The Development and Type Approval Testing of a Ballast Water Treatment Technology

By: T. P. Mackey (CEng, FIMarEST, FRINA, Hyde Marine, Inc), M. Granitto (Hyde Marine, Inc), Dr. M. J. W. Veldhuis (PhD, NIOZ), F. Fuhr (Dipl.-Biol., NIOZ), Dr. D. A. Wright (PhD, DSc, FIMarEST, Univ. of Maryland), Capt. G. Greensmith (MNI, Lloyds Register)

"Coral Princess" in Seward Alaska

This paper describes the Hyde Guardian™ BWT system, which uses no chemicals or other active substances, and its development and testing programs. It also reviews the many intermediate steps leading up to final acceptance of the "Coral Princess" into the USCG STEP program and IMO type approval. The challenges and occasionally the frustrations of being one of the pioneering technologies, the vital support and patience of many professionals from the scientific and regulatory communities, and the rewards of persevering and finally succeeding are related and acknowledged.

INTRODUCTION

The Problem

The introduction of aquatic invasive species into new environments by ships' ballast water, attached to ships' hulls and via other vectors is a global challenge and one of the most severe pollution problems facing the world's oceans.

Shipping moves more than 90% of the world's freight and annually transfers billions of tonnes of ballast water internationally. A similar volume may also be transferred domestically within countries and regions each year. Ballast water is essential to safe and efficient operation by providing balance and stability to unladen ships. It may also unintentionally lead to a serious ecological, economic and health threat.

There are many examples of the significant effect and cost of invasions caused by ballast water discharge. The zebra mussel problem, which began on the US Great Lakes 20 years ago and has now spread through much of the United States, is well known (Fig. 1). It is believed to have been caused by invaders carried in ballast water from the Black Sea. The Black Sea and the nearby Eurasian seas, the Aegean Sea, the Sea of Marmara, the Sea of Azov and the Caspian Sea have also experienced significant invasions (see below). Coincidently more than two thirds of the exotics introduced into the Black Sea originated from the North Atlantic. Among these is the comb jelly, which is native to the US east coast and believed to have been introduced in ballast water. (Zaitsev and Öztürk 2001)

The invasive species problem has been accelerated by changes in shipping practice and increases in traffic volume. Dedicated ships such as tankers and bulk carriers now routinely sail to one port with cargo and

return to the loading port in ballast carrying millions of gallons of water and repeatedly introduce water from the cargo discharge port into the waters of the loading port. This reinforces colonies of invasive species deposited on previous visits.

Figure 1. Adult zebra mussels

While some invasive species appear benign, others are a threat to biodiversity, fisheries and aquaculture. The US National Oceanic and Atmospheric Administration view the threat of invasion by these organisms as "the greatest immediate threat to most coastal state ecosystems" Some introduced species severely deplete native populations or deprive them of food. Others form colonies which can damage other existing fauna.

Introduced toxic dinoflagellates cause red tides and algal blooms that can affect or even kill shellfish, fish and sea birds. When eaten by humans, contaminated shellfish cause paralysis or even fatality.

In the Black Sea, the filter-feeding North American jellyfish *Mnemiopsis leidyi* has on occasion reached densities of 2 lbs. of biomass per 9 sq.ft. It has depleted native zooplankton stocks to such an extent that it has contributed to the collapse of entire Black Sea commercial fisheries in the 1990's.

The fish pathogen, Viral Hemorrhagic Septicemia (VHS) (Fig. 2) was reported in the North American Great Lakes in 2003 (Wehlen G, VHS Briefing Paper, Michigan Dept. of Natural Resources). The rapid transfer of the virus through all of the waterways frequented by vessels discharging ballast taken up on the Great Lakes is a matter of serious concern.

Figure 2. Great lakes fish infected with VHS

The Chinese mitten crab (*Eriocheir sinensis*) was banned for importation and aquaculture in the U.S. in the late 1980's; however the crab was discovered in San Francisco Bay in 1994. The crab burrows into river banks, dykes and levees causing erosion and siltation. Introduction by ballast water transit is probable.

International, national and local efforts have been initiated to address the problem of ballast water facilitated translocation of species. Under some of these laws, ships have the option to conduct mid ocean ballast water exchange (BWE). However, even when conducted, BWE is considered to be at best 95% effective at removing near coastal organisms from ships ballast, thus leaving some threat of successful species translocation. A better solution needs to be found.

The Response to the Problem

The effects of unwanted aquatic organisms being transferred in ships ballast water was first reported to the International Maritime Organisation (IMO) in 1988. (The IMO is a specialist United Nations body responsible for the international regulation of ship safety and the prevention of marine pollution. The IMO was born in 1948 and fully established in 1958. It has its headquarters in London.) In subsequent years more information on the problem was submitted to the IMO, who in 1991, adopted voluntary guidelines to prevent the introduction of unwanted aquatic organisms and pathogens into the marine environment. These guidelines recommended that ships undertake precautionary practices when taking ballast onboard, for example not ballasting in darkness, shallow water or in sediment laden waters whenever possible. The guidelines also recommended that, if possible, ships exchange their ballast in deep ocean as it was recognised that organisms from coastal water may not survive in ocean water due, for example, to the differences in salinity. It was also recognised that the

length of time the ballast spent onboard would have an effect on the survival of organisms due to changes in light, nutrient and oxygen levels. Most importantly, the guidelines identified a need to research and develop additional measures to minimize the risk of the transfer of aquatic organisms and pathogens using methods such as chemical biocides, heat treatment, oxygen deprivation, filters and ultraviolet light. The guidelines stipulated that proposed chemical or biological treatment should be environmentally safe and compliant with international conventions. This prompted numerous research and development initiatives that have lead to a number of ballast water treatment systems that are commercially available. However, only a few of these are currently fully approved, and several more are in the process of gaining approval.

In 1992 the United Nations Conference on Environment and Development called upon the IMO to keep the issue of the transfer of unwanted aquatic organisms and pathogens under review and to consider the adoption of appropriate rules on ballast water discharge to prevent the spread of non-indigenous organisms. As a result, the IMO reviewed the existing guidelines and adopted revised guidelines [IMO Resolution A.774 (18)] in 1993. In 1997 the guidelines where further revised and updated [IMO Resolution A.868 (20)].

In 1994 the IMO's Marine Environmental Protection Committee (MEPC) Ballast Water Working Group (BWWG) was given the specific task of considering the problem and the effects of the transfer of unwanted aquatic organisms and developing regulations to control the transfer of and establishment of unwanted aquatic organisms and pathogens. The deliberations eventually lead to the adoption on Friday 13 February 2004 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (The BWM Convention). The BWM Convention will enter into force 12 months after not less than 30 states representing not less than 35% of the world fleets' gross tonnage have ratified the convention.

As of October 2008, 16 states representing 14.24% of the world's gross tonnage have ratified the convention. The main requirements of the BWM Convention are that ships adopt precautionary practices when taking ballast, keep records of ballast operations and have onboard an approved ballast water management plan. It allows the exchange of ballast until a certain date dependent on the ship's build date and ballast water capacity and, thereafter, requires the use of an approved ballast water treatment system. The dates are from 2009 to 2016. However, these dates will not become effective until the BWM Convention enters into force. These dates were primarily chosen to set a time scale for manufacturers of treatment equipment.

Ballast water treatment systems are required to meet the performance standard in regulation D-2 of the Convention as follows

1) Discharge less than 10 viable organisms per cubic metre greater than or equal to 50 micrometers in minimum dimension and less than 10 viable organisms per millilitre less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension; and discharge of the indicator microbes shall not exceed the specified concentrations.
2) Indicator microbes, as a human health standard, shall include:

1. Toxicogenic *Vibrio cholerae* (01 and 0139) with less than 1 colony forming unit (cfu) per 100 millilitres or less than 1 cfu per 1 gram (wet weight) zooplankton samples;
2. *Escherichia coli* less than 250 cfu per 100 millilitres;
3. Intestinal Enterococci less than 100 cfu per 100 millilitres.

In addition ballast water treatment systems are required to be approved and certified in accordance with IMO resolution MEPC.125(53) Guidelines for approval of ballast water management systems and if the treatment system uses an 'active substance' i.e. a chemical or chemical process the chemical or chemical process must be approved by the IMO in accordance with IMO resolution MEPC.169(57) Procedure for approval of ballast water management systems that make use of active substances

It should be noted that a number of countries have introduced national ballast water management regulations that are either mandatory or voluntary. For example, regional guidelines are in place in North West European waters, although none of these regulations or guidelines currently require ships to use treatment systems.

In the United States, there are proposed federal and state regulations that set standards for treatment systems. The April 2008 U.S. Coast Guard authorization Act (HR 2830, Section 503, sub-section 1101; Ballast Water Management) contains standards that are up to 100x stricter than the IMO standards, and even more stringent standards were adopted in January 2008 by the state of California. Federally sanctioned shipboard testing in the U.S. is currently under the auspices of the U.S. Coast Guard through the Shipboard Technology Evaluation Program (STEP). The STEP program is designed to reward ship owners and vendors for their contribution to treatment technology development by granting an "equivalency" to finally ratified standards, based on working trials of shipboard technologies showing compliance with the aforementioned standards. Equivalency is granted on a system-by-system basis for the lifetime of the vessel, contingent on a reasonable demonstration of sustained

maintenance, usage and efficacy. A growing list of similarly approved provisional treatments is being compiled by coastal jurisdictions such as Washington State (encompassing Puget Sound in the N.W. United States). Such treatments include both mechanical technologies such as filtration, UV irradiation and cavitation as well as biocides. More stringent standards have been adopted by the State of California in the U.S.A., essentially representing the complete elimination of plankton in the >50 µm (minimum dimension) size class and a live density of 0.01 organisms/ml. in the >10 - <50 µm (minimum dimension) size class. California ballast water legislation also includes standards for total live bacteria post treatment, (less than 1,000 bacteria per 100 ml.) and viruses (less than 10,000 viruses per 100 ml.) as well as more rigorous standards relating to indicator bacteria, i.e. concentrations of microbes that are less than 126 colony forming units/100 ml. of *Escherichia coli*; 33 colony forming units per 100 ml. of i*ntestinal enterococci* and 1 colony forming unit per 100 ml. or 1 colony forming unit per gram of wet weight of zoological samples of toxicogenic *Vibrio cholerae* (serotypes 01 and 0139).

In Washington State the interim ballast water discharge treatment standard is 95% zooplankton and 99% phytoplankton/bacteria elimination, with the stipulation that "Vessels that have not adequately exchanged their ballast water must treat their ballast to meet or exceed the Washington State interim ballast water discharge standard prior to discharging in Washington waters". Washington State legislation further states that only approved technologies may be used *on specified vessels* to discharge treated ballast in Washington waters. For approval, technologies must meet one of the following criteria:

- Previously approved by Washington Department of Fisheries and Wildlife for use in WA waters.
- Approved by U.S. Coast Guard for use in national waters
- Enrolled in U.S. Coast Guard Shipboard Technology Evaluation Program (STEP).
- Approved by the State of California for use in California waters
- Approved by the International Maritime Organization (IMO) and authorized by U. S. State Department and U.S. Coast Guard for use in national waters.
- Vessel is enrolled in IMO approval process and is authorized by the U.S. State Department and U.S. Coast Guard for use in national waters.

A table with the IMO and US federal and state ballast water treatment standards is shown in Appendix 1.

Hyde Marine's Ballast Water History

Hyde Marine has been involved in ballast water treatment (BWT) since 1996, when it partnered with the University of Michigan to study potential BWT technologies. This led to Hyde's participation as the engineering contractor for one of the first BWT research programs in North America, the Great Lakes Ballast Technology Demonstration Project (GLBTDP).

Hyde began testing and operating its own BWT equipment in 2000, when it installed a full scale, first generation system (UV combined with cyclonic separator) aboard the *Regal Princess*. In 2001 Hyde installed four additional systems, two on cruise ships and one each on a container ship and chemical tanker. There were many lessons learned from the first five BWTS installations. This shipboard operating experience led to a complete redesign of the system to one using auto-backflush disk filtration, in place of cyclonic separation, and a higher powered, more robust, medium pressure, cross-flow UV system, in place of the low pressure, axial flow system used on the original five installations.

This redesigned state-of-the-art filtration and UV treatment system, namely Hyde Guardian™, was installed aboard the *Coral Princess* in 2003. The Hyde Guardian™ was tested extensively in land-based installations and onboard *Coral Princess* in the fall 2004. The onboard tests demonstrated that the Hyde Guardian™ was capable of meeting the IMO BWT Convention requirements, and the *Coral Princess* with the Hyde system was the first ship accepted into the US Coast Guard Shipboard Technology Evaluation Program (STEP) on Oct. 31, 2008. STEP and the unique experience of being the first system to be accepted are described in a later section of this paper.

In the fall of 2006, an essentially identical system was installed aboard Royal Caribbean Cruise Line's *Celebrity Mercury*, and it was commissioned early in 2007. The Hyde Guardian™ systems aboard the *Coral Princess* and *Mercury* were granted interim approval for use in Washington State waters by the State of Washington in 2004 and 2007, respectively. The Hyde Guardian™ has been commercially available since early 2003.

The Hyde Guardian™ Ballast Water Treatment System

The Hyde Guardian™ has two main components, the automatic back-flushing disk filter and the medium-pressure inline UV system. The filter ensures reliable removal of solids and larger organisms, containing several modules of "stacked-disc" filter elements that capture and store large amounts of solids. The filter is designed to automatically back-flush itself at the end of

each ballasting operation and when necessary, clean one module at a time using the filtered water from the remaining modules. This allows for continuous ballast flow and immediate discharge of the filtered material back into the ballast water source.

The UV system uses high-output lamps perpendicular to the fluid flow. An automatic cleaning mechanism keeps the quartz sleeves around the UV lamps clean, ensuring consistent and reliable UV dosage. The UV treatment chamber is made of heavy-duty, 316L stainless steel for a long, trouble-free service life.

During ballasting, the flow is processed through the filter and UV system, then back to the main ballast system. During deballasting, the filter is bypassed and the water flows only through the UV system and then overboard through the discharge line (Fig. 3).

A single control panel operates the entire ballast water treatment system (filter, UV, valves, and booster pump, if required). All operations and indications can be viewed via the LCD panel, and the system can easily be integrated into the ship's ballast control system to allow for operation and monitoring in the control room. A detailed description of how the filtration and UV technologies work in the Hyde Guardian™ system to eliminate viable organisms in ships' ballast water is described in the next section.

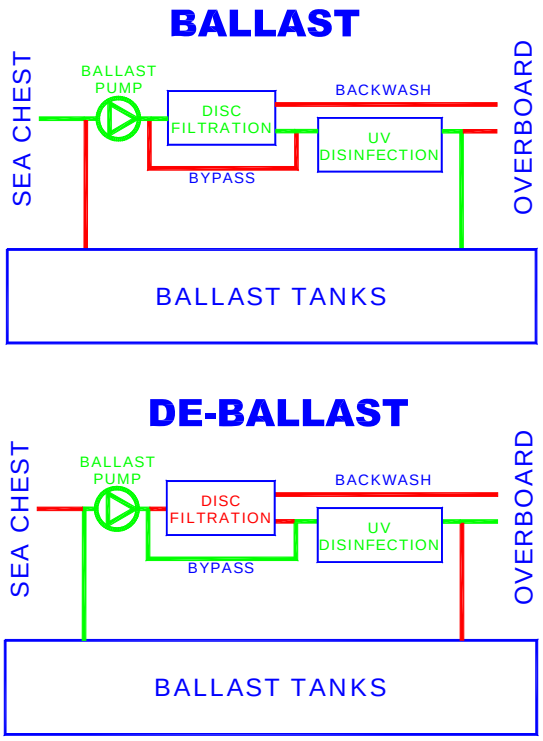


Figure 3. The flow diagram of the Hyde Guardian Ballast Water Treatment System

The system is modular in configuration so that the components can be installed separately to fit the available space on existing vessels. Hyde has also developed a complete skid mounted Hyde Guardian™ system, which has been offered for several new building programs and will result in a considerably lower installation cost. Skid-mounting uses a steel platform that forms part of the foundation for all of the BWT system components and is suited for new building applications, where it can be designed into the BWT system (Fig. 4). The modular system is shown, installed aboard the cruise ship *Mercury* in Fig. 5.

Figure 4. The Hyde Guardian™ Model HG 300 single skid mounted BWT system

Figure 5. Hyde Guardian™ system, aboard the M/V *Mercury*.

In early 2008 Hyde Marine Inc. received an order from the UK Royal Navy to provide Hyde Guardian™ Ballast Treatment Systems for their new Future Aircraft Carrier (CVF) program. Three BWT systems were supplied for each of the two carriers to serve the three segregated ballast systems on each ship. The Hyde Guardian™ was selected after an exhaustive study of all available technologies for BWT. The system was chosen because of its compact, single skid mounted design and because of its demonstrated

effectiveness and reliability. The system is fully automatic and will be integrated into the ship's ballast control system.

The Type Approval Process

The Hyde Guardian™ Ballast Treatment System completed the test requirements according to IMO Resolution MEPC.125(53) "Guidelines for Approval of Ballast Water Management Systems (G8)" during 2008. The G8 guidelines define the test and performance specifications for an approval of BWMS, which requires that the BWMS be tested onboard a ship in addition to land-based tests.

The land-based tests were conducted by the Royal Netherlands Institute for Sea Research (NIOZ) at their facilities on Texel between April and June 2008. The results indicated that the Hyde Guardian™ performed well and achieved the requirements set by IMO. The test procedures and results are described in a later section of this paper. The testing included system challenges well in excess of the requirements of the G8 Guidelines.

The shipboard testing was completed aboard the cruise ship *Coral Princess* (*Frontpiece*) over a six month period, as required by the G8 Guidelines, during the vessel's regular schedules in the Caribbean Sea and in the North East Pacific. The shipboard trials were conducted by a team from the University of Maryland in accordance with both IMO and STEP guidelines, and the testing was completed in October 2008. The shipboard testing procedures and results are described in a later section of this paper including observations on the many challenges of scientific testing aboard an operating ship.

After all the tests were completed and the required documentation prepared, the type approval application was submitted to the Maritime and Coastguard Agency in the UK via Lloyds Register, MCA's designated technical representative.

The type approval process for the Hyde Guardian™ system was coordinated together with the VTT Technical Research Center of Finland, an impartial expert organization providing research, development, testing and information services to the public and private sectors. VTT is a non-profit research organization.

The IMO type approval process is described in detail in a later section from the point of view of the approving authority's technical representative.

THE HYDE GUARDIAN™ AT WORK

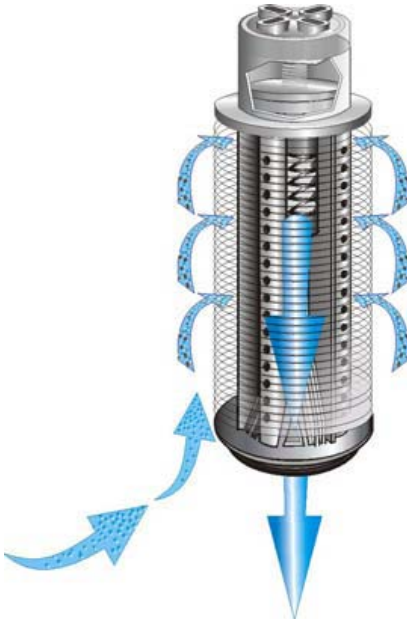
The ballast water treated by the Guardian is subjected to two different processes. The first of which is filtration. This is followed by the first of two rounds of disinfection. The second round of disinfection is done during the deballasting process. These two processes have proved to be extremely synergistic. It is possible to use strictly mechanical filtration to meet the IMO requirements but it would be very unrealistic due to the size of the required filter. It is also possible to simply use disinfection via ultraviolet radiation but this is unfeasible due to power requirements. By combining the two technologies the Hyde Guardian takes full advantage of each process' strengths while keeping the downsides to a minimum. In simple terms the ballast water is treated by removing the large organisms and killing the small organisms.

The Hyde Guardian is a fully automated system that once integrated into the ships ballast system requires no operator input for operation.

FILTRATION

Choosing a filter is typically dependant on flow rates and challenge. While the flow rates of ballast water systems are a known the challenge is constantly variable and almost completely unknown. Further complicating the equation is the lack of available footprint and the maintenance requirements. At first glance it seems like an unsolvable equation, too many variables. The Hyde Guardian solves this equation using a unique stacked disc filtration system.

The Hyde Guardian Systems uses a specially designed disc filtration technology. Thin, color coded, modified nylon discs are diagonally grooved on both sides to a specific micron size. A series of these discs are then stacked and compressed on a specially designed spine. When stacked, the groove on top runs opposite to the groove below, creating a filtration element with a series of intersections for trapping solids. The stack is enclosed in corrosion and pressure resistant housing.



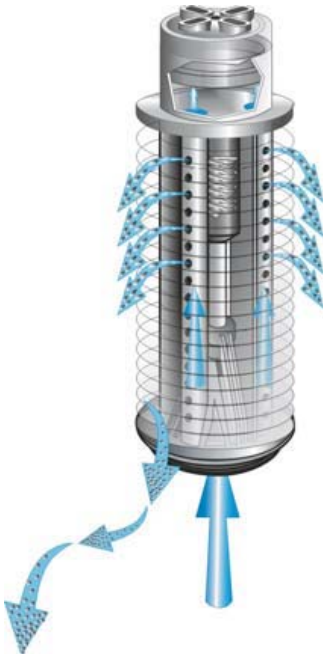
Filtering

During the filtration process, the filtration discs are tightly compressed providing high filtration efficiency. As water flows from the outside of the stacks to the inside the larger particles are captured by the intersections of the score lines. As there are many intersections to pass through before reaching the center of the stack the possibility of a particle or organism passing though on its narrow dimensions diminishes. In other words, even if an organism can get though one intersection on its smallest axis it is likely to be caught by the next intersection on its larger axis.

After the effectiveness of filtration, the second most important feature of the filter technology is how it is cleaned. The Hyde Guardian's filtration system uses a patented backflushing process that quickly and efficiently cleans the entire module with as little waste as possible.

The backwashing of the filter can be manually initiated, or time based but for maximum effectiveness the Hyde Guardian typically uses the differential pressure switch. The control system constantly monitors the differential pressure across the filter. As the filter clogs the differential pressure will rise. Once the preset limit has been reached a backwash cycle will begin.

The first step in the backwash cycle is to activate the 3-way valve which closes the inlet and opens the drain. By removing the differential pressure in the system the spine piston rises up, releasing the pressure on the discs. Tangential jets of clean water are pumped at high pressure in the opposite direction through nozzles at the center of the spine. The discs spin free and clear, loosening the trapped solids. Solids are quickly and efficiently flushed out through the drain and immediately overboard.



Backwash Cycle

An entire module, up to 8 stacks of discs, is completely cleaned in approximately 10 seconds. Cleaning the entire module at once makes it virtually impossible to overload the filter to the point where manual cleaning would be required.

The backwash water leaves the filter through the drain line, which is connected to the ships overboard discharge line. As this water contains only organisms that were recently picked up they are simply being returned to the environment, from which they came.

DISINFECTION

After leaving the filtration system, the ballast water still contains a large amount of smaller organisms. In order to meet the ballast water requirements, the Hyde Guardian uses ultraviolet radiation as a disinfectant to kill or inactivate the remaining organisms. The ballast water is passed through the UV system a second time on its way out to ensure that organisms living in the tanks are also destroyed before being put overboard.

Ultraviolet or UV energy is the band of light just beyond the short wavelength end of the visible light spectrum. It is the range of light associated with the natural germicidal action of sunlight. UV works by

affecting the DNA of microorganisms, eliminating their ability to reproduce or survive. All microorganisms can be disinfected by UV light without the concern of an organism's self-defense mechanisms. It is not possible for an organism to become UV resistant in the same way organisms become resistant to certain chemicals.

Ultraviolet light is the natural, environmentally friendly alternative to chemical disinfection. Many common chemicals such as chlorine are hazardous to handle, remain in the environment for long periods, can form dangerous reaction by-products, and alter the products and processes, in which they are used. The plague of disinfection byproducts such as trihalomethanes (THM) halogenic acetic acids (HAA) can be worse than the organisms they are trying to control. Over the past couple of decades there has been a concerted effort to move away from hazardous chemicals. Ultraviolet light has been the preferred technology for replacing chemical systems world wide.

Ultraviolet light is produced inside special lamps, i.e. light bulbs. There are 2 technologies that dominate the UV disinfection field, low pressure and medium pressure lamps. Low pressure lamps are monochromatic producing UV light at a single wavelength, 254nm. These lamps are typically rated between 80 to 200 watts. Many lamps are used in order to provide a sufficient UV dose.

The Hyde Guardian uses medium pressure lamps. Medium pressure lamps are polychromatic in that their output spans the wavelengths 240-280nm, which corresponds to the entire germicidal action curve. The lamps used by the Guardian range from 2kW each up to 7kW each, which means that fewer lamps are required to achieve the desired dose.

The lamps of a disinfection system never come into direct contact with the water being treated. Instead they are protected from the water by quartz sleeves or thimbles. The challenge of applying UV to any type of water stream is keeping the system clean enough for proper UV exposure. The Hyde Guardian utilizes an internal automatic wiping mechanism that was originally designed for unfiltered waste water. The wiper keeps the quartz sleeves clean and system maintenance to a bare minimum.

As there are no online techniques for testing ballast water the only way to ensure compliance is to make sure systems are operating correctly. The UV system continuously monitors all of the UV lamps as well as system variables such as UV intensity, relative transmission, water temperature and flow rate. The intensity of the lamps can be varied up to 30% to make up for aging lamps or poor water quality.

LAND BASED TESTING AT NIOZ

As indicated in the previous sections, the Hyde Guardian™ Ballast Treatment System consists of a filter combined with a UV-disinfection system. The filter is a first step to mainly reduce the number of larger organisms, i.e. larger than 50 microns. The UV system will inactivate the remaining organisms in such a manner that they will die or not be capable of reproduction (e.g. Leech & Williamson 2000 and references therein, Waite et al. 2003, Viitasalo 2005). UV-damage can alter or damage a variety of processes like the photosynthetic system (phytoplankton; Villafañe et al 2003), cellular enzymes or damage of the nuclear DNA (Buma et al 1996). Organisms may disintegrate immediately or retain their cell morphology but are effectively non-viable.

Figure 6. Test site at NIOZ, Texel, Netherlands.

Figure 7. Hyde Guardian containerized test system at NIOZ.

To examine the efficacy of the Hyde Guardian™ Ballast Treatment System it should be tested rigorously for at least 10 test runs. In order to determine the efficacy, the test water should contain a minimum number of organisms at intake. In addition, considering the large global biodiversity there is also a minimum requirement in terms of species diversity. Because of size-dependent abundance, different criteria are given for different (biodiversity) groups of organisms, see Table 1.

As Table 1 shows the minimum numbers of the various groups of organisms vary highly with (cell) size. Subsequently, also the allowed residual numbers at discharge are different (see the Introduction section).

.

Table 1: Minimal numbers and species diversity required at intake for different size classes and groups of organisms.

Influent test water		
Parameter	Unit (numbers/volume)	Remarks
organisms ≥ 50 micron	> 10^5/ m^3	At least 5 species from at least 3 different phyla/divisions
10 ≤ organisms size ≤ 50 micron	> 10^3/ ml (>10^9/ m^3)	At least 5 species from at least 3 different phyla/divisions
heterotrophic bacteria (< 5 micron)	> 10^4/ ml (>10^{10}/ m^3)	Not further defined

Unfortunately, the aquatic environment, fresh water or marine, is not an exclusive soup of living planktonic organisms but contains a mixture of organic and inorganic substances as well. Like the living biology these compounds often have an adverse affect on the performance of ballast water treatment systems. Therefore, additional criteria are given for other water characteristics (Table 2).

Table 2: Three different salinity ranges and minimum concentrations of TSS, POC and DOC in the water .

Salinity				
Parameter	> 32 PSU	3 – 32 PSU	< 3 PSU	unit
Total Suspended Solids (TSS)	> 1	> 50	> 50	mg/l
Particulate Organic Carbon (POC)	> 1	> 5	> 5	mg/l
Dissolved Organic Carbon (DOC)	> 1	> 5	> 5	mg/l

The additional particle load (silt and clay minerals) reduced the filter capacity significantly since the concentration of these substances exceeds that of that of the organisms by several orders of magnitude. Finally, not only particles but also dissolved organic carbon (DOC) absorbs light in particular in the UV-range of the light spectrum. This will reduce the light intensity of the applied UV-light source, hence the sterilizing ability of the secondary treatment. Because the particle load can be very high, in particular in harbours, there was an emphasis on studying the impact of this factor on the overall performance of the Hyde Guardian™ Ballast Treatment System. In this respect the turbid coastal waters of the North Sea surrounding the island of Texel (location of the land-based test site of the Royal Netherlands Institute for Sea Research; www.nioz.nl) provide a good environment for testing. Moreover with ample organisms in the water and a rich biodiversity these waters are representative of many harbours across the globe (Veldhuis et al. 2006). In addition the coastal water of the North Sea is often dominated by an outburst of the gelatinous producing phytoplankter *Phaeocystis globosa*.(Lancelot et al 1987). The mucus

of this algal species tends to clog nets as well as the filters in ballast water treatment systems. The density of this phytoplankter can be so high that the mucus produces massive foam on top of the water and on the shore (Fig. 8). Experience has shown that this phytoplankton species provides an ultimate challenge for any treatment system with a filtration step.

Land-based testing effectively mimics the whole sequence of ballasting and deballasting at a real scale in a semi-controlled mode. The total volume of processed water should be at least 200 m^3 and is stored in large (dark) basins for a period of 5 days prior to discharge. The Hyde Guardian™ Ballast Treatment System treats the water both at intake (filtration and UV) as well as during discharge (UV-treatment only) to ensure that organisms surviving the first treatment or those capable of re-growth in the tank after intake will receive a second dose of UV-radiation lethal to the remaining living organisms in the tank. During both treatment steps a set of basic parameters were measured to assess the water quality of the ballast water and potential changes therein during the 5 day holding period (Table 3).

Figure 8. Dense foam formation at the NIOZ test site during a bloom of the mucus producing phytoplankton species *Phaeocystis globosa*.

Results show that the Hyde Guardian™ system - tested for 5 repetitive test runs at each of two salinity regimes (ca. 22 and 32 PSU, respectively) - caused no significant alteration of the primary physical and chemical composition of the water compared to the control (the control was water pumped into a tank and not treated).

low salinity	**parameter**	**Control-T0**	**Control T5**	**HG-T0**	**HG-T5**	**unit**
5 test runs	salinity	21.7		22		PSU
	temp (range)	8.5 -	11.8	9.2 -	12.3	ºC
	TSS	42.5	9.6	29.9	11.1	mg/L
	POC	16.1	5.4	10.5	5.8	mg/L
	DOC	5.8	3.0	4.9	3.4	mg-C/L
	DO	117	96	112	97	saturation %
	PO_4	0.16	0.22	0.24	0.17	µmol/L
	NH_4	2.8	7.63	2.95	5.38	µmol/L
	NO_3	42.5	42	41.5	36.9	µmol/L
	NO_2	0.48	0.51	2.99	4.62	µmol/L
high salinity	**parameter**	**Control**	**Control T5**	**HG-T0**	**HG-T5**	**unit**
5 test runs	salinity	32		31.8		PSU
	temp (range)	14.9 -	18.2	15.1 -	18.1	ºC
	TSS	33.9	9.7	14	10	mg/L
	POC	10.2	4.8	7.2	4.5	mg/L
	DOC	4.0	3.3	4.3	4.1	mg-C/L
	DO	91	55	87	63	saturation %
	PO_4	0.41	0.56	0.48	0.82	µmol/L
	NH_4	7.33	6.74	7.69	7.32	µmol/L
	NO_3	0.46	0.45	0.84	1.33	µmol/L
	NO_2	6.87	6.28	6.85	6.00	µmol/L

Table 3 Average values of 5 test runs (three replicates) of salinity, temperature, total suspended solids, particulate organic carbon, dissolved organic carbon, dissolved oxygen inorganic nutrients (PO_4, NH_4, NO_3, NO_2) of the control tank at intake (T0) and at discharge (T5) and the tank with water treated with the Hyde Guardian (HG; intake T0 and discharge T5).

The filter step of the Hyde Guardian™ Ballast Treatment System reduced the amount of total suspended solids (TSS) by 30 to 60% and, since this size class also included larger organic particles, the amount of particulate organic carbon (POC) also declined. Concentrations of the major nutrients (PO_4, NH_4 and NO_3) remained virtually constant. Only in the case of NO_2 at the low salinity range the concentration increased by a factor of 6.2 immediately after the treatment at intake. In contrast, at the higher salinity range no effect was observed. Also the oxygen concentration, expressed as percentage of saturation, was unaffected by the treatment. In general the retention time of the water, 5 days prior to discharge, influenced the concentration of particles more than the original treatment (Table 3). At both salinity regimes TSS and POC dropped significantly mainly due to sedimentation. Nevertheless, the total amount of sediment in the treated tank was far less, compared to the control, due to the presence of an effective filtration step. Also when cleaning the tanks after each experiment the amount of sludge on the bottom was far less in the treated tank and it also lacked the typical smell associated with anaerobic sediment (hydrogen sulphide). With respect to the dissolved oxygen concentration (DO), there was a minor reduction in the first series after 5 days - expressed as percentage of saturation. In contrast, during the second series of test runs oxygen dropped by 30% in the treated tank but on average 40% in the control tank. The main reason for this was the onset of microbial degradation (see also Table 4) due to the higher temperatures of the water during the second series of test runs. In general, the storage time had only a minor effect on the concentration of dissolved nutrients with the exception of NH_4 during the first series, where in both control and treated an elevation of 2.7 and 1.8, respectively, in the ammonia concentration was observed.

While the data as expressed in Table 3 provide an indication of the effect of the treatment on the general physical and chemical features of the test water prior to and after the treatment and holding, the ultimate aim of the Hyde Guardian™ Ballast Treatment System is the successful reduction of the number of organisms to an undetectable level. During the first series of test runs and also during two out of five of the second series, the test water was dominated by a large bloom of the mucus containing phytoplankter *Phaeocystis globosa* (Table 4). Combined with the high sediment load this turned out to be an ultimate challenge for the filters. This resulted in an automatic self-cleaning process of filters with an interval of less than 5 minutes. Nevertheless, the treatment effectively removed the larger organisms (> 50 micron) already at intake.

low salinity	parameter	Control T0	Control T5	Control-Inc-T5	HG T0	HG T5	HG-Inc-T5	HG-Dis-Tx	unit
zoo/phytoplankton	> 50 µm	2016267	3896	n.d.	4.4	2.9	n.d.		org./m^3
plankton	10-50 µm	1417	147	7951	522	186	15	2.3	cells/mL
phytoplankton	*P. globosa*	8447	589	8788	4977	1654	43	12	cells/mL
phytoplankton	< 6 µm	3372	268	2583	4080	2201	5.5	2.1	cells/mL
bacteria	total bact.	3.85E+06	2.09E+06	5.10E+06	2.76E+06	2.40E+06	1.61E+06	0.29E+06	cells/mL
heter. bacteria	plate counts	32	43	n.d.		234	n.d.	<10	cfu/mL
E.coli	human path.	<0.1	<0.1	n.d.		<0.1	n.d.	<0.1	cells/mL
enterococci	human path.	<1	<1	n.d.		<1	n.d.	<1	cells/100 mL
high salinity	parameter	Control T0	Control T5	Control-Inc-T5	HG-T0	HG-T5	HG-Inc-T5	HG-Dis-Tx	
zoo/phytoplankton	> 50 µm	749313	15429	n.d.	13.3	2.4	n.d.		org./m^3
plankton	10-50 µm	1628	140	6973	1245	56	6.1	1	cells/mL
phytoplankton	*P. globosa*	2264	290	11277	2600	547	4.7	1.9	cells/mL
phytoplankton	< 6 µm	6401	319	5106	5415	431	17	10	cells/mL
bacteria	total bact.	3.78E+06	2.15E+06	5.74E+06	4.69E+06	0.884E+06	2.08E+06	0.64E+06	cells/mL
heterotrophic. bacteria	plate counts	26	26	n.d.		30	n.d.	<10->1000	cfu/mL
E.coli	human path.	<0.1	<0.1	n.d.		<0.1	n.d.	<0.1	cells/mL
enterococci	human path.	<1-27	<1	n.d.		<1	n.d.	<1	cells/100 mL

Table 4 Average values of 5 test runs (three replicates) at 2 salinity ranges of organisms larger than 50 micron (>50 µm), plankton in 10 - 50 micron range, a dominant phytoplankton species (*P. globosa* with a cell diameter of ca. 6 micron), mixture of smaller phytoplankton (phytoplankton < 6 µm) total bacteria numbers, heterotrophic bacteria (as cultivable bacteria in cfu/mL), *E. coli* and enteroccoci. Data are given for the control tank at intake (T0) and at discharge (T5) and the treated tank (HG; intake T0 and discharge T5) as well as subsamples incubated under optimal growth conditions (Inc.). HG-Dis-Tx = incubation of water sample taken at discharge for varying period (x= 5 – 7 days); n.d.= not determin

For the plankton in the size class larger than 50 micron, counts on discharge, i.e. after the second treatment, were not always 0 (per m^3), but nevertheless well below the D2 standard. The numbers were actually so low that the viability of the few remaining organisms in this size class could not be tested properly in sub samples. The delayed effect of UV on organisms is well known (Leech & Williamson 2000 and references therein) and, judging from the results of the first treatment, it is assumed that the remaining organisms were not viable in a scientific sense.

With respect to the plankton in the size class of 10 – 50 microns, numbers also declined significantly after the treatment at intake and even further after the second UV-treatment at discharge. However, in terms of numbers, the total counts were still high on discharge on day 5. Additional tests for viability and, in the case of phytoplankton, also their photosynthetic system revealed that the population was almost entirely dominated by non-viable cells. Taking into account the results of the viability tests the actual number of viable organisms was <0.1 per mL. For completeness, the fate of the phytoplankton with a cell size of less than 10 micron was also monitored. Besides the presence of single cells of *P. globosa* (cell diameter of ca 6 micron) the test water also contained a mixture of smaller sized phytoplankton, collectively indicated as the group < 6 micron. The numerical abundance of both these groups of phytoplankton exceeded that of the 10 – 50 micron size class significantly (see control at intake in table 4). Nevertheless, treatment resulted in a substantial decline in the numerical abundance. Like the larger phytoplankton, the remaining cells were classified as non-viable.

In order to examine the growth potential of the remaining organisms a large subsample of the treated water, at intake and at discharge, was incubated under optimal conditions and inspected for the presence of phytoplankton. The general idea is that, if the remaining organisms would have survived the treatment, they could grow and produce a new plankton population. The holding time of 5 days and the potential growth rates of the phytoplankton would be long enough to produce a sufficient new population. The incubation experiments indicated that in the control water (only pumped into the tank and not further treated) the growth potential of the phytoplankton was extremely high. In all size classes, including phytoplankton > 10 micron there was an extensive increase in the number of phytoplankton cells. In contrast in the treated water the cell numbers of phytoplankton declined to extremely low values. In fact numbers were much lower than those observed in the tank samples (water was kept in the dark). The second UV-treatment at discharge therefore results in a further reduction in the number of planktonic organisms. Besides the larger planktonic organisms the presence of two groups of human pathogens was also determined at different stages of the treatment. In general numbers of the two pathogens were already below the limit of the Standard-D2 in the test water. In the case of enterococci, the treatment reduced the amount of enterococci to nearly undetectable numbers.

SHIPBOARD TESTING ABOARD THE "CORAL PRINCESS"

Shipboard testing as a component of the IMO approval procedure is regarded as supplemental to land-based testing, although it serves an important and unique role in the overall process. There is at present no clear consensus on promulgated ballast water treatment standards. For example, current IMO regulations differ significantly from those appearing in the (April 2008) U.S. Coast Guard authorization Act (HR 2830, Section 503, sub-section 1101, Ballast Water Management), and more stringent standards adopted in January 2008 by the state of California. Provision is made for regional differences in standards in the current wording of the IMO Convention: 'A Party, individually or jointly with other Parties, may impose on ships additional measures to prevent, reduce, or eliminate the transfer of Harmful Aquatic Organisms and Pathogens through ships' Ballast Water and Sediments'. However, there is the potential for confusion here, particularly for a vessel that might travel between different jurisdictions, and where one region wishes to adopt stricter standards, '--- the Party or Parties should consult with adjoining or nearby States that may be affected by such standards or requirements and should communicate their intention to establish additional measure(s) to [IMO] at least 6 months, except in emergency or epidemic situations, prior to the projected date of implementation of the measure(s).

Figure 9. Shipboard testing of Hyde Guardian system aboard M/V *Coral Princess*

With both IMO G8 and the U.S. Coast Guard Shipboard Technology Evaluation Program (STEP) an important component of shipboard testing concerns the safe installation and operation of the shipboard system in a manner that maximizes and maintains its efficacy. So, there is clearly a need to confirm that a treatment

system operates under normal operational conditions at sea as effectively as under the more easily controllable land-based situation. Provision is made in the IMO Ballast Water Convention for Port States to verify whether the vessels are carrying valid certification and have up-to-date ballast water log books. Inspectors will have the authority to collect ballast water samples and may subject these to detailed inspection to determine whether appropriate management or treatment has been carried out. Current shipboard testing programs may, therefore, act as prototypes for this aspect of eventual compliance testing.

The testing program reported here draws on the experience of conducting several trials of ballast water treatment systems aboard a variety of vessels under different seasonal and geographic conditions and using different sampling techniques. (Wright et al. 2005; Wright et al. 2007a,b) Additionally, dockside testing of the Guardian system was performed as part of the Baltimore Harbor Ballast Water Treatment Demonstration Project (Wright 2007a).

In common with earlier testing of this system an inline sampling strategy was adopted wherein the sampling port was located downstream from the UV system in the machinery space of the ship (figure 9). In these trials, the untreated (control) water was collected downstream of the BWT system, but with the filter by-passed and the UV turned off. Treated water was collected from the same port, but with the filter in-line and the UV system on. IMO G8 regulations remain focused on specific densities of live organisms found in treated water, rather than a comparison of treated and untreated water per se. Nevertheless, reference is made to the collection of both treated *and* untreated water as part of the shipboard testing procedure, and a requirement is made for the collection of triplicated untreated (control) samples, both at uptake and discharge. Challenge water, defined as control water at the time of uptake, should contain densities of live organisms at least 10x the values of D-2.1, and control water at the time of discharge should contain densities of live organisms exceeding D-2.1 values. It was assumed that the challenge water was identical for both treated and control tanks despite the fact that these tanks were filled sequentially. On a moving ship this could represent a difference in uptake water of several miles (Wright 2007b). A more comprehensive sampling strategy applies to treated samples, where triplicate samples are required at the beginning, middle and end of a sampling event; a 3 x 3 matrix. The sampling regime adopted during these shipboard trials actually exceeded IMO G8 requirements. In trial 1, quintuplicate samples of both treated and control water were collected at the time of uptake (ballasting), which represents T=0 on the treatment timeline, and full 3x3 matrices of both treated and control water samples were collected following a 96h residence time in the tanks. In trial 2, seven control and nine treated samples were collected at T=0 and a full 3x3 matrix of both treated and control water samples was collected following a 114h residence time in the tanks. In trial 3 9 treated and untreated samples were collected at T=0 and at de-ballasting (T=10 Days). It should be noted that the designated treatment stipulated by the vendor (Hyde Marine Inc.) consists of filtration + UV irradiation on ballasting plus UV irradiation on discharge. Therefore, treatment is only deemed complete following the second pass through the UV system during de-ballasting. While this means that, technically, T=0 treated samples do not represent fully treated samples, they can provide important, and sometimes crucial information on system performance. An illustration of this came from the second trial (June/July 2008), where clear differences were seen between treated samples examined at T=0 and samples retrieved from the treated tank nearly five days later.

Results of zooplankton counts from all three trials are summarized in table 5. In all trials the numbers of live zooplankton >50µm (narrowest dimension) complied with all published ballast water treatment regulations, in that no live zooplankton in this size class were seen at the time of ballast water discharge. While some smaller taxa survived treatment, e.g. marine nematodes, these were very much narrower than 50µm. In trial 1 results indicated a 98.4% mortality of zooplankton (>50µm minimum dimension) immediately following treatment on ballasting relative to untreated samples collected during the same sampling event, and a 100% mortality of zooplankton (>50µm minimum dimension) after a period of 4 days in the ballast tank followed by UV irradiation on de-ballasting. In contrast, untreated control samples demonstrated good survival following the 96h residence time in the tank. Overall there was no statistical decline in control numbers relative to those recorded from the intake water, although organism numbers were seen to increase from the beginning to the end of the de-ballasting cycle, reflecting a probable difference in plankton densities throughout the water column in the tanks. For example zooplankton densities at the end of the de-ballasting cycle were nearly double those at the beginning of the de-ballasting cycle. In trial 2 results indicated a 99.99% mortality/removal of zooplankton (>50µm minimum dimension) immediately following treatment on ballasting relative to untreated samples collected during the same sampling event. Samples were characterized by a dramatic difference in biomass between the treated and untreated samples. In treated samples a mean of 1.14 live organisms >50µm in minimum dimension per ton were found at T=0. No dead organisms were found in this size range. In control samples at T=0, 15,373±6118 live organisms >50µm and 141±117dead organisms >50µm per ton were found. It is of interest to note that the live density of organisms >50µm in the challenge water showed a 35-fold increase relative to the much more oligotrophic

conditions encountered in Caribbean waters during the first, April 2008, trial. However, a significant qualitative difference in fauna between T=0 samples and those retrieved at de-ballasting. In trial 3 treated samples at T=0 zooplankton in this size category showed 100% mortality.

Phytoplankton counts from treated and untreated (control) samples from shipboard trials are shown in table 6. Initial cell densities in challenge water in trial 1 (Caribbean Sea) were very much lower than in trials 2 and 3. Based on microscopic examination, cells were scored as 'live' based on morphological characteristics such as chloroplast integrity and the ability to concentrate the vital stain Neutral Red. Based solely on these criteria, initial treatment (filter + UV during ballasting) in trial 1 resulted in an immediate 41% reduction in live cell numbers relative to untreated samples at T=0.. However, following a 96h residence time in the tank, untreated 'live' cell numbers had fallen to 7% of the initial, untreated T=0 density, and treated 'live' cell numbers had fallen to 4.7% of that initial concentration (i.e. 95.3% removal). Under such circumstances a comparison between treated and control 'live' densities at 96h probably has little meaning as it is clear that the ballast tank provides an inhospitable environment for treated and untreated cells alike. If it is assumed that viability is best described by growth potential this assumption is further reinforced by cell counts following grow-out. Concentrations of treated cells following grow-out, shown in red in table 6, clearly indicate a failure to grow, based on the fact that they represent a mean *reduction* in cell numbers of 65% relative to the corresponding samples before grow-out. Based on growth potential, treated phytoplankton at 96h could reasonably be described as non-viable. This assessment is reinforced by measurement of chlorophyll a concentrations before and after grow-out (table 6).
In trial 2, unlike trial 1, initial treatment (filter + UV during ballasting) resulted in an immediate and dramatic (97%) reduction in live cell numbers based solely on morphological characteristics. Following a 114h residence time in the tank, untreated 'live' cell numbers had fallen to 30% of the initial, untreated T=0 density (compared with 7% in trial 1), and treated 'live' cell numbers had fallen to 1.9% of that initial concentration (i.e. 98.1% removal). As with trial 1, it is clear that the ballast tank provides a poor environment for treated and untreated cells alike. Concentrations of treated cells following grow-out, indicated some growth capacity in 3/9 T=0 controls and 5/9 T=0 treated samples, although taken overall cell numbers after grow-out show reductions in control cell densities in control and treated samples of 70% and 58% respectively.

In trials phytoplankton numbers following treatment (at de-ballasting) were well below the standard of 10^7 live cells/m^3 set by IMO under G-8 guidelines. When cell concentrations following grow-out are compared to the U.S. Coast Guard standard of 10^5 live cells/m^3 (=100,000 live cells/m^3), the grand mean from all three trials (2,222, 75,667, 103,300/3 = 60,398 live cells/m^3) complies with the standard, although the individual value from trial 3 (103,300 live cells/m^3) is marginally higher than the 100,000 live cells/m^3 U.S. Coast Guard standard. Another way of looking at these data takes note of the fact that cell densities following grow-out represent reductions in cell densities of 65%, 60% and 83% for trials 1-3, compared with cell numbers before grow-out. A case can, therefore, be made for assuming that *all* these natural populations of phytoplankton are incapable of growth, and therefore non-viable. This was reinforced by measurement of chlorophyll a concentrations before and after grow-out. While some positive growth was seen in untreated control samples at T=0, treated samples at T=0, no growth relative to intake water was recorded from treated samples at T=114h.

As judged by indicator bacteria, water examined from trials 1 and 3 indicate relatively pristine conditions. Trial 1 showed very low densities of coliforms and Enterococci in control (untreated) samples at T=0, but there was no evidence of these groups in any other samples from this trial. Counts were made of heterotrophic cultural bacteria in all samples. Although they are not regulated by IMO or the U.S. Coast Guard, January 2008 California regulations set a standard of 100cfu/100ml for this group (Table 7). While cfus for cultural bacteria exceed this standard in trial 1 at T=0, both treated and untreated numbers declined at the time of discharge to levels below the California standard. At de-ballasting, cfus in treated samples were as low as one tenth of that standard. Samples from trial 3 were similar to trial 1. No indicator bacteria were reported in either treated or untreated samples at T=0, although low numbers of coliforms, including *E. Coli*, appeared in untreated samples at the time of discharge. No indicator bacteria were reported from any treated samples from trial 3. Cultural bacteria were present in both treated and untreated samples at T=0 in trial 3 (Table 7) although, as in trial 1, numbers at the time of discharge were lower than the California standard, particularly in treated samples.

Bacterial counts from trial 2 differed markedly from the other two trials, and were characterized by:

1. High counts of cultural bacteria at the time of discharge (de-ballasting)
2. Appearance of intestinal enterococci in both treated and untreated samples at time of de-ballasting, despite the fact that no cfus from this taxa were recorded in the respective T=0 samples.

While IMO and the U.S. Coast Guard have no standards applicable to culturable heterotrophic bacteria (see Appendix 1), the numbers of cfu in these

samples clearly exceeded the California standards. No coliforms were recorded from any samples in this trial. With respect to Enterococci, numbers of cfus in treated samples at de-ballasting, 36±27cfu/100ml (table 7), were noticeably higher than in untreated samples (2±1cfu/100 ml.). The figure of 36±27cfu/100ml is below the standard of 100cfu/100ml set for this group by IMO and, therefore, complies with IMO regulations. However it marginally fails the corresponding standard of 33 cfu/100ml set jointly by U.S. Coast Guard and the state of California. These anomalous figures should be viewed, however, within the context of the zooplankton samples, which had high detritus loads and large zooplankton specimens that were not seen in T=0 samples. These included several harpacticoid copepod adults >1000µm (some >2000µm), and indicated a quite different population that that sampled at T=0. Despite the presence of these organisms at the time of de-ballasting, all specimens in the treated samples were dead; some recently, others in varying states of decay. It must be borne in mind that the filtered was turned off at de-ballasting as per normal de-ballasting protocol, and would not have filtered out large organisms during the discharge cycle.

It seems reasonable to conclude that the appearance of Enterococci in samples withdrawn from the tank at discharge would result from the decay/disintegration of these planktonic organisms with the concomitant release of endogenous bacteria that had been shielded from the effect of UV irradiation. In contrast, the corresponding T=0 samples were free from Enterococci and were remarkably "clean", indicating that the filter appeared to be working correctly. Two explanations could explain the presence of large planktonic organisms identified at discharge but not previously seen:

1. An earlier ballasting operation (before trial 2) may not have properly employed the filter, or
2. Small eggs and/or juvenile stages (<50µm) may have passed through a correctly functioning filter rated for a 50µm cut-off, then subsequently grew and formed a live population within the tank.

A similar situation has been observed in previous shipboard trials (Wright et al. 2007a and unpublished). A drawback of conducting shipboard tests, therefore, relates to the fact that it is impossible to know if residual flora/fauna inhabit the tank prior to the onset of a trial. If such a situation exists, there may be significant, extraneous, qualitative and quantitative differences between the discharged water and that characterized by T=0 sampling. Such differences are avoided in land-based testing, where the collection/storage tanks can be vigorously rinsed between trials. In shipboard trials a similar problem relates to the flushing of the, often lengthy, piping and associated dead-space that constitutes the ballasting system.

Current IMO shipboard testing protocols simply require a comparison between treated and untreated water in shipboard trials following a certain defined residence time in the tanks, although there is an additional requirement to characterize the challenge (untreated) water at ballasting (T=0). For a system such as the one tested here, where treatment is not deemed complete until the second pass through the UV system at de-ballasting, it is clear that, from a regulatory standpoint, that the definitive samples should be those collected at discharge. Nevertheless, problems such as those described above illustrate the importance of inline sampling and analysis of a representative number of treated samples as well as untreated samples at T=0, particularly where a filter is involved.

Table 5. Zooplankton Counts from treated and untreated (control) samples collected during shipboard trials.

	Trial 1 (April 2008, Caribbean Sea)		**Trial 2 (June/July 2008, Alaska)**		**Trial 3 (September/October 2008, S. California)**	
Zooplankton	**Alive (>50µm). Density/m^3**	**Dead (>50µm) Density/m^3**	**Alive (>50µm). Density/m^3**	**Dead (>50µm) Density/m^3**	**Alive (>50µm). Density/m^3**	**Dead (>50µm) Density/m^3**
	T=0		**T=0**		**T=0**	
Control (untreated)	453±269	66±66	15,373±6118	141±117	1,391±918	192±233
Treated	6.4±6.7	1.6±3.6	1.14±2.8	0	0	11±4
	T=96h		**T=114h**		**T=10 Days**	
Control Start de-ballast (N=3)	432±345	232±236	504±291	0	24±0	32±13

Control Mid de-ballast (N=3)	296±343	536±385	437±624	1,123±572	8±7	13±19
Control End de-ballast (N=3)	755±164	1,195±352	43±74	971±654	16±17	13±10
Treated Start de-ballast (N=3)	0	125±21	0	75±16	0	0
Treated Mid de-ballast (N=3)	0	131±99	0	144±194	0	3±4
Treated End de-ballast (N=3)	0	75±72	0	224±89	0	3±4

Table 6. Phytoplankton Counts from treated and untreated (control) samples collected during shipboard trials (ND = No Data)

	Mean Live Phytoplankton/m^3 (after grow-out)			
	Untreated controls, T=0h	**Treated, T=0h**	**Untreated controls, T=96h**	**Treated, T=96h**
Trial 1, (April 2008, Caribbean)	133,829 ±60,055 (44,646 ±23,111)	79,322 ±5,692 (8,982 ±578)	12,444 ±6,770 ND	6,327 ±1,421 (2,222 ±1,483)
Trial 2 (June/July 2008, Alaska)	9,726,400 ±7,880,600 (2,936,800 ±6,608,000)	298,400 ±229,700 (125,600 ±143,800)	2,877,600 ±6,168,400 (2,962,122 ±5,613,127)	189,500 ±69,800 (75,667 ±41,861)
Trial 3 (September/October 2008, S.California)	6,504,381 ±3,458,482 (2,469,400 ±1,866,202)	1,511,770 ±719,434 (n=9) (1,181,737 ±1,141,830 (n=3))	2,815,977 ±1,505,752 (n=9) (1,271,768 ±951,515(n=4))	614,273 ±677,711 (103,300 ±101,585)

Table 7 . Summary of Bacterial endpoints for Trial 1 (April 2008), Trial 2 (July2008) and Trial 3 (September 2008). Numbers are reported as cfu/100ml.

			Total Culturable Heterotrophic Bacteria	Coliforms	*E. Coli*	Enterrococci	*Vibrio cholerae*
Treatment	**Time**	**Trial**					
Control	t=0	1	122±129	0.2±0	ND	0.2±0	0
Treated	t=0	1	194±104	ND	ND	ND	0
Control	t=96h	1	50±57	ND	ND	ND	0
Treated	t=96h	1	10±17	ND	ND	ND	0
Control	t=0	2	522±707	ND	ND	ND	0
Treated	t=0	2	211±262	ND	ND	ND	0
Control	t=114h	2	1156±1201	ND	ND	2±1	0
Treated	t=114h	2	1978±881	ND	ND	36±27	0
Control	t=0	3	341±342	ND	ND	ND	0
Treated	t=0	3	71±67	ND	ND	ND	0
Control	t=10 days	3	27±29	6±5	3±5	ND	0
Treated	t=10 days	3	8±23	ND	ND	ND	0

IMO BALLAST WATER CONVENTION TYPE APPROVAL PROCESS

In order for a ballast water treatment system to be approved by a flag administration the system must meet the requirements of the IMO's Guidelines for Approval of Ballast Water Management Systems, MEPC.125(53). However if the system uses or produces an 'active substance' the active substance must first have been approved by the IMO.

Flag Administrations can authorize Classification Societies to act on their behalf for approvals in accordance with MEPC.125(53). Lloyd's Register has been approved by the United Kingdom Maritime and Coastguard Agency (MCA) to approve ballast water management systems and acted on their behalf for the approval of the Hyde Guardian system.

Classification Societies have a great deal of experience approving shipboard equipment in accordance with IMO guidelines, examples of equipment approved by classification societies include: lifeboats, life jackets, oil/water separators, fire extinguishing systems and fire detection systems.

The approval process for a ballast water management system is in some respects similar to any other approval as it shares the same basic process of plan approval, testing and issue of a certificate. However the approval of ballast water management systems is unique in some respects and more complex than the other approvals. The approval of most other types of systems, for example, is concerned with its physical performance. In contrast, the approval of a ballast water treatment system is concerned with the system's biological performance. However, the approval process does consider some of the physical aspects of the system, as it must be able to be installed and integrated as part of the ships equipment and must, therefore, meet the same requirements as any other item of installed equipment.

The IMO guidelines require that a ballast water management system undergo land based and shipboard testing to evaluate its biological efficiency to confirm it meets the performance standards for ballast water management systems in regulation D-2 of the Ballast Water Managements Convention. The details of the testing are dealt with in other parts of this paper and are not discussed here.

The approval process can be considered in a number of stages leading to the issue of the approval certificate.
The process is initiated when the treatment system vendor applies to a flag administration or a classification society for the approval of their system. The vendor will then be requested to provide details of their equipment, when and where the land based and ship board testing will take place, who will undertake the shipboard testing, and a list of plans required to be submitted for approval. A quotation for the approval fee will then be prepared.

In approving the Hyde Guardian system it was found that holding face to face meetings with the various parties involved was of great benefit. Not only did these meetings assist in building good working relationships, they also simplified the planning of the approval, resolving problems and understanding each others' role in the process.

The land-based and shipboard test protocols were provided by the land based facility and the shipboard test team, which were then agreed by the classification society. Once these preliminary steps had been

completed a time table for both the shipboard and land based testing was established enabling the vendor to provide a working unit to the test facility and for it to be installed on site.

Prior to commencing land based testing, a visit was made to the test facility to ensure that it was capable of carrying out the test and that it met the requirements for a test facility as required by MEPC.125(53).

During both the land based and shipboard tests a number of site visits were made to witness the test runs of the equipment, taking of samples, verifying the chain of custody of the samples and some of the laboratory tests.

Once all the testing, both on land and onboard ship, was completed, reports of the test results would be provided to the administration or classification society and then reviewed to ensure that the tests confirmed that the equipment had met the D-2 standard and that the tests had followed the agreed protocols

Provided that all the tests results and supporting documentation, the plan approval, and all other required criteria are verified as being completed and found to be satisfactory, and, if required, final approval for an active substances is granted by the IMO, a "Type Approval Certificate of Ballast Water Management System" in compliance with MEPC.125(53) can be issued. This certificate will then allow the manufacture to market the system as a fully approved system. The certificate gives a ship owner confidence that he is purchasing a system that will meet the requirements of the Ballast Water Convention.

In conclusion, the approval of a ballast water management system is a complex process involving many participants and many different disciplines. In order for the approval process to be completed it has proved vital that a good working relationship between all parties is established at an early stage in order that the objectives are fully understood by all involved.

THE U.S. COAST GUARD SHIPBOARD TECHNOLOGY EVALUATION PROGRAM (STEP)

To facilitate the invention of systems to address organisms in ships ballast water, the US Coast Guard developed the Shipboard Technology Evaluation Program (STEP) to provide an incentive for ship owners to participate in experimental evaluations of promising technologies on operational cargo vessels.

Under STEP, successful applicants receive an "equivalency", whereby the use of the experimental system is deemed by the Coast Guard to satisfy the BW management requirements that apply to the vessel under Coast Guard regulations. STEP enrollment includes a rigorous evaluation of the likelihood of the success for the prototype based on thorough review of the science and engineering behind the technology. Following this efficacy review the applicant's study plan is peer reviewed for scientific rigor and validity. Finally, a thorough evaluation of the potential environmental impacts associated with the use of the system in the specific marine areas that the ship operates in is completed. This includes review under the Endangered Species Act, the National Marine Sanctuaries Act, Marine Mammal protection act and the National Environmental Policy act. Only upon completion of these screening measures are systems accepted and allowed to begin use in US waters.

The Hyde Guardian system was installed aboard the *Coral Princess* in June 2003 and soon after that an application was made for acceptance into STEP. Although the approval process moved slowly, the *Coral Princess* became the first ship accepted into STEP on Oct. 31, 2008. More information of STEP and the vessels enrolled can be found at: http://www.uscg.mil/hq/g-m/mso/step.htm

Reflections on the process.

For a pioneering manufacturer of Ballast Water Treatment Systems, particularly in the United States, the approval process seemed daunting and essentially endless. Because no mechanism was in place for a US administration to provide type approval under the IMO BWM Convention or an equivalent requirement, Hyde Marine and other US manufacturers were forced to approach administrations in the European Union or in other countries for approval. Hyde Marine, with the assistance of its customer the Royal Navy, reached an agreement with the UK Maritime and Coastguard Agency (MCA) and their nominated party, Lloyds Register (LR), and the process was carried out smoothly and efficiently thanks to excellent cooperation and effective planning and execution by all parties involved in the land based and shipboard testing and in the type approval process itself.

The USCG STEP process was well conceived, but fraught with challenges and bureaucratic delays that created a more than four year ordeal for Princess Cruises and Hyde Marine and similar delays for the other US ship operators and manufacturers, who sought early acceptance into STEP. In contrast, the IMO type approval process required only about one year from the initial application until completion.

In the end, however, perseverance and hard work paid off and made the success of receiving type approval and STEP acceptance a unique and rewarding experience for all involved.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the continuing support of Princess Cruises, a Carnival Corporation fleet, who were the first ship operator to install a Hyde BWT system in 2000 and also the pioneers, with Hyde Marine, in the USCG STEP program after the installation of the first Hyde Guardian™ system aboard the *Coral Princess* in June of 2003. Princess Cruises also made the *Coral Princess* available for testing in 2004 to provide the necessary data for the STEP application and again in 2008 for the IMO type approval shipboard testing and STEP post-acceptance testing. Their foresight and support during the long development, testing and approval process was a vital and very significant contribution to the effort to head off aquatic invasive species transported in ships' ballast water

REFERENCES

[IMO guidelines to be cited] example:
Anonymous (2005) Guidelines for approval of ballast water management systems (G8). Annex3 Resolution MEPC.125(53) Annex: Parts 1,2,3 and 4

Buma, A.G.J., E.J. van Hannen, M.J.W. Veldhuis, W.W.C. Gieskes (1996). UV-B induces DNA damage and DNA synthesis delay in the marine diatom Cyclotella sp. Scientia Marina 60, 101-106.

Leech, D.M. and C.E. Williamson (2000). Is tolerance to UV radiation in zooplankton related to body size, taxon, or lake transperancy. Ecological Applications 10(5), 1530-1540.

Lancelot, C., G. Billen, A. Sournia, T. Weisse, F. Colijn, M.J.W. Veldhuis, A. Davies, P. Wassman 1987 *Phaeocystis* blooms and nutrient enrichment in the continental coastal zones of the North Sea Ambio 16, 38-46.

Veldhuis, M.J.W., F. Fuhr, J.P. Boon and C.C. ten Hallers-Tjabbes (2006). Treatment of ballast water; how to test a system with a modular concept? Environmental Technology 27, 909 – 921.

Viitasalo, S., J. Sassi, J. Rytkönen, E. Leppäkoski (2005). Ozone, Ultraviolet light, Ultrasound and Hydrogen peroxide as Ballast Water Treatments – Experiments with Mesozooplanktone in low-saline brackish water. J. of Marine Env. Engg. 8, 35-55.

Villafañe, V.E., K. Sundbäck, F. Figueroa, E.W. Helbling (2003). Photosynthesis in the aquatic environment as affected by UVR. In E.W. Helbling and H.E. Zagarese [Eds.] UV effects in Aquatic Organisms and Ecosystems. The Royal society of Chemistry, Cambridge, UK pp. 357 – 398.

Waite, T.D., J. Kazumi, P.V.C. Lane, L.L.Farmer, S.G. Smith, S.L. Smith, G. Hitchcock, T.R. Capo (2003). Removal of natural populations of marine plankton by a large-scale ballast water treatment system. Mar. Ecol. Progr. Ser. 258, 51-63.

Wright, D.A., R. Dawson, S.M. Moesel and C.E.F. Orano-Dawson (2005). Shipboard trials of ballast water management options: Part 1. Efficacy of ultraviolet irradiation. Proc. Inst. Mar. Eng. Sci. Technol.. (C3). J. Mar. Sci. Environ., 3-13.

Wright, D.A., R. Dawson, C.E.F. Orano-Dawson and S.M. Moesel (2007a). A test of the efficacy of a Ballast Water Treatment System aboard the Vessel *Coral Princess.* Mar. Technol. 44, 57-67.

Wright, D.A., R. Dawson, C.E.F. Orano-Dawson (2007b). Shipboard Trials of Menadione as a Ballast Water Treatment. Mar. Technol.. 44, 68-76

Wright, D.A. (2007). Logistics of shipboard and dockside testing of ballast water treatment systems in the United States. In: "Biological invaders in inland waters: Profiles, distribution and threats". Pp. 657-668. Edited by Francesca Gherardi. Springer Publ. Co. New York.

Wright, D.A. (2007) Problems associated with performance compliance testing for ballast water treatment. Proc. Inst. Mar. Eng. Sci. Technol. J. Mar. Design Ops. (B12) 25-38.

Zaitsev Yu. and Öztürk B. (Eds) Exotic Species in the Aegean, Marmara, Black, Azov and Caspian Seas. Published by Turkish Maritime Research Foundation, Istanbul, TURKEY, 2001, 267 pp.

APPENDIX 1

Comparison of IMO, US Federal and US State Ballast Water Treatment Standards

	IMO Regulation D-2 and Transport Canada	**2008 Ballast Water Management Act Section 1101 (f)i**	**2008 California Standard**	**Washington Administrative Code 222-170**
Management approach	Exchange moving towards treatment only	Exchange moving towards treatment only	Exchange moving towards treatment only	Exchange or treatment
Standard:	**Proposed**	**Proposed**	**Recommended Interim**	**Adopted Interim:**
1) Organisms greater than 50 microns in minimum dimension:	<10 viable organisms per cubic meter	< 0.1 living organisms per cubic meter	No detectable living organisms	Technology to inactivate or remove 95% zooplankton
2) Organisms 10-50 microns in minimum dimension:	<10 viable organisms per ml	< 0.1 living organisms per ml	$<10^{-2}$ living organisms per ml	
3) Organisms less than 10 microns in minimum dimension:	No standards	No standard	$< 10^{3}$ cfu bacteria/100 ml	99% bacteria & phytoplankton
4) *Escherichia coli*	< 250 cfu/100 ml	<126 cfu/100 ml	<126 cfu/100 ml	
5) Intestinal Enterococci	<100 cfu/100 ml	< 33 cfu/100 ml	<33 cfu/100 ml	
6) Toxicogenic *Vibrio cholerae* (O1& O139)	<1 cfu/100 ml <1 cfu/gram of wet zooplankton samples	<1 cfu/100 ml <1 cfu/gram of wet weight of zoological samples;	<1 cfu/100 ml < 1 cfu/gram of wet zoological samples $<10^{4}$ viruses/100 ml **Final standards** – no discharge of living organisms	