiler suit was soaked with the chemical mixture so that it came into contact with his skin.

A chemical suit would have been necessary to fully protect the Motorman from the splashing chemicals. His boiler suit would have only been able to protect the skin from smaller splashes occurring during the decanting. The possibility of a violent reaction and the extent of the spill was not foreseen (cf. 4.3.2.1). Additionally, the MSDSs only refer to the substance for which they were created. Hazards from combining two different chemicals are not considered and may be greater than the risks associated with the individual handling of each chemical. Therefore, a chemical suit was not considered to be required.

4.3.2.4 Missing, inconspicuous or obstructed visual indications

It is unclear what led to the Motorman's slip in retrieving the wrong chemical from the store. Not being very familiar with the chemicals' properties and hazards (cf. 4.3.2.1) or an inattentive mindset may have contributed to his error, in combination with missing, inconspicuous or obstructed visual indications. Any or a combination of these reasons may have led to his accidental mix-up going unnoticed until both chemicals were combined and reacted violently. Specific safety barriers that were supposed to prevent such a mix-up (colour-coding, signage) were in place but proved to be ineffective due to the following factors:

- Colour-coding inconspicuous – Black and white are neutral colours with minimal visual impact, making it more difficult to instantly recognize important information or hazards. The colouring of the engine room is dominated by light grey, white and black (cf. Figure 13). Striking, bright colours would be more effective as they provide a more apparent visual distinction and contrast compared to the STP's surroundings;
- Colour-coding interrupted by transfer container – The labels on the storage containers as well as their colours could not be directly compared with the dosing tank's plastic bund and signage to ensure that the correct chemical was taken from the store (cf. 4.3.1). The transfer containers were used universally and there were no designated black and white transfer containers for the STP-chemicals;

- Colour-coding disrupted by third party chemicals – Storage canisters of third-party chemicals do not follow the STP's manufacturer's colour scheme. This was also the case on board CORALIUS where the $NaHSO_3$ solution was delivered in a bright green canister;
- Plastic bunds not very visible – As the STP was installed very close to a wall/piping, the person refilling the dosing tanks stands to the side of, but not directly in front of them. This means that the plastic bunds and their different colouring were not immediately visible (cf. Figure 13). Additionally, only the bunds had different colours but not the white ten-litre dosing tanks supplied by the STP's manufacturer. This may contribute to the colour-coding remaining unnoticed;
- Signage at dosing tank holder not immediately visible – The STP's position near a wall/piping affected the visibility of the signs mounted to the front of the dosing tanks' holder near the floor. This obstructed the view of the colour-coded arrows as well as the chemical's names and respective safety information.

4.4 Additional observances

Additional to the factors contributing to the accident described above, the following safety-relevant observations were made during the investigation:

- chemicals not separated in the chemical store → Chemicals with different properties (e. g. pH-values, flammability, etc.) should be stored separately in order to avoid hazardous reactions and/or the formation of dangerous products, to prevent cross-contamination and for easier access. As crew members should be familiar with the properties of chemicals to be used, a separated storage can make it easier to find chemicals and reduce the risk of mistakes or confusion. E. g. oxidizing agents should be kept separate from flammable substances, acids should be separated from bases, and toxic/harmful substances should be kept in separate, designated and secured areas.
- company/operator not informed about new STP signage and manual by STP manufacturer → While lessons were learnt and changes initiated for a safer operation of this type of STP (cf. 6.2), these lessons and changes were not shared with operators of existing STPs. It is not normal industry practice for the manufacturer to service installed STPs on board vessels. Therefore, it is unlikely that other users would find out about the dangers identified on CORALIUS or the consequently updated signage.

4.5 Emergency response management

The crew's response to the emergency evolved in several stages. The immediate reaction of the Motorman was to flee from the engine room's platform deck to the workshop in order to rinse his eyes using a designated eyewash bottle, and to take off contaminated clothing to rinse remaining chemicals from his body. This was the appropriate reaction to minimize the chemicals' effect on his body, because self-protection takes priority – especially if the affected person is also exposed to toxic gas.

While initial confusion about the cause of the incident delayed the identification of the chemical hazard, the crew quickly adapted to the evolving situation. The C/E's decisive actions in attempting to investigate the engine room and assist the injured Motorman together with the 1/E showed a strong sense of responsibility.

However, the initial misinterpretation of the source of the loud bang at 1047 delayed the full recognition of the hazardous situation. Although an injured crew member was known to be on board, the decision was made to depart the port before having consulted with the TMAS. This decision might have been influenced by the Captain's impression that berth access was restricted to LNG vessels by the port authority, as well as an uncertain assumption that a medical evacuation was not required. Shifting to another berth for the casualty's evacuation was not considered and therefore not requested.

Upon the BSU's request, the port authority stated that there are no safety regulations preventing an LNG tanker from disembarking an injured person in an emergency. On the day of the accident, there would have been a suitable berth available for CORALIUS at Skandinavienkai, where the casualty could have been handed over to the emergency services. As the vessel was manned by a pilot during the bunkering process and would only have had to move a short distance, this would have been the quickest option for a medevac.

The communication between the bridge, engine room, and external parties (VTS, JRCC, pilot, TMAS) was calm, structured and generally effective, although some initial misunderstandings regarding the involved chemicals caused a slight delay in the evacuation decision. The collaboration between the crew and the pilot was essential, and the decision to evacuate via the pilot boat rather than a helicopter was sound, as it minimized the further delay in getting the Motorman ashore.

The evacuation of the Motorman via the pilot ladder, although initially discussed with some concern and probably not the safest way given the Motorman's physical condition, was ultimately a successful solution. A complete assessment of his ability to climb the ladder should have been conducted, with more emphasis on his medical symptoms, including the numbness in his hand. The injured person was additionally secured against falling while climbing down the pilot ladder, so that preventive measures were taken even for a sudden deterioration in the injured person's condition.

The pilot had the impression that the additional safety measure somewhat hindered the Motorman’s descent, as the safety line inevitably got in his way when climbing and restricted his freedom of movement, especially when changing grip with his hands. However, in the pilot’s opinion, the descent was generally successful and safe. Had there been a higher sea sate, the safety line could have posed a greater risk to the Motorman. A ship and a pilot boat are two systems that move independently from one another and at different speeds and intensities. It would be dangerous to be attached to either of them while transferring in heavier seas, as there would be no guarantee that the person would be released from the safety line at the exact moment they transferred. The transfer always takes place when the pilot boat is at the crest of a wave. A transfer is relatively spontaneous, and as soon as the boat drops back into the next trough, a person who has not been released in time would be suspended between the vessels.

A notable positive aspect was the pilot’s decision to photograph and relay the material safety data sheets (MSDS) of the chemicals involved. This proactive measure ensured that the emergency medical services were well-prepared for treating the chemical burns when the Motorman was transferred ashore. The pilot noted that copies of the MSDS would have been useful to make available to other treating physicians. By handling the handover of the casualty to the emergency services, the pilot avoided any misunderstandings between the Motorman and the emergency personnel that could have arisen due to language difficulties.

5 CONCLUSIONS

5.1 Cause of the accident

The bursting of the NaOCl dosing tank and subsequent injury of the Motorman was caused because while he intended to obtain NaOCl from the chemical store, he inadvertently took $NaHSO_3$ solution instead. This unintended, attention-based execution error (slip) went unnoticed until both chemicals mixed in the NaOCl dosing tank and reacted violently, leading to its bursting as it was made of plastic.

In the previous chapters, factors contributing to the occurrence as well as consequences of the accident were described. Additionally, one safety-relevant observance was made. This led to the identification of the following safety issues and lessons learned.

5.2 Safety issues and lessons learned

5.2.1 STP design required pouring of chemicals

- When dangerous chemicals/substances have to be refilled, engineering controls should be put in place to isolate operators from the dangers posed by these substances if the hazard cannot be otherwise reduced or removed. – Manual pouring of chemicals should be avoided at the design stage, as such a practice increases the risk of coming into contact with them. It is preferable to replace chemical containers directly at the plant in order to avoid pouring.

5.2.2 Restricted access to STP due to installation near a wall

- When planning the layout of an engine room, the installation instructions of equipment manufacturers as well as operational considerations should be taken into account in order to allow for sufficient space during regular maintenance. – After a newbuilt ship is commissioned, changing the position of plants in the engine room is rarely feasible.

5.2.3 Inadequate safety information management and unidentified risks

- Before and when installing, commissioning and operating a piece of equipment, the manufacturer’s instructions should be observed, as they may contain important safety information. – There might be hidden risks that are not easily identified which should be mitigated and included in the operators’ safety management system.

- Existing safety barriers should be (regularly) evaluated as to their effectiveness, especially when operating conditions change. – Signage, labelling or colour-coding can only be effective measures when easily seen and not visually obstructed, inconspicuous, or interrupted in any way.

- Where multiple dangerous chemicals/substances are used/have to be refilled in close proximity or at the same piece of equipment (such as an STP or potable water generator), the holding vessels/tanks, holders, bunds, etc. of each substance should be marked by signage and other visual indications such as a distinctive colour-coding. – Appropriate measures should be taken in order to minimize the risk of accidently mixing up dangerous substances.
- If a piece of equipment requires different chemicals/substances that pose a danger when coming into contact with each other, operators should be warned about the consequences of mixing both substances. – Hazards from combining two different chemicals may be greater than the risks associated with the individual handling of each chemical. This might require increased caution and PPE when handling each substance in proximity to the other.
- Whether in safety management documents, MSDSs or other instructions, safety-relevant information and requirements should be presented in a user-friendly, clear, concise and unambiguous format to encourage personnel to consult it before performing a job. – MSDSs should be clear and concise and can be supplemented with a summary containing the most important information for all chemicals on board and their daily handling.
- When it is necessary to use transfer containers for carrying/refilling substances, these containers should be included in a colour-coding scheme if such a scheme exists. – If the colour-coding is interrupted, it loses its full effectiveness, as the colours cannot be directly compared. Additionally, designated transfer containers and funnels reduce the likelihood of chemical reactions occurring due to residues inside multi-use appliances.
- If safety-critical observances are made by an equipment manufacturer or brought to their attention (e. g. pertaining to lessons learned from accident investigations) and/or if changes are made to safety information or signage, the manufacturer should endeavour to inform clients that have purchased affected equipment in the past. – Operators of the equipment should be informed in order to take lessons learned and recommendations into account during daily operations, and/or upgrade their equipment with safety-relevant engineering controls to reduce operational hazards.

5.2.4 Spontaneously carrying out an unplanned job

- Before (spontaneously) carrying out an unplanned job, a risk assessment should be conducted in order to be able to take appropriate safety measures. – When working with or handling chemicals, this includes consulting the MSDS or other specific information on the substance’s properties and hazards, as well as PPE requirements.

5.2.5 Misconception regarding protection by PPE

- Chemical goggles should even be worn when using a face shield. – When it comes to protecting the eyes, a visor is not superior to tight-fitting chemical goggles or safety spectacles with side shields. Because it is usually open to the sides, splashes can reach the eyes and face when coming from the side rather than the front. Wearing a visor for full face protection, in addition to safety googles or spectacles, can nonetheless make sense.

5.2.6 Obtaining concentrated dangerous chemicals

- Dangerous chemicals should be obtained in the desired concentration in order to avoid the necessity of dilution. – Manual dilution creates additional risks for human errors and for contact with concentrated chemicals when pouring them.

5.2.7 Emergency response management

- If an incident or accident occurs shortly before departure, thoroughly investigating the consequences of the occurrence (injuries, damage) should take priority in order to evaluate if the departure should be postponed because machinery has to be repaired or casualties have to be disembarked. – Only minor injuries can confidently be treated with the resources available on board a cargo ship and technical failures can pose an increased risk during manoeuvring in port areas.

- In the event of an occupational accident involving chemicals, a copy of the MSDSs of all involved chemicals should be provided to the emergency services when handing over the casualty. – MSDSs provide valuable information for the treatment of injuries caused, especially if the affected person is unable to give a detailed account on what happened or which exact substances were involved.

6 ACTIONS TAKEN

6.1 Company/operator and crew of CORALIUS

6.1.1 New signage and replacement of damaged equipment

Shortly after the accident, the names of the substances and the risk phrases posted at each tank were moved up to be visible in the normal line of sight. The dosing tanks, the connections, the dosing pumps as well as the holder of the plastic bunds were marked with the name of each required chemical to clearly identify the related system components. These labels were initially all yellow with black writing.

Figure 18: Highlighted changes of signs and labels[59]

[59] Source: BSU, picture taken on 19 August 2024.

Additionally, a notice was posted with a warning/information regarding risk of violent reaction if mixing these substances.

Figure 19: Warning sign above the dosing tanks[60]

As an interim solution, the OEM NaOCl container acted as dosing tank (cf. Figure 18 and Figure 19). Later on, a new white 10 l dosing tank and a new black plastic bund supplied by the manufacturer were installed. Additionally, the labels for all system components related to NaOCl were changed to white with black writing, introducing a clearer differentiation between the components related to each chemical.

After the BSU informed the operator of CORALIUS about the latest signage supplied by the STP's manufacturer (cf. 6.2.3), the signs highlighted in Figure 18 were updated to the latest version in December 2025. Furthermore, additional mandatory action signs were posted on the plant.

[60] Source: BSU, picture taken on 19 August 2024.

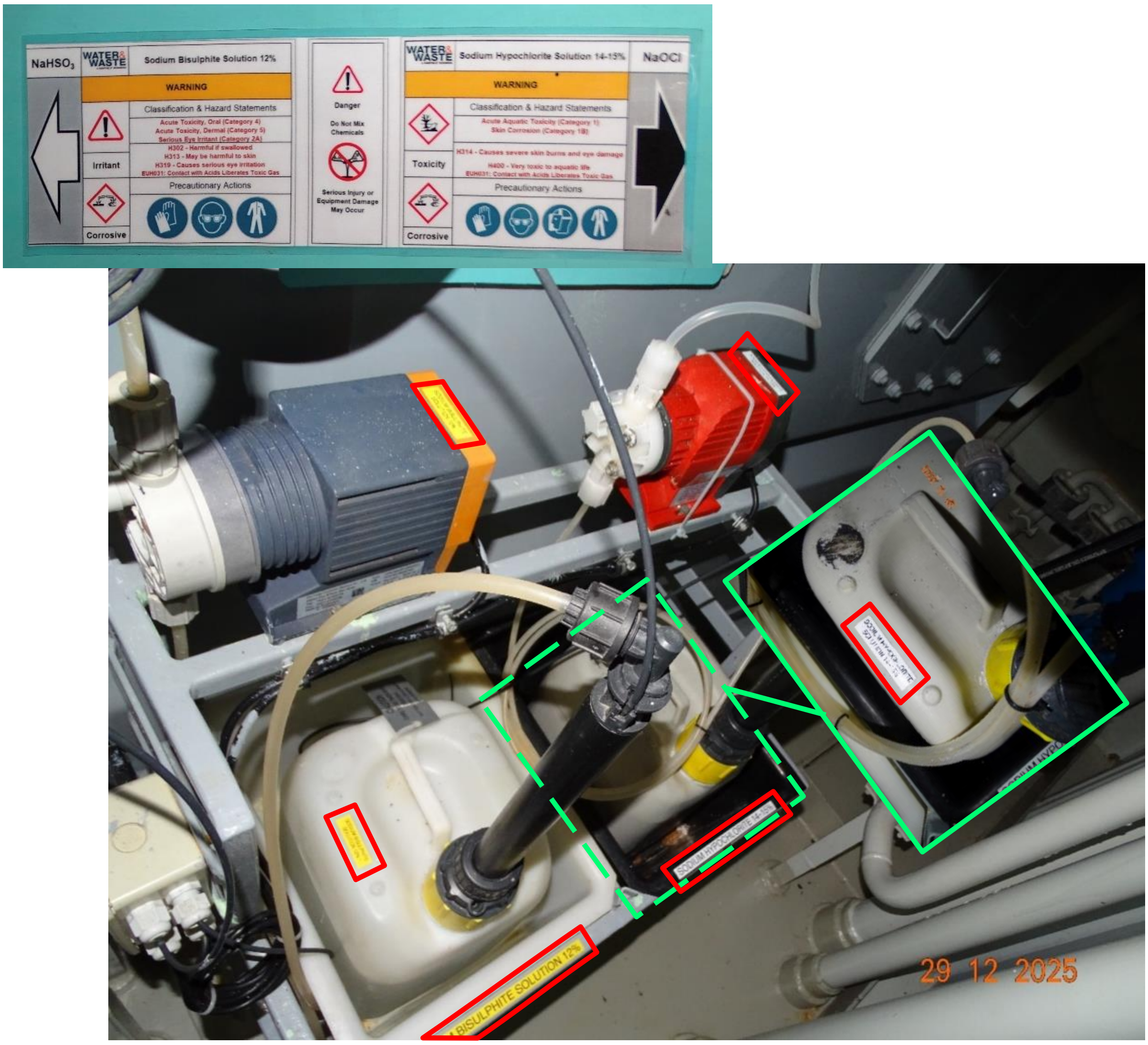


Figure 20: Latest signage and labelling, new dosing tank and bund[61]

For detailed depictions of the new signs above the dosing tank's holder, see Figure 23 and Figure 24.

[61] Source: Maritime Police Schleswig-Holstein, pictures taken on 29 December 2025.

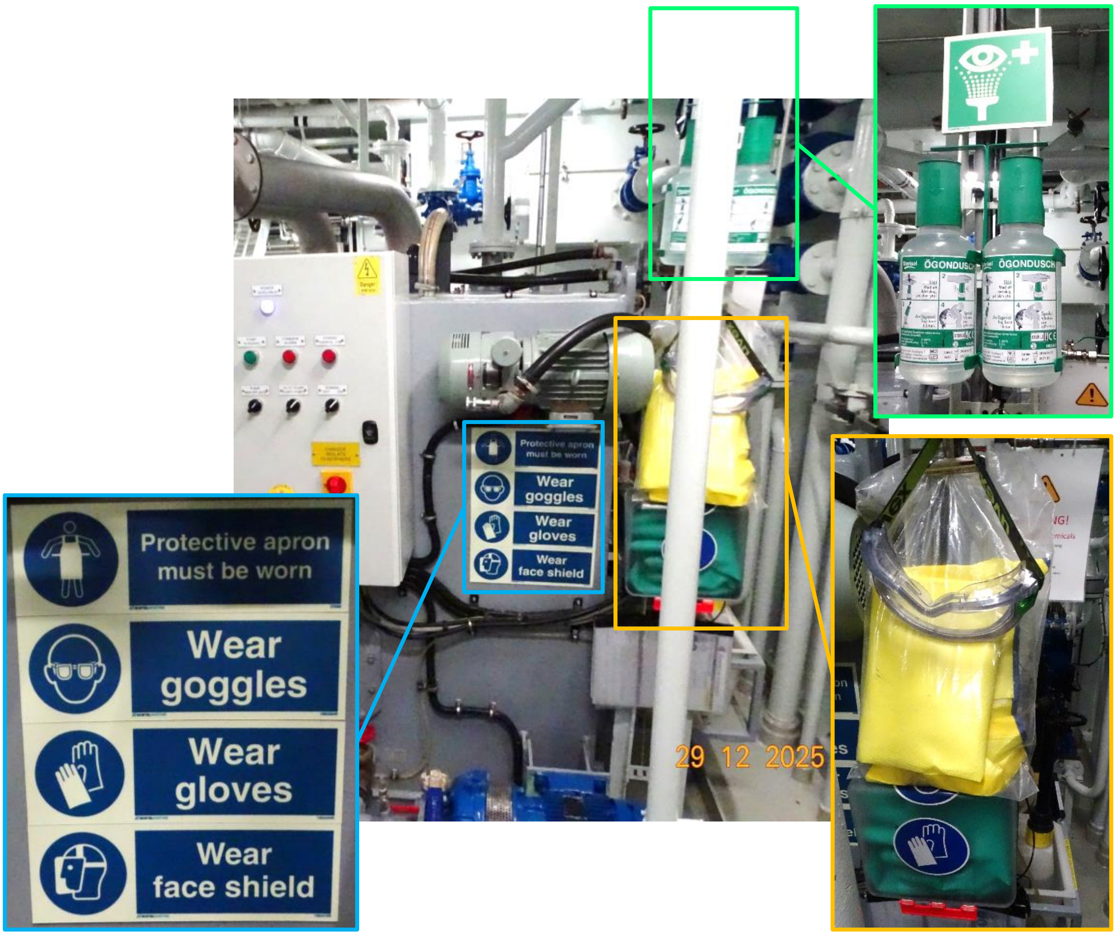


Figure 21: New mandatory action signs, PPE and emergency equipment[62]

6.1.2 Additional PPE and emergency equipment

Shortly after the accident, additional protective equipment, consisting of long chemical gloves and closed goggles, was provided and is now permanently stored on the plant, as can be seen in Figure 13 (cf. 3.2.3.1.2). During an examination of the situation on board in December 2025, it was noted that additional PPE (chemical apron, face shield) as well as two new eyewash bottles had been installed (see Figure 21 in 6.1.1).

6.1.3 New management system for chemicals

A new system for the documentation, management and risk assessment of the chemicals on board, supplied by the Swedish company *cDOC AB*, was implemented. This includes, *inter alia*

- a risk assessment of all chemicals on board including information on required PPE,
- additional labels for all chemical storage containers with the chemical's name and sorting category as well as mandatory action symbols for required PPE,

[62] Source: Maritime Police Schleswig-Holstein, pictures taken on 29 December 2025.

- segregation and labelling of chemicals by their properties on the shelves inside the chemical store,
- a one-page MSDS summary for each chemical,
- a PPE guide including information on which chemical gloves to use,
- safety information for the complete inventory of chemicals, supplied both in the chemical store and in an information portal, which can be accessed by all crew members (including mobile access, e.g. by tablet or smartphone).

6.1.4 Updated PPE matrix

The PPE matrix in the company's SMS was updated. It now includes a new column on cDOC recommended PPE as well as measures to roping off a worksite and performing a lockout/tagout[63] procedure. There are also new rows for work involving corrosive or poisonous chemicals and work on pressurized liquid systems. An extract of the updated matrix can be found below, changes are marked in blue.

Table 3: Extract of updated PPE matrix[64]

	Boiler suit	Safety shoes	Helmet	Ear protection	Harness	Goggles[1]	Gloves	cDOC recommended PPE	Visor	Fall arrestor	Floating aid	Breathing protection	Roping off worksite	Lockout/Tagout	Drain/Vent	Work permit	Gas detector
Machinery space work	at all times	at all times	as required	at all times		as required	as required										
Work involving corrosive/poisonous chemicals	at all times	at all times	as required			at all times	at all times	at all times	at all times			as required			as required		as required
Pressurized liquid system work	at all times	at all times	as required	as required		at all times	at all times		as required				as required	as required	as required		

■ at all times — protective equipment/precaution to be used at area/task

■ as required — protective equipment/precaution to be used at area/task as required – regarding use of chemicals PPE to be used in accordance with cDOC system General Risk Assessment Protective Equipment

[1] Goggles used onboard shall minimum comply with following marking of the frame: 3 = liquids and 4 = coarse dust particles

[63] LOTO – safety procedure used to ensure that dangerous equipment is shut off and not started up again prior to the completion of maintenance or repair work; lockout: physically locking isolated power sources or other isolated equipment to prevent unintended start-up; tagout: tagging/labelling power/operating switches to inform users of ongoing work and isolation of the equipment.

[64] Source: Company/operator.

6.1.5 Risk assessment, fleet directive and training

After the company/operator became aware of the recommendation for a risk assessment in the STP manufacturer's manual, such a risk assessment for handling STP-chemicals and dosing tanks was created in late 2025. All identified risks were considered to be low after mitigation through the defined actions.

In order to raise awareness of the dangers involved in handling the STP-chemicals as well as necessary precautions, the company's internal investigation report of the accident has been shared across the company fleet as a fleet directive. Additionally, an onboard chemical spill training and drill has been carried out in order to familiarise the crew with their emergency duties.

6.2 Manufacturer of the STP

6.2.1 OEM chemical supply and STP-design

CORALIUS' operator and the STP's manufacturer *Wärtsilä* carried out a joint evaluation whether the used substances could be substituted with less dangerous chemicals. This was declined because changing the chemicals would impact the performance of the plant and invalidate its type approval.

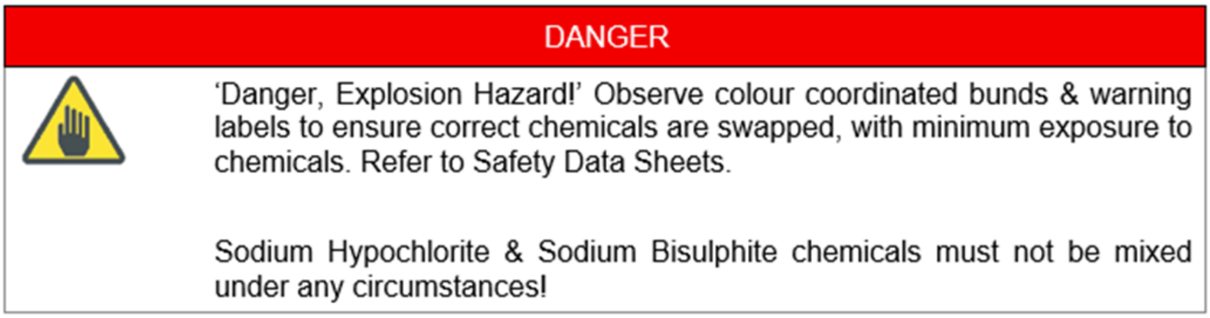
However, it was confirmed that OEM chemicals are now supplied in different 25-litre storage canisters that fit directly inside the black or white plastic bunds on larger STPs (ST04 and up), so that they may be swapped like for like. This eliminates the need of pouring the chemicals and reduces the risk of exposure during transfer. The storage canisters can now act as dosing tanks, with the dosing tubes being the only likely exposure to the chemicals during the transfer.

After additional review, since this solution only works on larger STPs, the plant's manufacturer decided to further change the 25-litre OEM chemical containers to white/black 20-litre containers that will fit <u>all</u> STP variants/models. In order to ensure that a like-for-like change of chemical containers can be achieved, bund sizes will also be increased on the smaller STP range to accommodate the 20-litre containers. Empty ten-litre containers will no longer be supplied with new plants to discourage the decanting of chemicals.

Furthermore, CORALIUS' company has reported that there are no more difficulties with the delivery of OEM chemicals.

6.2.2 STP-manual

The following warning has been included in an updated version of the STP-manual in order to bring attention to the danger of mixing NaOCl and $NaHSO_3$.


DANGER

'Danger, Explosion Hazard!' Observe colour coordinated bunds & warning labels to ensure correct chemicals are swapped, with minimum exposure to chemicals. Refer to Safety Data Sheets.

Sodium Hypochlorite & Sodium Bisulphite chemicals must not be mixed under any circumstances!

Figure 22: Updated warning in STP-manual[65]

6.2.3 STP-signage

Following further review in connection with the accident on board CORALIUS, the signage at the chemical dosing containers was updated. The following main changes were implemented:

- reintroduction of the EUH031 statement "Contact with acids liberates toxic gas";
- reintroduction of the black/white colour-coded arrows;
- reintroduction of mandatory action symbols instead of written directions for precautionary actions;
- new central sign with pictograms and written warnings about the dangers of mixing both chemicals.

[65] Source: STP manufacturer.

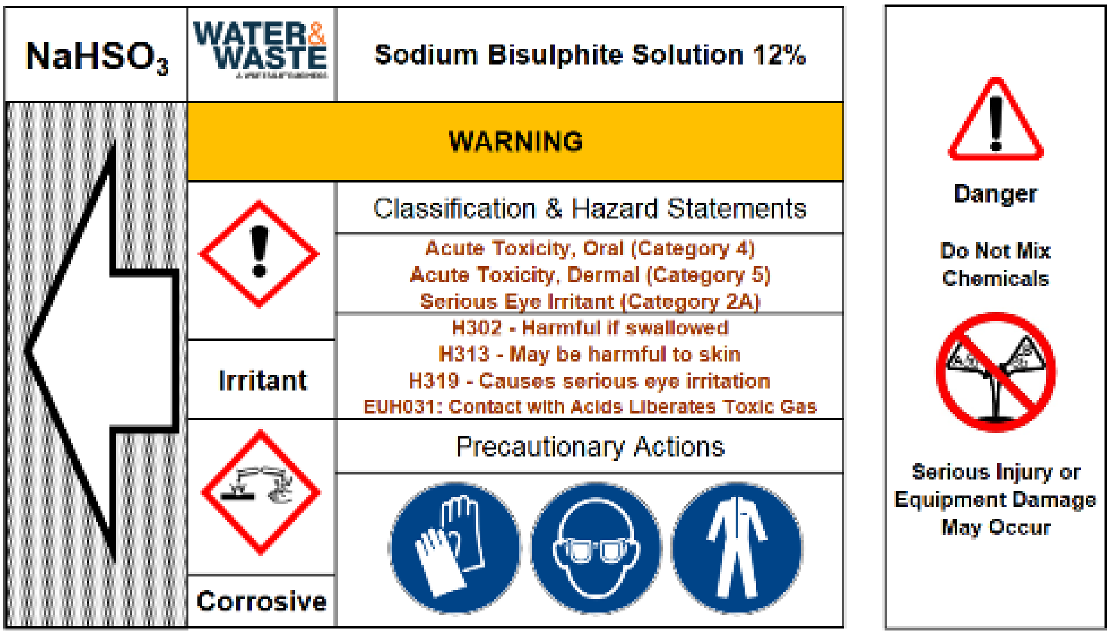


Figure 23: Updated signs at STP dosing tanks (2025), lefthand and central sign[66]

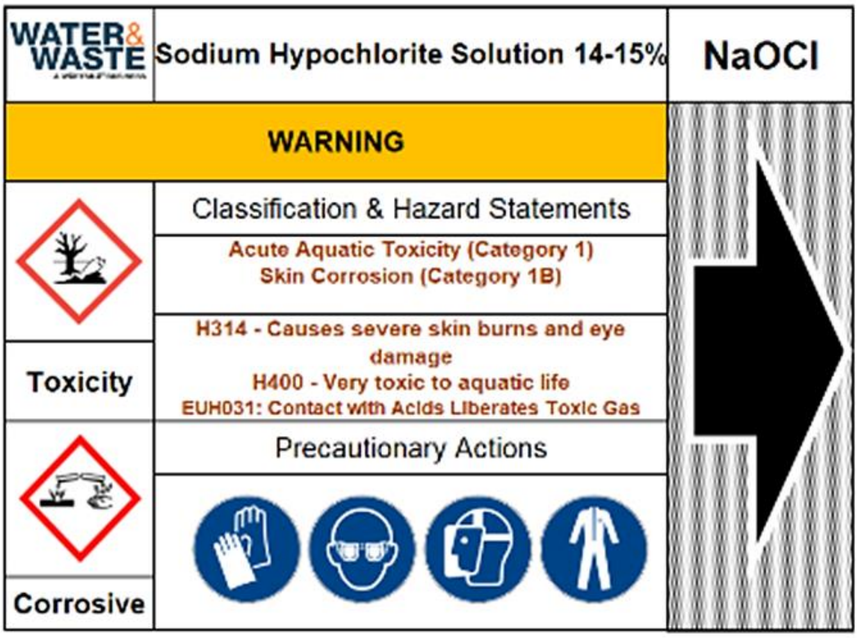


Figure 24: Updated signs at STP dosing tanks (2025), righthand sign[67]

[66] Source: STP manufacturer.
[67] Source: STP manufacturer.

7 SAFETY RECOMMENDATIONS

The following safety recommendations do not constitute a presumption of blame or liability in respect of type, number or sequence.

7.1 Wärtsilä Water Systems Ltd

The Federal Bureau of Maritime Casualty Investigation recommends that the STP's manufacturer, *Wärtsilä Waster Systems Ltd*,

.1 inform other customers of sewage treatment plants about updates to the Installation, Commissioning, Operating and Maintenance Manual as well as the signage on the plant.

.2 publish/distribute a safety notice about this accident and the danger of mixing both chemicals to their customers.

.3 choose more obvious colour-coding in the future.

7.2 International Labour Organization (ILO), World Health Organization (WHO) and European Commission

The Federal Bureau of Maritime Casualty Investigation recommends to the consortium of scientists from specialized scientific institutions concerned with occupational safety and health preparing and peer-reviewing International Chemical Safety Cards (ICSCs) as common undertaking between the ILO, WHO and European Commission to no longer give the option to substitute chemical goggles with a visor/face shield. When it comes to protecting the eyes, a visor is not superior to chemical goggles or safety spectacles with side shields, as chemical splashes can reach the eyes and face when coming from the side rather than the front, as demonstrated by this accident.

8 SOURCES

- Witness testimony from persons involved in the accident and emergency response
- Bridge audio data from the vessel's voyage data recorder (VDR)
- Data on vessel movements in the Bay of Lübeck (*MarineTraffic.com* and SEG (SafeSeaNet Ecosystem Grafic User Interface by EMSA)
- Company's internal investigation report
- Situation and progress log of Vessel Traffic Service centre Travemünde
- Operator log and audio recording by Swedish JRCC, with support of the Swedish Accident Investigation Authority (SHK) through explanation and translation
- Statements made in writing or by telephone:
  - Operator
  - Crew
  - Pilot
  - Manufacturer of the sewage treatment plant
  - Berufsgenossenschaft Verkehrswirtschaft Post-Logistik Telekommunikation (BG Verkehr), Prevention Department
- Navigational Chart: Federal Maritime and Hydrographic Agency (BSH)
- Various national and international pieces of legislation, standards and guidelines identified and explained in the text and/or in footnotes
- Internet and literature sources identified accordingly as footnotes