HARMFUL AQUATIC ORGANISMS IN BALLAST WATER

Application for Basic Approval of the ECOLCELL BTs
Ballast Water Management System

Submitted by Italy

SUMMARY

Executive summary: This document contains the non-confidential information related to the application for Basic Approval of the Azienda Chimica Genovese ECOLCELL BTs Ballast Water Management System in accordance with the Procedure for approval of ballast water management systems that make use of Active Substances (G9) adopted by resolution MEPC.169(57). The document contains a summary for translation purposes.\(^1\)

Strategic direction: 7.1

High-level action: 7.1.2

Planned output: 7.1.4

Action to be taken: Paragraph 10

Related documents: BWM/CONF/36; BWM.2/Circ.13/Rev.1 and BWM.2/Circ.47

Introduction

1 Regulation D-3.2 of the International Convention for the Control and Management of Ship’s Ballast Water and Sediments, 2004 stipulates that ballast water management systems that make use of Active Substances to comply with the Convention shall be approved by the Organization.

2 The Procedure for approval of ballast water management systems that make use of Active Substances (G9) stipulates the information to be submitted (resolution MEPC.169(57), annex 1, paragraph 4.2.1) and risk characterization and analysis to be conducted (resolution MEPC.169(57), annex 1, section 5), which according to section 6 of Procedure (G9),

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\(^1\) This document is over 20 pages long and, in accordance with paragraph 6.11 of the Committees’ Guidelines (MSC-MEPC.1/Circ.4/Rev.2), only the first three pages will be translated into the three working languages, with the annex in English only.
should be evaluated by the Organization. In accordance with BWM.2/Circ.13/Rev.1, the annex of this document contains the non-confidential part of the manufacturer's application dossier.

3 The receiving competent authority in Italy has verified the application dossier and believes it to satisfy the data requirements of Procedure (G9) adopted by resolution MEPC.169(57).

4 In accordance with BWM.2/Circ.47, Italy submits the non-confidential part of the manufacturer's application dossier in the annex hereto. The complete application dossier will be made available to the experts of the GESAMP-BWWG with the understanding of confidential treatment.

5 This Basic Approval application deals with the Azienda Chimica Genovese ECOLCELL BTs Ballast Water Management System.

**Summary of non-confidential information and technical description of the Azienda Chimica Genovese ECOLCELL BTs Ballast Water management System.**

6 Azienda Chimica Genovese (ACG), since 1947, has been providing solutions to the problems of marine fouling and marine corrosion for all types of vessels (from yachts, tankers, cruise ships to FPSOs). ACG supplies electrochlorination systems (ECOLCELL R) designed to control marine fouling where seawater is used as the process or cooling medium.

7 ACG has developed the ECOLCELL BTs system, using the technology of ECOLCELL R, and it has been developed to produce the proper sodium hypochlorite concentration to completely eliminate aquatic invasive species in large volumes of ballast water. The system has been designed to offer a minimum dosing of NaOCl related to the amount of ballast water to be treated. This operation is made using a special electrochemical control loop. ACG has a large experience in marine growth control in seawater cooling and other systems on board every kind of ship, in the disinfection of public swimming pools, cooling towers and wastewater treatment plants, based on Oxidation Reduction Potential (ORP). This is applied to the logic control of ECOLCELL BTs to regulate the parameters of the system in order to guarantee the effectiveness of the treatment, minimizing its environmental impact.

8 The ACG ECOLCELL BTs consists of the following main process:

1. filtration to remove some phytoplankton, zooplankton and larger sediments;

2. production of the disinfectant/biocide from seawater: the biocide is mainly a sodium hypochlorite solution produced through electrolysis, using special titanium cells;

3. disinfection: the biocide is injected into the ballast water tanks using the ORP control logic; and

4. neutralization at discharge, in order to obtain the residual total residual oxidant (TRO) at 0 ppm during de-ballasting.

9 The ECOLCELL BTs logic control regulates the system parameters in order to guarantee the effectiveness of the treatment, minimizing its environmental impact. The laboratory tests showed an excellent effectiveness in killing living organisms present in
the seawater before the treatment. This final result was obtained with low by-product disinfection. ACG worked on this project in compliance with regulation D-2 of the IMO Ballast Water Management (BWM) Convention and ECOLCELL BTs will meet the standards and procedures of the Guidelines for approval of Ballast Water Management Systems (G8) and will comply with the Procedure for approval of ballast water management systems that make use of Active Substances (G9).

**Action requested of the Committee**

10 The Committee is invited to consider the proposal for approval and decide as appropriate.

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**Note:**

In accordance with the decision of MEPC 63 (MEPC 63/23, paragraph 2.18), only the cover note is printed and distributed in hard copy. The full document (cover note and annex) is available electronically through IMODOCS.
ANNEX

NON-CONFIDENTIAL INFORMATION ON THE ECOLCELL BTs
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1 INTRODUCTION

1.1 From ECOLCELL R to ECOLCELL BTs: a natural evolution

The ACG ECOLCELL BTs Ballast Water Management System (BWMS) uses well-known technology to oxidize and disinfect aquatic invasive species (AIS) with sodium hypochlorite (NaOCl). NaOCl, a chlorine compound, has been utilized for many years to prevent marine fouling growth in seawater cooling circuits and heat exchanger systems, oil-platforms and shipboard installations. The most efficient method is the production of sodium hypochlorite as a biocide, in situ from seawater, via electrolysis, using an electrolytic generator; the produced NaOCl is injected into seawater intakes, without the handling of any chemical substance.

1.2 The ECOLCELL R System produces sodium hypochlorite

This technology is known in the worldwide shipping industry under the trade name ECOLCELL R. Azienda Chimica Genovese (ACG) is a leading supplier of electrochlorination systems designed to control marine fouling where seawater is used as the process or cooling medium. ACG has a Hi-Tech department with skilled senior engineers who perform R&D and technological experimentation to provide innovative solutions. Since 1947, ACG acquired experience through worldwide shipboard installations of ECOLCELL R that have allowed ACG to evolve the ECOLCELL R into the ECOLCELL BTs BWMS. The ECOLCELL BTs System has a lot of peculiar characteristics of design and it is based upon the electrochlorination System ECOLCELL R, developed for preventing the blocking up of the seawater main cooling circuits in every kind of ship and coastal installation, such as steel mills, refineries and power stations.

The marine fouling control, by means of the ECOLCELL R technology, has become very popular in the shipping industry, since the treatment can be carried out in an economical, reliable, eco-friendly and safe way.

The first ECOLCELL R system was installed on an Italian ship in 1954 with good results. Over 6000 ECOLCELL R Systems have been installed until today. These ECOLCELL R are protecting seawater systems on board oil tankers, container carriers, LNG carriers, FSO, FPSO, military ships and offshore facilities, from biological fouling, which can decrease seawater flow rates and heat exchangers efficiency, and can increase fuel and maintenance costs.

2 DESCRIPTION OF THE ECOLCELL BTs BALLAST WATER MANAGEMENT SYSTEM

ECOLCELL BTs uses the technology of ECOLCELL R and has been developed to produce the proper sodium hypochlorite concentration to completely eliminate AIS in large volumes of ballast water. The system has been designed to offer a minimum dose of NaOCl related to the amount of ballast water to be treated.

This operation is made using a special electrochemical control loop. ACG has a large experience in the disinfection of public swimming pools, cooling towers and wastewater treatment plants, based on Oxidation Reduction Potential (ORP): a measure, in millivolts, of the tendency of a chemical substance to oxidize or reduce another chemical substance. This is applied to the logic control of ECOLCELL BTs to regulate the parameters of the system in order to guarantee the effectiveness of the treatment, minimizing its environmental impact. The laboratory tests showed an excellent effectiveness in killing living organisms present in the water before the treatment.
This final result was obtained with low by-product disinfection. ACG worked on this project in compliance with regulation D-2 of the IMO Ballast Water Management (BWM) Convention, and ECOLCELL BTs will meet the standards and procedures of the Guidelines for approval of ballast water management systems (G8) and will comply with the Procedure for approval of ballast water management systems that make use of Active Substances (G9).

The milestones of ECOLCELL BTs as BWMSs are:

.1 the specialized bibliography reports the use and the effectiveness of sodium hypochlorite as an oxidant agent for marine anti-fouling both on board and in coastal installations;

.2 it was demonstrated that sodium hypochlorite produces a fast sterilization (bacteria and viruses) and destroys the AIS in a few hours;

.3 sodium hypochlorite decays quickly (a few hours);

.4 the concentration of sodium hypochlorite is near to zero ppm at the discharge overboard;

.5 hypochlorite dosing, engineered by ACG, uses an ORP based control logic;

.6 ECOLCELL BTs BWMS requires low maintenance;

.7 ECOLCELL BTs BWMS can be supplied as a customized assembly for existing vessels applications;

.8 ECOLCELL BTs BWMS does not produce any stray currents in the ballast water tanks; and

.9 ECOLCELL BTs BWMS is a skid-mounted type and can treat a ballast water flow from 200 m³/h and up to 5,000 m³/h.

2.1 Overview

ECOLCELL BTs BWMS consists of:

.1 a filtration process using self-cleaning strainers;

.2 electrolysis cell(s) to produce in situ sodium hypochlorite from seawater to disinfect ballast water;

.3 an ORP process of monitoring while underway; and

.4 a dechlorination unit to reduce the Total Residual Oxidants (TRO) at the level below approximately 0.05 ppm during de-ballasting.
2.2 Plant description

The ECOLCELL BTs BWMS uses a two-stage treatment process. The first stage is the filtration to remove some phytoplankton, zooplankton and larger sediments. The self-cleaning filter is installed directly on the ballast water crossover or on the main crossover having one bypass for any ballast water discharge operation.

The second stage is the disinfection with the disinfectant/biocide produced on board from seawater. The biocide is mainly a sodium hypochlorite solution produced through electrolysis, using special titanium cell(s). The biocide is injected into the ballast water tanks using the ORP control logic. Its dosing is designed to significantly decrease the corrosion and the by-products of the disinfection, as well as to minimize the residual biocide concentration in the ballast water discharge. All materials of construction are in agreement with RINA. Seawater is strained by self-cleaning filters, suitable for this application. The integration with the shipboard ballast system will include switch on, shutdown and emergency shutdown.

2.3 Measurement principles through ORP

Oxidation reduction potential (ORP) is the tendency of a chemical species to acquire electrons and thereby be reduced. In the ballast water treatment, the amount of reducing agents (AIS and pollutants) can vary from season to season at the same port, from port to port, or from the amount of total suspended solids (TSS) that are pumped on board during the ballasting. At these varying conditions, only the ORP can be used to guarantee the inactivation rate of AIS. ECOLCELL BTs uses this measurement procedure to modulate the appropriate chlorine dosing when and where it needs.
2.4 Principle of chlorine disinfection

Available chlorine for ballast water disinfection is generated from a diluted sodium hypochlorite solution using the ECOLCELL BTs system. Chlorination is a mature technique for water treatment and it is widely used for the sterilization of drinkable water, waste water and swimming pools.

The ECOLCELL BTs BWMS is based on the partial electrolysis of sodium chloride contained in raw seawater. The seawater enters into the ECOLCELL BTs electrolysis cell, equipped with electrodes energized with direct anodic and cathodic current. The aqueous solution of sodium chloride (NaCl) is totally dissociated in ions Na⁺ and Cl⁻. The anion Cl⁻ is oxidized at the anode to generate gaseous chlorine according to reaction (1).

**Reaction (1)**

\[ \text{NaCl} + \text{H}_2\text{O} + 2 \text{e}^- \rightarrow \text{NaOCl} + \text{H}_2\uparrow \]

Chlorine is produced to the anode of the electrolysis module according to the reaction (2)

**Reaction (2)**

\[ 2 \text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^- \]

The chlorine (gas) is dissolved in the seawater turning itself into hypochlorous acid as in the reaction (3)

**Reaction (3)**

\[ \text{Cl}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{HOCl} + 2\text{H}^+ \]

**Reaction (4)**

\[ \text{HOCl} \rightleftharpoons \text{OCl}^- + \text{H}^+ \]

Hypochlorous acid is partially dissociated in ions inside the solution, since it is a weak acid, in accordance with its \( K_a = 4.0 \times 10^{-8} \) at 25 °C, 1 Atm. The hydrogen (gas) and hydroxyl ions (OH⁻) are produced at the cathode according to the reaction (5). The reactions (3) and (4) are contemporary and the direction of the equilibrium shift is related to the pH of the medium. If the pH is less than 2.0 the whole chlorine is in molecular form (Cl₂). At pH 5 the molecular chlorine is totally transformed into hypochlorous acid (HOCl). At pH 10 the molecular chlorine is found combined 100% in ion hypochlorite (OCl⁻). At pH 7.8 it will have 33 per cent of HOCl and the 67 per cent of OCl⁻ in equilibrium at 25 °C and 1 Atm. The last datum is our case.
The trend of HOCl is strongly related to pH values of the ballast water. For example, the pH of ballast water taken in ports, with an abundant supply of river water, is close to 7.0 whereas the seawater in the Mediterranean Sea area and in the Middle East is between 7.8 and 8.2. During algal growth and/or bloom time, the pH can reach values greater than 8.2 for a long time. The condition above requires a higher chlorine dose. The pH value, chloride/bromide ratio, total dissolved solids (TDS) and temperature of the ballast water can change significantly from season to season (e.g. due to rainstorm) and from low to high tide within the same day. These variations have a significant impact on the concentration of undissociated HOCl & HOBr, thus the quantity required to provide the efficient treatment varies strongly.

**Reaction (5)**

\[
2 \text{H}_2\text{O} + 2 \text{e}^- \leftrightarrow \text{H}_2\uparrow + 2 \text{OH}^- 
\]

The chemical species produced at the anode and the cathode react in the solution to generate the respective end-products as illustrated by the preceding chemical reactions. Simultaneously, some reactions of hypochlorite decomposition take place giving chloride ion, chlorate and free oxygen; according to the reaction (6).
Reaction (6)

\[ 6 \text{OCI}^- + 3 \text{H}_2\text{O} \rightarrow 2 \text{OCl}_3^- + 4 \text{Cl}^- + 6\text{H}^+ + 3/2 \text{O}_2 + 6 \text{e}^- \]

Hypochlorite ion (OCI\(^-\)) can be decomposed at the cathode to chloride (Cl\(^-\)), according to the reaction (7). Reaction (6) occurs only if the temperature of the seawater in the electrolysis cell overcomes 30 °C. In this condition the formation of OCl\(_3^-\), at a concentration of 0.066 g/L, is possible.

**Note:** at the same temperature, pressure and pH, the hypochlorous acid has a reaction rate (RedOx) greater than hypochlorite anion (OCI\(^-\)). The half-life of the HOCl is, therefore, extremely low, if not negligible. The same behaviour is valid for HOBr.

Reaction (7)

\[ \text{OCI}^- + \text{H}_2\text{O} + 2\text{e}^- \leftrightarrow \text{Cl}^- + 2 \text{OH}^- \]

All the reactions described above occur in the electrolysis cell where anode and cathode are not separate from a semipermeable membrane. The antagonistic reactions (6 and 7) decrease the thermodynamic efficiency of the electrolytic cell. To compensate and to hinder this loss of efficiency is necessary to apply an electric input (Volt) greater than the theoretical one. Seawater approximately contains an average concentration of 60 mg/L of ion bromide (Br\(^-\)).

Reaction (8)

\[ \text{HOCl} + \text{Br}^- \leftrightarrow \text{HOBr} + \text{Cl}^- \]

The bromide (Br\(^-\)) reacts with the hypochlorous acid (HOCl) via RedOx reaction. The final products are hypobromous acid (HOBr) and ion chloride (Cl\(^-\)). HOBr is dissociated into its anion hypobromite (OBr\(^-\)) and H\(^+\) as the reaction (9) shows. HOBr is an effective biocide and a very strong disinfectant agent.

The preceding chemical reactions, in nature, can occur only during seawater electrolysis. The seawater contains high quantities of magnesium and calcium ions. These react with the hydroxyl (OH\(^-\)) ions, produced at the cathode to generate the respective hydroxides, which are subsequently transformed in Carbonates (due to the presence of carbon dioxide (CO\(_2\)) dissolved in seawater). They precipitate on the cathode surface. These hydroxides are suspended in the solution and they are easily dragged by the solution water flow during the electrolysis process. The precipitates are hard and tenaciously adherent to the cathode surface, so that a cyclic reverse polarization of the electrolysis cell must be done in order to avoid the adhesion and to keep the cell clean.

Deposition of minerals results from alkaline conditions created at the cathode by the reduction reaction:

\[ 2 \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^- \]

which precipitates calcium and magnesium minerals from seawater:

\[ \text{OH}^- + \text{HCO}_3^- + \text{Ca}^{++} \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} \]

\[ 2 \text{OH}^- + \text{Mg}^{++} \rightarrow \text{Mg(OH)}_2 \]
In contrast the anode becomes acidic due to:

\[ 2 \text{H}_2\text{O} \rightarrow 4\text{H}^+ + \text{O}_2 + 4\text{e}^- \]

and highly oxidizing conditions result in:

\[ 2 \text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^- \]

The sum of the net reactions at both electrodes should be neutral with regard to hydrogen ion production, and hence with regard to CO\textsubscript{2} generation through acid-base equilibriums and carbonic acid hydrolysis:

\[ 2 \text{HCO}_3^- \rightarrow \text{CO}_3^{2-} + \text{CO}_2 + \text{H}_2\text{O} \]

**Reaction (9)**

\[ \text{HOBr} \leftrightarrow \text{OBr}^- + \text{H}^+ \]

Seawater contains approximately 0.06 gr/L of bromide (Br\textsuperscript{-}) ion, which reacts with HOCl producing 0.08 gr/L of HOBr that is a very low concentration with a low half-life. It deduces that practically both HOCl and HOBr react immediately with reducing agents, giving bromide and chloride. The exact mechanism of the biocidal activity of hypochlorous acid is still unknown, but it is assumed that it penetrates the cellular membranes, attacking cellular enzymes and killing the living microorganisms or making them non-viable. We have to consider that the ORP of the two compounds are very close and, therefore, we can conclude that the RedOx reactions practically occur at the same reaction rate and contemporarily.

HOCl increases the HOBr oxidation rate. Therefore, the two weak acids work in synergy. We note that all the mentioned reactions are regulated by a chemical equilibrium law, and that they move in the right direction when the compounds meet a reducing agent such as an organic molecule. The reduction reactions move the equilibrium of HOBr and HOCl in the right direction giving the maximum concentration of ions useful for the disinfection (OCl\textsuperscript{-} and OBr\textsuperscript{-}). Hypobromous acid is an effective biocide too, more stable than hypochlorite acid in alkaline seawater. It was calculated that, at pH 8.0, the undissociated HOBr is 83% versus 28% for HOCl.

At the same time, the reactions between hypochlorous/hypobromous acid and ammonia in seawater produce chloramines (as monochloramine, dichloramine, trichloramine) and bromamines (as monobromamine, dibromamine, tribromamine). Chloramines and bromamines are two biocides, and it is well known that their bactericidal performances are weaker than the couples HOCl/OCl\textsuperscript{-} and HOBr/OBr\textsuperscript{-}. Nevertheless, the latest bibliography quotes that, if chloramines and/or bromamines have a contact time of between 40 and 60 minutes, they reach the efficiency of free chlorine in killing coliform bacteria.

Bactericidal action is carried out by the following compounds: HOCl/OCl\textsuperscript{-}/Cl\textsubscript{2}, HOBr/OBr\textsuperscript{-}/Br\textsubscript{2}, chloramines and bromamines, which are called by the acronym TRO (Total Residual Oxidants). As already seen previously, when sodium hypochlorite is dosed to the ballast water it can get reduced by various biological, organic and inorganic compounds present in the seawater. So, the chlorine dose required for treating the ballast water is habitually called chlorine demand. As described above, the hypochlorous acid reacts with nitrogen by-product to generate chloramines. A surplus chlorine dosing will lead to an increase of chlorine concentration in seawater, and so chlorine reacts with chloramines to produce nitrogen gas and chloride. Above certain levels, called breakpoint chlorination, the whole chlorine present in the seawater will be in the form of free chlorine,
normally named free available chlorine (FAC) or free available halogen (FAH). The breakpoint chlorination is used to treat ballast water where there are extremely high nitrogen by-products, such as Ammonia and Nitrite. The sum of FAC and chloramine concentration is usually known as combined chlorine.

Therefore, chlorine dosing may be shown through the following formulas:

\[ Dose = \text{chlorine demand} + \text{combined chlorine} \]

\[ \text{Combined chlorine} = \text{chloramines} + \text{free available chlorine (HOCl)} \]

Frequently combined chlorine is referred to as Total Residual Oxidant (TRO) and is used incorrectly to mean the disinfection efficiency. If both FAH and chloramines are in the ballast water, then just FAH performs the disinfection and not the combined chlorine. The efficiency of FAH is approximately 100 times greater than the efficiency of chloramines. Disassociation of HOCl is related to many parameters, such as water pH, temperature and Total Dissolved Solids (TDS).

The pH value is the most important parameter that is able to influence the effectiveness of the disinfection treatment using sodium hypochlorite (Figure 2.9). The value of pH, chloride/bromide ratio, TDS and temperature of the ballast water can change significantly from season to season (e.g. due to rainstorm) and from low to high tide within the same day. These variations have a significant impact on the availability of undissociated HOCl and HOBr and, as final result, the requested halogen dose must be adjusted to keep constant treatment performances. At the same time, ballast water filtration contributes in reducing the NaOCl dose.

**Free chlorine elimination (dechlorination)**

In natural water the molecular gaseous chlorine is not present and the term free chlorine indicates just the chlorine, in the form of its above mentioned compounds, still available and with its intact oxidant power.

The reaction used to eliminate the excess of free chlorine, in alkaline ambient, is:

\[ 4 \text{NaOCl} + \text{Na}_2\text{S}_2\text{O}_3 + 2 \text{NaOH} \rightarrow 4 \text{NaCl} + 2 \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} \]

2.5 Benefits of ECOLCELL BTs BWMS

As a result of appropriate evaluations, we can summarize the following advantages:

1. Safe for ship and crew since the system does not produce any harmful substance for the crew. All electronic and electrical wirings and components are safe and comply with the main international rules. The ECOLCELL BTs is manufactured to work automatically with minimal operator supervision. ECOLCELL BTs uses a Programmable Automation Controller (PAC), so that precautionary and protective actions can be taken in real time to eliminate potential dangers for crew and ship. The PAC uploads the data into a non-volatile memory.

   The system has a good and intuitive Human Machine Interface (HMI) that helps operator(s). The process is controlled by a Programmable Logic Controller (PLC) with customized software to manage all the operations
when the whole system conditions are satisfied. The PLC is practically the hand of the system while the PAC is the eye.

The ECOLCELL BTs process philosophy is based on ORP logical control and the biocide dosing is regulated to supply the minimum biocide concentration to guarantee the disinfection and contemporarily reducing disinfection by-products (DBP) and possible damages as corrosion, human exposure and environmental risks to marine life due to an excessive concentration of the biocide;

.2 friendly for the environment because ECOLCELL BTs does not produce any harmful emission of fumes, gas or dust when the system works (no free chlorine overboard due to the dechlorination process). Furthermore, the biocide is produced in situ only from seawater;

.3 easy operation since the setting and the tests of the system are made by the producer (by specialized ACG technicians) and the shipboard operations can be performed in fully automatic mode through PLC and PAC; and

.4 low cost for operating and maintenance: the cost of the complete treatment is approx. US$0.17 per m³ composed of US$0.02 for dechlorination reagent and US$0.15/kWh generation cost. The required maintenance is 4 hours per month, at least.

3 LABORATORY CHLORINE MAKER

ACG uses hypochlorite as Active Substances (i.e. chemical biocide) for the ballast water management system. ACG stated to generate free chlorine directly from raw seawater (taken from the same place) in order to produce a real TRO (mainly sodium hypochlorite), that could not be produced by synthetic seawater or HOCl laboratory concentrated solution.

For the laboratory analysis and toxicity tests, ACG generated a TRO solution, in situ, directly from raw seawater, using a titanium electrolytic cell module installed in the laboratory chlorine maker.

The laboratory chlorine maker is mainly composed of:

.1 titanium electrolytic cell module;

.2 AC/DC power supply complete with ammeter and voltmeter;

.3 raw seawater inlet tank;

.4 flow meter;

.5 sodium hypochlorite storage/degassing tank; and

.6 seawater pump and pump starter.
The DC current and raw seawater flow rate must be regulated to obtain a proper concentration of free chlorine solution. The hypochlorite concentration performances of the laboratory chlorine maker, used by a single person and under the same conditions, have shown good repeatability. The concentration value can be said to be repeatable since the variation is smaller than the agreed limit.

According to the Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, repeatability conditions included:

.1 the same titration procedure;
.2 the same observer;
.3 the same measuring instrument, used under the same conditions;
.4 the same location; and
.5 repetition over a short period.

The laboratory chlorine maker's reliability has been checked by measuring variable concentrations of hypochlorite which gave the same result every time.

Figure 3.1: Laboratory chlorine maker flow diagram
3.1 Efficacy screening of ballast water management system

In order to comply with the quality standards under regulation D-2 of the BWM Convention regarding efficacy testing of the treated ballast water, ACG has commissioned the Institute of Marine Science–National Research Council (ISMAR-CNR), Italy, to perform some preliminary efficacy tests on using a laboratory prototype of the ballast water management system (ECOLCELL BTs).

The efficacy of the laboratory ECOLCELL BTs laboratory unit was investigated against microorganisms, employing heterotrophic bacterium (*Enterococcus faecalis*), and against three other model organisms: one alga (*Skeletonema costatum*) and two crustaceans (*Artemia salina* and *Tigriopus fulvus*). The efficacy screening has been carried out on water immediately after treatment with the ECOLCELL BTs laboratory unit, running under nominal operating conditions, treating natural seawater sampled near the coast of the Mediterranean Sea. The treatment of the water was designed to simulate a relevant real case of ballast water treatment.

3.1.1 Killing efficiency test with microorganisms

The screening on killing efficiency was conducted on *Enterococcus faecalis* heterotrophic bacterium largely employed as faecal contamination index in water analyses. Samples of treated natural seawater were taken for the efficacy screening during the electrolychlorination process, immediately after the treatment, and after 96 h of ageing time to check if the ageing of the chlorinated water has some influence towards bacteria elimination.

Both non-aged chlorinated water and aged chlorinated water showed a 100% bacteria elimination efficiency and suggest that ECOLCELL BTs has the potential to satisfy the requirements of Guidelines (G8) regarding heterotrophic bacteria elimination, since effluent water must have less than 1 *Vibrio cholera* cfu/100 ml, 250 *Escherichia coli* cfu/100 ml, 100 intestinal *Enterococci* cfu/100 ml.

3.1.2 Viability test with *Skeletonema costatum*

Exponentially growing *S. costatum* are exposed in a static, microplate system to a dilution series of a test solution (treated and aged chlorinated water with the ECOLCELL BTs laboratory unit). The growth of the algae exposed to the test solution is compared with the growth of the algae in an appropriate control over a fixed period of time (96 h).

3.1.3 Efficacy bioassays with crustaceans

As regards efficacy screening with crustaceans, the same bioassays have been carried out several times during different sessions of water treatment. The efficacy test repetitions have been carried out just on un-diluted treated water. Free active chlorine was measured each time.

3.1.4 Killing efficiency test with *Artemia salina* and *Tigriopus fulvus*

The results of *A. salina* and *T. fulvus* efficacy tests repetition exposed to treated water (TSW) containing different concentrations of chlorine put in evidence that water treated with ECOLCELL BTs always causes 100% of mortality of both crustaceans. Mortality percentages in untreated seawater (SW) during all tests were lower than 10%.

3.1.5 Technical report on efficacy

The complete report of the efficacy screening is provided in the complete application dossier.
4 IDENTIFICATION OF THE SUBSTANCE, RELEVANT CHEMICALS AND OTHER CHEMICALS (G9: 4.1)

4.1 General Overview

Active Substance

ECOLCELL BTs utilizes the technology of electrolyzing seawater directly to generate the biocide in situ on board. In the treatment step, a side stream of filtered seawater flows through the electrolytic cell module, in which electrochemical reactions take place at the anode and cathode. At the anode, certain short-life oxygenated chemical compounds and oxygen gas are generated, while hydrogen gas is generated at the cathode. Chlorine dissolves into seawater with the generation of hypochlorous acid (HOCl), in equilibrium with hypochlorite anion (OCl\(^-\)); a part of HOCl reacts with bromine ion in seawater and generates hypobromous acid (HOBr), in equilibrium with hypobromous ion (OBr\(^-\)). Both HOCl/OCl\(^-\) and HOBr/OBr\(^-\) are effective biocides, usually called free available halogen (FAH). The electrolysed seawater containing HOCl/OCl\(^-\) and HOBr/OBr\(^-\) is injected back into the main ballast water stream by a dosing pump, to mix it with the ballast water.

Hypochlorite concentration should normally be expressed as % NaOCl in common water disinfection applications. However, to allow a comparison between this document and official criteria (which express NaOCl solutions in terms of active chlorine content) the term free active chlorine (FAC) is used in this dossier, and its concentration is expressed in ppm.

Hydrogen gas is completely removed in the storage/degassing tank, so it is considered as a by-product. Furthermore, the short-life oxygenated chemical species (mainly hydrogen peroxide and ozone) present in the side-stream decompose. For example, hydrogen peroxide will be reduced to water by FAC, and ozone will decompose into oxygen gas, with chlorine acting as a catalyst. Therefore, these oxygenated species will not be considered in the risk assessment process.

Relevant Chemicals

During the process of disinfection by chlorine in seawater, trihalomethanes (THM), haloacetic acids (HAA), haloacetonitriles (HAN) and bromate ion are considered as main potential chemicals, therefore are defined as relevant chemicals.

Other chemicals

On discharge of the treated ballast water, the hypochlorite as free active chlorine in ballast water is neutralized with sodium thiosulphate, which is defined as other chemical.

4.2 Chemical analysis results

The potential by-products in the seawater treated by ECOLCELL BTs have been tested and analysed by Laboratory IRIDE Acqua Gas Srl. Based on the analysis results reported in Figure 4.1 (included in confidential dossier only), the Active Substance, Relevant Chemicals and Other Chemicals identified are listed in Table 4.1.

In this step of evaluation, the haloacetic acids (HAAs) and other by-products analysis have not been performed; in fact the very low level of TOC revealed by the analysis suggest that a significant concentration of HAAs and others by-products is unlikely to occur. In fact, in Allonier et al. (1999) it is reported that chlorine is very reactive towards natural organic matter, leading to the formation of several by-products; among these, trihalomethanes (THMs)
are the major compounds formed. The type and relative amounts of the chlorination by-products vary with the organic content of the water and also with the inorganic species present.

The complete by-products evaluation will be performed during the land-based testing.

Table 4.1: Active Substance, Relevant Chemicals and Other Chemicals identified

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>CAS N°</th>
<th>Molecular weight</th>
<th>Formula</th>
<th>AS/RC/OC</th>
<th>(bio)degradation rate or half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hypochlorite</td>
<td>7681-52-9</td>
<td>74.44</td>
<td>NaClO</td>
<td>AS</td>
<td>1.4 hour (at PH 8)</td>
</tr>
<tr>
<td>THM: bromoform</td>
<td>75-25-2</td>
<td>252.73</td>
<td>CHBr₃</td>
<td>RC</td>
<td>Fresh water: 7.1 days</td>
</tr>
<tr>
<td>THM: chloroform</td>
<td>67-66-3</td>
<td>119.4</td>
<td>CHCl₃</td>
<td>RC</td>
<td>FW: 4.4 days</td>
</tr>
<tr>
<td>THM: dibromochloromethane</td>
<td>124-48-1</td>
<td>208.28</td>
<td>CHBr₂Cl</td>
<td>RC</td>
<td>FW: 6 days</td>
</tr>
<tr>
<td>Sodium thiosulphate</td>
<td>7772-98-7</td>
<td>158.09</td>
<td>Na₂S₂O₃</td>
<td>OC</td>
<td>Biodegrades fast</td>
</tr>
</tbody>
</table>

* Bromodichloromethane has not been considered in this step of evaluation because its concentration is very near to the detection limit.

According to appendix 6 of the revised Methodology for information gathering and conduct of work of the GESAMP-BWWG (BWM.2/Circ.13/Rev.1), information from the literature on physicochemical, ecotoxicological and toxicological properties of the listed compounds does not need to be submitted.

4.3 Analytical methods at environmentally relevant concentrations (G9: 4.2.1.5)

Laboratory scale simulations and bioassays were performed using natural seawater collected five nautical miles from the Genoa cost (Mediterranean Sea) and treated with the ECOLCELL BTs unit at ISMAR-CNR Laboratory. Salinity was adjusted to 37‰ and water temperature was maintained at 20 ±1 °C.


5 USE OF THE ACTIVE SUBSTANCE (G9: 4.2.6)

5.1 Manner of application

The ECOLCELL BTs treats ballast water in ballasting and de-ballasting. It is based on variable TRO dosing necessary to achieve a certain oxidizing power of the treated water – its ORP value. Required chlorine dosing is determined by the ORP measurement and controlled by TRO analyser to reduce or increase the free chlorine concentration.
5.2 TRO dosage monitoring and control

The concentration of the free chlorine is analysed by the TRO analyser (an automatic analyser "online and in real time") when the active agent is uniformly mixed with raw seawater in the main stream, through the injection point installed in it. The ORP level is measured by a specific analyser. ECOLCELL BTs works with controlled direct current to guarantee a constant solution of free chlorine (see section 2.1.8).

5.3 Neutralizing unit and TRO monitoring at discharge

Before de-ballasting, the whole electrochlorination system is automatically shut off. The ballast waters are withdrawn by a ballast water pump from the crossover to be discharged outboard. During this phase, ORP value is analysed "online and in real time" through the TRO automatic analyser connected to the dosing pump of the reducing agent sodium thiosulfate, necessary for the dechlorination. A metering pump will dose, into the intake of the de-ballast pump, the exact quantity of reducing agent, related to the concentration of the residual chlorine. The solution quantity of the reducing agent (sodium thiosulfate) will be such that the TRO in the ballast water discharged approaches zero ppm. The analytical data are memorized in the Data Logger, which will be ready for the printing of process data.

The "dechlorination module" will run after receiving an electric signal of "start" from the de-ballasting pump. The "dechlorination module" will stop the operation after receiving an electric signal of "stop" from the de-ballasting pump.

De-ballasting can begin only if the TRO sensors are operative and the neutralizer feed system is ready to work. The neutralizer dose is calculated from ORP value of seawater measured just before the neutralizer injection point, and then the dechlorination unit is enabled for dosing.

Figure 5.1 : Dechlorination dosing system

(1) SS metering tank (35 litre) (6) float switch for suction assembly
(2) SS stackable bund (35 litre) (7) discharge tap for tank
(3) lock for tank screw cap (8) calibration assembly
(4) electrical mixer/stirrer (9) metering pump
(5) suction assembly
5.4 Retention time

The laboratory tests show that the ORP controlled biocide treatment provides the disinfection conditions of the ballast water within the first day of treatment, most likely within a few hours. Moreover, the ECOLCELL BTs BWMS is able to keep constant at 1 ppm the concentration of free chlorine in the ballast tanks during sailing time, prior to its discharge into the sea. The surplus of free chlorine guarantees that the seawater is clean. The free chlorine, as already said, is removed by a dechlorination step, prior to the discharge.

6 MATERIAL SAFETY DATA SHEETS (G9: 4.2.7)

The Material Safety Data Sheets of the substances are well noted.

7 RISK CHARACTERIZATION

The study was performed for substances which were detected in discharged water on day 5 of the laboratory-scale plant experiment. Further studies will consider also the chemicals that will be detected during land-based test.

- THM:
  - bromoform;
  - chloroform; and
  - dibromochloromethane;

- sodium thiosulphate.

7.1 Screening for persistence, bioaccumulation and toxicity (PBT) (G9: 5.1)

7.1.1 PBT criteria for Active Substance (G9: 5.1.1.1)

Criteria for identification of PBT substances are reported in table 7.1.

**Table 7.1: Criteria for identification of PBT substances**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>PBT criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistence</td>
<td>Half-life: &lt;br&gt; &gt; 60 days in marine water, or &lt;br&gt; &gt; 40 days in freshwater, or &lt;br&gt; &gt; 180 days in marine sediment, or &lt;br&gt; &gt; 120 days in freshwater sediment</td>
</tr>
<tr>
<td>Bioaccumulation</td>
<td>BCF &gt; 2,000 or &lt;br&gt; Log P_{octanol/water} ≥3</td>
</tr>
<tr>
<td>Toxicity</td>
<td>Chronic NOEC &lt; 0.01 mg/L</td>
</tr>
</tbody>
</table>
### 7.1.2 Assessment of persistence (P), bioaccumulation (B) and toxicity (T) (G9: 5.1.1.2)

**Table 7.2: Assessment of persistence (P), bioaccumulation (B) and toxicity (T)**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Persistence</th>
<th>Bioaccumulation</th>
<th>Toxicity</th>
<th>Reference*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active Compound</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Sodium hypochlorite              | No          | No              | No       | P: MEPC 60/2/3  
|                                 | Half-life: 1.4 hour (at pH 8) | BCF: -2.19  
|                                 |             | Log P<sub>ow</sub>: -3.42 | NOEC: (fish) 0.04 mg/l/28 days | B: EU RAR, 2007  
|                                 |             |                 |          | T: EU RAR NaClO, 2007 |
| **Relevant chemicals**          |             |                 |          |            |
| Tribromomethane (Bromoform)     | No          | NO              | No       | P: HSDB - The Hazardous Substances Data Bank, 2010  
|                                 | Fresh Water: 7.1 days | BCF = 14  
|                                 |             | Log P<sub>ow</sub>: 2.4 | Lowest NOEC (fish): 4.8 mg/l/28 days | B: ATSDR 2005  
|                                 |             |                 |          | T: HSDB - The Hazardous Substances Data Bank |
| Chloroform                      | No          | No              | NOEC     | P: HSDB, 2010  
|                                 | Freshwater: 4.4 days | BCF = 2.9-10.35  
|                                 |             | Log K<sub>ow</sub>: 1.97 | Lowest NOEC (fish) 1.5 mg/l/9 months | B: ATSDR, 1997  
|                                 |             |                 |          | T: EU RAR CHCl3, 2007 |
| Dibromochloromethane            | No          | No              | No       | P: HSDB, 2010  
|                                 | Half-life:  Fresh Water: 6 days | BCF = 9  
|                                 |             | Log K<sub>ow</sub>: 2.16 | 21 days EC<sub>50</sub> = 1.5 mg/L | B: ATSDR 2005  
|                                 |             |                 |          | T: Istituto Nazionale di Tecnologia Giapponese (NITE) web site, 2010 |
| **Other chemicals**             | NO          | No              | No       | P: MEPC 59/2/16  
| Sodium thiosulphate             | Biodegrades fast | BCF: 3.162  
|                                 |             | Log P<sub>ow</sub>: -4.53 | LOEC = 95 mg/l | B: MEPC 59/2/16  
|                                 |             |                 |          | T: United States EPA ECOTOX Database, 2011 |

* Data are derived from reports and online databanks reported in the references column of the table.
7.2 Evaluation of the treated ballast water (G9: 5.2)

7.2.1 Toxicity test of the treated ballast water

According to the requirements of the Procedure for approval of ballast water management systems that make use of Active Substances (Procedure (G9), section 5.2), the toxic effects of seawater treated with laboratory ECOLCELL BTs prototype, before and after neutralization process, was investigated by the Institute of Marine Science – National Research Council (ISMAR-CNR) using organisms belonging to three trophic levels (Algae, Crustacean and Fish) in order to represent species variations and lifestyles with different feeding strategies, which account for differences in sensitivity among different organisms.

In order to mimic the real conditions in ballast tanks, toxicity tests have been performed on chlorinated water collected immediately after the electrochemical treatment, and after different storage periods of treated water (ballast-time simulation of 24-48-72-96 hours. Several repetitions of toxicity bioassays with algae, crustacean and fish were also performed using treated water with the ECOLCELL BTs laboratory unit before and after neutralization with sodium thiosulphate using different samples of natural seawater sampled near the coast of Mediterranean sea.

The toxicity of the neutralizing agent, sodium thiosulphate, was tested on algae and crustaceans; organisms were exposed to different concentrations, several orders of magnitude higher than the nominal operating concentration.

Marine algal growth inhibition test with Skeletonema costatum

The results of the *Skeletonema costatum* growth inhibition test exposed to different dilutions of treated water and the series of treated water after different storage periods suggest that the values of IC₉₀₋₉₆₉ₙₙ seems to decrease (enhancement of toxicity) with the increase in storage time. The results of the growth inhibition test during the five repetitions of ecotoxicological screening on untreated seawater (SW), treated seawater (TSW) and neutralized treated seawater with sodium thiosulphate (NTSW) highlight the total absence of toxic effect after treated water neutralization process even if in some cases (R₁-R₂-R₃) a low stimulation of algal growth is evident and suggest a hormesis phenomenon that is a generally-favorable biological responses to low exposures to toxins and other stressors.

Marine invertebrate toxicity test

*Artemia salina* toxicity test

The results of the *A. salina* mortality test exposed to different dilutions of treated water and the series of treated water after different storage periods put in evidence an irregular variation of LC₅₀₋₂₄ₙₙ values during the storage period. The values decrease (enhancement of toxicity) after 24 and 48 hours of storage and reverse the trend at 72 hours of storage.

Fortunately, the results of the *A. salina* mortality test during the five repetitions of ecotoxicological screening on untreated seawater (SW), treated seawater (TSW) and treated seawater neutralized with sodium thiosulphate (NTSW) highlight the total absence of toxic effect after treated water neutralization process. No significant differences are evident between untreated seawater (SW) and neutralized treated seawater (NTSW).

Also the results of ecotoxicological screening on different concentrations of sodium thiosulphate used as neutralizing agent confirm this evidence. Any toxic effect was
evident with this model organisms also if the test concentrations were several orders of magnitude higher than the nominal operating concentration.

**Tigriopus fulvus toxicity test**

The data of mortality of *T. fulvus* exposed to different dilutions of treated water and the series of treated water after different storage periods put in evidence, also with this crustacean an irregular variation of LC50-24h values during storage period. The values decrease (enhancement of toxicity) after 24 hours of storage and reverse the trend at 48 hours of storage.

Also the results of the *T. fulvus* mortality test during the five repetitions of ecotoxicological screening on untreated seawater (SW), treated seawater (TSW) and treated seawater neutralized with sodium thiosulphate (NTSW) highlight the total absence of toxic effect after the treated water neutralization process. No significant differences are evident between untreated seawater (SW) and neutralized treated seawater (NTSW).

The results of ecotoxicological screening on different concentrations of sodium thiosulphate used as a neutralizing agent confirm this evidence. The calculable LC50-24h value was one order of magnitude higher than the concentration utilized to neutralize the treated water under nominal operating conditions of the ECOLCELL BTs laboratory unit.

**Marine invertebrate chronic toxicity test**

**Dicentrarchus labrax (juveniles) toxicity test**

The data of mortality of juveniles of *D. labrax* exposed to different dilutions of treated water put in evidence that fish are the most sensitive organisms. The LC50-96h value is the lowest registered during this ecotoxicological screening on treated ballast water simulation.

The good performance of ECOLCELL BTs' neutralization process was confirmed also by results of juveniles of *D. labrax* exposition during the five repetitions of ecotoxicological screening on untreated seawater (SW), treated seawater (TSW) and treated seawater neutralized with sodium thiosulphate (NTSW) highlighting the total absence of toxic effect after treated water neutralization process. The data show no significant differences are evident between untreated seawater (SW) and neutralized treated seawater (NTSW).

**Technical report on toxicity**

The toxicity screening is provided in the complete application dossier.

7.3  Risk characterization and analysis (G9: 5.3)

7.3.1  Prediction of discharge and environmental concentrations (G9: 5.3.8)

Due to the neutralization process by Na2S2O3 the concentration of sodium hypochlorite is expected to be around zero.

**Introduction**

MAMPEC software (Version 3.0) was used to calculate the predicted environmental concentration (PEC) of Relevant Chemicals and other chemical substances in the port water receiving the discharged treated ballast water. The model implemented in this software was originally developed for predicting environmental concentrations of biocides released by ship hulls' antifouling coatings, but it can be used also for calculating the concentration of other...
substances released in the water, e.g. those produced by ballast water management systems and discharged during de-ballasting.

**Model parameters**

In order to calculate the PEC of the chemical substances discharged with the treated ballast water, MAMPEC requires several parameters, which define discharge scenario, released substances characteristics and concentrations. The GESAMP-BWWG Harbour Environment was employed as model environment (BWM.2/Circ.13/Rev.1, annex, appendix 5). The PEC was calculated for the chemicals detected in the treated water after the neutralization step. For running the model, the maximum measured concentration of each substance (section 4.2) was used (table 7.3). The MAMPEC default values for physical and chemical properties of Relevant Chemicals and Other Chemicals were used.

**Table 7.3: Maximum concentration of chemical substances measured in treated ballast water after neutralization process. DL= detection limit**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free chlorine</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,1,1,-Trichloroethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,1-Dichloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Cis 1,1-Dichloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Trans 1,1-Dichloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Bromochloromethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,1,2-Trichloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,2-Dibromoethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,2-Dichloropropane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>1,1,1,2-Tetrachloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Tetrachloroethylene + Trichloroethylene</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Chloroethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Bromodichloromethane</td>
<td>&lt; DL</td>
</tr>
<tr>
<td>Bromoform</td>
<td>120</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>17.6</td>
</tr>
<tr>
<td>Sodium thiosulphate (calculated)</td>
<td>5840</td>
</tr>
</tbody>
</table>

The GESAMP-BWWG Harbour Environment default value of daily ballast water discharge (100,000 m³, the average value of Port of Rotterdam; MEPC 60/2/3, annex, paragraph 7.3.3.2) was used. In the MAMPEC software it is possible to set a degradation rate for each substance. Adopting a worst-case scenario, it was assumed that no decay or degradation of the discharged substances occurs in the harbour waters. The background concentration of the discharged chemical substances was assumed to be 0 µg/L.
Modelling results

The MAMPEC modelling results are summarized in table 7.4. For the PEC/PNEC calculations, the Maximum Concentration of each substance was used. For the chemical substances not detected in the treated ballast water after the neutralization (table 7.3), the PEC is considered to be 0 µg/L.

Table 7.4: Predicted total concentrations, in the harbour, for the chemicals discharged with the treated ballast water

<table>
<thead>
<tr>
<th>Substance</th>
<th>Maximum Concentration (µg/L)</th>
<th>95% Concentration (µg/L)</th>
<th>Average Concentration (µg/L)</th>
<th>Median Concentration (µg/L)</th>
<th>Minimum Concentration (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromoform</td>
<td>1.29E-00</td>
<td>1.25E-00</td>
<td>7.62E-01</td>
<td>8.80E-01</td>
<td>4.08E-02</td>
</tr>
<tr>
<td>Chloroform</td>
<td>6.75E-03</td>
<td>6.45E-03</td>
<td>4.09E-03</td>
<td>4.73E-03</td>
<td>2.82E-04</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>1.61E-01</td>
<td>1.55E-01</td>
<td>9.60E-02</td>
<td>1.12E-01</td>
<td>5.61E-03</td>
</tr>
<tr>
<td>Sodium thiosulphate</td>
<td>1.57E+02</td>
<td>1.53E+02</td>
<td>8.79E+01</td>
<td>9.82E+01</td>
<td>2.99E-00</td>
</tr>
</tbody>
</table>

7.3.2 Assessment of potential for bioaccumulation (G9: 5.3.7)

The logarithm of the octanol/water partition coefficient (Log K_{ow}) of all chemical substances detected in the treated ballast water (table 7.3) is <3, and their BCF is below 500, therefore, according to Procedure (G9), paragraph 3.3.7, there is no need to assess their potential for bioaccumulation in marine or freshwater organisms.

7.3.3 Effects assessment

Considering the data for the substances associated with ECOLCELL BTs, it seems evident that there is a low potential for bioaccumulation, sediment adsorption, and persistence in the aquatic environment. Moreover, no effects or risks along the food chain or to sediment species are present; aquatic toxicity presents the only likely potential risk for aquatic organisms.

The results of toxicological screening (see annex 4 of the complete application dossier) using treated seawater neutralized with sodium thiosulphate (NTSW) by the ECOLCELL BTs laboratory unit (several toxicity bioassays with algae, crustacean and fish) highlight the total absence of toxic effects after the treated water neutralization process. No significant differences are evident between untreated seawater (SW) and neutralized treated seawater (NTSW) for any organisms and end-points tested during the different sessions of treated water neutralization process under investigation. In light of these results all data suggest that the water neutralization process is able to reduce any risk of toxicity at the ballast water discharge.

7.3.4 Effects on aquatic organisms

Predicted No-Effect Concentrations (PNEC) values were calculated using the aquatic toxicity data-set endpoints, and the appropriate assessment factor, as reported in table 7.5.

The appropriate assessment factors have been chosen according to what was reported in the guidance in the Methodology (MEPC 58/2/7) as well as the Technical Guidance Document on Risk Assessment (2004).
Table 7.5: Calculated PNEC values for the chemicals discharged with the treated ballast water

<table>
<thead>
<tr>
<th>Substance</th>
<th>Toxicity (mg/L)</th>
<th>Assessment factor</th>
<th>PNEC (mg/L)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromoform</td>
<td>4.8</td>
<td>100</td>
<td>0.048</td>
<td>Lowest L(E)C_{50} from a fish, crustacean and alga and Lowest NOEC from an algae and fish</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.5</td>
<td>100</td>
<td>0.015</td>
<td>Lowest L(E)C_{50} from a fish, crustacean and alga and Lowest NOEC from an algae and fish</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>1.5</td>
<td>100</td>
<td>0.015</td>
<td>Lowest L(E)C_{50} from a fish, crustacean and alga and Lowest NOEC from an algae and fish</td>
</tr>
<tr>
<td>Sodium thiosulphate</td>
<td>95</td>
<td>100</td>
<td>0.95</td>
<td>Lowest L(E)C_{50} from a fish, crustacean and alga and Lowest NOEC from fish</td>
</tr>
</tbody>
</table>

The potential risk for aquatic organisms caused by chemicals discharged with the treated ballast water was evaluated calculating the PEC/PNEC ratio. If this ratio is ≤ 1, the substance is not expected to be of concern. If this ratio is >1, the substance can be of concern. Active Substances and Relevant Chemicals not detected in the treated ballast water after the neutralization step were not considered.

The PEC/PNEC value (table 8.5) for all considered chemicals is <1, therefore the ballast water treated with the ECOLCELL BTs has low potential risk for the aquatic environment.

Table 7.6: Calculated PEC/PNEC ratio for the chemicals discharged with the treated ballast water

<table>
<thead>
<tr>
<th>Substance</th>
<th>PEC/PNEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromoform</td>
<td>0.0269</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.0005</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>0.0107</td>
</tr>
<tr>
<td>Sodium thiosulphate</td>
<td>0.1653</td>
</tr>
</tbody>
</table>

7.3.5 Effects on sediment

The K_{oc} value of all chemical substances detected in the treated ballast water, after the neutralization, was smaller than 500 L/Kg. Therefore, these substances will not readily partition to sediment and will not be of concern for the organisms in the sediment.

7.3.6 Comparison of effect assessment with discharge toxicity

Considering the results obtained during the toxicity testing with the laboratory scale ECOLCELL BTs (section 8.2), and the results of the chemical analysis (section 4.2), the toxic effects of the ballast water treated by ECOLCELL BTs to aquatic organisms would be low.
8 RISK ASSESSMENT

8.1 Risk to safety of ship

ECOLCELL BTs is designed considering the precautions to be taken to avoid or minimize risks to safety of the ship. Floor drains must be installed near the ECOLCELL BTs skid for flooding and for maintenance wash-downs. Valves and piping sections that are isolated for a long time are designed to prevent locking in. The strength of 800 ppm sodium hypochlorite solution falls below the hazardous materials threshold (1,000 ppm) and is typically exempted from the United States Environmental Protection Agency Risk Management Plan (EPA RMP) and HazMat regulations. The result is that the storage/degassing tank does not require a double walled storage vessel or a containment system. The storage/degassing tank is fastened on the skid with an appropriate tie-down system suitable for very rough seas that could occur in any geographic location.

The hypochlorite storage/degassing tank must be considered a confined space. To avoid any risk, nobody may remove a hatch or work side or on the storage tank until it is vapour free and in accordance with confined space entry requirements. Due to the potential for hydrogen off-gassing, two hydrogen detectors are installed near the storage/degassing tank and in the ballast room ceiling.

According to United States industrial standards and practices, the area around the ECOLCELL BTs can be considered as a "safe area" in normal operation (see section 9.1.3). This is due to the high degree of artificial ventilation and the safeguards that assure system shutdown in case of ventilation failure.

ECOLCELL BTs has multiple layers of safety protections built into the system, so there is a slight risk of hydrogen gas being released from the electrolytic cell or other system piping. In this extremely unlikely condition (such as a broken pipe), a release could create a potential hazard, although very narrow. Directed ventilation and air exchange and the type of auxiliary equipment placed in this area can reduce the severity of this potential hazard.

ECOLCELL BTs does not have any shutoff valves in the cell outlet piping. In fact, if the piping is inadvertently blocked by the valve, there could be creation of hydrogen gas at high pressures, which may damage or burst the electrolytic cell or piping.

The air blowers are mounted above the skid, and are located no higher than 2/3 the height of the hypochlorite storage/degassing tank. All horizontal runs maintain an upward slope toward the vent termination, of at least 3 cm/m (1/8" per lineal foot) of horizontal vent run, in order to allow proper discharge of diluted hydrogen gas, as well as drainage of condensation. Each dilution blower has a power-driven shutter installed. The installed blowers are two, one working and one in standby; in case of failure the one in standby starts automatically, in order to prevent the lack of hydrogen dilution.

ECOLCELL BTs piping is made of heavy CS pipes, PVC-lined internally, joined by flanges for an easy installation and maintenance. The whole piping is free from drops and sags. Vertical runs of piping are supported at a minimum of 1.5 m (5 ft.) centres. Horizontal runs of piping are supported at a minimum of 0.9 m (3 ft.) centres. All ventilation piping is made of FRP, flanged type, with a sparking discharge wiring in the vent duct. Two air flow switches are installed on the vent pipe line to continually check the air flow, ensuring the appropriate hydrogen dilution. In case of no-air flow, or of flow below the offset value, the system shuts off automatically. This safeguard avoids hazardous hydrogen/air mixtures (LEL 4% or UEL 96%). The air blowers can be switched on when there is the possibility of
maintenance personnel close to the ECOLCELL BTs skid, even if the system is off. A screen is installed to prevent insects or animals intrusion in the vent duct.

8.1.1 Flooding

A flooding event is practically impossible, since multilayer safeguards are present. If there is a piping failure or a hypo-line failure, the ECOLCELL BTs is immediately hydraulically isolated, automatically closing the pneumatic valves. Consequently, the system is shut off, except the air blowers, which are always running. For greater safety, a water leak detector is installed on the ballast room floor and it is interlinked with the other safeguard layers.

8.1.2 Corrosion

ACG Italy will address the comprehensive corrosion testing in the application for Final Approval. An official laboratory will evaluate the corrosion effects through long-term testing (>6 months) of several materials at the maximum treatment concentration, with the test conditions reported below:

.1 the testing will include uncoated substrates and epoxy coated steel. Coatings will comply with the IMO Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers (MSC.215(82));

.2 the testing will be performed using the following substrates that will be exposed to the Active Substance, reducing agent and disinfection by-products:

   .1 low carbon steel;
   .2 stainless steel AISI 316 L;
   .3 Cupronickel 90/10; and
   .4 non-metals (i.e. seal and gasket materials);

.3 the passive materials exposed to the Active Substances, reducing agent or disinfection by-products, will be examined for localized corrosion resistance by immersion, with specimen configurations as defined in ASTM G78 Standard Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments.

As an additional evaluation, short term laboratory tests will be carried out complying with ASTM G61 – 86(2003) e1 Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron-, Nickel- or Cobalt-Based Alloys;

.4 testing of coated substrates will be conducted according to ISO 2812-2:2007 Paints and varnishes – Determination of resistance to liquids – Part 2: Water immersion method as guidance;

.5 testing will be conducted with controls treated, untreated and effluents under continuous exposure and intermittent exposure of specimens at the maximum treatment concentration of the ECOLCELL BTs BWMS,

The testing should be conducted using full strength, once through (not refreshed) natural seawater. Testing will include immersion in brackish water as well;

for uncoated supports, the corrosion rate will be evaluated by weight loss, and the depth and density of localized corrosion (e.g. pitting rust or crevice attack). These evaluations will be made following ISO 11463 Corrosion of Metals and Alloys –, Evaluation of Pitting Corrosion and ASTM G 46 Guide for Examination and Evaluation of Pitting Corrosion;

subsequent evaluations of painted materials and coating properties of both controls and samples exposed to treatment conditions will include:

coatings adhesion according to ISO 4624 Paints and Varnishes; Pull-Off Test for Adhesion;

degree of blistering according to ISO 4628-2 Paints and Varnishes, Evaluation of Degradation of Coatings, Designation of Quantity and Size of Defects, and of Intensity of Uniform Changes In Appearance, Part 2: Assessment of Degree of Blistering;

degree of rusting according to ISO 4628-3 Paints And Varnishes, Evaluation of Degradation of Coatings, Designation Of Quantity And Size of Defects, and of Intensity of Uniform Changes in Appearance, Part 3: Assessment of Degree of Rusting;

degree of cracking according to ISO 4628-4 Paints and Varnishes, Evaluation of Degradation of Coatings, Designation Of Quantity And Size of Defects, and of Intensity of Uniform Changes in Appearance, Part 4: Assessment of Degree of Cracking;

8.1.3 Fire and explosion – Hazardous Area Analysis of the ECOLCELL BTs

ACG Italy decided to follow the United States rules instead of EU rules, since the former are more exhaustive than the latter ones. This analysis is based upon the two primary standards for hazardous area classification practice in the United States:

ANSI/ISA-TR12-24.01 (1988) – Recommended Practice for Classification of Locations for Electrical Installations Classified as Class 1; Zone 0, Zone 1, or Zone 2

NFPA 497 – Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapours and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas – 2004 Edition

Hydrogen characteristics

Hydrogen is much lighter than air with a vapour density of 0.1. For comparison, another common gas that is lighter than air, methane has a vapour density of 0.6. Quoting NFPA 497, "These gases tend to dissipate rapidly into the atmosphere" and "Except in enclosed spaces, such gases seldom accumulate to form an ignitable mixture near grade level". However, the
lower explosive limit (LEL) of hydrogen is 4% and it is classified as a Group B gas. It is explosive when accumulated in large quantities and has a low minimum ignition energy (MIE) of 0.019 mJ.

ECOLCELL BTs creates free gaseous hydrogen and, therefore, it has been engineered with care and consideration with regard in the hazardous area consequences of the process. Users of the system must be aware of the potential for hazard and maintain the system properly.

**Safety principles**

The primary safety principles for hazardous area systems are paraphrased from TR12-24-01: "Installations in which flammable materials are handled or stored should be designed, operated and maintained so that any releases of flammable material, and consequently the extent of hazardous areas, are kept to a minimum, whether in normal operation or otherwise, with regard to frequency, duration and quantity."

"In the situation in which there may be an explosive gas atmosphere, the following steps should be taken:

a) eliminate the likelihood of an explosive gas atmosphere occurring around the source of ignition [...]".

The ECOLCELL BTs is designed to address these principles explicitly by incorporating as a standard feature, an "artificial ventilation" sub-system. Artificial ventilation is defined as "an air/vapour extraction system applied to an item of process equipment which continuously releases flammable vapour". The purpose of this sub-system is to "eliminate the likelihood of an explosive gas atmosphere occurring".

**Cell generation process**

Hydrogen is created inside the ECOLCELL BTs electrolytic cells due to the electrolytic process. The cells output is a sodium hypochlorite and water solution with hydrogen bubbles. The hydrogen devolves rapidly from the cell output mixture at the junction with the vertical vent pipe and rises through the pipe to exhaust upward. The rising hydrogen gas is immediately joined by the strong ventilation flow in the sodium hypochlorite storage tank and diluted. The system is designed to assure a dilution bringing the exhaust gas to LEL <1% (volume) when it is vented into the air above the facility.

A small Zone 0 (or Division 1) hazardous area exists in the piping at the cell outlet until exhaust is diluted in the vent pipe. This piping is closed and sealed during normal operation and no gas would be expected to be released during normal operation. The hydrogen production of the ECOLCELL BTs system is relatively small by industrial process standards.

**Storage generation process**

A small amount of hydrogen devolves from the hypochlorite surface in the local storage/degassing tank. A primary consideration of this process from a hazardous area perspective is that the water/sodium hypochlorite liquid in the tank is not flammable by itself. The hazardous area standards normally assume such gaseous generation above a surface results from a flammable liquid (such as gasoline).

Therefore, any Zone 0 area at the liquid hypochlorite surface would be negligible and it can be ascertained that a very small area above the liquid surface would be more correctly
classified as Zone 1 (Note: The older NEC division classification would still consider this Division 1). It should be noted that the tank is fully sealed with no uncontrolled venting in the ballast room.

Ventilation overview

The ECOLCELL BTs is designed to operate with continuous ventilation that is controlled and monitored by the PLC & PAC systems. The "artificial ventilation" sub-system is to operate safely the system process and to reduce the hazardous areas created by it. The principle standard for the process ventilation is TR12-24.01, specifically Section 5 and Annex B (Informative) – Ventilation. The major points of these sections, related to the ECOLCELL BTs, are addressed as follows:

"Artificial ventilation" as a specific safety mechanism is defined as "an air/vapour extraction system applied to an item of process equipment which continuously releases flammable vapour". The purpose of artificial ventilation is to "eliminate the likelihood of an explosive gas atmosphere occurring".

In order to judge the effectiveness of the ECOLCELL BTs "artificial ventilation" sub-system and determine the hazardous area classification around the equipment, standard TR12-24.01 provides Table B.1 - Influence of Ventilation on Type of Zone to be used as a guideline. To utilize the table for this determination, several parameters have been ascertained for the system in question. The first is the Grade of Release and its precursor, the Classification of Openings where the hazardous material could be released, next is the Degree of Ventilation and lastly the Availability of Ventilation.

Grade of release

There are three categories of Grade of Release: Continuous, Primary and Secondary.

1) Continuous – "a release which is continuous or expected to occur for long periods". An example would be "the surface of a flammable liquid in a fixed roof tank, with permanent vent to the atmosphere".

2) Primary – "a release which can be expected to occur periodically or occasionally during normal operation". Examples would be "seals, sample points, relief valves, and vents which are expected to release flammable material into the atmosphere during normal operation".

3) Secondary – "a release which is not expected to occur in normal operation and if it does occur, is likely to do so only infrequently and for short periods".

Table A.1 – Effect of openings on grade of release. The two determinants for this table are the "Zone upstream of the opening" and the "Opening type" can be used to define which grade of release has to be applied to a particular apparatus.

As already stated, the release of hydrogen creates a Zone 0 area in the piping at the ECOLCELL BTs cell outlet and a Zone 1 area is created on the surface of the hypochlorite tank directly above it. The cell hydrogen output was then vented to a vertical vent pipe open to the safe atmosphere above the ballast room.
The stream in the vent pipe is further diluted by ventilation flow into the hypochlorite tank. From this it can be concluded that the worst case “Zone upstream of the opening” is Zone 0. Classification of Openings defines just two possibilities in the ECOLCELL BTs case as follows:

- Type A – openings that are not normally closed - "fixed ventilation outlets in rooms, buildings, and similar openings".

- Types B, C, & D – openings that are normally closed (the particular type varies with frequency of opening and the sealing).

With both the open vertical vent pipe from the cell and the open hypochlorite tank roof vent feeding into the stack’ it is clear that a Type A classification is the only possibility.

Examination of the standard table A.1 – Effect of openings on grade of release shows that the Grade of Release in the ECOLCELL BTs case is equal to Continuous. This is as would be expected from a common sense perspective.

**Degree of ventilation**

The degree of artificial ventilation has three categories which are high ventilation, medium ventilation, and low ventilation. As per the standard, high ventilation "can reduce the concentration at the source of release virtually instantaneously, resulting in a concentration below the lower explosive limit. A zone of small (even negligible) extent exists."

It is intended as a design objective of the ECOLCELL BTs system that it meets the criteria for high ventilation. The blower’s sub-system, which creates the "artificial ventilation", is sized to provide an air flow that is 100 times the system's hydrogen release rate. This results in a significant ventilation dilution of air flow ranging from 24 m³/h (14.2 scfm) for a smaller 11 kg per day (24 lb. per day configuration) to 300 m³/h (177 scfm) for a medium 136 kg per day (300 lb. per day configuration). The piping of larger installations is carefully engineered to assure this ratio is maintained. In all cases, testing has shown that the resultant released hydrogen concentration is below 1% by volume (less than 0.25 LEL).

**Availability of ventilation**

The last criteria for use of TR12-24.01 table B.1 - Influence of Ventilation on Type of Zone is the Availability of Ventilation which provides for three levels. Only the highest level is applicable to the ECOLCELL BTs which is defined as:

"Good: ventilation is present virtually continuously"

As a further clarification the standard states, "Good availability will normally require, on failure, automatic start-up of standby blowers. However, if provision is made for preventing the release of flammable material when the ventilation has failed (for example, by automatically closing down the process), the classification determined with the ventilation operating need not be modified, i.e. the availability may assume to be good."

As it was stated previously the ECOLCELL BTs continuously monitors the ventilation sub-system and shuts down cell operation and the hydrogen generation, if the dilution flow is lost. There are several system sensors which accomplish this function: two flow detectors on the blower's delivery, three hydrogen detectors, according to 2 out of 3 voting logic, and one hydrogen detector at the delivery of the hypochlorite tank vent.
Conclusions on Hazardous Area Classification TR12-24.01 – table B.1 – Influence of Ventilation on Type of Zone- can now be drawn, using the parameters defined above for the ECOLCELL BTs, that are:

1. Continuous Release;
2. High Degree of Ventilation (Artificial); and
3. Good Availability of Ventilation.

The table, consequently, defines the area surrounding the ECOLCELL BTs as a "(Zone 0 NE) non-hazardous area". Further, the term Zone 0 NE (non-explosive) is additionally explained as "indicates a theoretical zone that would be of negligible extent under normal conditions". Therefore, it can be concluded for United States practice that the area is "unclassified".

**NFPA 497 considerations**

NFPA 497 is a second standard that is more attuned to common United States practice and was updated as recently as 2004. It states the following, in section 5.4.1 – Unclassified Locations:

"For example, it is not usually necessary to classify the following locations where combustible materials are processed, stored or handled: locations that have adequate ventilation, where combustible materials are contained within suitable, well maintained, closed piping systems [...]".

"The volume of combustible material release is of extreme importance in determining the extent of the hazard (classified) location [...]".

The objective of these clarifications is to avoid over classifying areas and creating unnecessary restrictions.

**8.1.4 Hydrogen gas and chlorine gas**

The hypochlorite generation process utilizes electrolysis cells which generate an amount of hydrogen gas as a normal by-product. The system is fully sealed and subjected to internal forced ventilation which quickly dilutes the hydrogen. In addition, there are several automatic safeguards that shut down the system in case of failure. Any gas leak from the ECOLCELL BTs can only result from a situation where part of the system is accidently damaged. In this unlikely case, good room ventilation will assure that the hydrogen gas is quickly dispersed.

As hydrogen will rise to the ceiling, the ventilation system must be designed to provide for exhaust air exits near the ceiling. Mechanical ventilation equipment must be situated to provide for cross-flow circulation near and above the ECOLCELL BTs. It is mandatory that the ventilation system is interlocked with ECOLCELL BTs, to assure air flow in the ballast room when the chlorine generator is working. Air is 14 times heavier than hydrogen, therefore the hydrogen rises rapidly. Possible physical gas trap pockets must be avoided near the ceiling where hydrogen could potentially accumulate.

If the ballast room requires heating or cooling, consideration must be given to the vent inlet and outlet locations. Inlets must be located near the floor, away from the ECOLCELL BTs. Heating and cooling units must be ducted appropriately to prevent any abnormal hydrogen release from infiltrating ductwork and reaching any motors, heat exchangers, or other sources of ignition inside the unit.
Hydrogen detection alarm

One hydrogen detector alarm is installed at the ceiling ballast room and another one on the vent line of hypochlorite storage/degassing tank. A third hydrogen detector must be located at a position where good engineering inspection could indicate a hydrogen accumulation may occur. This should be preferably far from the hypochlorite sampling port at the discharge of the electrolytic cell, to prevent false alarms.

The detector is set to provide a remote alarm when the hydrogen gas is at a LEL > 1% and shut off completely the system, while one blower keeps working for 30 minutes. One Cl₂ detector is installed near the ECOLCELL BTs skid in a low position, since gaseous chlorine is heavier than the air. Gas detection system monitors chlorine gas level in the ballast room, with a threshold of 2 ppm of Cl₂, and it will generate an alarm if the level exceeds the set-point.

Rectifier heat load

Typical heat generated by the rectifier is 1.28 kWh (4,377 Btu/h) per 48 kg/day (100 lb/day) chlorine generation capacity. Ballast room heat load calculations should also take into consideration the heat produced by the rectifier. The rectifier heat is provided in a water cooled configuration to reduce this heat load. For the fire and explosion risk see section 9.1.3.

Taking into account all safeguards installed, the equation

\[ RISK = POSSIBILITY \times CONSEQUENCES \]

is close to zero since the POSSIBILITY approaches zero.

Chlorine risk

Gaseous chlorine, during the process of electrochlorination, can be only generated in the ballast room if hypochlorous acid is mixed with hydrochloric acid. Hypochlorous acid also generates gaseous chlorine, not only at the presence of hydrochloric acid, but also of other acids, such as acetic acid (CH₃COOH, vinegar and alike).

The reactions are the following:

\[ \text{.1} \quad \text{HOCl} + \text{HCl} \leftrightarrow \text{H}_2\text{O} + \text{Cl}_2↑ \]

\[ \text{.2} \quad 2\text{HOCl} + 2\text{HAc} \leftrightarrow \text{Cl}_2↑ + 2\text{H}_2\text{O} + 2\text{Ac}^- \quad (\text{Ac} : \text{CH}_3\text{COO}^-) \]

Gaseous chlorine is not generated at high pH (>7.0). The pH of sodium hypochlorite in seawater is between 7.8 and 8.4, so the presence of gaseous chlorine is impossible when the electrochlorination process is running.

The toxic endpoint is 3 ppm for chlorine. The United States National Advisory Committee for Acute Exposure Guideline Levels (AEGL) states that:

\[ C^2t = k \]

where "k" is a constant that has different values for AEGL-1, AEGL-2, and AEGL-3, "C" is the average airborne concentration and "t" is the exposure time.

For AEGL-1, \( C^2t = 60 \text{ ppm}^2 \times \text{min} \); for AEGL-2, \( C^2t = 240 \text{ ppm}^2 \times \text{min} \); and for AEGL-3, \( C^2t = 24,000 \text{ ppm}^2 \times \text{min} \). Focusing on the AEGL-2 as being closest to the EPA's toxic
endpoint, C for chlorine is 2 ppm for t = 1 hour, 2.8 ppm for t = 30 minutes and 4.9 ppm for t = 10 minutes.

For more safety one chlorine detector is installed at low elevation in the ballast room, to monitor the chlorine presence due to abovementioned and unwanted reactions. The set point of Cl₂ detector is less than 2 ppm.

**A word about safety**

Following the best practices contained in the ECOLCELL BTs Operating & Instruction Manual that represents a commitment to the safe use and handling of hydrogen, it should be recognized that no information resource can provide 100% assurance of safety. ACG Senior Engineers took care in designing and engineering techniques to minimize the potential safety risk.

The ECOLCELL BTs Operating & Instruction Manual provides unambiguous explanations to follow safe practices and procedures when working with and around hydrogen. Like virtually all energy forms, hydrogen can be used safely when proper procedures are followed, but its use still involves a degree of risk that must be respected.

Regarding occurred incidents related to hydrogen produced by electrochlorination from seawater, ACG did not find any citation either on International databases nor in specialized bibliography.

### 8.1.5 Storage and handling of the substances

**Sodium hypochlorite**

Engineering controls: check that the system is closed, provide local exhaust ventilation where vapour or mist may be generated, ensure compliance with applicable exposure limits.

Personal protective equipment: eye protection, wear splash resistant safety goggles with a face shield, and provide an emergency eye wash fountain and quick drench shower in the immediate working area.

Respiratory Protection: a NIOSH approved respirator with N95 (dust, fume, mist) cartridges may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits, or when symptoms have been observed that are indicative of overexposure. Acid gas cartridges may be required if decomposition products are present. A respiratory protection program that meets 29 CFR 1910.134 must be followed whenever workplace conditions warrant use of a respirator.

**Sodium thiosulfate pentahydrate**

Storage: hygroscopic, keep container tightly closed, keep container in a cool, well-ventilated area.

Precautions: do not breathe dust, wear suitable protective clothing, in case of insufficient ventilation wear suitable respiratory equipment. If you feel unwell, seek medical attention and show the label when possible. Keep away from incompatibles such as oxidizing agents, acids.

Engineering Controls: use process enclosures, local exhaust ventilation or other engineering controls to keep airborne levels below recommended exposure limits. If user operations
generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal protection: safety glasses, lab coat, dust respirator (be sure to use an approved/certified respirator or equivalent), gloves.

Personal protection in case of a large spill: splash goggles, full suit dust respirator, boots, gloves. A self-contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult Material Safety Data Sheet (MSDS) before handling this product.

Small spill: use appropriate tools to put the spilled solid in a convenient waste disposal container, finish cleaning by spreading water on the contaminated surface and dispose of it according to local and regional authority requirements.

Large spill: use a shovel to put the material into a convenient waste disposal container, finish cleaning by spreading water on the contaminated surface and allow to evacuate through the drainage system on ship.

8.1.6 Noise

Exposure to noise and vibrations is regulated and limits for maritime vessels are given in the ISO standard 6954: Guidelines for permissible mechanical vibrations on board seagoing vessels to protect personnel and crew.

At the design table, the ACG engineer team made the necessary choices concerning the component and structure to achieve an optimized design towards noise and vibration control.

Control at source: to control the vibrations at the origin, isolating fittings, elastic mounting of motor, elastic holding of pipes or dampers has been considered. These will absorb a part of the vibrations (and the noise) produced by the ECOLCELL BTs. ACG reached the conclusion that the N&V value is 40 dB as maximum for the ECOLCELL BTs.

8.2 Risks to human health

The basic approach for the quantitative human health risk assessments is in accordance with the United States EPA (1989) risk assessment guidance. In general, this is a four-step process:

Step 1: the hazard identification process consisting of the identification of chemicals of potential concern (COPCs) and their existing analytical data in environmental media with potentially complete exposure pathways and comparing detected concentrations with risk-based screening levels;

Step 2: identifying current and future potential exposure points, receptors, exposure scenarios, and exposure point concentrations (EPCs) and refining the preliminary conceptual exposure model (CEM) as necessary;

Step 3: identifying relevant toxicity values for COPCs; and

Step 4: estimating potential risks associated with exposures to COPCs.

Following this scheme, the COPCs associated with the use of ECOLCELL BTs have been described in this report (section 4.3) and they are summarized in table 8.1.
These compounds, either stored and added to the system or formed in situ, could have the potential to adversely impact human health under either routine operating conditions, maintenance operations, or during an emergency resulting in an unexpected release.

Table 8.1: COPCs associated with the use of ECOLCELL BTs

<table>
<thead>
<tr>
<th>COPC</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hypochlorite (measured as free chlorine)</td>
<td>Active Substance</td>
</tr>
<tr>
<td>Bromoform</td>
<td>Relevant Chemical</td>
</tr>
<tr>
<td>Chloroform</td>
<td>Relevant Chemical</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>Relevant Chemical</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>Other Chemical</td>
</tr>
</tbody>
</table>

8.2.1 Human exposure scenario (HES)

As reported in the United States EPA (1989) the exposure pathway is the course a chemical or pollutant takes from the source to the organism exposed, and the exposure route is the way a chemical or pollutant enters an organism after contact.

In order to identify the potential exposure pathway a conceptual exposure model (CEM) has been prepared (Figure 8.1) to identify mechanisms through which people may be exposed to sodium hypochlorite, bromoform, chloroform, dibromochloromethane and sodium thiosulfate (COPCs).

Primary, secondary and tertiary sources of exposure to COPCs have been considered. The primary source is a consequence of a very unlikely failure of storage tanks or pipeline. If such a scenario occurs, COPCs will reach secondary that is the on board area of the vessel and the seawater; from these sources they can reach the tertiary ones, such as migration to shorelines and/or docking areas.

To complete the CEM, the potentially exposed populations have been identified. Even if it is very unlikely that people may be exposed to Active Substance, Relevant Chemicals and sodium thiosulfate, in this analysis we consider the technicians belonging to Azienda Chimica Genovese (ACG) as the population with the highest possibility to be exposed COPCs during routine maintenance or chemical resupply (sodium thiosulfate).

Considering a worst-case scenario, ship crew on board could also be exposed to COPCs during a pipeline or chemical tank failure. Considering that ballast water tanks are closed, technicians and ship's crew are not expected to have direct contact with treated ballast water; however, either the ship's crew or dock workers could have dermal contact with released ballast water as a result of spray drift. Others with potential for COPC contact include the general public recreating at beaches near areas where treated ballast water has been discharged from the ship, although this exposure scenario is highly unlikely. Volatilization of COPCs from storage tanks and treated ballast water was not evaluated quantitatively because considered very unlikely to occur.
Figure 8.1: Conceptual Exposure Model (CEM)

The exposure point concentrations used in the risk assessment are reported in table 8.2.

Table 8.2: COPC Exposure Concentrations (mg/L)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Technician</th>
<th>BW sampling, Tanks cleaning, Ship’s Crew, Dock Workers</th>
<th>General Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hypochlorite (measured as free chlorine)</td>
<td>8.00E+02</td>
<td>8.00E+00</td>
<td>NA</td>
</tr>
<tr>
<td>Bromoform</td>
<td>1.20E-01</td>
<td>1.20E-01</td>
<td>1.29E-03</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.20E-03</td>
<td>1.20E-03</td>
<td>6.75E-06</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>1.78E-02</td>
<td>1.78E-02</td>
<td>1.61E-04</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>3.50E+05</td>
<td>7.00E+00</td>
<td>1.57E-01</td>
</tr>
</tbody>
</table>

The concentrations considered in the risk assessment are the following:

sodium hypochlorite:
- $8.00 \times 10^2$ mg/L = maximum production concentration prior to injection; and
- 8.00 mg/L = maximum operational value.

bromoform:
- $1.2 \times 10^{-1}$ mg/L = maximum concentration measured using laboratory scale plant; and
- $1.29 \times 10^{-3}$ mg/L = PEC (Predicted Environmental Concentration) calculated with MAMPEC software (see section 7.3.1).
chloroform:
- $1.2 \times 10^{-3}$ mg/L = maximum concentration measured using laboratory scale plant; and
- $6.75 \times 10^{-6}$ mg/L = PEC (Predicted Environmental Concentration) calculated with MAMPEC software (see section 7.3.1).

dibromochloromethane:
- $1.78 \times 10^{-2}$ mg/L = maximum concentration measured using laboratory scale plant; and;
- $1.61 \times 10^{-4}$ mg/L = PEC (Predicted Environmental Concentration) calculated with MAMPEC software (see section 7.3.1).

sodium thiosulfate:
- $3.60 \times 10^{5}$ mg/L = this compound is stored in holding tanks as a 36% aqueous solution;
- $7$ mg/L = maximum operational concentration (worst case scenario); and
- $1.57 \times 10^{-1}$ mg/L = PEC (Predicted Environmental Concentration) calculated with MAMPEC software (see section 7.3.1).

8.2.2 Quantitative exposure assessment

Following the example in the revised Methodology (BWM.2/Circ.13/Rev.1) (based on ECHA R15, 2010), the potential risk for dermal uptake of chemicals from the ballast water during ballast water sampling and tanks cleaning has been calculated using the equation below:

$$U_{sd} = \frac{(A_{\text{hands}} \cdot TH_{\text{dermal}} \cdot PEC_{\text{mampec}} \cdot BIO_{\text{derm}})}{BW}$$

Where

- $U_{sd}$ = dermal uptake (mg/kg-d)
- $A_{\text{hands}}$ = surface area of one hand (0.084 m$^2$)
- $TH_{\text{dermal}}$ = thickness of the product layer on the skin (0.0001 m)
- $PEC_{\text{mampec}}$ = concentration of chemical in treated ballast (mg/m$^3$)
- $BIO_{\text{derm}}$ = dermal bioavailability (1)
- $BW$ = bodyweight (default = 60 kg)

For the general public, exposure via dermal uptake of chemicals when swimming has been calculated using the following equation (BWM.2/Circ.13/Rev.1):

$$U_{sd} = \frac{(PEC_{\text{mampec}} \cdot TH_{\text{dermal}} \cdot n_{\text{swim}} \cdot A_{\text{skin}} \cdot BIO_{\text{derm}})}{BW}$$

Where

- $U_{sd}$ = dermal uptake per day during swimming (mg/kg-d)
- $PEC_{\text{mampec}}$ = concentration of chemical in water derived from MAMPEC (mg/m$^3$)
- $TH_{\text{dermal}}$ = thickness of the product layer on the skin (0.0001 m)
\( n_{\text{swim}} \) = number of events (5/d)
\( A_{\text{skin}} \) = surface area of whole body being exposed to water (1.94 m\(^2\))
\( B_{\text{Oderm}} \) = bioavailability for dermal intake (default= 1)
\( B_{\text{W}} \) = bodyweight (default= 60 kg)

The oral uptake via swimming has been calculated according to the following equation (BWM.2/Circ.13/Rev.1):

\[
U_{so} = \left( C_{\text{MAMPEC}} \cdot IR_{\text{swim}} \cdot n_{\text{swim}} \cdot Dur_{\text{swim}} \cdot B_{\text{Oderm}} \right) / B_{\text{W}}
\]

Where

\( U_{so} \) = amount of chemical swallowed (mg/kg-d)
\( C_{\text{MAMPEC}} \) = concentration of chemical in water derived from MAMPEC (mg/L)
\( IR_{\text{swim}} \) = ingestion rate of water while swimming (0.025 L/h)
\( n_{\text{swim}} \) = number of swims per day (5)
\( Dur_{\text{swim}} \) = duration of each swim (0.5 h)
\( B_{\text{Ooral}} \) = bioavailability for oral intake (default= 1)
\( B_{\text{W}} \) = bodyweight (default= 60 kg)

The Risk Characterization Ratios (RCRs) compare the exposure levels to Derived No Effect Levels. The RCR is calculated according to the following formula (BWM.2/Circ.13/Rev.1):

\[
\text{RCR} = \frac{\text{Exposure}}{\text{DNEL}}
\]

If the RCR <1 the exposure is deemed to be safe.

As DNEL, the reference dose (Rfd; table 8.3) of each chemical, from the Integrated Risk Information System (IRIS; United States EPA 2011), was employed, except for sodium thiosulfate, whose data are not available on IRIS. The Rfd, expressed in milligrams per kilogram-day (mg/kg-d), represents the daily intake of a substance (averaged over a year) per kilogram of body weight that is below the effect threshold for that substance (United States EPA 1989).

For sodium thiosulfate, the Rfd value was derived from the chronic NOEL for mammalian toxicity reported in Section 5.2.3, i.e. 70 mg/kg-d, applying an uncertainty factor of 100: 10 for the extrapolation of data from laboratory animals to human and 10 for intraspecies differences.

### Table 8.3: Toxicity Criteria

<table>
<thead>
<tr>
<th>Substance</th>
<th>Oral Reference Dose (mg/kg-d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hypochlorite</td>
<td>1.00E-01</td>
</tr>
<tr>
<td>Bromoform</td>
<td>2.00E-02</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.00E-02</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>2.00E-02</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>7.00E-01</td>
</tr>
</tbody>
</table>

Since all the calculated RCRs (table 8.4) are well below 1, no risks to human health can be foreseen due to the exposure to the water treated with ECOLCELL BTs, in the mentioned conditions.
Table 8.4: Summary of calculated RCRs

<table>
<thead>
<tr>
<th>Substance</th>
<th>Ballast water sampling</th>
<th>Ballast water tanks cleaning</th>
<th>Swimming*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hypochlorite</td>
<td>1.12E-02</td>
<td>2.59E-02</td>
<td>NA</td>
</tr>
<tr>
<td>Bromoform</td>
<td>8.40E-04</td>
<td>1.94E-03</td>
<td>1.04E-03</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.68E-05</td>
<td>3.88E-05</td>
<td>1.09E-05</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>1.25E-04</td>
<td>2.88E-04</td>
<td>1.30E-04</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>1.40E-03</td>
<td>3.23E-03</td>
<td>3.63E-03</td>
</tr>
</tbody>
</table>

* dermal + oral uptake

To ensure an accurate evaluation of quantitative exposure to COPCs and related risk, also for prolonged and chronic exposure, the methodology based on the United States EPA 2004 and MEPC 60/2/9 recommendations was employed too.

To determine the intake of COPCs via dermal contact pathway, the following equation was used:

\[ I_d = \frac{C_w \cdot SA \cdot PC \cdot CF \cdot ET \cdot EF \cdot ED}{BW \cdot AT} \]

Where

- \( I_d \) = intake by dermal contact with COPC in water (mg/kg-d)
- \( C_w \) = maximum concentration of COPC in water (mg/L)
- \( SA \) = skin surface area in contact with water (cm\(^2\))
- \( PC \) = chemical-specific dermal permeability coefficient (cm/h)
- \( CF \) = conversion factor \( 10^{-3} \) (L/cm\(^3\))
- \( ET \) = exposure time (h/d)
- \( EF \) = event frequency (d/y)
- \( ED \) = exposure duration (y)
- \( BW \) = body weight (kg)
- \( AT \) = averaging time (d), \( AT = ED \cdot 365d/y \) (non carcinogens)
- \( AT = 70y \cdot 365d/y \) (carcinogens)

To determine the intake of COPCs via oral ingestion pathway, the following equation was used (United States EPA 2004, MEPC 60/2/9):

\[ I_o = \frac{C_w \cdot IR \cdot ET \cdot EF \cdot ED}{BW \cdot AT} \]

Where

- \( I_o \) = intake by oral ingestion of COPC in water (mg/kg-d)
- \( C_w \) = maximum concentration of COPC in water (mg/L)
- \( IR \) = ingestion rate (L/h)
- \( ET \) = exposure time (h/d)
- \( EF \) = event frequency (d/y)
- \( ED \) = exposure duration (y)
- \( BW \) = body weight (kg)
- \( AT \) = averaging time (d), \( AT = ED \cdot 365d/y \) (non carcinogens)
- \( AT = 70y \cdot 365d/y \) (carcinogens)

The value of the parameters used in these equations are listed below.
ACG technicians

**Ingestion rate:** a conservative value of 0.05 L/hour, the same suggested by the United States EPA (1989) for swimmers, was used.

**Skin surface area available for contact:** hands and arms may be significantly exposed during an accidental spill, therefore a 3300 cm$^2$ surface area was used (United States EPA 2004).

**Permeability constant:** 0.001 cm/hour for sodium hypochlorite and sodium thiosulfate, 0.0022 cm/hour for bromoform, 0.0068 cm/hour for chloroform, 0.0032 cm/hour for dibromochloromethane (United States EPA 2004).

**Body weight:** the adult body weight used by default in risk assessment studies is 70 kg (United States EPA 2004).

**Exposure time:** it was assumed to be 0.25 hours (MEPC 60/2/9).

**Event frequency:** 1 spill event per year (MEPC 60/2/9).

**Exposure duration:** 10 years (MEPC 60/2/9).

**Averaging time:** 70 years (25550 days) for carcinogenic effects (United States EPA 2004), 10 years (3650 days), as the exposure duration, for non-carcinogenic effects.

**Ship's crew, dock workers**

Since incidental ingestion is considered to be very unlikely to occur, only dermal contact, due to accidental spray drifts, has been taken into account for ship's crew and dock workers. For accidental spills, and consequent dermal/oral intake, ACG technicians exposure scenario is considered to be the worst-case.

**Skin surface area available for contact:** there may be a limited contact with hands, arms and face during an accidental spray drift, therefore a 1800 cm$^2$ surface area was used (10% of total adult body; United States EPA 2004, MEPC 60/2/9).

**Permeability constant:** 0.001 cm/hour for sodium hypochlorite and sodium thiosulfate, 0.0022 cm/hour for bromoform, 0.0068 cm/hour for chloroform, 0.0032 cm/hour for dibromochloromethane (United States EPA 2004).

**Body weight:** the adult body weight used by default in risk assessment studies is 70 kg (United States EPA 2004).

**Exposure time:** it was assumed to be 0.25 hours (MEPC 60/2/9).

**Event frequency:** 1 spraying event per year (MEPC 60/2/9).

**Exposure duration:** 10 years (MEPC 60/2/9).

**Averaging time:** 70 years (25550 days) for carcinogenic effects (United States EPA 2004), 10 years (3650 days), as the exposure duration, for non-carcinogenic effects.
General public

About the general public, \( I_d \) and \( I_o \) were calculated for beachgoers taking into account 6 years of exposure as a child and 24 years of exposure as an adult, following United States EPA guidelines (1989, 1991).

**Ingestion rate**: 0.05 L/hour (United States EPA 1989).

**Skin surface area available for contact**: 18000 cm\(^2\) for adults and 6600 cm\(^2\) for children (United States EPA 2004).

**Permeability constant**: 0.001 cm/hour for sodium hypochlorite and sodium thiosulfate, 0.0022 cm/hour for bromoform, 0.0068 cm/hour for chloroform, 0.0032 cm/hour for dibromochloromethane (United States EPA 2004).

**Body weight**: the adult and child body weights used by default in risk assessment studies are 70 kg and 15 kg, respectively (United States EPA 2004).

**Exposure time**: 1 hour (United States EPA 1997).

**Event frequency**: 10 events per year (MEPC 60/2/9).

**Exposure duration**: 30 years, divided into 6 years of exposure as a child and 24 years of exposure as an adult (United States EPA 1989, 1991).

**Averaging time**: 70 years (25550 days) for carcinogenic effects (United States EPA 2004), 30 years, divided into 6 years (2190 days) of exposure as a child and 24 years (8760 days) of exposure as an adult, as the exposure duration, for non-carcinogenic effects.

For the evaluation of non-carcinogenic effects, the same toxicity reference criteria used to calculate the RCR were employed (table 8.3). For the evaluation of cancer risk, the oral cancer slope factor (per mg/kg-d) was used (table 8.5).

### Table 8.5: Toxicity criteria

<table>
<thead>
<tr>
<th>Substance</th>
<th>Oral Cancer Slope Factor (per mg/kg-d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hypochlorite</td>
<td>NA</td>
</tr>
<tr>
<td>Bromoform</td>
<td>7.90E-03</td>
</tr>
<tr>
<td>Chloroform</td>
<td>*</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>8.04E-02</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA = Not Applicable.

* A dose of 1.00E-2 mg/kg-d (equal to the RfD) can be considered protective against cancer risk.

The resulting risk levels are listed in Tables 8.6 to 8.9. As it can be seen, the risk associated with all the COPCs is extremely low, since all the non-cancer hazard values (\( I/RfD \)) are well below 1, and all the cancer risk values (\( I \times \text{cancer slope factor} \)) are below 1E-6, the value used by United States EPA (1989) as point of departure for individual cancer risk. The cancer risk is below the point of departure even summing the child risk to the adult risk, for the general public.
Table 8.6: Summary of potential risks for ACG technicians

<table>
<thead>
<tr>
<th>Substance</th>
<th>Non-cancer hazard</th>
<th>Cancer risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dermal</td>
<td>Oral</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>2.58E-04</td>
<td>3.91E-03</td>
</tr>
<tr>
<td>Chloroform</td>
<td>2.63E-08</td>
<td>5.87E-08</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>9.20E-08</td>
<td>4.35E-07</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>1.61E-02</td>
<td>2.45-01</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not Applicable.
* Calculated on the dose considered to be protective against cancer risk, reported in table 8.5.

Table 8.7: Summary of potential risks for ship's crew and dock workers

<table>
<thead>
<tr>
<th>Substance</th>
<th>Non-cancer hazard</th>
<th>Cancer risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dermal</td>
<td>Oral</td>
</tr>
<tr>
<td>Sodium hypochlorite</td>
<td>1.41E06</td>
<td>NA</td>
</tr>
<tr>
<td>Bromoform</td>
<td>2.32E-07</td>
<td>NA</td>
</tr>
<tr>
<td>Chloroform</td>
<td>1.44E-08</td>
<td>NA</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>5.02E-08</td>
<td>NA</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>1.76E-07</td>
<td>NA</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not Applicable.
* Calculated on the dose considered to be protective against cancer risk, reported in table 8.5.

Table 8.8: Summary of potential risks for general public – children

<table>
<thead>
<tr>
<th>Substance</th>
<th>Non-cancer hazard</th>
<th>Cancer risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dermal</td>
<td>Oral</td>
</tr>
<tr>
<td>Bromoform</td>
<td>1.71E-06</td>
<td>5.89E-06</td>
</tr>
<tr>
<td>Chloroform</td>
<td>5.53E-08</td>
<td>6.16E-08</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>3.11E-07</td>
<td>7.35E-07</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>2.70E-06</td>
<td>2.05E-05</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not Applicable.
* Calculated on the dose considered to be protective against cancer risk, reported in table 8.5.

Table 8.9 : Summary of potential risks for general public – adults

<table>
<thead>
<tr>
<th>Substance</th>
<th>Non-cancer hazard</th>
<th>Cancer risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dermal</td>
<td>Oral</td>
</tr>
<tr>
<td>Bromoform</td>
<td>1.00E-06</td>
<td>1.26E-06</td>
</tr>
<tr>
<td>Chloroform</td>
<td>3.23E-08</td>
<td>1.32E-08</td>
</tr>
<tr>
<td>Dibromochloromethane</td>
<td>1.81E-07</td>
<td>1.58E-07</td>
</tr>
<tr>
<td>Sodium thiosulfate</td>
<td>1.38E-06</td>
<td>4.39E-06</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA = Not Applicable.
* Calculated on the dose considered to be protective against cancer risk, reported in table 8.5.
8.2.3 Acute health effects

The in situ generated COPCs are at concentrations too low to cause serious eye and skin irritation. The only substance which can present this kind of hazard is sodium thiosulfate (36% aqueous solution). This will require the use of appropriate PPE when using this substance, to minimize the risk of acute health effects, and only trained personnel should handle this solution.

8.2.4 Potential risks related to seafood consumption

Since the Log $K_{ow}$ of all the COPCs presented here is below 3, they are not expected to persist in the food web (MEPC.169(57)).

9 ASSESSMENT REPORT (G9: 4.3)

Overview of toxicity data

In regard to the Active Substances and Relevant Chemicals by the laboratory prototype of the ballast water management system (ECOLCELL BTs), all of the toxicity data for the aquatic organisms and mammals were investigated from literatures and toxicology databases provided in several international research institutes, such as Toxicology Data Network (ToxNet), Hazardous Substances Data Bank (HSDB), Eco-toxicity (United States EPA), and European Chemical Bureau (ECB).

The chemical analyses on the Active Substances and Relevant Chemicals of ECOLCELL BTs laboratory unit were conducted by Laboratori Iride Acqua Gas Srl. All chemical analyses were carried out according to the references methods. Also, the laboratory-scale test of ECOLCELL BTs system is adequate for the Guidelines (G8) MEPC.174(58), annex, part 2, paragraph 2.3.20 (as well as regulation D-2 of the BWM Convention).

The toxicity screening on the water treated by ECOLCELL BTs laboratory unit was conducted by the Institute of Marine Science – National Research Council (ISMAR-CNR), Italy. The acute toxicity test was carried out in accordance with the relevant international recognized guidelines (ISO 10253, 2000; Artoxkit, 1990; ISO 14669, 1999; OECD n° 203, 1992) on algae (Skeletonema costatum), crustacean (Artemia salina and Tigriopus fulvus), and fish (Dicentrarchus labrax), respectively.
REFERENCES


DATA BANK:


ANNEXES

ANNEX 1 – Efficacy
ANNEX 2 – Chemical analyses
ANNEX 3 – MSDS
ANNEX 4 – Toxicity
ANNEX 5 – Quality Management System