Environmental acceptability evaluation of the Hyde GUARDIAN^{TM} Ballast Water Treatment System as part of the Type Approval Process

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Glossary

BWM	Ballast Water Management
BWTS	Ballast Water Management System
CAS	Chemical Abstracts Service
DBP	Disinfection By-products
DOC	Dissolved Organic Carbon
FAO	Food and Agriculture Organization
GESAMP-BWWG	Group of Experts on the Scientific Aspects of Marine Protection - Ballast Water Working Group
G2	Resolution MEPC.173(58) Sampling for Compliance Control (G2)
G8	Resolution MEPC.174(58) Guidelines for Approval of Ballast Water Management Systems (G8)
G9	Resolution MEPC.169(57) Guidelines for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9)
HAA	Haloacetic Acids
IMO	International Maritime Organization
IMO D-2	Regulation D-2 Ballast Water Performance Standard
LC_{50}	Lethal Concentration, 50%
LPHO	Low Pressure High Output (lamps)
MEPC	Marine Environment Protection Committee (of the IMO)
MSDS	Material Safety Data Sheet
NIOZ	The Royal Netherlands Institute for Sea Research
NOEC	No Observed Effect Concentration
NOM	Natural Organic Matter
Pa	Pascals
PAH	Polycyclic Aromatic Hydrocarbon
PSU	Practical Salinity Units
STEP	U.S. Coast Guard Shipboard Technology Evaluation Program
THM	Trihalomethane
TOC	Total Organic Carbon
TOX	Total Organic Halides
US EPA	U.S. Environmental Protection Agency
UV-A	Ultraviolet Light, wavelength 315-400 nm
UV-B	Ultraviolet Light, wavelength 280-315 nm
UV-C	Ultraviolet Light, wavelength 200-280 nm
UV-Vac	Ultraviolet Light, wavelength 10-200 nm (UV-V)
VOC	Volatile Organic Compound
WET	Whole Effluent Toxicity
WHO	World Health Organization

1 Introduction

With this document, accompanying the type approval test reports (land based and shipboard tests) Hyde Marine Inc. whose registered office is at 28045 Ranney Parkway, Cleveland, OH 44145 USA, applies for approval of environmental acceptability according to International Ballast Water Management Convention Guideline G8 (Guidelines for Approval of Ballast Water Management Systems) and in agreement with G9 (Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances),where appropriate. The document is structured to support evidence that no active substances are used or generated for ballast treatment and that relevant chemicals and other compounds (DBPs) are either not produced or not produced at unacceptable levels.

The document first argues the case for absence of active substances by the treatment method (filtration and UV irradiation) and then presents information on potential by- and end products, their toxicological profiles and the actual presence or absence of such products in the treatment process under the different circumstances the system might meet.

Reference is made to the relevant paragraphs of BWM Guideline G9: Resolution MEPC.169(57) – Procedure for approval of ballast water management systems that make use of Active Substances (G9) and the GESAMP-BWWG Methodology as described in MEPC/58/2/7, 6th GESAMP-BWWG Meeting report, Annex IV.

The environmental performance of the Hyde GUARDIAN^{TM} system is being evaluated according to the definitions in G9, the guideline for approval of ballast water management systems that make use of active substances, to which G8 (Resolution MEPC.174 (58) - Approval of ballast water management systems) refers in the paragraphs on environmental acceptability, and according to the methodology developed by the GESAMP-BWWG.

This review is based on the existing literature and on the results from land based and shipboard toxicity tests in the application of Hyde GUARDIAN^{TM} in fully marine and brackish water. It is known from e.g. oxidation processes that the formation of disinfection by-products (DBPs) in marine waters may differ considerably from those in the more frequently studied drinking-, process- and wastewater applications[1]. Therefore it was important to document whether similar problems as those that occur in some of the fresh-water applications may also arise from UV ballast water treatment saline waters.

2 UV light and disinfecting action

Ultraviolet light (UV) is an electromagnetic radiation of shorter wavelengths (λ) than visible light, with wavelengths ranging from 10 – 400 nm and energies from 3 eV to 124 eV. The ultraviolet spectre consists of frequencies (*f*) above those of the visible colour violet.

Ultraviolet (UV) wavelengths 10-400 nm lay outside the visible light spectre. UV is classified according to spectral bands (expressed in nanometres – nm):

- UV-A – 315-400 nm
- UV-B – 280-315 nm
- UV-C – 200-280 nm
- UV-Vac – 10-200 nm (UV-V).

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[1] Kornmüller A (2007) Review of fundamentals and specific aspects of oxidation technologies in marine waters. Water Science and Technology 55, 1-6

Natural solar UV includes the full spectrum of UV; artificially UV is made by specific devices, including a UV lamp and a generator, which, depending on construction, can be specialised to generate UV of a specific spectral band or of one single wavelength. Artificial UV is used for several purposes in and outside water treatment. This paper will focus on UV as used in water treatment, where UV is mainly used for disinfection and for photolysis of chemical bonds. For optimal action both processes require specific spectral bands that differ from each other. UV-C is optimal for disinfection, while UV-V results in photolysis of chemical bonds. Wavelengths below 200 nm can also result in unwanted by-products due to photolysis, such as ozone.

Physical process

UV disinfection is a physical form of disinfection, as opposed to the chemical form of chlorine and other chemicals. Some molecules, when subjected to UV light, will absorb its energy. Once absorbed, the electronic energy is sufficient to break bonds and promote the formation of new bonds within the molecule, leaving it damaged. For this reason, UV-C light is called phototoxic (toxic light). The most important molecules of living cells, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), are very sensitive to phototoxicity. The most common effect of UV-C is the formation of a cyclobutyl ring between two adjacent thymine nucleic acids located on the same strand of DNA/RNA, as shown on Figure 2-1.

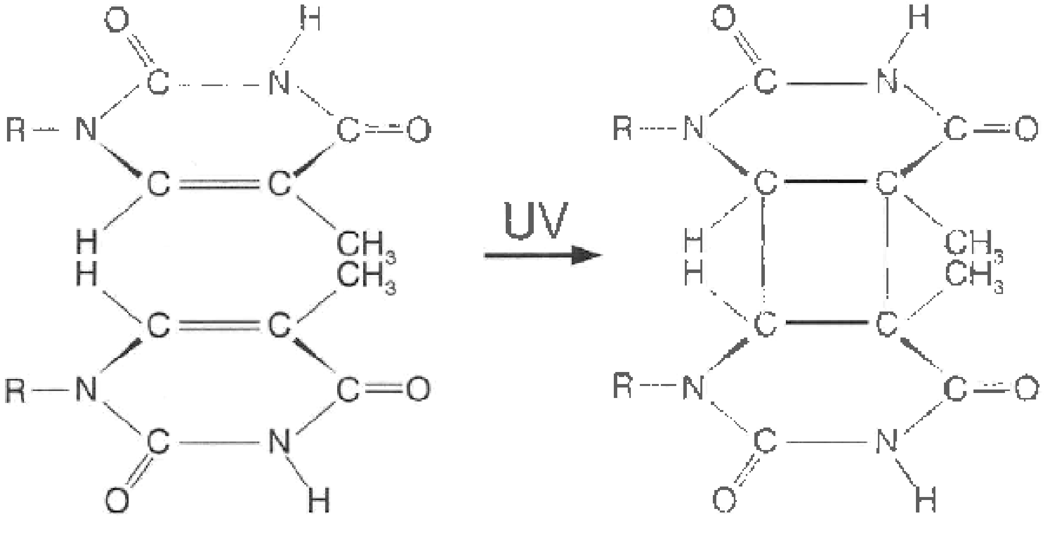

Figure 2-1. Formation of thymine – thymine dimer from adjacent thymine residues[2].

The resulting structure, called a thymine dimer, locally distorts the helical structure of the DNA/RNA molecule preventing the proper attachment of transcriptional and replicating enzyme complexes. This damage most commonly results in inhibition of the transcription and replication of the genetic molecules within the affected cell, which results in death of that single cell. [3]

Structural damage to DNA material, rendering the DNA unable to replicate, inhibits reproduction of the organism. For disinfection and germicidal purposes UV-C penetrates through cell membranes and cyto-

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[2] New York State Energy Research and Development Authority (NYSERD) (2004) Evaluation of Ultraviolet (UV) radiation disinfection technologies for wastewater treatment plant effluent.). Final Report 04-7. December 2004.

[3] New York State Energy Research and Development Authority (NYSERDA) (2004) Evaluation of Ultraviolet (UV) radiation disinfection technologies for wastewater treatment plant effluent.). Final Report 04-7. December 2004.

plasm and can enter the cell nucleus; in both nucleus and cytoplasm UV-C damages or destroys genetic material, rendering the DNA unable to reproduce. The optimal wavelength for disinfection is 265 nm. The treatment method is nonintrusive and does not alter the chemistry or physical property of the water to be treated. No organisms have been demonstrated to be resistant to UV.

UV-B, of larger wavelengths, penetrates less deep in fluids and is hence less fit for disinfection. UV-V risks the formation of by-products due to ionisation and dissociation of chemical compounds by photolysis.

Artificial UV-C is generated by purpose-constructed devices that generate UV-C through different process, pressures and temperature regimes.

Low pressure UV lamps consist of a quartz lamp with attached electrodes. The lamp is filled with inert gas and a minor amount of mercury. For disinfection purposes the quartz should be natural, as artificial quartz causes the generation of not only UV at 254 nm, but also UV-V of 185 nm. The latter bears the risk of generation of ozone as a by-product. A low pressure UV generator has typically a pressure of 1.3 – 0.13 Pa. The temperature in a low pressure UV lamp is 40.5 – 43°C. The lamp functions optimally in water of around 21°C, else the UV is less effective. The lamp functions at 120-140 V, with a current of < 500 mA and a power output of 40 - >100 W. The mercury in the lamp is partly vaporised. The lamp typically emits light of one specific wavelength.

Medium pressure UV-C lamps function at much higher pressures (13-1300 kPa). Temperatures inside the UV lamp rise to 500-600 °C, at which temperature the mercury is completely vaporised. The lamp is stable in all temperature conditions and has a broad spectral output. The high temperature and pressure creates a plasma excitation of the mercury, which collapses emitting characteristic absorption lines. The principle of the construction of the medium pressure lamp that operates with a reactor is similar as that of the low pressure lamps. Here too the quartz of the lamp should be natural, so as to prevent the formation of potentially harmful by-products.

UV irradiation for disinfection is most effective at germicidal wavelengths (240-280 nm, Figure 2-2). The effectiveness of the UV treatment (adequate destruction of the genetic material) requires that a sufficient energy dose is absorbed by the organism. The energy dose is measured as the product of the lamps intensity (rate at which photons are delivered to the target) and the time of exposure. UV lamps at low pressure and low intensity are most common in disinfection, however for shipboard use, medium pressure lamps (>3 kW) are better suited for the application due to compact size and lower power consumption.[4]

Basically, low pressure lamps have a mercury vapour pressure of between 0.1 and 10 Pa, whereas medium pressure lamps have a mercury vapour pressure (when hot) of between 50 and 300 kPa.

Low intensity (normal) low pressure lamps have only mercury present (plus an argon buffer gas), whereas high intensity low pressure (usually called low pressure high output or LPHO lamps) either have an amalgam spot (a compound with mercury and another metal such as indium) or a special long electrode section with a 'cold spot' (Bolton, James R., Bolton Photosciences Inc. 2009. Personal communication).

The low pressure low intensity lamps are typically about 65 W each. The low pressure high intensity lamps can go as high as 300 W. Regardless of the intensity low pressure lamps are monochromatic (Granitto, Matt, Hyde Marine Inc. 2009. Personal communication)

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[4] Techneau (2007) UV disinfection and UV/H2O2 oxidation: by-product formation and control. Techneau D2.4.1.1, May 2007.

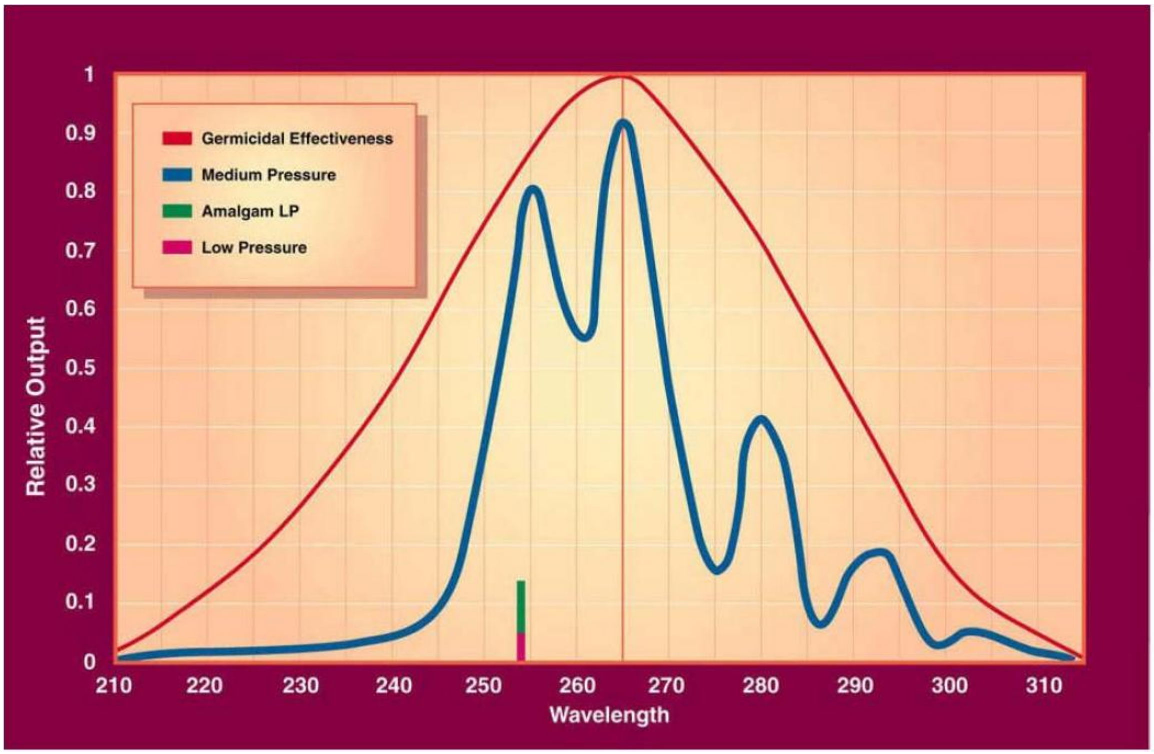

Figure 2-2. Graph depicting the germicidal curve and typical lamp technology outputs.

All organisms have different responses to UV irradiation. The way in which UV is measured is called dose. The UV dose is simply a multiplication of the intensity of the UV and contact time. An organism exposed to 140 mW/cm^2 radiation (intensity) for 0.5 s would receive a UV dose of 70 mWs/cm^2 or 70 mJ/cm^2. As an example of appropriate amounts of UV, the US EPA's standard for using UV to disinfect drinking water requires a dose of 40 mJ/cm^2.

The Hyde GUARDIAN^{TM} system is designed to provide a minimum average dose of 200 mJ/cm^2. This average minimum dose to be effective for disinfection is calculated using the expected end of lamp life intensity of the UV lamp and at a water transmission of T10 = 92%.

BWT through the use of UV is repeatedly proven to be effective against zooplankton, phytoplankton, bacteria and viruses (Malmlook et al 2007[5]). In addition, ”UV irradiation is an attractive, rapid means of disinfection, as it leaves no harmful residues[6]”.

3 Identification of Preparations, Active Substances and Relevant Chemicals

3.1 Preparations (G9: 2.1.3; GESAMP-BWWG 6, Annex IV: 1.1.3)

“Preparation” means any commercial formulation containing one or more Active Substances including any additives. This term also includes any Active Substances generated on board for purposes of ballast water management and any relevant chemicals formed in the in the ballast water management system that makes use of Active Substances to comply with the Convention.

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[5] Malmlook R, Badran O, Abu-Khader MM, Holdo A, Dales J (2008) Fuzzy sets analysis for ballast water treatment systems: best available control technology. Clean Technologies and Environmental Policy 10, 397-407

[6] Oemcke DJ, Van Leeuwen J (2007) Chemical and physical characterization of ballast water. Part 1: Effects on ballast water treatment processes. Journal of Marine Environmental Engineering 7, 47-64

Following this definition the Hyde GUARDIAN^{TM} system is not using any preparations other than UV light.

3.2 Active Substances (G9: 2.1.1; GESAMP-BWWG 6, Annex IV: 1.1.4)

"Active Substance" means a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens.

Hyde GUARDIAN^{TM} system does not use or generate Active Substances, but only uses MP UV-light for disinfection; the photons emitted by the UV light are energy packages and therefore not substances or organisms. The process of disinfection is demonstrated by the description of the system in Chapter 2.2.

3.3 Relevant Chemicals (G9: 2.1.4; GESAMP-BWWG 6, Annex IV: 1.1.6)

"*Relevant Chemicals*" means transformation or reaction products that are produced during and after employment of the ballast water management system in the ballast water or in the receiving environment and that may be of concern to the ship's safety, aquatic environment and/or human health.

UV from solar radiation produces short-lived OH radicals that can act as an intermediate to reaction by-products. In that sense OH radicals may be considered relevant chemicals. The potential to form OH radicals by the Hyde GUARDIAN^{TM} system is discussed below. Ozone is only formed at wave lengths below the spectre of the Hyde GUARDIAN^{TM} system (below 200 nm) and should therefore not be considered a relevant chemical for the Hyde GUARDIAN^{TM} system.

Formation of OH radicals is enhanced by the presence of chlorine radicals in the water, a situation particular for drinking water purification by UV when chlorine is present in the upstream water to be purified[7]. Little is known about the fundamental photochemistry of free chlorine. Following photolysis of aqueous free chlorine to HOCl, the HOCl may absorb a photon ($\lambda < 511$ nm), leading to an OH radical and a Cl radical. Although in seawater chlorine is present in NaCl, the situation as described for drinking water is not to be expected to play an important role in seawater. For fresh water shipping areas, NaCl is not present or only at very low levels. The other situation where OH formation is enhanced is in the presence of added hydrogen peroxide (H_2O_2)[8] or added ozone (O_3). This situation is not to be expected in an aquatic environment. Solar UV OH formation might be promoted by the ozone when that is present in natural circumstances. As neither H_2O_2, not excess chlorine is present in the conditions that the Hyde GUARDIAN^{TM} system operates, the formation of OH radicals is not expected to be at a level that may cause adverse effects; levels may even be too low to be detectable at all, even when measured at the nanosecond life span of OH radicals. By using UV of $\lambda > 200$ nm only, the potential to form by-products, such as OH and O_3, through photolysis is prevented. Such by-products may be formed at lower wave length, typically at λ 185 nm, a wave length that is emitted when the lamp is made of synthetic (artificial) quartz. Pure quartz (quartz of natural origin) does not emit wavelengths below λ 200 nm. The lamps used in the Hyde GUARDIAN^{TM} system are all made of pure quartz. Furthermore, the UV source in the Hyde GUARDIAN^{TM} system is shielded by double pure quartz layer, since also the quartz sleeve that covers the UV lamp is made of pure quartz.

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[7] Watts MJ, Linden KG (2007) Chlorine photolysis and subsequent OH radical production during UV treatment of chlorinated water. Water Research 41, 2871-2878

[8] Techneau (2007) UV disinfection and UV/H_2O_2 oxidation: by-product formation and control. Techneau D2.4.1.1, May

3.4 Other components (GESAMP-BWWG 6, Annex IV: 1.1.5)

"Other components" of a preparation means any other substances in a preparation, other than the Active Substance(s) or Relevant Chemicals, produced during the treatment of ballast water.

For evaluating the presence of other components, the reaction by-products from the Hyde GUARDIAN^{TM} system, we investigate disinfection by- and end products (DBPs), i.e., chemical organic and inorganic substances that can form during a reaction of UV as disinfectant with the treated ballast water and/or with organic matter in the ballast and receiving water[9].

4 Data on Effects on Aquatic Plants, Invertebrates and Fish, and Other Biota, Including Sensitive and Representative Organisms (G9: 4.2.1.1; GESAMP-BWWG 6, Annex IV: 3.3)

Disinfection by UV is a physical process, where bonds are broken through photolysis. Such bonds can either be DNA and other cell material in living organisms or bonds of hazardous organic chemicals, such as may be present in wastewater streams. The administered energy should be sufficient to break the bonds. For disinfection this means sufficient energy to destroy the genetic material so as to render it incapable of reproduction (recombining DNA material). When the administered energy is too low DNA material might be damaged only, but still able to recombine, which can result in mutations that might prove harmful[10]. In the UV spectral band produced by the Hyde GUADRIAN^{TM} system (200-400 nm) the energy delivered to the ballast water is 200 mJ/cm^2 per treated m^3. This minimum dosing, which is considerably higher than the US EPA's standard for UV to disinfect drinking water (40 mJ/cm^2), is set sufficiently high to prevent the possibility that DNA can still recombine.

4.1 Environmental effects

Scientific and technical reports on UV disinfection and by- and end products are only partly applicable to screening of environmental and health impacts of ballast water treated by UV. UV disinfection is common in treatment of drinking water purification and wastewater treatment, reducing bacterial and microorganism loads as well as breaking down organic contaminants. By-products formed by UV disinfection on waters containing hazardous chemical compounds, not present naturally in an aquatic environment (such as disinfection products of wastewaters containing PAHs), are mentioned in this report but are not considered relevant for the purpose of environmental evaluation of MP UV in ballast water treatment.

By-products from UV treatment arise (1) directly through photochemical reactions, and (2) indirectly through reactions with products of photochemical reactions. By-products formed at manufacturing of drinking water are rather well documented. It was shown in several studies that UV disinfection at UV doses < 400 mJ/cm^2 does not affect formation of trihalomethanes (THMs), haloacetic acids (HAAs) and Total Organic Halides (TOX)[11].

UV treatment on its own was shown to have very little impact on the organic constituents in raw water. At low irradiation intensities, UV treatment does not change pH, turbidity, dissolved OC level, colour,

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[9] www.lenntech.com/water-disinfection/disinfection-byproducts.htm

[10] Kalisvaart BF (2001) Photobiological effects of polychromatic medium pressure UV lamps. Water Science and Technology 43, 191-197; Taghipour F, Sozzi A (2005) Modeling and design of ultraviolet reactors for disinfection by-product precursor removal. Desalination 176, 71-80; Cooper WJ, Jones AC, Whitehead RF, Zika RG (2007) Sunlight-induced photochemical decay of oxidants in natural waters: implication in ballast water treatment. Environmental Science and Technology 41, 3728-3733

[11] Malley J, Show J, Ropp J (1996) Evaluation of the by-products produced by the treatment of groundwaters with ultraviolet radiation. American Water Works Association Research Foundation, Denver, CO; Liu W, Andrews SA, Bolton JR, Linden KG, Sharpless C, Stefan M (2002) Comparison of disinfection byproduct (DBP) formation from different UV technologies at bench scale. Water Science and Technology: Water Supply 2, 515-521; Kashinkunti RD, Linden KG, Shin G-A, Metz DH, Sobsey MD, Moran MC, Samuelson AM (2004) Investigating multibarrier inactivation for Cincinnati-UV, by-products, and biostability. American Water Works Association Journal 96,114-127·

nitrite, nitrate, bromide, iron or manganese of the water being treated[11]. The maximum UV dosage used (1.6 Ws/cm2) did not result in any significant reduction of TOC (total organic carbon), chloroform or HAA (haloacetic acids) formation potentials[12].

There is a plethora of applications, other than ballast water treatment, in which UV has been used for water purification for years or even decades. Among these, commonly known uses in e.g. disinfection of drinking water and municipal wastewater, and uses in pharmaceutical and cosmetic industries, laboratories, food and brewery industries etc, have been evaluated and accepted by administrations worldwide. Many references focus on disinfection of drinking water (i.e. freshwater), the DBPs reported and discussed being chlorine and different daughter substances formed by chlorination. Often UV treatment of drinking water is combined with ozonisation or chlorination[13]. Research has focused on drinking water and on the impact of UV on the formation of halogenated DBPs after subsequent chlorination, and on the transformation of organic material to more degradable components[14]. Addition of chlorine may result in the formation of different DBPs, such as trihalomethanes (THM), haloacetic acids (HAAs), carboxylic acids, aldehydes, and increase of TOX (Total Organic Halogen).[15] Buchanan et al. (2006) reported on the formation potential of THM, HAA, nitrite and peroxide resulting from UV photo-oxidation followed by biological treatment for the removal of natural organic matter (NOM). Samples exposed to different doses of UV were found to be non-cytotoxic and non-mutagenic[16].

For groundwater and filtered drinking water, UV disinfection at typical doses did not impact the formation of THMs and HAAs. Several studies have shown the formation of low levels of (in the US non-regulated) DBPs, such as aldehydes. In filtered drinking water no significant change in aldehydes, carboxylic acids, or total organic halides was found (Kashinkunti et al. 2004).

UV-radiation is also used in seawater reverse osmosis (SWRO) desalination plants. Munshi et al. (1999) noted that UV did not cause any phase change in water, which does not lead to any large-scale accumulation of toxic by-products in the water phase; in summary, UV-radiation was found to be a potential alternative to chlorination [17].

At hospitals water is treated by UV to insure pure water for pathology laboratories and kidney dialysis where bacteria-free water is of utmost importance[18]. For water used in the preparation of dialysis fluid, chemical contaminant levels are set very low. The additional treatment ensures that the water meets the more stringent requirements.

Application of UV disinfection for wastewater treatment is considered environmentally positive: (1) no chemicals are added to the effluent stream, reducing the risk of detrimental effects to aquatic life; (2) no trihalomethane (THM) are formed and (3) UV disinfection reduces safety, handling or explosion risks[19].

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[12] Chin A, Berube PR (2005) Removal of disinfection by-product precursors with ozone-UV advanced oxidation process. Water Research 39, 2136-2144

[13] E.g., Watts MJ, Linden KG (2007) Chlorine photolysis and subsequent OH radical production during UV treatment of chlorinated water. Water Research 41, 2871-2878

[14] Swaim PD, Cotton CA, Jeyanayagam SS (2004) Ultraviolet disinfection. In: Water Treatment Plant Design. McGraw-Hill

[15] Kashinkunti RD, Linden KG, Shin G-A, Metz DH, Sobsey MD, Moran MC, Samuelson AM (2004) Investigating multibarrier inactivation for Cincinnati-UV, by-products, and biostability. American Water Works Association Journal 96, 114-127

[16] Buchanan W, Roddick F, Porter N (2006) Formation of hazardous by-products resulting from the irradiation of natural organic matter: Comparison between UV and VUV irradiation. Chemosphere 63, 1130-1141

[17] Munshi HA, Sasikumar N, Jamaluddin AT, Mohammed K (1999) Evaluation of ultra-violet radiation disinfection on the bacterial growth in the Swro Pilot plant, Al-Jubail. Proceedings of the 4th Gulf Water Conference, 1 Bahrain, Feb.13-17, 1999. 17 pp

[18] E.g., Hoenich N, Levin R (2008) Water Treatment for Dialysis: Technology and Clinical Implications In: Ronco C, Cruz DN (eds): Hemodialysis - From Basic Research to Clinical Trials. Contribution to Nephrology Basel, Karger, 161, 1-6

[19] Lau PJ (1997) Applying disinfection alternatives to wastewater treatment. Pollution Engineering 29, 64-66

4.2 Aquatic toxicity

The results from land- and ship-based toxicity tests used in this document were performed in full marine (31.9 PSU) and in brackish water (22.1 PSU). It is known from, e.g., oxidation processes that the formation of disinfection by-products (DBPs) may be considerably different in marine waters from fresh water applications[20]. Therefore it was important to document whether similar problems may arise also from UV treatment for water of higher salinities.

4.2.1 Acute Aquatic Toxicity (GESAMP-BWWG 6, Annex IV: 3.3.2)

Some few examples only of acute (eco)toxicity of UV-treated were found during the literature search. In an acute immobilisation test, UVC-treated freshwater appeared to be toxic to the water flea *Daphnia carinata*. The observed toxicity was attributed to photo-oxidative degradation of metal-binding sites in natural organic matter, which resulted in the release of bioavailable copper ions[21].

Nitrite toxicity in seawater
Some changes in nutrient levels were recorded during the shipboard tests[22]. For example, both phosphate and nitrate levels at deballasting were higher in treated samples relative to untreated samples at the time of deballasting. It was not possible to definitively conclude that these changes directly resulted from UV irradiation: part of the differences could be attributed to an increase in the degradation of planktonic organisms resulting from the treatment process, rather than UV irradiation directly.

Photolysis of nitrate to nitrite has been demonstrated in UV-irradiated drinking water (e.g. Sharpless & Linden 2001)[23]. In shipboard tests, the concentration of NO_2 (µgN L^{-1} increased from an initial concentration of 0.6 up to 1.75 – 2.73 µgN L^{-1} in treated samples 10 days after treatment. In the land-based tests[24], at the low salinity test series only the nitrite concentration increased by a factor 6.2 after the UV reactor, up to 4.62 µM at discharge (day 5). The observed elevated concentration was nevertheless within the range typical for the test water used and therefore not excessively high. It is also possible that the prolonged dark incubation also increased the nitrite concentration in both the reference and treated tank.

The observed concentrations of nitrite were lower than the US (EPA) and EU maximum allowed concentration for drinking water of 71.4 and 7.9 µM (1000 µg-N/L and 110 µg-N/L), respectively[25]. In seawater conditions these nitrite levels seem not to be of any toxicological significance. High concentrations of chloride ions effectively reduce the toxicity of nitrite. Seawater fish are usually less sensitive to nitrite than freshwater fish[26]. For example, nitrite was found to be 55 times more toxic to juvenile milkfish (*Chanos chanos*) in fresh water than in brackish (16 psu) water. The 48-h median LC_{50} values were, respectively, 12 and 675 mg NO^2-N L^{-1} [27]. The 96-h LC_{50} of nitrite-N for European eel (*Anguilla anguilla*) can range from 84.0 mg L^{-1} in freshwater to 812.0mg L^{-1} in full strength seawater (salinity = 36.0

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[20] Kornmüller A (2007) Review of fundamentals and specific aspects of oxidation technologies in marine waters. Water Science and Technology 55, 1-6

[21] Parkinson A, Barry MJ, Roddick FA, Hobday MD (2001) Preliminary toxicity assessment of water after treatment with uv-irradiation and UVC/H2O2. Water Research 35, 3656-3664

[22] Wright DA (2009) Shipboard Trials of Hyde 'Guardian' system in Caribbean Sea and Western Pacific Ocean, April 5 th - October 7th, 2008. Final Report to Hyde Marine and Lamor Corp. University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons Maryland, 122 pp

[23] Sharpless CM, Linden KG (2001) UV photolysis of nitrate. Effects of natural organic matter and dissolved inorganic carbon and implications for UV water disinfection. Environmental Science and Technology 29, 2949-2955

[24] Veldhuis MJW, Fuhr F, Stehouwer P-P (2009) Final report of the land-based testing of the Hyde-Guardian™ -System, for Type Approval according to Regulation-D2 and the relevant IMO Guideline (April – July 2008). Royal Netherlands Institute for Sea Research, Den Burg, Texel, the Netherlands, 42 pp

[25] Sharpless C, Page M, Linden K (2003) Impact of hydrogen peroxide on nitrite formation during UV disinfection Water Research 37, 4730 - 4736

[26] Avilez IM, de Aguiar LH, Altran AE, Moraes G (2004) Acute toxicity of nitrite to matrinxã, *Brycon cephalus* (Günther, 1869) (Teleostei-Characidae). Ciência Rural, Santa Maria 34,1753-1756

[27] Spotte SH (1992) Captive Seawater Fishes: Science and Technology. Wiley, 976 pp

psu)[28]. Similar results were obtained when the relative toxicity of nitrite to chinook salmon fingerlings (*Oncorhynchus tshawytscha*) was measured by static bioassay. In freshwater, the 48-h median lethal nitrite concentration was 19 mg L^{-1}. In seawater, 1,070 mg L^{-1} nitrite caused only 10% mortality in 48 h[29].

Bromate formation in UV-treated seawater through ozone
It is known that (1) ozone can be produced by ultraviolet light and (2) ozonation or chlorination of bromide-containing water can facilitate the conversion of bromide into bromate (BrO_3(-), which is a carcinogenic chemical[30].

No data were found on concentrations of ozone produced during short-term exposure of seawater to UV-C nor the risk of production of bromate (and its derivates) in UV-treated seawater. In April 2006, a thorough assessment of environmental risks of bromate as a relevant chemical was performed by Japan MEPC 55/2 in connection with basic approval of active substances used by Special Pipe Ballast Water Management System (combined with ozone treatment) in accordance with the Procedure for approval of Ballast Water Management Systems that make use of active substance (G9)[31]. The risk evaluation to the environment focused on the bromate ion. It was considered that the short-term toxicity of ballast water discharged after being treated in the system is basically insignificant: acute toxicity of the bromate ion in seawater was low (NOEC 32 mg/L). Since the concentration of bromate ions (oxidant concentration) at the time of discharge is lower than 0.16 mg/L, Long-term effects are unlikely to occur. Therefore the bromate ion to be discharged from this system will not cause any long-term or short-term effects on aquatic organisms. The Japanese system, submitted to MEPC 55 for approval, uses ozone as an active substance whereas in Hyde GUARDIAN^{TM} system ozone is not likely to be produced since the Hyde GUARDIAN^{TM} operates in a higher UV spectral bandwidth (above 200 nm).

4.2.2 Chronic aquatic toxicity (GESAMP-BWWG 6, Annex IV: 3.3.3)

The most applicable and relevant indirect evidence of zero NOEC (No Observed Effect Concentration) of UV-treated saltwater originates from uses in marine aquariums and hatcheries, in which bacteria-free water prevents disease agents (bacteria, fungi) from growing without producing any DBPs harmful to marine organisms. In mussel and oyster culture, UV-treated water is used for rearing all stages of spat, from fertilization to larvae and juveniles[32], which are regarded as the most sensitive life-cycle stages. Ultraviolet treatment is sometimes employed also in water purification systems for tropical freshwater, marine and cool water aquaria and pond systems, not only to reduce microbial levels but also to aid in oxidation of organics, phosphate and nitrogenous compounds through the collateral production of ozone (O_3)[33].

In fish aquaculture, the applications include treatment of water in hatcheries, and fry rearing tanks[34]. UV is ideally suited for these applications as it uses no chemicals and does not create by-products, which would harm the fish stock, or other aquatic life, on discharge[35] [36]. However, the results from a 5-month experiment indicate that seawater recently disinfected with ultraviolet radiation (254 nm) can increase

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[28] Saroglia MG, Scarano G, Tibladi E (1981) Acute toxicity of nitrite to sea bass (*Dicentrarchus labrax*) and European eel (*Anguilla anguilla*). Journal of the World Aquaculture Society 12, 121-126 (quoted in Avilez et al. 2004)

[29] Crawford RE, Allen GH (1977) Seawater inhibition of nitrite toxicity to chinook salmon. Transactions of the American Fisheries Society 106, 105-109.

[30] Huang X, Gao N, Deng Y (2008) Bromate ion formation in dark chlorination and ultraviolet/chlorination processes for bromide-containing water. J Environ Sci (China) 20, 246-51

[31] MEPC 55/2, submitted by Japan in 2006

[32] Helm MM, Bourne N, Lovatelli A (eds) (2004) Hatchery culture of bivalves. A practical manual. FAO Fisheries Technical Paper. No. 471. Rome, FAO.177 pp. www.fao.org/docrep/007/y5720e/y5720e06.htm

[33] Saltwater Aquariums. http://saltaquarium.about.com

[34] Shackley SE, King PE (2006) A sterile sea water circulating system for the jar culture of developing fish eggs. Journal of Fish Biology 12, 235-237

[35] Hanovia News (2007) UV water disinfection in fish farms and hatcheries. http://halmapr.com/news/hanovia/2007/09/28/aquaculture/

[36] Øye AK, Rimstad E (2001) Inactivation of infectious salmon anaemia virus, viral haemorrhagic septicaemia virus and infectious pancreatic necrosis virus in water using UVC irradiation. Diseases of Aquatic Organisms 48, 1-5

the frequency of cataract (cloudiness of the lens of the eye) in juvenile cod. It is hypothesized that ozone or other photoproducts formed by UV-C radiation may cause cataract in fish[37]; however, other studies on this topic found seem to deal with natural exposure to UV-A and UV-B[38], not UV-C.

In 2002, chlorine was replaced by UV treatment for water purification in a dolphinarium in Edmonton, Alberta, Canada[39]. A routine water-testing package consisted of a number of common water parameters (sodium, potassium, calcium, magnesium, total nitrate, iron, manganese, sulphate, chloride, carbonate, bicarbonate, fluoride, hardness, alkalinity, and total dissolved solids). The total nitrate level was the only parameter that changed with the implementation of the UV system. Other parameters that were measured throughout the implementation process included dissolved oxygen, pH, suspended solids, and temperature. It was found that both prior to and after implementation the aforementioned parameters did not undergo any change.

4.2.3 Endocrine disruption (GESAMP-BWWG 6, Annex IV: 3.3.4)

No evidence has been found that the by-products that could be formed or have been found to be present at low levels (nitrite) can cause endocrine disruption.

4.2.4 Sediment toxicity (GESAMP-BWWG 6, Annex IV: 3.3.5)

No evidence has been found that by-products could result in sediment toxicity.

4.3 Bioavailability/Biomagnification/Bioconcentration/Food web/Population effects (GESAMP-BWWG 6, Annex IV: 3.3.6, 3.3.7)

No evidence has been found that short lived nitrites as a DBP of UV-C treatment could result in biomagnification or bioconcentration.

5 Data on Mammalian Toxicity (G9: 4.2.1.2; GESAMP-BWWG 6, Annex IV: 3.4)

Mammalian toxicity studies have not been performed on DBP (nitrite) specifically for Hyde GUARDIAN^{TM} system. There are no scientific data available indicating that nitrite concentrations at the levels found in the Hyde GUARDIAN^{TM} discharge can be expected to be toxic to mammalians.[40]

5.1 Data on mutagenicity and genotoxicity (GESAMP-BWWG 6, Annex IV: 3.4.8)

An environmental concern, which has been assumed but not investigated in depth, is the risk of genetic mutation. If the exposure to UV-C is insufficient to kill all of the organisms, the damage to the genetic material might lead to viable mutations and reproduction might still be possible, and hence pose an environmental risk[41]. Even if most or all of the surviving organisms with damaged genetic material will fail to reproduce, a possibility exists that genetically altered DNA will benefit the surviving (micro)organisms.

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[37] Björnsson B (2004) Can UV-treated seawater cause cataract in juvenile cod (*Gadus morhua* L.)? Aquaculture 240, 187-199

[38] Cullen AP, Monteith-McMaster CA, Sivak JG (1994) Lenticular changes in rainbow trout following chronic exposure to UV radiation. Current Eye Research 13, 731 – 737; Sharma JG Masuda R, Tanaka M (2005) Ultrastructural study of skin and eye of UV-B irradiated ayu *Plecoglossus altivelis*. Journal of Fish Biology 67, 1646-1652; Formicki G, Stawarz R (2006) Ultraviolet influence on catalase activity and mineral content in eyeballs of gibel carp (*Carassius auratus gibelio*). Science of the Total Environment 369, 447-450

[39] Dombrosky J (2002) The use of ultraviolet irradiation for sole disinfection of an inland marine mammal facility.www.trojanuv.com/en/images/IC/Dolphin%20Lagoon.pdf

[40] FAO/WHO (2003): Nitrite (and potential endogenous formation of N-nitroso compounds). In: Safety evaluation of certain food additives and contaminants. Geneva, World Health Organization, Joint FAO/WHO Expert Committee on Food Additives. WHO Food Additives Series No. 50; http://www.inchem.org/documents/jecfa/jecmono/v50je05.htm

[41] Buchholz K, Tanis D, Macomber S, Farris E (1998) Ballast Water Secondary Treatment Technology Review. Final Report to Northeast-Midwest Institute. www.nemw.org/Balsurv2_UV.htm

The risk of thriving mutants is prevented by the high minimum dosing of UV (200 mJ/cm^2 - 5 times the dose required by the US EPA drinking water disinfection standard), which dose is sufficiently high to ensure the adequate level of DNA damage. As an extra precaution the Hyde GUARDIAN^{TM} system exposes ballast water to UV-C disinfection once more to the same high dose during de-ballasting.

6 Data on Environmental Fate and Effect under Aerobic and Anaerobic Conditions (G9: 4.2.1.3; GESAMP-BWWG 6, Annex IV: 3.5)

Nitrite released with ballast water will enter the natural nitrogen cycle run by the marine ecosystem where NO_2 is present in low concentrations, produced by e.g. planktonic algae and through decomposition of fecal pellets and dead zooplankton organisms[42]. It is expected that NO_2 from BWT will follow the same reduction and oxidation pathways as NO_2 from natural sources; NO_2 will be oxydised to NO_3 and reduced to NH_4.

7 Physical and Chemical Properties for the Preparations, Active Substance and Treated Ballast Water (G9: 4.2.1.4; GESAMP-BWWG 6, Annex IV: 3.6)

Nitrite is the univalent radical NO_2 or a compound containing it, such as a salt or an ester of nitrous acid. Its regulatory name is nitrite, molecular formula NO_{2}-, and molecule weight is 46 g/mol [43]. Nitrite CAS number is 14797-65-0.[44]

8 Analytical Methods at Environmentally Relevant Concentrations (G9: 4.2.1.5; (GESAMP-BWWG 6, Annex IV: 3.7)

DBPs (nitrite) had been analysed using standardised methods. The impact of by-products in the discharge was analysed in 20-days incubation studies in a climate room.

9 Use of Active Substance or the Preparation (GESAMP-BWWG 6, Annex IV: 4)

The Hyde GUARDIAN™ system does not use or generate Active Substances.

10 Material Safety Data Sheets (GESAMP-BWWG 6, Annex IV: 5)

Material safety data sheet for nitrite is presented in Appendix 1.

11 Risk Characterization

Nitrite is not persistent and does not bioaccumulate. Nitrite is not toxic at the concentrations resulting from the Hyde GUADRIAN™ system.

11.1 Evaluation of the treated ballast water (G9: 5.2; GESAMP-BWWG 6, Annex IV: 6.2)

11.1.1 Results from the Land Based Tests

The land based test trials of the Hyde GUARDIAN^{TM} system were carried out at the Royal Netherlands Institute for Sea Research (NIOZ), Texel, the Netherlands, from March till July 2008. The System was tested according to the D-2 Standard and the IMO Guidelines for Type Approval testing (G8).

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[42] Carlucci AF, Hartwig EO, Bowes PM (1970) Biological production of nitrite in seawater. Marine Biology 7, 161-166

[43] http://www.lenntech.com/hazardous-substances/nitrite.htm

[44] http://www.epa.gov/OGWDW/dwh/t-ioc/nitrates.html

The main findings from the test trials are summarised below[45]:

- The basic chemistry and physical properties of the water were not altered by the treatment and no factors could be detected effecting the vitality of the treated water upon discharge;
- With respect to the water chemistry a slight increase in the nitrite concentration was observed during the low salinity test runs in the discharge. This is in agreement with findings by Sharpless & Linden[46]. Yet the increase was only half of the natural nitrite concentrations observed during the second test series at high salinity and should therefore be considered to be within the natural range. The values were also below the maximum allowed concentration for drinking water[47]
- The treated water did not contain toxic or growth inhibiting substances, neither were other chemicals than nitrite found that could have been formed as by-products from the treatment.

The complete report of Veldhuis et al. (2009) has been submitted to Lloyds Register and to Maritime and Coastguard Agency in December 2008.

11.1.2 Results from the shipboard tests

The three shipboard test trials were conducted aboard the Princess Cruise Lines ship M/V *Coral Princess* in 2008 to test the efficacy of the Hyde GUARDIAN^{TM} system under normal working conditions. The trials took place during the vessel's regular spring schedule in the Caribbean Sea, the summer schedule in the N.W. Pacific Ocean between Whittier, Alaska and Vancouver, Canada, and during the repositioning cruise from the western Pacific to the vessel's winter base in Fort Lauderdale, Florida. Trials consisted of determination of water quality parameters and a comparison of biological endpoints in treated and untreated ballast water samples, with reference to both IMO G8 and the U.S. Coast Guard Shipboard Technology Evaluation Program (STEP).

In the report from the shipboard test trials[48] the following conclusions can be found:

- While, to date, no potentially toxic chemical changes resulting from UV irradiation have been identified, this resolution adopts an approach requiring tests for residual toxicity that essentially follow IMO G9 guidelines, even for systems not involving the addition of active substances. The resolution was adopted too late for such testing to be incorporated into land based testing of the system, which ended in July 2008. Hence, three tests, one chronic (growth based) and two acute toxicity bioassays, were incorporated into the third trial in order to provide empirical toxicological evidence on this point.
- Results of Whole Effluent Toxicity (WET) bioassays conducted during trial 3 indicated no significant differences between the toxicity of treated vs. untreated water samples at the time of discharge from the vessel. In invertebrate and vertebrate larval assays undiluted water from both treated and untreated tanks appeared not to show any significant toxicity relative to laboratory controls. In the case of phytoplankton there appeared to be a small degree of toxicity associated with water retrieved from ballast waters following the (10 day) residence time, although the toxicity did not differ significantly between treated and untreated water."
- It might be concluded from those data that any toxic element present in discharged water did not

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[45] Veldhuis MJW, Fuhr F, Stehouwer P-P (2009) Final report of the land-based testing of the Hyde-Guardian™ -System, for Type Approval according to Regulation-D2 and the relevant IMO Guideline (April – July 2008). Royal Netherlands Institute for Sea Research, Den Burg, Texel, the Netherlands, 42 pp

[46] Sharpless CM, Linden KG (2001) UV photolysis of nitrate. Effects of natural organic matter and dissolved inorganic carbon and implications for UV water disinfection. Environmental Science and Technology 29, 2949-2955

[47] Sharpless C, Page M, Linden K (2003) Impact of hydrogen peroxide on nitrite formation during UV disinfection Water Research 37, 4730 – 4736

[48] Wright DA (2009) Shipboard Trials of Hyde 'Guardian' system in Caribbean Sea and Western Pacific Ocean, April 5 th - October 7th, 2008. Final Report to Hyde Marine and Lamor Corp. University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons Maryland, 122 pp

> result from UV irradiation. Such results have been supported by an extensive literature search that has revealed no evidence of residual chemical toxicity in water resulting from prior UV irradiation of that water. While some changes in nutrient levels appeared to be associated with water treatment it was not possible to definitively conclude that these changes directly resulted from UV irradiation. For example, both phosphate and nitrate levels at de-ballasting were_higher in treated samples relative to untreated samples at the time of discharge from the ship. It is possible that part of this difference could be attributed to an increase_in the degradation of planktonic organisms resulting from the treatment process, rather than UV irradiation directly. Nitrite levels were also higher in treated samples 10 days after treatment. While UV photolysis of nitrate to nitrite has been demonstrated in UV-irradiated drinking water[49], the levels involved are very small relative to the U.S. drinking water standard of 1000μg L^{-1}, or the European standard of 100μg L^{-1}. Nitrate levels reported in this trial were negligible relative to these standards and pose no toxicological threat associated with discharge.

The final report of Wright (2009) has been submitted to Lloyds Register and to Maritime and Coastguard Agency in January 2009.

11.2 Prediction of discharge and environmental concentrations (GESAMP-BWWG 6, Annex IV: 6.3.3)

The nitrite levels measured from the treated ballast water during the land based testing were 4.62 µM in low salinity seawater. In water intake the nitrite concentration was 2.99 µM. The nitrite concentration in the treated water, in high salinity water, was 6.00 µM. In water intake the concentration was 6.85 µM. During the shipboard testing nitrite levels showed a 3-4 fold increase, from 0.8 to 2.73 µg/l in trial #3, in treated samples after 10 days.

11.3 Effects on sediment (G9: 5.1; GESAMP-BWWG 6, Annex IV: 6.3.7)

Particles and organisms larger than 50 µm are removed by the filter. This means that small particles, that may have a higher organic content, will accumulate inside the ballast tanks. Experience from the ships that have had the Hyde GUADRIAN™ system installed show little sediment accumulation inside the ballast tank and only a thin layer of silt (< 2 mm) has been observed. The DBP (nitrite) is not expected to have adverse effects on sediment.

12 Quality Control/Quality Assurance (G9: 4.2.4)

The Quality Control and Quality Assurance issues have been addressed in two separate reports. Concerning the shipboard trials of the Hyde GUADRIAN™ system the QA/QC protocol has been presented in the Appendix D and the Standard Operating Procedures (SOP) for UMCES Analytical Services Division in the Appendix E of the reference (Wright, 2009). [50]

Regarding the land based test trials a description of the Test Protocol and Quality Assurance Project Plan (QAPP) has been presented in the reference (NIOZ, 2009)[51]. According to the reference it has been approved by Maritime Coastguard Agency (UK) and Lloyds Register (LR) in April 2008.
The both reports have been submitted to LR in January 2009.

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[49] E.g. Sharpless CM, Linden KG (2001) UV photolysis of nitrate. Effects of natural organic matter and dissolved inorganic carbon and implications for UV water disinfection. Environmental Science and Technology 29, 2949-2955

[50] Wright, DA (2009). Shipboard Trials of Hyde 'Guardian' system in Caribbean Sea and Western Pacific Ocean, April 5th – October 7th, 2008. Final Report to Hyde Marine and Lamor Corp. University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, Maryland 20688.

[51] Royal Netherlands Institute for Sea Research (NIOZ) (2009). Test protocol and Quality Assurance Project Plan (QAPP) for the biological efficacy testing of the Hyde Marine Ballast Water Treatment System (HBWTS, Hyde Marine Inc) as part of the Type Approval Process under Resolution MEPC 125.53.

13 Use of the Active Substance and Preparations

The Hyde GUARDIAN™ system does not use or generate Active Substances for its treatment.

14 Risk Assessment (G9: 6, 7)

14.1 Risk to safety of ship (GESAMP-BWWG, Annex IV: 7.1)

The potential risk to the safety of the ship and crew raised by the operation of the Hyde GUARDIAN™ system is assessed, in sections below.

14.1.1 Ship Integrity and the BWTS

The Hyde GUARDIAN™ system is installed in parallel with the ship's ballast piping system. The system is always installed somewhere down the ballast pipe line after the ballast pump. There are no specific requirements or restrictions as of distance from the ballast pump or any of the associated ballast tanks. The Hyde GUARDIAN™ filtration system can be installed separately from the disinfection system. The disinfection system (UV unit) can be installed either vertically or horizontally as this has no affect on the operation or efficacy of the system. However the multi spine Galaxy filter system is recommended to be installed in a vertical position in order for the back-flush of the filter spines to be efficient. A small inclement (less than 30º) does not have affect but a horizontal (90º) installation position could make the back-flushing to be more inefficient, as the spines would back-flush against each other. This recommendation does not apply for the single spine Crystal filter system.

The Hyde GUARDIAN™ system is normally isolated from the ballast piping system by inlet and outlet pneumatically actuated butterfly valves which are normally closed when the Hyde GUARDIAN™ system is not in operation. For emergency use the inlet and outlet valves can be operated via the fail safe Supervisory Control System, but also mechanically at valve location. Aside from the in-built by pass pipe which by-passes the filter system during de-ballasting but forces ballast water flow through the UV disinfection unit, the entire system can be bypassed in case of emergency by operation of ships valves.

Operation of the system bypass valves should be restricted to emergency operation only as this will violate the ballast water treatment convention. Theses valves should remain locked and their use should require permission of the chief or captain. The bypassing of the treatment system will need to be recorded in the ballast water log book.

The Hyde GUARDIAN™ system is fully automatic and the system can be fully integrated to the ships control. If any of the logged operating parameters of the BWMTS are not within the acceptable and predetermined tolerances, it will shut down the Hyde GUARDIAN™ system and not allow untreated water to pass.

Generally speaking the Hyde GUARDIAN™ system after installed on the ship will be one of the ships equipment that requires least attention by the ships crew in terms of operation of the system (especially if fully integrated into ships control) but also in terms of maintenance. The ships crew can easily be trained on site how to operate the system from the Supervisory Control Board (local control) LCD display and control panel. The control panel, as a standard Hyde GUARDIAN™ option, features simple function buttons and a simple and clear LCD text display. The ships crew can start and stop the BWTS system pressing simple function buttons and also control and monitor the BWTS operating parameters, simply by following the clear instructions on the LCD text display.

If the Hyde GUARDIAN™ system is chosen not to fully integrate into ships control, but installed as stand alone equipment. The ships crew need to manually start the BWTS system locally after having started the ships ballasting pump(s). After starting the Hyde GUARDIAN^{TM} at the Control Panel and choosing either ballast or de-ballast mode, the system opens the inlet valve to the system and keeps the delivery valve closed, and waits for the UV unit to heat up to its operational temperature. After the UV unit has reached its operational temperature and is ready for treating the water, only then the delivery valve of the system is opened and water flows through the system. The warm up time is slightly dependant on the ambient water temperature, but normally the operating temperature is reached within 2 min from starting of the system. The system will continue to run automatically without input from the ships crew.

When filling or emptying the ballasting tanks (i.e. ballasting procedure), is finished, the crew needs to stop the BWTS system locally. The system will close the delivery valve and conduct a final back-flush cycle of the filters (only if ballasting of tanks has taken place). After this the system will shut down and the UV unit cools down.

If the Hyde GUARDIAN™ system is fully integrated into ships control via a digital link, (such as Modbus and Profibus), the controls and monitoring of the BWTS are managed from the station where ballasting the procedure is taking place, without manual interface from the ships crew. In that case the starting signal to the ballast pump and the selection of ballasting or de-ballasting mode, enabled by the ships crew, will give the signal to the Hyde GUARDIAN™ Control system to run the system without input of the ships crew.

14.1.2 Hazardous Area

The Hyde GUARDIAN™ system can be safely installed onboard ships having hazardous areas, e.g. tankers. However there are limitations what concern the location of the individual system components.

The Hyde GUARDIAN™ filter system can be installed safely inside a hazardous area since it's completely pneumatically operated. The Hyde GUARDIAN™ UV disinfection chamber can, with a small modification, be made into an explosion proof system by simply purging the UV chamber. This is principally done by pressurizing the internal part of the UV chamber which features the electrical components. Hence no dangerous gases or vapours can enter inside the UV chamber which if penetrated could get in touch with the electrical system and potentially cause an electrical arc and consequential fire/explosion by igniting the gas and/or vapour. By requirement also the areas which are classified as hazardous areas, e.g. a Cargo Pump room features also on-line constant gas and vapour monitoring equipment which potentially would give an alarm even before gas and/or vapour would enter into the UV chamber. However a fail safe pressure switch is installed to the UV chamber which constantly measures the pressure inside the UV chamber. In case of pressure loss inside the chamber, the pressure switch would give a signal disconnect all power to the UV system.

The Hyde GUARDIAN™ Power Panel and Control Panel would be installed outside the hazardous area, e.g. machinery room space. All the penetrations through the bulkhead into the hazardous area would have to be done by type approved penetration gland and sealing for hazardous areas. The booster pump, which is only used during the back-flush mode of the filters, would be supplied with an explosion proof electric or hydraulic motor.

14.1.3 Corrosion

The Hyde GUARDIAN™ system does not cause corrosion of the ships structure or the ships systems to which the Hyde GUARDIAN™ system is in contact with. The Hyde GUARDIAN™ filtration stage is pure solid liquid separation system and the UV disinfection treatment does not change the treated water by any means which could have an affect on corrosion. If a corrosion problem exist onboard the ship where the Hyde GUARDIAN™ system is installed, the system will not enhance nor will it reduce the corrosion rate, since the Hyde GUARDIAN™ system has no affect on corrosion.

14.1.4 Fire and Explosion

The Hyde GUARDIAN™ system does not possess any risk for explosion. The filters are pressure rated to 10.0 bar and under exceptional circumstances the water pressure of a ships ballast system rarely reaches above 7.0 bar. Under normal circumstances the operating pressure of a ships ballast system is in the range of 1.5 to 5.0 bars. In the case of the Hyde GUARDIAN™ system, during the back-flushing and when the delivery valve of the system is closed the pressure is temporarily raised to 5.0 bar pressure by external booster pump to enable efficient back flushing. If the ships own ballast pump deliver 5.0 bar pressure, the external booster pump is not required. The Hyde GUARDIAN™ filter system is however equipped with a simple pressure relief valve fitted on the centre manifold which in case of pressure build up would let out excessive pressure and drain small amounts of the ballast water to ships bilge system. There is no risk of explosion in the UV chamber.

The Hyde GUARDIAN™ system features an electrically powered UV disinfection unit, power panel, and control cabinet components. These Hyde GUARDIAN™ components are encapsulated in steel frames and ingress protected to min IP 54 standard in accordance with general industry standard and in accordance with ships classification society rules. And hence does not possess any higher risk of fire then any other electrical system onboard. In case of fire e.g. short circuited system caused by any of the Hyde GUARDIAN™ electrical components or in case of fire from external source which would damage any of the Hyde GUARDIAN™ electrical components, the Supervisory Control system will shut down the BWTS.

14.1.5 Chemical Storage

There are no chemicals used in the Hyde GUARDIAN™ system.

14.1.6 Accidental Chemical Release

There are no chemicals used in the Hyde GUARDIAN™ system.

14.2 Risk to technicians and/or ship's crew

The Hyde GUARDIAN™ system does not possess any risk for the ships technicians and/or ships crew. The system does not feature any mechanically rotating parts which could cause damage or injury to personnel operating, or conducting maintenance to, the Hyde GUARDIAN™ system. The Hyde GUARDIAN™ system which does not use any active substance nor produce any active substance during the treatment process is completely safe for the crew to operate or inspect during operation and also when the system is idle or when stopped.

As of ships crew conducting routine maintenance to the system, as the Hyde GUARDIAN™ system features electrical components, proper safety procedures are to be adhered to. These safety procedures are general and are not different from any other safety procedure for a ships electrical systems or components. All the safety procedures specific to the Hyde GUARDIAN™ system are well described in English language in the Owners Operating and Maintenance Manual supplied with each system. Also all the electrical components on the Hyde GUARDIAN™ system are labelled with industry accepted WARNING signs for electrically powered components.

14.3 Risks to human health (GESAMP-BWWG, Annex IV: 7.2)

There is no direct human health risk associated with the Hyde GUARDIAN™ system. The system is very robust, totally isolated from the outside world; the routine maintenance is simple and robust and is easy to adhere to. Only by violating the simple and easy to read safety procedures related to the routine maintenance of the system there might be a risk for human health. Even in such case or in an emergency direct eye contact with a powered up UV-C lamp should be prevented at all times. Under normal operation there is no possibility for a person to get in contact with UV-C as the UV is well confined inside the UV chamber. And the small amount of UV light which might be visible through drain hose connected to the UV chamber does not cause any harm to eye sight. The UV-lamps contain a small amount of mercury (< 200 mg/lamp) that that is well enclosed within the device under normal operation. If a lamp breaks during lamp replacement work, the mercury can be rendered harmless by binding it with sulphur powder. Contact with skin and eyes and inhaling vapours should be prevented

14.4 Risks to the aquatic environment (GESAMP-BWWG, Annex IV: 7.3)

With the Hyde GUARDIAN™ system there are no currently known risks to the aquatic environment. The Hyde GUARDIAN™ system does not use an active substance nor is a active substance produced during the treatment process so there is no risk of any active substance being released to the aquatic environment which could cause a risk for the same

14.5 Noise

The power cabinet of the Hyde GUARDIAN™ does emit a slight hum, <40db from the transformers. The cabinet also has cooling fans will contribute to the ambient noise level.

The treatment part of the Hyde GUARDIAN™ system does not generate any sound or noise except of the sound of water flowing through a standard ships ballast pipe system, which in the case of a ship installation will be absorbed or is neglected by the ambient noise level existing onboard a ship in a machinery -, a pump room or a cargo pump room space.

15 Assessment Report (G9: 4.3; GESAMP-BWWG, Annex IV: 8)

The Hyde GUARDIAN^{TM} system, using UV (λ 200-400 nm) does not use or produce active substances for its meant ballast water treatment.

The Hyde GUARDIAN^{TM} ballast water treatment system does not produce any DBPs that would fit into either of the two distinct classes[52] of undesirable DBPs - those that affect water's aesthetic quality and those that are harmful to the environment or human health. Based on literature that is currently available, it was also found that UV treatment produces neither odour nor taste.

As the result from the land-based tests it can be concluded that the present configuration of the Hyde GUARDIAN^{TM} system was found to offer a reliable and environmentally safe cleaning of the ballast water resulting in organism numbers well below the IMO Standard D2.

Additionally, the results from the ship-board tests prove that under the conditions encountered during these trials, the system was found to comply with all IMO G-8 standards relating to the elimination of biota and with respect the issue of residual toxicity of treated water related to chemicals generated during treatment.

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[52] Wolfe RL (1990) Ultraviolet disinfection of potable water. Environmental Science and Technology 24, 768-773

When the shipboard and land-based tests with the Hyde GUARDIAN^{TM} system were agreed on in early 2008, the valid G8 Guidelines at that time (Resolution MEPC.125(53)) did not include the requirements for the environmental acceptability of the discharged water, which are included in the revised G8 Guidelines as adopted in October 2008. The land-based tests were performed in the spring and early summer of 2008. During those tests the discharge water was analysed for potential by- or end products of the UV treatment, as a precautionary action. Only a slight increase in nitrite, formed by conversion of nitrate in the water was found. As stated in this report, nitrite is a constituent of sea and fresh waters.

The revised Guidelines G8 (Resolution MEPC.174(58)) were adopted on 10 October 2008. The revised Guidelines include a reference to environmental acceptability, as introduced in paragraph 1.8*: "These Guidelines contain recommendations regarding the design, installation, performance, testing, environmental acceptability and approval of ballast water management systems".*

The Resolution also states in paragraph 5.1.5 that "*if it can reasonably be concluded that the treatment process could result in changes to the chemical composition of the treated water such that adverse impacts to receiving waters might occur upon discharge, the documentation should include results of toxicity tests of treated water. The toxicity tests should include assessments of the effects of hold time following treatment, and dilution, on the toxicity. Toxicity tests of the treated water should be conducted in accordance with paragraphs 5.2.3 to 5.2.7 of the Procedure for approval of ballast water management systems that make use of Active Substances (G9), as revised, (Resolution MEPC.169(57))*". Resolution MEPC.174(58) was adopted after all land-based tests with the Hyde GUARDIAN^{TM} system were completed in July 2008.

To accommodate the environmental acceptability requirements of the revised G8, all possible effort was made by the testing bodies to provide toxicity data required in Resolution MEPC.174(58). During the last shipboard test trial Whole Effluent Toxicity (WET) tests were conducted on treated and untreated water samples. The objective was to identify any residual chemical toxicity that could have resulted from the Hyde GUARDIAN^{TM} ballast water treatment system. Results of the WET bioassays indicated no significant differences between the toxicity of treated vs. untreated water samples at the time of discharge from the vessel.

The reviewed literature did indicate that in the UV BW treatment process no relevant chemicals (i.e., metabolites, intermediates, residual substances) are produced at levels that are expected to cause adverse impacts on aquatic life by the discharge of UV-treated ballast water. These findings are also supported by the results of the Hyde GUARDIAN^{TM} land based and shipboard test trials.

Based on the practical operational experience from the first Hyde GUARDIAN^{TM} system installed on board the Coral Princess in 2003, the system has proven its reliability and safety to the ship and its crew. Based on the results from the land-based and ship-board tests, and on the findings from the literature, it can reasonable be concluded that the Hyde GUARDIAN^{TM} Ballast Water Treatment System could not result in changes to the chemical composition of the treated water such that adverse impacts to receiving waters might occur upon discharge.

16 Appendices

Annex 1.

Technical Factsheet on: NITRATE/NITRITE [53]

As part of the Drinking Water and Health pages, this fact sheet is part of a larger publication: **National Primary Drinking Water Regulations**

Drinking Water Standards (in mg/L)

Nitrate- MCLG: 10; MCL: 10; 10-day HAL: 10
Nitrite- MCLG: 1; MCL: 1; 10-day HAL: 1
Total (Nitrate+Nitrite)- MCLG: 10; MCL: 10; 10-day HAL: 10

Health Effects Summary

Acute: Excessive levels of nitrate in drinking water have caused serious illness and sometimes death. The serious illness in infants is due to the conversion of nitrate to nitrite by the body, which can interfere with the oxygen-carrying capacity of the child's blood. This can be an acute condition in which health deteriorates rapidly over a period of days. Symptoms include shortness of breath and blueness of the skin.

Drinking water levels which are considered "safe" for short-term exposures: For a 10-kg (22 lb.) child consuming 1 liter of water per day, a ten-day exposure to 10 mg/L total nitrate/nitrite.

Chronic: Effects of chronic exposure to high levels of nitrate/nitrite include diuresis, increased starchy deposits and hemorrhaging of the spleen.

Cancer: There is inadequate evidence to state whether or not nitrates or nitrites have the potential to cause cancer from lifetime exposures in drinking water.

Usage Patterns

Most nitrogenous materials in an aquatic environment tend to be converted to nitrate, so all sources of combined nitrogen, particularly organic nitrogen and ammonia, should be considered as potential nitrate sources. Primary sources of organic nitrates include human sewage and livestock manure, especially from feedlots.

The primary inorganic nitrates which may contaminate drinking water are potassium nitrate and ammonium nitrate. Potassium nitrates are used mainly as fertilizers (85%), with the remainder in heat transfer salts, glass and ceramics, and in matches and fireworks. Ammonium nitrates are used as fertilizers (84%) and in explosives and blasting agents (16%).

Release Patterns

The major environmental releases of inorganic sources of nitrates are due to the use of fertilizers. According to the Toxics Release Inventory, releases to water and land totalled over 112 million pounds from 1991 through 1993. The largest releases of inorganic nitrates occurred in Georgia and California.

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[53] http://www.epa.gov/OGWDW/dwh/t-ioc/nitrates.html

Environmental Fate

Due to its high solubility and weak retention by soil, nitrates are very mobile in soil, moving at approximately the same rate as water, and has a high potential to migrate to ground water. Because it does not volatilize, nitrate/nitrite is likely to remain in water until consumed by plants or other organisms. Ammonium nitrate will be taken up by bacteria. Nitrate is more persistent in water than the ammonium ion. Nitrate degradation is fastest in anaerobic conditions.

Chemical/Physical Properties

CAS Number: Nitrate ion: 14797-55-8; Nitrite ion: 14797-65-0

Color/ Form/Odor: Domestic fertilizer grade ammonium or potassium nitrates are in prilled (beaded) or crystalline forms, usually coated with an anti-caking agent and adsorbed fuel oil.

Solubilities: Nitrates and nitrites are highly soluble in water

Soil sorption coefficient: N/A

Bioconcentration Factor: N/A

Trade Names/Synonyms: Potassium salt: Potnit, Hitec, Niter, Nitrate of potash, Saltpeter.Ammonium salt: German or Norway saltpeter, Varioform I, Merco or Herco prills, Nitram.

Other Regulatory Information

Monitoring:
-- For Ground Water Sources:
Initial Frequency-Nitrate: 1 sample annually
Nitrite: 1 sample during first 3-year compliance period
Repeat Frequency-Nitrate: 1 sample annually
Nitrite: determined by State
-- For Surface Water Sources:
Initial Frequency-Nitrate: 1 sample each quarter
Nitrite: 1 sample during first 3-year compliance period
Repeat Frequency-Nitrate: 1 sample annually
Nitrite: determined by State
--Triggers - If detect at > 5 mg/L nitrate, sample quarterly.
If detect at > 0.5 mg/L nitrite, sample quarterly.
If detect total nitrate + nitrite > 5 mg/L, sample quarterly

Analysis

Reference Source	Method Number
EPA 600/4-79-020	353.1; 353.2; 353.3; 300.0; 354.1
Standard Methods	418C; 418F
ASTM	D3867-85A; D3867-85B

Treatment/Best Available Technologies: Ion exchange; Reverse osmosis; Electrodialysis (nitrate only)

For Additional Information:

Sources of toxicological and environmental fate data include:
Toxic Substance Control Act Information Line - 202/554-1404
Toxics Release Inventory, National Library of Medicine - 301/496-6531
Agency for Toxic Substances and Disease Registry - 404/639-6000