

Evaluation of Ballast Water Treatment Technology for Control of Nonindigenous Aquatic Organisms



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STATE WATER RESOURCES CONTROL BOARD
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

In consultation with
The California State Lands Commission
and
The California Department of Fish and Game

Preface



This report has been prepared in compliance with section 71210 of the California Public Resources Code, in consultation with the Department of Fish and Game, the California State Lands Commission, the United States Coast Guard, the regulated industry, and other stakeholders. The report presents treatment alternatives currently available, under development, or potentially available in the future for managing ballast waters for the purpose of eliminating the discharge of nonindigenous species into waters of the state.

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Abbreviations

SWRCB	State Water Resources Control Board
IMO	International Maritime Organization
O&M	Operating and Maintenance
BWE	Ballast Water Exchange
ERE	Empty and Refill Exchange
FTE	Flow Through Exchange
UV	Ultraviolet
BWT	Ballast Water Treatment
U.S.	United States
DFG	California Department of Fish And Game
CSLC	California State Lands Commission
USCG	U.S. Coast Guard
NRC	National Research Council
ESTUARY	San Francisco Bay Estuary
NOBOB	No Ballast On Board
NISA	National Invasive Species Act
DWT	Dead Weight Tonnage
MGD	Million Gallons Per Day
PPM	Parts Per Million
NM	Nanometers
LP	Low Pressure
MP	Medium Pressure
GPM	Gallons Per Minute
HPUP	High Power Ultrasonic Process
OSHA	Occupational Safety and Health Administration
MT	Metric Ton

Executive Summary



California Public Resources Code section 71210 requires that the State Water Resources Control Board (SWRCB) evaluate ballast water treatment alternatives for the purpose of eliminating the discharge of nonindigenous species into the waters of the state. The law also requires that SWRCB submit to the Legislature, on or before December 31, 2002, a report that includes (1) a recommendation of the best available and economically feasible technologies that reflect the greatest degree of reduction in the release of nonindigenous aquatic species, (2) the effectiveness of these technologies, and (3) the costs of implementing them.

This report evaluates thirteen possible alternative options for treatment of ballast water, including two established practices that are presently recommended under the International Maritime Organization (IMO) guidelines and are mandated under California Public Resources Code section 71204. The evaluation focused principally on five considerations: safety, biological effectiveness, environmental acceptability, status of technology, and cost.

There are a number of treatment technologies that have been identified as possible solutions to address the ballast water discharge problem. At present, there is not enough conclusive information to recommend a single treatment option or a combination of treatment options for certification in California. The initial assessment of the status of the various treatment options using the information collected indicates that most of the technologies are in either developing or conceptual stage. Many of the treatment technologies discussed in this report may be available in the future. At present, some have been tested under laboratory conditions and only a few have undergone full scale testing aboard ship. There are many fundamental scientific, engineering, and operational questions that need to be answered for each of the proposed onboard treatment systems before certification for use in California is possible.

Ballast Water Uptake/Release Practices

California Public Resources Code section 71204(b) also requires the vessels to take a series of actions to minimize the uptake and release of nonindigenous species. For example, vessels must avoid discharge or uptake of ballast water in areas within marine sanctuaries, minimize or avoid uptake of ballast water in areas known to have infestations or populations of harmful organisms and pathogens, and discharge only the minimal amount of ballast water essential for vessel operations while in the waters of the state. These requirements are established practices that are recommended by IMO. They are considered readily available as long as ship safety is not compromised. However, the procedures should only serve as primary avoidance strategies and should be used in combination with other treatment methods or technologies.

Ballast Water Exchange

Ballast Water Exchange (BWE) is one of the ballast water management practices required under California Public Resources Code section 71204(a). Empty and Refill Exchange (ERE) and Flow Through Exchange (FTE) procedures are considered established BWE practices and are recommended under IMO guidelines. However, there are many uncertainties associated with BWE procedures regarding safety, biological effectiveness, and locations where exchange might be carried out.

Onshore Treatment

Despite concerns regarding the cost of establishing and operating onshore treatment facilities, this alternative remains an attractive option. At this point, onshore treatment may be an option for ports that have a limited number of dedicated ship visits, or for older vessels that discharge smaller volumes of ballast water or vessels that are unable to retrofit because they are either nearing the end of their service life or it would be too costly to retrofit. The viability of this alternative should increase as future generations of ships and port systems develop.

Filtration/Separation Systems

Filtration and cyclonic separation systems are considered safe. Both systems have been and continue to be tested under different scenarios. The consensus is that either system must be combined with a secondary technology to appropriately control or eliminate nonindigenous species from ballast water.

Biocides

Investigation of the use of biocides on board ship for the treatment of ballast water is just beginning. Preliminary observations seem to indicate a high level of biological effectiveness. However, questions regarding the

discharge of residual chemical compounds have not been adequately addressed thus far.

Heat Treatment

Much of the technology necessary to implement heat treatment is currently available. Concerns regarding thermal and air pollution can be avoided through engineering modifications and design. Cost will vary based on the retrofitting, ship type, and amount of ballast water to be treated. Preliminary studies have been carried out on its effectiveness, yet further evaluation is needed.

Ultraviolet Radiation

The effectiveness of ultraviolet (UV) radiation is influenced by the amount of suspended organic and inorganic particles in the water to be treated. The system should be coupled with some type of filtration so that larger organisms and particles are removed before the UV treatment is administered. The system is currently under evaluation to better define the exposure time and intensity of UV application to achieve adequate inactivation or elimination of ballast water entrained organisms, as well as to address engineering questions regarding the installation and operation on board different types of ships. Studies also suggest that re-growth occurs after retention in the ballast system.

Ultrasound

Ultrasound achieves a high level of biological effectiveness on Zebra mussel veliger, nematodes, bacteria, and viruses, but the technology has not been tested on a large flow system capable of treating large volumes of ballast water on board ship.

Magnetic Treatment

Magnetic treatment effects will vary according to type and size of the organisms. Studies with fuel cleaning systems have indicated that high levels of biological effectiveness have been achieved against microbial organisms and fungi. It is feasible to design and manufacture a magnetic system, but such treatment systems have not yet been developed or tested for ballast water treatment.

Ozone

Ozone treatment is another type of oxidizing biocide capable of causing direct oxidation and destruction of the cell walls of organisms. Preliminary studies indicate that the treatment is highly effective, but further investigation is needed.

Pulse Plasma

Pulse Plasma studies indicate that the treatment is effective against the Zebra mussel, algae, and bacterial growth. It is presently being further tested with Zebra mussels for land-based applications. No system has been developed for shipboard testing.

Deoxygenation

Deoxygenation treatment could be effective at killing larval, juvenile, and adult oxygen-consuming organisms but may be less effective on taxa adapted to low oxygen environments or with resistant stages such as cysts.

Ballast Tank Coating

Anti-fouling coat application inside ballast tanks would probably prevent benthic organisms from attaching to the tank's surfaces but would not affect organisms within the water column.

B W E Effectiveness Equivalency

California Public Resources Code section 71204(a)(3) requires that any alternative method of ballast water management be at least as effective as BWE in removing or killing nonindigenous organisms. BWE should not be used to determine the biological effectiveness of ballast water treatment (BWT) technologies because the effectiveness of BWE has not been established and varies widely. In addition, while all of the proposed treatment technologies are designed to kill or remove organisms, BWE methods result in an unpredictable combination of killing, removing, and adding organisms. The effectiveness of BWE is dependent upon the volume of ballast water exchanged and the likelihood that the organisms that have been exchanged and then discharged will not be able to tolerate coastal, estuarine and freshwater environments. It is therefore difficult to meaningfully compare BWE organism replacement results with BWT killing results.

Recommendation

There is not enough conclusive information at this time to recommend a single treatment option or a combination of treatment options for certification in California. Most of the treatment technologies discussed in this report are under development or potentially available in the future. Some have been tested under laboratory conditions and only a few have undergone full-scale testing aboard ship. There are many fundamental scientific and engineering questions that need to be answered. Further research and onboard testing are necessary.

Problems caused by ship ballasting are an international issue and should be addressed by appropriate federal agencies in coordination with the state

and the shipping industry. The California State Lands Commission (CSLC), which regulates shipping operations in state's waters, is currently the lead state agency working with the U.S. Coast Guard (USCG) on ballast water management issues. CSLC, in consultation with USCG, is implementing a detailed procedure to evaluate experimental or prototype ballast water treatment systems with demonstrated potential for effective destruction of nonindigenous aquatic organisms. Additional efforts that could be included in this joint program are the following:

- Focused research and engineering studies that would guide the development of promising treatment alternatives towards a working prototype. The research and development would incorporate the specific constraints and requirements of defined classes of vessels. This should include land-based testing, where the technologies are evaluated in an environmentally safe location, that would facilitate objective testing using scientifically designed protocols for standardized land-based tests under highly controlled conditions.
- Shipboard installation and testing that would guide the research and development of a prototype system toward application on board ship. This should include fitting and refining prototypes through shipboard trials over extended periods and under a broad range of operating conditions and biological testing to evaluate the effectiveness of the system.
- Tested technologies that are proven effective should subsequently be certified as suitable for use and implemented throughout the maritime industry.

Introduction



Ships arriving at California ports discharge approximately four million metric tons (MT) of ballast water annually, releasing thousands of nonindigenous aquatic organisms into the state's marine and estuarine ecosystems. This type of discharge is one of the primary mechanisms for transporting nonindigenous aquatic organisms to California waters. The organisms inadvertently discharged with ballast water can potentially become established causing substantial environmental and economic impacts. The problem has become more acute as international commerce increases and ships and port systems become larger.

In recognition of this threat, the Legislature in 1999 added Division 36 (section 71200 et seq.) to the California Public Resources Code for controlling the introduction of nonindigenous organisms to waters of the state. Under this new law, all foreign and domestic vessels carrying ballast water into waters of the state after operating outside the United States (U.S.) Exclusive Economic Zone are prohibited from discharging ballast water unless the operator has carried out ballast water exchange (BWE) procedures or any alternative ballast water treatment technology that is as good or better than BWE.

In addition to making ballast water management practices mandatory in California, the law also established a coordinated interagency effort, requiring an inventory of the locations and geographical range of resident nonindigenous species populations, and an evaluation of alternative methods for the control of the discharge of nonindigenous aquatic organisms. The State Water Resources Control Board (SWRCB) is responsible for the evaluation of treatment alternatives, in consultation with the California Department of Fish and Game (DFG), the State Lands Commission (CSLC), the U.S. Coast Guard (USCG), the regulated industry, and other stakeholders. The evaluation must be completed and reported to the Legislature by December 31, 2002.

Background



The Problem

Over 80 percent of the world's commodities are moved through maritime shipping operations. In this process, ships transfer millions of tons of ballast water from one place to another worldwide, inadvertently transferring and discharging nonindigenous aquatic organisms into receiving waters (Carlton and Geller, 1993; National Research Council [NRC], 1996). The introduction of nonindigenous aquatic organisms in this manner has created substantial environmental and economic impact on ports, estuaries, and other water resources of the state as well as on other parts of the world.

Depending on where ships take on ballast water, virtually all organisms in the water column, either swimming or stirred up from bottom sediments, can be taken into ships' ballast tanks. These organisms include holoplakton (free-floating), meroplakton (larval stages of bottom dwelling organisms), upper water column nekton (active swimming), and demersal (near bottom dwelling nekton) organisms. These include a wide variety of animals and plants such as mollusks, shrimp, crab, fish larvae, seaweed and sea grasses, phytoplankton, zooplankton (including larvae of bottom-dwelling organisms), viruses, bacteria, fungi, molds, protozoans, many types of parasites, pathogenic organisms, egg, cysts, and larvae of various species. The problem is compounded by the fact that many marine benthic organisms are also taken into the ballast tanks during the early life stages, which are spent suspended in the water column. These organisms may include benthic invertebrates such as sea anemones, corals, hydroids, oysters, clams, barnacles, sea stars, sea cucumbers, and tunicates.

At present, there is no way to determine when and/or whether an introduced species will survive to become established. Fortunately, most organisms discharged in ballast water do not survive to establish viable populations (Cohen and Carlton, 1995). However, the few that survive can become established, disrupting the natural ecological balance of the

receiving ecosystem by outcompeting native species for resources and upsetting predator-prey relationships. Nowhere is this more evident than in the San Francisco Bay Estuary (Estuary) where more than 230 nonindigenous species have become established. These organisms have become dominant within specific communities, often accounting for up to 99 percent of biomass in the Estuary (Cohen and Carlton, 1998). The overall rate of invasion, based on an invasion record spanning 145 years, indicates that roughly half of all invasions recorded have occurred in the last 40 years. Recent studies indicate that the rate of invasion is increasing exponentially with more invasions being reported along the Pacific coast than along the Atlantic or Gulf coasts (Ruiz et al., 2000). The rate of new introductions will probably continue to increase as ships and port systems become larger in response to growing global commerce and as more investigators find newly introduced organisms.

For example, in the Estuary, the Asian Clam (*Potamocorbula amurensis*) became established and, within a year, became the most abundant clam in the northern part of the Estuary. These organisms are capable of filtering the entire water column as much as twice a day, significantly disrupting the phytoplankton and native zooplankton food web in the Estuary (Cohen, 1998). The Chinese mitten crab (*Eriocheir sinensis*), a native to coastal rivers and estuaries of Korea and China, was introduced to the Estuary in the late 1980s or early 1990s. The most likely mode of introduction to the Estuary is believed to have occurred through the accidental release of ballast water and the deliberate release for the purpose of establishing a fishery (Cohen and Carlton, 1997). Commercial shrimp trawlers in South San Francisco Bay first collected the organism in 1992 and in San Pablo Bay in 1994. By 1996, it had spread throughout the lower tributaries of South San Francisco Bay, San Pablo Bay, Suisun Bay, the Suisun Marsh, and the Sacramento-San Joaquin Delta. Documented impacts as a result of the population explosion of these nonindigenous species include disruption of commercial and recreational fisheries and disruption of fish salvage operations at the federal and state pumping plants located in the south delta.

Since the late 1980s, the European Zebra mussel has caused extensive economical and ecological problems in the Great Lakes. Damage has been caused by blockage of water intake pipes in power plants as well as intake and delivery pipes used in municipal and industrial systems. They have also caused navigational hazards by attaching in large numbers to ship and boat hulls, marine structures, and navigational buoys. The population explosion has disrupted the food web and threatened the biodiversity of the Great Lakes. The average cost of damage over ten years has been estimated in the billions of dollars. The problem has now spread to other parts of North America and Canada.

Concentrations of bacteria, virus-like particles, and the bacteria *Vibrio cholera* which causes human epidemic cholera, have been identified in the ballast water of vessels arriving from foreign ports into Chesapeake Bay (Ruiz et al., 2000). In 1991, fish and oysters in Mobile Bay, Alabama, were found contaminated with the epidemic strain of cholera that was discharged with ballast water. The U.S. Food and Drug Administration discovered that five out of 19 ships arriving from South America were carrying the epidemic strain (Federal Register, 1998).

Other ports such as Prince William Sound in Alaska, Puget Sound in Washington, Coos Bay in Oregon, Chesapeake Bay, the Hudson River Basin, Long Island Sound, the Florida Everglades, near-coastal portions of the Gulf of Mexico, Elkhorn Slough National Estuary Research Reserve, and the harbors of Los Angeles and San Diego have had significant invasions of nonindigenous organisms. In other parts of the world (from Australia and New Zealand to the Persian Gulf) there has been documentation of increased levels of aquatic invasions in coastal and estuarine waters. The Atlantic comb jelly introduced into the Black and Azov seas in the early 1980s consumed much of the seas' crustacean zooplankton, contributing to the decline of the fishery industry of six nations (Cohen, 1996).

Sediment accumulated in ballast tanks when discharged (usually a mix of harbor, port, or estuarine mud and small debris from other destinations) is also an important mode by which nonindigenous organisms are introduced (Cawthron Report No. 417, 1997). Introductions of toxic dinoflagellates from the discharge of sediments in Australia, New Zealand, and Japan have produced red tides killing fish and invertebrates. Some have produced human neurotoxins that accumulate in mussels and clams, causing toxic effects in humans who consume these organisms.

Although the introductions of many of these aquatic organisms can be attributed to ship hulls, anchors, and other vessel surfaces, the discharge of ballast water and sediment is currently considered the most important vectors of nonindigenous organisms around the world.

The Root of the Problem

Broadly defined, ballast is any solid or liquid placed in a ship to increase the depth of submergence of the vessel in the water to change the trim, to regulate stability, or to maintain stress loads within acceptable limits (NRC, 1996). Proper ballasting reduces stresses on the hull, provides stability, aids propulsion and maneuverability, and compensates for weight lost from loading and unloading cargo and from fuel and water consumption. The use of ballast water varies among vessel types, the type of trade, different ports, and sea conditions. Ships carrying little or no cargo tend to ride high in the water. This makes them vulnerable to being

knocked about by heavy weather conditions, increasing the potential for slamming the bow or stern over high waves or raising the propeller out of the water. To remedy this, ballast water is taken on in order to lower the ship to a more safe and efficient position in the water. A ship partially loaded with cargo will carry some ballast water (“with ballast”), and a fully loaded ship will report carrying no ballast (“NOBOB” or no ballast on board). NOBOB vessels raise a special concern because, while reporting no ballast on board, such ships still retain residual volumes of unpumpable water and sediment in the ballast tanks containing a wide assortment of aquatic organisms. The organisms in the residual volume of ballast water are re-suspended when new ballast water is taken in and subsequently discharged when the vessel takes on new cargo (Doblin et al., 2001). The end result of these ship-safety procedures is that a vessel accumulates organisms from multiple ballasting at several sites. Therefore, under all conditions, ballast water containing potentially harmful invasive aquatic organisms will be discharged into ports receiving waters and surrounding coastal regions.

The accumulated organisms are not strictly estuarine, coastal, or mid-oceanic in origin, or strictly represent organisms from the last port of call. The ballast water may be many hours or months old and may contain living organisms for an extended period of time. In addition, the sediment accumulated in the ballast tanks may also reflect an even longer history of ballasting and may include accumulation of life forms from many ports around the world. In these cases, a highly diverse permanently submerged, multi-origin assemblages of benthic organisms may become established in the sediment layers of ballast tanks. These benthic organisms may release planktonic larvae into the overlying ballast water, and resistant stages of cysts and spores become re-suspended or induced to excyst or hatch and subsequently become discharged into receiving waters.

It has been generally assumed that only major ports are at risk from introduction of organisms. However, the movement and discharge patterns of ballast water are such that no coastal site, whether it receives direct shipping or not, is immune to ballast introduced organisms.

Regulatory Activities



Many governments, international maritime environmental entities, and public health organizations have recognized the environmental, economic, and health threat caused by the translocation and release of ballast water. This has prompted the adoption of laws throughout the world requiring vessel operators to manage their ballast water in ways that will prevent the transfer of nonindigenous species through this media. Most national and regional regulations have been modeled after the guidelines established by International Maritime Organization (IMO) [1997-resolution A.868 (20), *Guidelines from the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens*]. These guidelines are not binding unless specific nations adopt them for their own use. Presently, IMO guidelines remain largely voluntary. The guidelines include several operational procedures related to loading and discharging ballast water and sediment and recommend that ships carry out BWE of coastal ballast water in deep ocean water (at least 200 nautical miles from shore). The intent of this procedure is that any water of coastal origin (fresh, estuarine, or coastal marine) is exchanged with mid-ocean water during the ship's voyage to the port of destination. At arrival, mid-ocean water is subsequently discharged into receiving waters. The assumption is that mid-ocean organisms will not survive when discharged into near coastal or fresh water.

The discharge of ballast water and the uncertainties associated with the biological efficacy of treatment options presently available to the shipping industry have caused regulatory jurisdictions to consider regulatory actions. This regulatory response has resulted in an increase of unilateral

national and regional actions to control the spread of nonindigenous aquatic organisms into local waters. At present, there are 14 countries with regulations in place including Australia, Argentina, Brazil, Canada, Chile, Ecuador, Israel, United States (U.S.), New Zealand, and some European Union countries. Several states in the U.S. have developed their own regulation, including California, the Great Lakes states, Oregon, and Washington. In addition, there are several ports around the world that have established ballast water management laws within their jurisdictions, including Buenos Aires in Argentina, Scapa Flow in Scotland, and Vancouver in Canada (GloBallast, 2001). Many of these regulatory responses have remained consistent with the current IMO guidelines, while others have imposed new and different requirements. Such developments have caused major concerns to the shipping industry which must operate across many of these jurisdictions and are severely affected when rules change from port to port.

The problem caused by the discharge of ballast water worldwide, the regulatory response, and the lack of effective treatment alternatives to address the problem have created a heightened demand for more effective, practical, flexible, and cost effective ballast water treatment (BWT) alternatives over the use of BWE methodologies. BWT would offer a number of advantages to ship owners, including the flexibility to readily visit ports that have adopted ballast water management laws, and the resale enhancement of ships that already have BWT installed (Royal Haskonin Global Market Analysis Report, 2001). At present, no BWT technologies are available for application. Most technologies are just emerging or presently under development or testing.

No single BWT technology currently being developed or tested can meet all the needs of the shipping industry. A range of certified technologies is needed so that one or a combination of them could be used to manage ballast water effectively, comply with all regulatory requirements, and be compatible with different ship designs and types of voyages.

Treatment Evaluation Considerations



This evaluation focuses on the following considerations: safety, biological effectiveness, environmental acceptability, status of technology, and cost. These considerations address the mandates of the existing law and the factors that could potentially affect the quality of the state's waters.

The actual implementation of any ballast water treatment technology will be limited by feasibility of application, retrofitting potential, compatibility with vessels of different size, and types, and the loading and discharge capacities of ballast pumping and piping systems. These design and engineering issues should be addressed as part of a state certification and verification program that would subject candidate treatment options through a rigorous scientific and engineering evaluation process.

All the technologies and practices discussed in this report are assessed from different perspectives based on available information gathered for each treatment alternative. For some treatment options, there is not enough information to form an opinion. The five evaluation considerations addressed are defined as follows:

1. **Safety** — Safety considerations of ship and crew while implementing any ballast water treatment controls.
2. **Biological effectiveness** — The capacity of a treatment option to adequately reduce or eradicate the number of viable organisms in ballast water.
3. **Environmental acceptability** — The capability of dealing with ballast residues of organisms or the production of chemical treatment residues in an environmentally safe manner.

4. **Status of Technology** - The current development status of a specific treatment technology, performance test results, and its practical current and future application potential.
5. **Cost** – Capital and operating cost considerations.

Treatment Alternatives



The treatment options described and discussed in this section are classified into three different categories as follows:

- Established management practices and procedures that do not require special equipment or the design and installation of unique systems to accomplish treatment.
- Onshore treatment systems that would be designed to accomplish treatment either on land or on some type of mobile system.
- On board treatment alternatives including those options requiring installation of some type of system to either control the intake of aquatic organisms or eliminate organisms in the ballast tanks.

Practices and Procedures

Ballast Water Uptake/Release Practices

Description

Ballast water uptake/release practices are strategies aimed at reducing the number of organisms taken on during ballasting operations or avoiding the discharge of ballast water in sensitive coastal areas. These strategies include avoiding ballasting in waters that are likely to contain unwanted organisms, in areas of sewage discharge, at ports with high sediment

loads, in certain areas at certain times of the year, or at night when planktonic organisms migrate upward in the water column.

These procedures are currently recommended by IMO and are included in the guidelines issued by USCG pursuant to the National Invasive Species Act (NISA). They are also required under section 71204 of the California Public Resources Code. The management procedures are:

1. Avoid the discharge or uptake of ballast water in areas within or that may directly affect marine sanctuaries, marine preserves, marine parks, or coral reefs.
2. Minimize or avoid uptake of ballast water in all of the following areas and circumstances:
 - Areas known to have infestations or populations of harmful organisms and pathogens
 - Areas near sewage outfalls
 - Areas near dredging operations
 - Areas where tidal flushing is known to be poor or times when a tidal stream is known to be more turbid
 - At night when bottom dwelling organisms may rise up in the water column
 - Where propellers may stir up the sediment

Safety

The need for ballast to ensure ship safety during cargo loading and unloading imposes practical restrictions on this control option. Ballasting operations may need to be carried out in port to maintain ship transverse stability, and to maintain both the clearances under cargo loading or cargo discharge facilities and under-keel clearance so the vessel remains safely afloat. This prevents hull bending and keeps shear forces within safe limits to avoid damage that can result from incorrect loading. It also helps maintain the ship upright by trimming or heeling the ship and helps establish efficient ballast conditions for the voyage ahead.

Implementation of the uptake/release procedures must take into account the ballast requirements for safe ship operations, the locations, the times of ballasting, as well as the practical limitations of treating ballast water as it is loaded. Despite such concerns, these procedures are considered safe

when a ballast water management plan is developed in conjunction with the ship cargo plan to ensure that both ballast loading and discharge needs and the constraints on ballasting in certain locations are met.

Biological Effectiveness

These practices can only serve as the first line of defense, and it is recommended that they be used in combination with other treatment methods or technologies. Careful control of where, when, or how ballasting is done could be very helpful in reducing the intake of organisms. However, these practices may not always be possible since ballasting is highly dependent on operational needs.

Environmental Acceptability

This option is environmentally acceptable since these control practices simply reduce the number of organisms picked up or discharged by ballasting operations on or before departure.

Status of Technology

No additional or special equipment is needed to implement these management practices.

Cost

Ships arriving into California waters are required to maintain records of ballast water operations. Examination of ships' logs and records containing mandatory information for monitoring purposes would not impose any additional economic burden on the shipping industry. There would be no other additional costs to carry out ballasting avoidance procedures except perhaps in the cases where additional monitoring would be necessary. This assumes that the vessels already use ballast water management procedures. However, additional costs could be incurred if a vessel moves offshore in an attempt to minimize uptake of organisms.

Ballast Water Exchange (BWE)

Description

The concept behind BWE is that freshwater, estuarine or near shore coastal organisms taken during ballasting operations at a port of origin are replaced with deep mid-oceanic organisms during the voyage. Upon arrival at a port of destination, mid-oceanic organisms are discharged into a near shore coastal, estuarine, or freshwater environment. An important underlying assumption of BWE is that mid-ocean organisms cannot survive in coastal and freshwater habitat. This assumption is strongest when ships carry out BWE while traveling between freshwater ports of

call. The assumption is weakest when mid-ocean organisms are discharged in coastal and estuarine environments where environmental conditions may not be different significantly enough to provide an inhospitable environment to the incoming organisms.

The amount of ballast water carried by ships depends on the type of ship, cargo load, weather, and the depths at different ports. Some ships may carry as much as 36 percent of the ship's dead weight tonnage (dwt) in ballast water (Cohen, 1996). During ballasting and de-ballasting operations, a ship will flood or empty its tanks by gravity or by using high volume pumps. Most ships' ballast tanks are interconnected with pipes leading to a common water intake. The intakes are located in the ship's side, covered by a metal grating to exclude large objects and larger aquatic organisms. Behind the grating is the sea chest that functions as a reservoir to the ballast water delivery pipe system, which finally enters the ballast tanks. In most ballast tanks, the end of this ballast pipe system is typically located at several inches above the bottom of the tank, invariably contributing to the accumulation of water and sediments in the ballast tanks.

BWE operations are currently accomplished by two methods:

- Empty-refill exchange (ERE) – This method requires a ballast tank to be pumped empty and then refilled during a voyage. The emptying and refilling procedure is commonly accomplished using the existing water intake/suction piping system and the ballasting pumps, which are also used to empty and refill the tanks. IMO guidelines recommend that ballast water be discharged until suction in the ballast tanks is lost. It has been suggested that during full tank ballasting procedures, large changes in loading conditions could affect stability, strength, draft, and trim of the ship. However, newer and larger vessels have been reported to conduct ERE without harmful consequences to the ship.

ERE was originally reported to accomplish over 90 percent ballast water exchange efficiency. However, various studies have indicated that such efficiency is rarely achieved. Lower efficiency can result from a number of factors, including ballast tank size and design, pumping system, volume of unpumpable ballast water and sediment residual at the bottom of the tanks, and sea conditions during ballasting operations. Studies referenced by Dames and Moore (1999) have reported that exchange efficiencies ranging from 70 to 90 percent are more realistic. Furthermore, Hay and Tenis (1998) concluded that, in terms of the efficiency of eliminating nonindigenous organisms, ERE would not be as efficient because much of the sediment and organisms at the bottom of tanks would not be removed during ballasting

operations. Emptying and refilling tanks would probably result in re-suspending sediments and organisms that are not discharged.

- Flow Through Exchange (FTE) – In this method, ballast tanks are flushed out by pumping mid-ocean water into the ballast tanks during voyage allowing port water to overflow out. This method requires a separate uptake and outflow system. Water is delivered to the tanks from the common water intakes originating from the sea chest. Water out flow is subsequently accomplished via ventilators and manholes on the ships' weather deck. IMO recommends that, at a minimum, the volume of the tank should be pumped out three times. This recommendation was based in part on theoretical dynamics of dilution calculations and on some field trials (Rigby and Hallegraeff, 1995; Parsons, 1998). In theory, 95 percent of the original ballast tank water should be replaced if volumes equivalent to three times the tank volume are pumped through the tank.

The Petrobras Company, a Brazilian oil company, developed a variation of FTE by reversing the process (IMO, 1998). In this system, water is taken in through the sea chest as usual and pumped up to a ballasting pipeline on the weather deck. The deck-ballasting pipeline then distributes water to each tank from above. A separate set of ballast pumps located at the bottom of the tanks is then used to discharge ballast water overboard. This system has all the advantages of the FTE system plus the additional benefits of being able to remove accumulated sediment along with water because ballast water discharge occurs from the bottom of the ballast tanks.

Safety

It has been reported that ERE is unsafe for ships over 40,000 dwt because the procedure requires ballast tanks to be completely emptied before the tank can be refilled. During the empty and refill process, the ship's stability and maneuverability may be compromised due to the temporary lack of water in ballast tanks that maintain safe operation at sea. However, ships larger than 130,000 dwt entering New Zealand (Hay and Tenis, 1998) have reported carrying out ERE without any problems. Modeling studies have further demonstrated that ships of up to 188,000 dwt have no stability or shear force problems if ERE is carried out in the correct exchange sequence. The hydrostatic analysis of data from a dry bulk carrier, a tanker, and a container ship showed that hull bending and stability did not exceed allowable still water values while ballasting and deballasting operations were carried out. In addition, strength calculations made for significant wave height of 20 feet indicated that bending moments and shears resulting from wave action were below American Bureau of Shipping design values. The study concluded that ERE could be carried out at sea safely as long as wave height is lower than 10 and 20 feet (Woodward et al., 1994).

The FTE method is generally considered safer, but, in order to achieve the effectiveness of ERE in exchanging ballast water, it is recommended that the volume of the tanks be pumped out at least three times. Beyond having a ship's crew on deck opening or checking vents in preparation for the FTE procedure, this method is not considered to compromise a ship's stability as has been claimed for the ERE procedure (Hay and Tenis, 1998). The FTE procedures are also safer than ERE when carried out during heavy weather conditions. Other safety considerations associated with FTE operations are that large volumes of water are overflowed through the ship's air ventilators pouring over the weather deck. These air ventilators are not designed for constant water flow. While large volumes of water pouring over the weather deck may not be a problem on flushed decked bulk carriers, having water erupting from numerous air vents on container ships may not be desirable. Conversely, the Dilution Method system developed by the Brazilian company mentioned above is a closed process. Ship vents or manholes do not have to be used to discharge water, and the crew does not have to be on the weather deck during heavy weather conditions or exposed to waters that may contain pathogens. In addition, stability issues may not be as much a problem since in the Brazilian system ballast water is replaced and emptied simultaneously.

Biological Effectiveness

The effectiveness of BWE procedures for treating ballast water is not well known. Some studies have been conducted on a broad range of ballast water systems configurations involving ships of different ages. These studies used salinity dilution and dye tracers to quantify the percent of water exchanged, or measured a variety of organisms to determine the biological effectiveness of BWE. Preliminary results from salinity and dye tracer on the bulk carrier, Iron Whyalla, have indicated that roughly 95 percent of original water in ballast tanks is replaced after three tank exchanges in a FTE system (Rigby and Hallegraeff, 1995). However, exchanging 95 percent of ballast water may not mean that 95 percent of the organisms in the tank have been replaced or eliminated. Results of other studies, where the effectiveness has been measured using the abundance of biota, vary widely in the calculated percent reduction of organisms as a result of exchange procedures. Table 1 presents some published BWE effectiveness data. These data are from studies using different methods of calculation, different study designs, a variety of different ship types, and different taxonomic groups to evaluate the exchange of organisms.

The effectiveness of BWE methods may be further compromised by the length of voyage since the time needed to carry out effective ballast exchange operations may be longer than the actual duration of the specific voyage. In addition, coastal routes occurring less than 200 miles from the coast in waters shallower than 2000 meters may affect the biological

effectiveness of exchange procedures since the main objective of carrying out BWE is to accomplish the replacement of coastal, estuarine, or fresh water organisms with deep oceanic organisms. Only in this way can BWE procedures potentially achieve the most effective control of the introduction of nonindigenous species.

TABLE 1: REPORTED ESTIMATES OF BALLAST WATER EXCHANGE EFFECTIVENESS

Reference	Effective-ness	Type of BWE	Taxa	Type of Ships	Number of Ships	Methods and Approach
Locke et al., 1993	67% reduction in organisms	Unknown	Zooplankton and rotifers	Various	24	Calculation based on living zooplankton of different taxa found in ballast tanks from 24 ships originating from fresh and brackish ports. Eight ships were found to contain rotifers considered to be freshwater tolerant that could survive discharge into a freshwater environment.
Locke et al., 1993	86% reduction in organisms	Unknown	Zooplankton and rotifers	Various	14	Calculation based on same data as above. Out of the 24 vessels, 14 were found to have completed BWE with final salinity of $\geq 30\%$. Two of the 14 ships contained living freshwater tolerant organisms.
Zhang and Dickman, 1999	87% reduction in organisms	ERE	Diatoms and dinoflagellates	Container	34	Calculation based on the percentage reduction of diatoms and dinoflagellates. Mid-ocean exchange decreased the total abundance of harmful organisms on average from 4235 to 550 cells l^{-1} .
Zhang and Dickman, 1999	83% reduction in organisms	ERE	Diatoms and dinoflagellates	Container	34	Calculation based on the percentage reduction of total abundance of diatoms and dinoflagellates. Mid-ocean exchange decreased the total abundance of diatoms and dinoflagellates on average from 6600 to 1100 cells l^{-1} .
Dickman and Zhang, 1999	48% reduction in organisms	ERE	Diatoms and dinoflagellates	Container	3	Calculation based on the percentage reduction of total abundance of diatoms and dinoflagellates. Mid-ocean exchange decreased the total abundance of diatoms and dinoflagellates on average from 838 to 436 cells l^{-1} .
Rigby and Hallegraeff, 1995	95% water replaced	FTE	Phytoplankton	Bulk carrier	1	Calculation based on measurements of resident time of methyl blue dye and the dilution of stained phytoplankton. Under a complete mixed flow model, original water in a tank should be replaced if three tank volumes are allowed to flow through. It was assumed that the rate of water replaced equals rate of reduction in organisms.

Environmental Acceptability

Acknowledging the uncertainty of BWE effectiveness, IMO specifically recommends that exchange be carried out in deep ocean water at least 200 nautical miles offshore. NISA guidelines also require BWE be carried out by ships entering the Great Lakes and the upper Hudson River, and suggests voluntary implementation of BWE in the rest of the country. California law requires the implementation of the same practices included in NISA guidelines unless an alternative technology can be employed that is as effective as BWE in treating ballast water. This requirement also extends to ships traversing coastal water unless an alternative exchange zone has been identified and approved. It is generally acknowledged that even under ideal conditions the method will be less than 95percent effective.

Status of Technology

BWE is currently the most widely used method worldwide, despite the reported 70 to 95 percent effectiveness in water replacement and 48 to 99.9 percent in aquatic organisms reduction.

Cost

The cost of conducting exchange procedures depends on the type of exchange being carried out, the age of the vessel, pump size, and the percentage of ballast water being exchanged. Full ballast tank ERE including initial new piping, pumps, maintenance, labor costs, and the development of a ballast water management plan has been estimated to cost approximately \$0.02 per MT. FTE has been estimated to range between \$ 0.06 and \$0.08 per MT (Rigby, 1994; Rigby and Hallaegraff, 1995). Furthermore, very large crude carriers (250,000 to 500,000 dwt) have been estimated to carry out ERE at a cost of approximately \$0.12 to \$0.35 per MT, based on 10 trips/year and 45 percent of the vessel's dwt in ballast water (Dames and Moore, 1999).

Onshore Treatment Alternatives

Onshore Ballast Water Treatment, Treatment Ship, or Mobile Transport Facility

Description

These treatment alternatives require that ballast water be transferred to an onshore treatment facility for treatment. In some ports, there may be enough space to establish a large-scale, shore-based facility to treat ballast water. The size of the treatment facility would depend on the number, timing, and type of ships entering the port system. It is conceivable that treatment could be done in treatment facilities specifically designed and

dedicated to treat ballast water, or perhaps in already existing facilities designed to treat wastewater.

Alternatively, ballast water could be collected directly from a docked ship by barge or pipeline and transported to a centralized onshore facility. In these cases pipelines would be needed between the treatment facilities and all berths of a port system. Ships would also need to have their ballast water pumping system or other piping systems, such as the fire extinguishing water pipeline, modified to be able to connect to the berth piping system. In addition to shore-based facilities, a port authority would need to establish a mobile system for deballasting operations to lessen the ship draft before crossing shallow bars or entering a shallow port. This would be an additional cost to the ports. Depending on the amount of water needed for ballasting operations, land-based treatment facilities could also store treated water for use as ballast to allow a visiting ship to exchange untreated ballast water for treated ballast water.

Safety

The safety considerations associated with land-based treatment facilities are the safety concerns over actual construction of land-based facilities, the vessel and port retrofitting operations, and ship and crew safety during pumping operations while docked.

Biological Effectiveness

Onshore treatment, in principle, could have several advantages over onboard treatment options since there are already established effective and cost-effective methods for treating large quantities of wastewater. A land-based treatment facility operated by professional wastewater treatment specialists would allow a better control of the treatment processes. In theory, the port authority would be responsible for the operation and maintenance of the facilities and would be able to constantly monitor to determine extent of effectiveness of treatment. In addition, deposited or suspended sediments and organic materials could be effectively treated through the use of settling ponds or filtration. In a similar manner, cysts and spores, which are the forms most resistant to treatment, could also be removed. Vessels using the onshore treatment system might need to pay a per MT charge to have ballast water treated and disposed of in an environmentally acceptable manner in compliance with existing discharge regulations. Since ships often need to deballast in near coastal areas prior to entry into port, a deballasting mobile system must be in place to transport untreated ballast water to the onshore treatment facility. Without a mobile transport or mobile treatment system onshore treatment would otherwise be inherently ineffective.

Environmental Acceptability

Waste from a treatment process would be disposed of in an environmentally acceptable manner in compliance with appropriate state and federal laws and regulations.

Status of Technology

One example of an onshore facility that treats ballast water in the U.S. is located at the Valdez Marine Terminal in Alaska. The facility is not designed to prevent the introduction of nonindigenous species but rather to treat non-segregated oily ballast water from oil tankers. The ballast water onboard oil tanker is typically carried in cargo holds where oil is also stored. The facility treats the oily ballast water by extracting the residual oil from the water. The segregated water is then treated to remove aromatic hydrocarbons and control pH levels and is later returned to receiving waters. The oil recovered from the treatment process is then returned to the oil tankers (Greenman et al., 1997).

Ballast water treatment on land could be very effective in eliminating introduced species. Such a treatment facility could be designed in a similar fashion as the Alaska facility but with the specific objective to treat ballast water to prevent the introduction of nonindigenous organisms. It would be technically feasible to retrofit vessels and berths, build onshore storage tanks and treatment facilities, and dispose of treated water in an environmentally safe manner. However, without some form of transportation system to collect ballast water discharged outside of ports, it would not be operationally possible to treat all ballast water discharged into receiving waters for the purpose of reducing hull draft to pass over shallow port areas. A barge transfer system could help in this respect by providing the ability to collect ballast water while the ship is either at anchor, moored at the port terminal, or while navigating within port waters. Onshore treatment facilities could certainly be considered for terminals that handle smaller volumes of ballast water and have predetermined regular vessel calls (e.g., passenger vessels).

Cost

The cost of onshore or mobile treatment options varies depending on the location of the facility and the amount of ballast water that would be treated. Capital cost of a port-based facility located either on land or on a mobile barge system ranges from \$9 million to \$19 million. Operating costs would range from \$90 to \$414 per MT of ballast water treated (Greenman et al., 1997). In a feasibility study recently conducted by Dames & Moore (2000) for the California Association of Port Authorities, four conceptual onshore ballast water treatment facilities with four different treatment capacities were designed. The ballast water treatment capacities considered in the study were: 1.0 million gallons per day (mgd)

(3,785 MTs/day) to account for the demands of the Ports of Los Angeles and Long Beach, 0.2 mgd (757 MTs/day) for the Ports of Humboldt Bay, Oakland, and San Francisco, 0.1 mgd (379 MTs/day) for the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton, and 0.001 mgd (4 MTs/day) for Port Hueneme.

The main purpose of the Dames & Moore study was to assess at a conceptual level the technical and operational feasibility of onshore ballast water treatment at public port facilities. The cost calculations were based on a set of narrow assumptions and may not be representative. They only serve to give a general idea of how much it would cost to build and operate onshore ballast water treatment facilities of different capacities. Estimated capital costs for onshore treatment facilities (excluding costs for port piping and storage tanks) at specific California ports would range from approximately \$1.6 million for the 0.1 mgd facilities for the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton to over \$2.2 million for the 1.0 mgd facilities at the Ports of Los Angeles and Long Beach. A treatment facility was not designed for Port Hueneme due to the very small volumes of ballast water involved. Total capital cost including all onshore treatment components needed to treat ballast water was estimated to range between \$8 million and \$50 million.

The annual operating and maintenance (O&M) costs, including chemicals, electricity, labor (facility operators), laboratory costs, and landfill disposal costs were calculated for each port and would range from \$142,000 to \$223,000. Table 2 summarizes port specifications and estimated costs for land-based ballast water treatment facilities.

TABLE 2: PORT SPECIFICATIONS AND ESTIMATED COSTS TO INSTALL SHORE-BASED TREATMENT FACILITIES IN CALIFORNIA

Specifications				Capital Costs					
Port	Piping Length (km)	2-Day Storage Tank (million gallons)	Treat. System Capacity (mgd)	Piping Cost	Storage Tank Costs	Treatment System Capital Costs	Outfall Cost	Total	Annual O&M Costs
Hueneme	1.6	0.1	0.001	\$ 1,056,000	\$ 55,000	NA	\$100,000	NA	NA
Humboldt	19.3	.9	0.2	\$12,672,000	\$ 4,000,000	\$1,781,000	\$100,000	\$18,553,000	\$149,800
Long Beach	43.6	10.2	1.0	\$28,617,600	\$ 5,100,000	\$2,220,400	\$100,000	\$36,038,000	\$223,454
Los Angeles	41.2	40.6	1.0	\$27,033,600	\$20,400,000	\$2,220,400	\$100,000	\$49,754,000	\$223,454
Oakland	24.1	7.3	0.2	\$15,840,000	\$ 3,800,000	\$1,781,000	\$100,000	\$21,521,000	\$149,800
Redwood City	2.4	8.4	0.1	\$ 1,584,000	\$ 4,300,000	\$1,631,500	\$100,000	\$ 7,615,500	\$142,400
Richmond	8.9	6.6	0.1	\$ 5,808,000	\$ 3,400,000	\$1,631,500	\$100,000	\$10,939,500	\$142,400
Sacramento	2.1	9.4	0.1	\$ 1,372,800	\$ 4,800,000	\$1,631,500	\$100,000	\$ 7,904,300	\$142,400
San Diego	14.2	6.0	0.1	\$ 9,292,800	\$ 3,100,000	\$1,631,500	\$100,000	\$14,124,300	\$142,400
San Francisco	12.9	12.4	0.2	\$ 8,448,000	\$ 6,300,000	\$1,781,000	\$100,000	\$16,629,000	\$149,800
Stockton	8.2	10.9	0.1	\$ 5,385,600	\$ 5,500,000	\$1,631,500	\$100,000	\$12,617,100	\$142,400

Depending on the port configuration and ballast water discharge volume, the report estimated that the cost of treatment on land-based facilities would range between \$1.40 and \$8.30 per MT.

A recent study prepared for the Port of Seattle by Glosten (2002) examined ballast water transfer to shore-based facilities and/or mobile systems as a way to manage ballast water in Puget Sound. The study included a survey of five different types of ships to identify the extent and capital costs of modification required to accomplish ballast water transfers. The modification costs calculated for each type of ship is shown in Table 3. The calculations assumed (1) the different types of ships are retrofitted with a universal deck connector to transfer the ballast water, and (2) the ship ballast system has been modified to minimize schedule delays imposed by ballast water transfer operations.

TABLE 3: TRANSFER COST TO TREAT BALLAST WATER IN SHORE-BASED OR MOBILE SYSTEMS FACILITIES

Type	Transfer Modification Capital Costs	Ballast Capacity MTs (Approximate Gallons)
Tanker	\$ 1,892,100	75,850 (20,160,000)
Grain Ship	\$ 106,700	35,000 (9,018,190)
Break-bulk	\$ 303,400	26,850 (6,922,740)
Container	\$ 438,400	19,670 (5,069,120)
Car Carrier	\$ 160,700	6,600 (1,701,180)

On Board Treatment Technologies

Filtration and Hydrocyclonic Separation Systems

Description

These technologies have been considered a viable option for preventing or minimizing the intake of unwanted organisms into ballast tanks. The systems can be simple or complex requiring different levels of detailed engineering to achieve the filtration needed to provide the appropriate level of protection. A simple filtration system can be comprised of the installation of various types of screens, strainers or membranes designed to physically remove organisms above a specific size from ballast water during ballasting operations.

Strainers are simple mesh layers that can clog when the effective opening of the screens is reduced. In water treatment processes where filtration is used, large areas of filtering screens are required to maintain working flow of water for any period of time. Generally, backup systems are included so that continual flow stream can be achieved despite rapid rates of plugging. Self-cleaning strainers have been developed with automatic control systems incorporating cleaning cycles that can be activated by differential pressure or on a time cycle. Some research on the effectiveness of screen filters with filtration in the range of 20 to 100 microns has been completed. These screen filters appear to be most suitable for onboard ballast water treatment, but the filter system must include the automatic back-flush capability to meet the requirement of unattended automatic operation.

On the opposite end of the spectrum is a continuous flow centrifuge capable of separating solids and large organisms from water at extremely high flow rates (cyclonic separation systems). This flow-through centrifugation system accomplishes the separation of solids and organisms through the creation of a strong vortex in the flow as water flows through the machine. As ballast is pumped onboard, water enters the separator producing a cyclonic flow inside the machine. The centrifugal force concentrates solid particles and large organisms against the outer wall, allowing water to move through the center of the separator. An advantage of this system is that there are no movable parts, no filter elements or screens to clean. Consequently, no back washing operation is needed. The system is reported to require little or no maintenance and, if properly designed, could be operated through simple controls. However, preliminary results from field trials onboard ship carried out in California (2002) indicate that the system does not perform as claimed.

The biggest drawback of filters and cyclonic separator systems is that it can not be applied as a single system treatment option. These systems can

be used as a primary system to separate the larger particles from ballast water as it is taken onboard. Smaller materials such as sediments, microplankton, bacteria, and viruses will not be separated from the water using this approach.

Safety

Both technologies are considered safe since both are installed after the ballast pumps and do not affect normal ballasting operations.

Biological Effectiveness

The Great Lakes Ballast Technology Demonstration Project investigated the effectiveness of an automatic backwash screen filtration system. Testing was carried out aboard the dry bulk carrier, the M/V Algonorth, and later onboard a stationary barge (Parsons et al., 1999). The shipboard system consisted of two filter units (a 250-micron pre-filter unit and a 25-micron, 50-micron, 100-micron, or 150-micron filter unit) connected in series. The barge tests were conducted at two different locations within Lake Superior. The barge-based tests not only evaluated a similar filtration system evaluated on the M/V Algonorth but also tested cyclonic separation and an ultraviolet radiation system as well. Biological effectiveness was measured by comparing zooplankton, phytoplankton and microbial concentration with and without filtration treatment. Results showed that the two smallest filters achieved 95-99 percent effectiveness at removal of macrozooplankton, and 70-80 percent removal of microzooplankton and phytoplankton. While bacteria that attach to organisms and other material were reduced significantly, total bacteria counts were unaffected by filtration. The study concluded that filtration with automatic back-flush screen filters was feasible with existing technology down to approximately 50 microns (Cangelosi et al., 1999).

Environmental Acceptability

Both treatment technologies are presently considered attractive options to prevent or minimize the intake of unwanted organisms in ballast water. Further studies are being conducted to determine operational capabilities and biological effectiveness. In the final portion of the cyclonic separation system process, filtered organisms could be disposed of simultaneously as ballasting operations are underway. Preliminary studies suggest that such systems could help reduce the risk of introduction of harmful organisms by ships. However, it is likely that there would be a need for a secondary treatment system to achieve a more effective control of organisms introduced into ballast water.

Status of Technology

The Singapore Environmental Technology Institute, in collaboration with the Maritime and Port Authority of Singapore and the National University

of Singapore, has been testing various ballast water treatments including screen filtration (Matheikal et al., 2001). It is believed that this type of filtering system has the potential to be the most effective treatment technology for ballast water management if designed in the appropriate size with automatic self-cleaning to handle large volumes of ballast water without clogging. This is due to advances in manufacturing technology that enable filters to remove particles down to the 10 micron range and the engineering designs that allow filtration systems to be very small, less complex, and simple to operate.

As mentioned previously, filtration and cyclonic separation systems have been and are currently being tested as part of the Great Lakes Ballast Technology Demonstration Project. Early experimental work by the Northeast-Midwest Institute has led to important improvements in the combined two stage Cyclonic/Ultraviolet treatment system developed by Hyde Marine, Inc. Most recently, the Stolt-Nielson Transportation Group has agreed to install the Cyclonic/Ultraviolet system on the chemical tanker *M/T Aspiration* in order to provide further information on the operational and biological effectiveness of the treatment system.

In California, as part of the West Coast Demonstration Project, the *R.J. Pfeiffer* of Matson Navigation and the *Sea Princess* of Princess Cruises have also installed the Hyde Marine, Inc. Optimar Ballast System. The first stage of this two-staged treatment system includes an in-line cyclonic separator designed to remove material heavier than sea water. This stage is used during ballasting operations where separated particles can be discharged back into the source waters. The second stage treatment uses ultraviolet irradiation (discussed later) to kill or deactivate biological organisms, including bacteria and viruses. Preliminary results from at-sea evaluations on the *Sea Princess* are inconclusive, but further evaluations are planned.

A consensus emerging from these tests and tests that are currently being conducted on other technologies is that the effectiveness of other treatments is enhanced when a primary filtration stage is installed to remove larger particles in ballast water.

Cost

Estimated costs for a hydrocyclone/ultraviolet combination system is approximately \$120,000 (Hyde Marine Inc., 2001) to \$140,000 (Cangelosi, 2001). Capital costs for installing a filtration system is approximately \$40,000, although this cost can vary depending on ship type and extent of retrofitting necessary. Installation of the Optimar Ballast System on the *R.J. Pfeiffer* of Matson Navigation was estimated to cost \$380,000, but the actual cost was closer to \$500,000. Larger vessels

may require several systems to properly manage large volumes of ballast water, and, as a result, the cost would be several times higher.

Biocides

Description

This type of treatment consists of using either oxidizing or non-oxidizing biocide chemicals to treat ballast water. Oxidizing biocides include, but are not limited to, such chemicals as chlorine, chlorine dioxide (Simpson, 2001), ozone, bromine, hydrogen peroxide, and Paraclean® peroxy acetic acid (Fuchs et al., 2001). Many of these chemicals have been widely used in wastewater treatment facilities for years. Organic structures, such as cell membranes, are destroyed with the use of some of these chemicals. Non-oxidizing biocides include a large number of compounds generally used in industry for killing and preventing the growth of organisms in cooling water towers, intake pipes, and other industrial system process areas where large amounts of biological growth or sediment accumulation occur. Non-oxidizing biocides work like pesticides; they interfere with the physiological and metabolic processes of organisms. Non-oxidizing biocides include, but are not limited to, such compounds as Acrolein® (Baker Petrolite, 2001), Seakleen® (Wright, 2002), tributyltin, dissolved copper, dissolved silver, glutaraldehyde, and organic acids.

Biocides can be added to ballast water by metering concentrated solutions through chemical injection pumps that feed directly to the main ballast pumps during ballasting operation. Biocides such as chlorine, copper, and silver can also be generated electrolytically from sea water but the electrolytic generation system requires significant amounts of electricity. Biocides such as Acrolein® are injected into the ballast tank by allowing increased nitrogen pressure to displace the biocide from the container into the treatment ballast tank (Baker Petrolite, 2001). Other application methods consist of diluting appropriate amounts of soluble biocide compound into a 55-gallon drum and then pumping the biocide into the influent ballast water stream.

Safety

Although many hazardous industrial compounds are routinely carried on ships, there are some safety issues associated with handling and storage of biocides on ship. Residual amounts of some chemicals left on the ship or in ballast tanks after treatment may cause corrosion of piping, pumps, and other structural components of the ship. There are also some concerns about the addition of powerful oxidative biocides such as chlorine to ballast water since chlorine could react with sea water and produce toxic byproducts.

Biological Effectiveness

Although biocides have been widely used in wastewater treatment processes, testing onboard ship to treat ballast water is just beginning. Laboratory tests of exposure of target organisms to a variety of biocides have had varying levels of biological effectiveness. For instance, in laboratory tests, 24-hour exposure to copper sulfate, an algicide, at concentrations of 200 parts per million (ppm) up to 10,000 ppm at varying levels of pH and salinity was found to be ineffective in killing dinoflagellate cysts. Other biocides such as chlorine tested at 10 to 2000 ppm, and hydrogen peroxide tested at 100 to 60,000 ppm were found to be effective only at high concentrations (Cohen, 1996). However, laboratory tests conducted with Acrolein® detected no viable motile dinoflagellates in any Acrolein® treated samples and a significant reduction of test bacteria samples with the lowest concentration of Acrolein® used (Baker Petrolite, 2001). In laboratory tests exposing the biocide Seakleen® to a wide variety of marine and freshwater aquatic organisms representing major taxonomic groups indicated that a high degree of toxicity was achieved with the administration of low concentration of the biocide (1 ppm). An effective treatment dose is estimated at approximately 1-2 gallons per MT of ballast water. Seakleen® is reported to be an organic oxidant that contains no corrosive properties that could affect the structural elements of a ship (Wright et al., 2002).

Environmental Acceptability

Biocide treatment equipment could be relatively simple and requires little maintenance. Nevertheless, the application of chemicals to kill aquatic organisms in ballast water has generated the following concerns:

1. Residual chemical compounds discharged to receiving waters after treatment occurs.
2. Uncertainties regarding the biological effectiveness of biocide and the relative concentrations of chemicals needed to achieve satisfactory level of organism inactivation. This would need to be tested under full-scale conditions.
3. Compliance with discharge regulations not only in U.S. waters but internationally.

These concerns need to be addressed through adequately designed field tests and through appropriate legal, economic, and political analyses.

Status of Technology

At present, few biocides have been tested under laboratory conditions. Some are being tested on ship, but most biocides proposed for use in treating ballast water have not been field-tested.

Cost

The cost for dosing equipment to apply Seakleen® is estimated to be at approximately \$1600. The biocide would retail at less than \$.20 per MT of ballast water (Wright et al., 2002). Acrolein® application is estimated to cost between \$.16 to \$.19 per MT. Other than necessary minor ship modifications, capital cost could be negligible for the ship owner because little or no new equipment would be needed. That is, biocides could be applied by a service company in port. The service company would be responsible for its own application equipment. (Bonnivier, personal communication, 2002).

Heat Treatment

Description

In this process, heat would be used to elevate the temperature of ballast water to the level necessary to kill all aquatic organisms. The methods used to accomplish this would vary from ship to ship. The exhaust gases from operation of diesel engines and the use of engine cooling water during a voyage have been proposed as possible sources of heat. Regardless of heat source, water to be disinfected is drawn into a heat exchanger circuit where it is heated to the temperature needed to disinfect the water.

A heat exchanger is a device that transfers heat from a higher temperature fluid or gas to a cooler fluid via a conducting surface. There are two basic kinds of heat exchangers: shell and tube, and plate type. In a shell and tube heat exchanger, a bundle of tubes is placed within a cylindrical shell. On a plate type heat exchanger, a number of pressed plates are surrounded by seals and held together by a frame (Taylor, 1990).

In the exhaust gas system, exhaust from an engine is used to heat the ballast water to the required temperature by transferring waste heat to a heat exchanger. The extra exhaust heat is then discharged through the stack. The ballast water is either routed directly through the heat exchanger and then back to the ballast tanks or from the ballast tank to the heat exchanger and then to the ballast tanks. Alternatively, the ballast water can also be routed to a holding tank in order to increase the amount of time required to do proper treatment at the prescribed temperature. (Hi Tech Marine, 2001).

A system using exhaust gases as a heating medium would require additional piping in order to move the exhaust gases, and/or heated cooling water from the engines to the heat exchanger. Additional piping would also be needed to connect the ballast water system to the heat exchanger. Units using a boiler to raise the temperature of ballast water are similar. This system must also include a fuel source for the boiler and the removal of exhaust gases.

Safety

The use of heat to treat ballast water could create minor hot water hazards, but fortunately many of these hazards can be removed or ameliorated during the design and installation phase of the system. Steps are normally taken aboard ship to prevent injury from hot surfaces, as it is a common hazard on ships. Pipes conducting heated fluid are typically insulated to prevent loss of energy and to protect crew members. Whenever possible such a system, especially the heat generating exchangers or boilers, should be installed away from potential contacts with crew and other industrial machinery.

Some concerns have been raised regarding the effects of higher temperature on ballast tank corrosion, but studies have indicated that this effect is not major (Rigby et al., 1999). There is also a potential risk that filling empty ballast tanks with hot water could result in expansion and contraction of steel structures. This could compromise the structural integrity of the ship. Further analysis is necessary to determine if a risk is present (Buchholz, 1998).

Not accounting for the installation of heat exchangers to strip and recycle heat from treated water, there are concerns about the discharge of hot water overboard. The heated water that is discharged overboard could represent a thermal threat to nearby marine life.

Biological Effectiveness

The effectiveness of a heat treatment system depends on the ability of the equipment to raise the temperature of the ballast water to the thermal-threshold of the target organisms. Thermal threshold is the point at which an organism is killed due to either denaturing of cellular proteins or increasing the organism metabolism beyond sustainable levels. Thermal threshold varies among different species, so does the species' ability to endure periods of high temperatures that are below their thermal thresholds. In general, temperatures close to an organism's thermal threshold can be tolerated for short periods of time with little nonreversible damage. In temperatures cooler than the thermal threshold organisms can survive for longer periods. The ballast water should be heated to 110-150°F in order to kill a wide variety of organisms. The

exact temperature and length of exposure will vary according to system capabilities and the target organism (Buchholz, 1998).

The most effective technique of heat treatment lies in continuous rather than batch treatment. In initial laboratory tests, Bolch and Hallegraeff (1993) showed that heating to temperatures of 40°C (104°F) to 45° C (113°F) for 30 to 90 seconds would result in 100 percent mortality for *Gymnodinium catenatum* cysts (red-tide dinoflagellate). Sea trials carried out by Rigby et al. (1999) on the Bulk Carrier *Iron Whyalla* indicated that heat treatment of ballast water to temperatures of 38°C (100.4°F) for several days was sufficient to destroy all zooplankton and a major portion of the phytoplankton in the test ballast tank. There have been concerns that this temperature is not sufficient to kill pathogenic bacteria such as *Vibrio cholera*. However, some onboard heating systems are reported to be capable of attaining temperatures of 65°C (149°F), which would be adequate to kill the cholera bacterium (Hi-Tech Marine, 2001). Further onboard heating treatment trials on the Australian Bulk Carrier *Sandra Marie* reported to achieve 80 to 90 percent effectiveness despite the fact that it was sailing in heavy seas and gale force winds and only 80 percent of the ballast water was treated. Of course, longer exposure times would be needed to achieve the same results at lower temperatures.

Status of Technology

The components of heat treatment technology are commonly available. Boiler parts and units and heat exchangers are available from a large number of vendors around the world. Much of the technology is already developed and very reliable. The actual layout of a heat treatment system will vary widely and will depend on the size of the power generator and the physical layout of the ballast tanks.

A major disadvantage of this type of system is associated with ship retrofitting. Retrofitting could require extensive piping modifications because water would need to be redirected from the ballast system to the heating medium. The main advantage, however, is that all the components needed to carry out a retrofitting project are also readily available. In addition, the crew would only need minimal training to operate the equipment since it is comprised of components that are commonly used on ships.

Environmental Acceptability

The only two environmental concerns associated with heat treatment systems are potential thermal pollution and air quality problems. Thermal pollution may occur if large volumes of heated water are discharged into receiving waters, causing localized thermal effects on the immediate aquatic environment. However, heated water in the ballast tanks tends to dissipate gradually from the ship during voyage, reducing the potential of

a thermal impact on receiving aquatic environment. Also, using recovery heaters, which would remove much of the residual heat from treated water before it is discharged, could control any excess heat.

Air pollution problems may occur if heat-generating equipment needs to be operated during extended periods of time in order to heat ballast water to required temperature. This problem can be avoided through the use of heat already generated by the main boiler system and engine cooling jackets.

Cost

The cost of this system varies due to many factors. The most important factors are the amount and type of piping that must be installed to interface with the ballast water system, and the type and size of the heat exchangers or boiler. All of this would be determined by the amount of ballast water to be treated. Rough cost estimates are \$28,000-\$45,000 for a heat exchanger, and \$60,000 to \$600,000 for a boiler system (Buchholz, 1998). Rigby et al. (1999) estimated that it would cost approximately \$.03 per MT to treat ballast water not including installation costs for additional piping or equipment.

Ultraviolet Light

Description

Ultraviolet treatment works to achieve sterilization by exposing target organisms to Ultraviolet light (UV) energy waves.

These systems are usually constructed with stainless steel to help prevent corrosion, and the lamps are enclosed in protective quartz sleeves. In a disinfecting system, UV lamps are submerged in an open channel of water, or installed within pipe systems so the water flows past the UV lamps exposing the organisms to the required lethal dose of radiation. Lamps are generally used in a linear configuration, but they can also be twisted into loops or in a spiral configuration to increase the intensity along a linear axis. The exposure time and the intensity of the UV light application would determine the effectiveness of a lethal dose. In addition, the system performances would not only be affected by the dose and flow rate but also by the water quality of the water being treated. Ultraviolet absorbing constituents in water, such as organics, turbidity, and color, can influence the effectiveness of the system. As UV transmission decreases, additional UV energy would be required to maintain peak effectiveness.

UV waves can be emitted in two ways: continuous-wave and pulsed-wave delivery. The continuous-wave delivery provides a constant flow of low

level UV waves and is segregated into low and high intensity treatments. The pulsed-wave UV delivery system provides radiation doses through a flashing of the source lamp. This pulsing technique provides short bursts of higher energy into the system. High intensity UV waves, whether pulsed or continuous, will increase the range of transmittance and allow for more effective treatment of higher turbidity water or larger volumes of low turbidity water (Buchholz et al., 1998). The disadvantage of high intensity treatment is proportionately higher energy demands.

Typical maintenance procedures to maintain peak effectiveness in these systems include cleaning the quartz sleeves, replacing lamps, and checking proper function of the power module, inspecting the overall structural integrity of the system which includes a pretreatment unit. Training required for these procedures would be minimal.

Safety

As proven technology, UV systems are currently used for multiple purposes in primarily fresh water systems. Existing land-based applications are reported to need minimum maintenance and monitoring while in operation. Although the technology has existed for some time, it has just recently been tested for shipboard operation (Cangelosi, 2002). Some of the concerns raised with regard to UV systems are:

- The use of mercury-containing lamps to generate UV radiation could be of concern onboard a ship where there is a high potential for physical damage during storage and installation.
- Exposure of plastic piping to UV radiation for prolonged periods could cause degradation and eventual failure of such systems.
- Although other treatment systems may also induce mutagenic effects, organisms that survive the UV treatment process could be genetically altered from the damage caused by UV photons. These genetically altered organisms could have a better survival potential when discharged into receiving waters environment. It is expected that most or all of the surviving organisms with damaged genetic material would fail to reproduce (Buchholz et al., 1998).

Biological Effectiveness

Ultraviolet radiation is electromagnetic energy within the range of 4-400 nanometers (nm) wavelength. This range of wavelengths is further subdivided into three levels, UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (15-280 nm). The shorter wavelengths (< 280 nm) are generally considered to be the most effective against bacteria and viruses. Damage occurs through photodegradation, resulting in cell wall

destruction and alteration of cell genetic material and thereby prevent successful reproduction.

There are several variations of two different types of lamps commercially available today. These are the conventional low-pressure (LP) mercury arc lamp that emits monochromatic UV light at a wavelength of 253.7 nm in the UV-C germicidal range, and the higher intensity medium pressure (MP) mercury arc lamp that emits a UV polychromatic light at all wavelength (UV-A, B, and C) but concentrated at selected peaks within the germicidal wavelength region (Cairns, 2001). UV irradiation from efficient LP mercury lamps or from less efficient but more intense MP mercury lamps brings about photochemical transformations in the nucleic acids of the target microbes. The amount of damage caused by the UV radiation (the effectiveness of treatment) is related to the intensity of UV light (germicidal effective range) and the exposure time target organisms are exposed at the germicidal effective range. The UV dose can therefore be expressed as units of intensity of UV light in milliwatts per square centimeter and exposure time in seconds. Typical UV doses for drinking water range between 16 and 40 milliwatts per squared centimeter per second (mW/cm²/sec). Table 4 shows the percent reduction of different bacteria and viruses when irradiated with a dose of 20 mW/cm²/sec (Cairns, 2001).

TABLE 4: PERCENT REDUCTION OF DIFFERENT BACTERIA AND VIRUSES IRRADIATED WITH 20-MW/CM²/SEC DOSE

Organisms	Percent Inactivation	Organisms	Percent Inactivation
<i>Bacillus anthracis</i>	99.9964	<i>Shigella dysenteriae</i>	99.9999
<i>Clostridium tetani</i>	97.8456	<i>Streptococcus faecalis</i>	99.9972
<i>Corynebacterium diphthera</i>	99.9999	<i>Vibrio cholera</i>	99.9162
<i>Escherichia coli</i>	99.9999	Influenza virus	99.9997
<i>Legionella pneumophila</i>	99.9999	Poliovirus	99.7846
<i>Mycobacterium tuberculosis</i>	99.9536	Rotovirus	98.3014
<i>Pseudomonas aeruginosa</i>	99.9769	<i>Saccharomyces cerevisiae</i>	99.8179
<i>Salmonella paratyphi</i>	99.9999		

The ability of UV to treat unfiltered water is dependent on water clarity and turbidity. Since most coastal waters contain large amounts of inorganic and organic particles, which will decrease the effectiveness of UV treatment, it is recommended that some type of filtration in addition to UV treatment be used to remove larger organisms and solid matter from the flowing water. To achieve the kill rate of a combined filtered/UV unit, an unfiltered/UV unit must expend more energy to be as effective. It has been recommended that a filter between 25-50 μ is ideal for removing sediment, and organisms larger than bacteria, and viruses (Cangelosi et al., 1999). Length of exposure time at prescribed dose also helps determine effectiveness of the kill rate. Also, the UV wavelength delivered determines both effectiveness of kill and the energy required for operation. Studies of low and medium treatment on Zebra mussels indicate that medium pressure systems yield nearly 100 percent inhibition of mussel settlement (Lewis et al., 1996). Other studies have been conducted using xenon arc lamps (500 watts) that are capable of delivering higher levels of UV radiation over a greater portion of the UV spectrum. Results of these studies have indicated that veliger (free swimming mussel larvae) and post-veliger larvae were extremely sensitive to short exposures to a wide UV range, ceasing all swimming or crawling motions after exposure (Chalker-Scott et al., 1994).

The Great Lakes Demonstration Project's studies indicated that UV radiation alone is effective at reducing zooplankton, phytoplankton and bacteria growth, but physical and chemical conditions influence the UV performance. Further studies have suggested that re-growth occurs after retention in the ballast system and recommended that UV treatment be conducted on both intake and discharge (Cangelosi et al., 1999; Cangelosi, 2001). Recent studies (work in progress) being carried out by scientists from the San Jose State University Foundation and the San Francisco State University suggest similar results.

Environmental Acceptability

There are concerns with UV treatment and the accidental release of low level mercury if mercury-containing lamps are broken or improperly disposed. In most UV disinfection applications, the short wave portion or UV-C (200-280 nm) is used for the most effective treatment. Exposure to this UV range interrupts normal DNA replication and the organisms are either killed or inactivated. Although the risk that mutated organisms survive to invade a new environment is considered low (Buchholz et al, 1998), the treatment has the potential of causing genetic mutations in microorganisms that survive treatment process.

Status of Technology

The UV system process has been in common use for some time in hospitals, laboratories, and associated industries as well as in food

processing, potable water sterilization, aquaculture, municipal and industrial wastewater treatment, and other operations requiring the elimination of microbial contamination. Recently, systems have been designed for use onboard ship. The Great Lakes Demonstration Project reported that such systems, when coupled with some type of filtration, could be effective in controlling the introduction of nonindigenous aquatic species in ballast water. However, there are still outstanding engineering questions that need to be answered regarding the installation and operation onboard different types of ships. In addition, the exposure time and intensity of UV application to achieve adequate inactivation or elimination of ballast water entrained organisms have not been well defined.

Cost

Ultraviolet treatment systems are a readily available technology. These systems are already commonly used onboard for treatment of sewage. They are reported to be simple to operate and maintain, and ship crews only need minimal training to operate the system. The cost of this technology depends on the amount of water to be treated, the pumping and pre-filtering costs, and the UV dosage to be administered. Cost estimates based on a 1200 to 8000 gallons per minute (gpm) treatment system range from \$10,200-\$542,000 (Buchholz, 1998). Operating costs for a 1200 gpm system range between \$2,200 to \$4,000 per year assuming 10 percent duty cycle, one set of backup lamps, and normal maintenance procedures (Buchholz et al., 1998).

Ultrasound

Description

Ultrasound (sonic spectrum ranging from 20 kHz and 10 MHz) can be used to generate high frequency energy that cause liquids to vibrate producing physical and chemical effects in the treated liquid. A high voltage current actuates an ultrasonic transducer, which in turn generates vibration in a liquid. The generated waves tend to travel perpendicular to the resonated surface. When liquids are exposed to these high frequency vibrations, the physical and chemical changes result in cavitation. Cavitation can be defined as the rapid formation and collapse of microscopic gas bubbles in liquid as the molecules in the liquid absorb ultrasonic energy. Sound waves of different density and intensity rapidly move through the liquid media. Waves of sufficient intensity will break the attractive forces in the existing molecules and create gas bubbles. As additional ultrasound energy enters the liquid, the gas bubbles grow until they reach a critical size. Upon reaching the critical size, the gas bubbles implode or collapse. The cavitation effects kill the organisms within the liquid medium. The implosion of microscopic gas bubbles of the liquid ruptures the cell membranes, and collisions with other organisms and

particulate matter can also cause further mortality within the target area (Buchholz et al., 1998).

Ultrasound transducers are usually constructed of steel, titanium, aluminum, ceramic material, or in combinations such as aluminum stacked with ceramic discs. In cases where space is at a premium, transducers can be submerged into the ballast tanks.

Safety

The most prominent concerns with the use of ultrasound systems is that the transducer can generate high temperatures while in operation, which would necessitate the use of cooling water to avoid overheating.

Biological Effectiveness

In an ultrasound unit, small organisms and the cell walls of larger organisms are ruptured by the frequency of the ultrasonic energy, causing death to the target organisms. This technology has been researched for shipboard applications other than ballast water treatment. The ultrasound equipment has been developed for small-scale flow [< 100 gpm] degreasing and cleaning purposes. An appropriately designed ultrasound system could achieve a high level of biological effectiveness on bacteria and viruses.

Some manufacturers have developed systems that could be effective in treating ballast water and the water flow associated with large volumes of water. However, these systems have not been tested on ships. Nevertheless, laboratory tests have shown good results. Table 5 shows the biological effectiveness on various organisms using a 100-gpm ultrasound unit for processing unfiltered water (Buchholz et al., 1998).

Filtration also has a mixed effect on the effectiveness of an ultrasound system. Although filtering out larger particles will increase the effectiveness by removing organisms that have higher resistance to the energy waves, removal of particulate matter that might kill small organisms through collision may reduce the overall effectiveness.

Environmental Acceptability

There are no known or anticipated environmental concerns associated with this technology.

Status of Technology

Ultrasound technology is relatively new and has only been applied within the past few years in the wastewater treatment field and industrial cleaning applications. Ultrasound units already in existence are typically smaller scale units that can handle loads of 60-100 gpm. This flow rate is too low

for maritime application, which usually requires around 1200-gpm flow for ballast operations.

TABLE 5: BIOLOGICAL EFFECTIVENESS ON VARIOUS ORGANISMS USING A 100 GPM ULTRASOUND UNIT FOR PROCESSING UNFILTERED WATER

Organism	Type	Size	Performance
Zebra Mussel Veligers	Mollusk	70 microns	100% mortality ¹
Polio Virus	Virus	<5 microns	7 log ₁₀ reduction
Heliminth ova, <i>Ascaris</i>	Nematode	8-10 microns	100% inactivation
<i>Cryptosporidium parvum</i>	Bacteria	~5 microns	6-7 log ₁₀ reduction

Data source: Innovatech Environmental Solutions Inc., Advance, NC

¹100% mortality of zebra mussel veligers has also been demonstrated in 600 gpm-flow systems

One system, the High Power Ultrasonic Process (HPUP), reportedly shows promise. This system delivers energy vibrations into the liquid at a much greater intensity than other conventional systems. The HPUP produces more intense cavitation, thereby requiring less exposure time for mortality to occur and allowing high flow rates of the treated liquid (Buchholz, 1998).

Another way to increase the capacity of the ultrasound treatment is to locate the unit in the ballast tanks. This would require a costly retrofit and, therefore, would probably only be economically feasible for new ship construction. Another problem with placing the unit in the ballast tank is maintenance, because access would be difficult. Grouping a number of smaller ultrasound units together could also solve flow rate problems. These ideas seem plausible but research and field trials still need to be completed.

Cost

The cost of an ultrasound unit is high – approximately \$250,000 for a 600 gpm unit. Cleaning and maintenance costs are considered minimal since it is estimated that only two hours would be needed to carry out these tasks approximately every 12,000 hours. The energy usage could range approximately from 28 kW for a 1,000 gpm unit to 206 kW for a 7350 gpm unit and 840 kW for a 30,000 gpm unit. The cost for power generation would depend on the cost of fuel, but it is estimated at approximately \$.03 per kWh. Based on this rate, estimated monthly energy usage cost would range from \$605 for a 1,000 gpm unit to \$18,144 for a 30,000 gpm unit (Buchholz et al., 1998).

Installation of an ultrasound unit might require major modification of ballast water system piping. Electrical power and controls would need to be wired into the unit and, due to the large amount of power required for operation, an extra generator might need to be installed. In some cases, non-essential equipment might need to be taken off-line when the ultrasound unit is being used.

Magnetic Treatment

Description

This treatment involves the application of a strong magnetic field to pipes systems. The technology has been primarily used for treatment of scale and minerals within a piping system or for the treatment of boiler feed water. The magnetic field created by the system polarizes hard water particles (Calcium Carbonate), making them less prone to settle or attach themselves to piping surfaces. The technology has also been applied for the elimination of microbes that are found within fuel oils and more recently to purify water. A typical magnetic system consists of a magnet or electromagnet attached to the piping system. These units can be compact and would require little or no energy to operate. Preliminary results from industrial and commercial research suggest that a magnetic field can also be used to control such aquatic organisms as Zebra mussels by causing tissue degeneration associated with the gill and other structures specialized for gas exchange and feeding (Barnes et al., 1998).

Safety

One safety concern associated with electromagnetic treatment systems is the application of electric power to operate the system. Different manufacturers use different voltage, ranging from 120 volts for a small system to 230 volts or more. Typically, marine electrical systems are insulated and grounded, and considered safe, which would prevent the threat of fire in an enclosed space that might have flammable gases.

Biological Effectiveness

The effect of magnetic treatment on organisms would vary with the size and type of organism. When exposed to single cell bacteria it is very effective. Studies from a magnetic fuel cleaning system indicate near 100 percent destruction of microbial organisms and 97 percent kill of fungi. Strong magnetic forces interfere with organism pH levels, which in turn supports the cell's organelles and proteins. Magnetic forces also interfere with the flow of ions in the cell membrane, resulting in death. Yeast and fungi are affected in a similar manner (De-Bug Limited, 2001). Although larger organisms are more resistant to this treatment, damage can be caused to the tips of exposed surface areas such as fins and gills and reproduction. Zebra mussels subjected to magnetic treatment over the course of 78 days displayed aberrations in gill tissue suggesting the mussels are affected when exposed to magnetically treated water (Barnes et al., 1998).

Environmental Acceptability

The effects of magnetic treatment are few, if any. There is a concern though that magnetic treatment reduces oxygen saturation levels in treated water (Florestano et al., 1996). This reduces corrosion in pipes but could pose a potential hazard to marine life in the immediate area where the treated water is discharged.

Status of Technology

The installation of a magnetic water treatment system on board a vessel may be feasible since there are magnetic treatment units currently in use to treat marine fuel oil systems. It is possible that, in time, manufacturers will offer treatment systems for ballast water.

The units are typically constructed of stainless steel in order to resist corrosion. The units themselves are robust enough for marine operation and can be designed to fit within confined ships' engine spaces.

The maintenance for these systems is minimal. The units do require periodic monitoring to ensure proper operation. Crew training would be required because maintenance is necessary after prolonged use. However, the application of this technology has not been fully evaluated. The preliminary results on the effects of this treatment are by no means clear or conclusive. More time is needed to properly test and apply this technique to ballast water operations (Federal Technology Alerts, 2001).

Cost

Capital and operating costs vary widely, depending on the size of the equipment. Installation for a large magnetic unit designed to connect with 12-inch to 18-inch pipes using flange type fittings could require

approximately one to four person-days and less than \$1,000 in additional materials. A non-electric magnetic industrial water softening system has been estimated to cost approximately \$10,000 to treat 1000 gpm, or \$10 per gpm. An electromagnetic system would be more expensive. Depending on the size, a 1000 gpm treatment unit could cost as much as \$1,000 per gpm. (Federal Technology Alerts, 2001). This does not take into account the special installation and retrofit that would be required on a ship's ballast water system.

Ozone

Description

This is another type of oxidizing biocide treatment technology used to treat potable and a variety of industrial process water. Ozone (O_3) is a naturally occurring form of activated oxygen produced during lightning storm discharges and is continuously occurring in the stratosphere by ultraviolet action. Ozone can also be artificially produced by the action of high voltage discharge in the presence of air or pure oxygen (O_2). Due to the fact that the gas breaks down rapidly, users must generate the gas on site. The high oxidation potential of ozone increases its reactivity with other elements and compounds and achieves high kill rates of fungus, bacteria, and viruses.

An ozone generator requires several different components to operate, including a clean oxygen supply and a source of high voltage, typically 6 to 20 kilovolts of alternating current. Generators have two concentrically placed electrodes through which high voltage flows. The electrodes are separated by a dielectric discharge gap that contains the discharge chamber through which oxygen flows. The incoming oxygen molecules are broken down in the electric field, subsequently attaching to other free oxygen molecules forming ozone. After generation, the ozone is fed into a down-flow contact chamber containing the water to be disinfected (U.S. EPA, 1999).

Safety

Ozone is very reactive and corrosive and requires corrosion resistant materials when used. In low concentrations (0.05 ppm) it imparts a sweet odor. However, prolonged exposure to high levels (> 100 ppm) can produce headaches and nausea. The off gases from the contact chamber in an ozonation system must be treated to destroy any remaining ozone before release into the atmosphere. In addition, the gas reacts violently when combined with ultraviolet waves creating reactive hydroxyl ion (U.S. EPA, 1999).

Biological Effectiveness

Ozone is a very strong oxidant-causing direct oxidation and destruction of the cell walls of organisms. The rupture of the cell walls exposes the organism to the external environment and cause immediate death to the cell (OzonePure, 2001). This is in contrast to chlorine, which kills organisms by diffusing into the cell protoplasm, inactivating cell enzymes. Ozone levels of 0.4 ppm have been reported to control most vertebrate species, unicellular, and some benthic organisms. Control of more resistant cysts can be achieved at 10 ppm (Laughton et al., 2001). Preliminary results of a recent study of an ozone system installed on the *Tosina*, a 869 foot double-hull American-flag oil tanker, indicate that the treatment killed more than 99.9 percent of the bacteria after five hours of ozonation and over 90 percent of the zooplankton after ten hours (Cooper, 2002).

Environmental Acceptability

Ozone treatment is reported to have no harmful residuals that would need to be removed after treatment. In addition, the ozonation process tends to elevate the dissolved oxygen concentration of the effluent, eliminating the need to re-aerate treated water before it is discharged into receiving waters. Due to its oxidative power, ozone can also decompose organic and inorganic pollutants in treated water that can easily be separated by filtration before discharged. The biggest health concern associated with ozone is the possible exposure at high concentration (>100 ppm) in enclosed spaces. Natural ozone background concentrations is approximately 0.03 ppm (Hughes, 2001). The federal Occupational Safety and Health Administration (OSHA) has set ozone exposure limit guidelines for industry and recommends short-term exposure limit at no more than 0.3 ppm, 0.1 ppm for an 8 hour exposure, and 0.05 ppm for 24 hours of exposure.

Status of Technology

There are currently a number of companies manufacturing ozonation systems for various wastewater and industrial applications. Only recently has this type of system been applied to the treatment of ballast water (Cooper, 2002). Ozone generators used in industry are usually very large and complicated systems that require a significant cooling water system for the generator and an air compressor for the oxygen separator. New units are becoming smaller as the technology improves. Some smaller ozone generators use air rather than liquid as a cooling medium. One of the major engineering problems is to manufacture a system that is small enough to fit in confined ship space but still has the capacity to handle the large volume of water used in a ballast system.

Space considerations are very important when a system is to be installed on ship. Retrofitting older ships with this type of system could prove costly due to the space available for installation and piping reconfiguration.

Cost

In the past, ozone generators have been very expensive in both capital and operation costs. The cost of such units has begun to decrease with the advent of new materials, power supplies, high frequency generators, and new types of cooling systems. The cost of an ozonation system will depend on the manufacturer, the size of the unit, the water treatment capacity, and the characteristics of the wastewater being treated. Cost estimates for an ozone disinfection system used to disinfect 1 mgd based on the wastewater passing through a primary and secondary treatment process are \$245,000 for an oxygen feed gas and compressor and \$800 to \$1,200 for the destruct unit.

There are other costs associated with the installation and operation of the system. Annual operations and maintenance costs were estimated at \$12,000 for labor, 90 kW for power and approximately \$6,500 for filter replacements, compressor oil, and spare parts (U.S. EPA, 1999).

Pulse Plasma

Description

Pulse Plasma can be loosely defined as an electrically conducting gas. At normal temperatures and pressures gases are not very good conductors because the electrons contained within gas atoms can not move in response to externally applied magnetic fields. However, through ionization some or all the electrons can be removed from their parent atom. The gas then becomes a mixture of negative charged electrons and positive charged ions and unionized charged particles. Under this condition, the electrons and ions are free to move under the action of an applied electromagnetic field, and the gas can then conduct electricity. Pulse plasma treatment is a relatively new technology, and its application to ballast water is untested. The system works on the same principle as a spark plug where a voltage of 5000 volts at 25,000 amps is applied between two electrodes for approximately 400 microseconds, creating an ionization field producing a high-energy plasma arc.

This high-energy plasma arc produces a pressure shock wave. The shock wave kills the target organisms by causing physical damage to the cellular matrix either by the sudden recoil of cell tissue or by micro-eddies created on the internal cell structure (OCETA, 2001). Currently, the technology is undergoing tests for its effectiveness against Zebra mussel colonies in

intake pipes for onshore industrial facilities. In this application, the pulse is directed into a water intake pipe and the pressure wave is contained traveling down inside the pipe.

Safety

The shock wave produced by this technology is powerful and over time could lead to materials failure or enhanced corrosion, resulting in damage to the piping in a ballast water system. Further studies are needed to fully evaluate the effects on a ship's piping.

Biological Effectiveness

Pulse plasma is reported to be able to remove aquatic fouling organisms such as Zebra mussels, alga colonies, and bacterial growth. At present, only one pulse power plasma spark system has been developed for full-scale operation. The system is designed to treat relatively high flows of water. This prototype system was tested (Smythe et al., 1999) and was reported to have induced Zebra mussel mortality. However, it is not known if it will be effective against hardy organisms such as cysts or larger aquatic organisms or whether it can be operational onboard ship.

Environmental Acceptability

Pulse Plasma treatment technology for water treatment application is at an experimental stage. Environmental acceptability at this point is unknown although it would be expected that treated ballast water could be discharged into receiving waters safely.

Status of Technology

This technology has been well developed on a theoretical and research basis. Its reliability and practicality for ship-based use is yet to be proven. The shock wave produced is very effective but application aspects aboard ship will require further research. The equipment has not been proven in a marine environment that is subject to physical stresses such as extreme heat, corrosion, lateral, and transverse movement. Land-based systems are not subject to such stresses.

This technology would require training to operate and maintain. Equipment malfunctions might be beyond a crew's ability to repair while at sea, which could lead to not having the treatment equipment available for extended periods of time.

Cost

Estimated costs range between \$100,000 to \$200,000 not including installation. Operation and maintenance are estimated to be approximately \$150 per hour excluding electric power requirements. Electrode

replacement after 10,000 hours of operation would cost approximately \$5,000 (NRC, 1996).

Other Treatment Options

The following treatment options have been presented as other possible alternatives to treat ballast water. They are described here in a general manner based on limited information available.

Deoxygenation

Description

This treatment accomplishes the removal of ballast water organisms by extracting the dissolved oxygen from ballast water. This can be accomplished by either purging the oxygen from the ballast tanks with nitrogen through the use of chemical additives or by use of a vacuum chamber over time. Nitrogen treatment is reported to be safe with the proper equipment and training. The treatment would be partially effective, causing substantial mortality of ballast tank organisms that are not adapted to low oxygen environments. It may be cost effective because it could decrease the rate of corrosion in ballast tanks. Preliminary laboratory results showed substantial reduction in the survival rate of polychaete worms, green crabs, and the Zebra mussel (Tamburri et al., 2001). Preliminary results from a prototype study involving a 72-ton per hour high speed ballast water treatment system fitted with a vacuum chamber showed an immediate kill of live zooplankton ranging from 50 to 75 percent and nearly complete reduction within two days of treatment (Browning et al., 2001).

Ballast Tank Coating

Description

Anti-fouling paints have been commonly used on the bottom of ship hulls to prevent marine organisms from attaching. Ballast tank anti-fouling coating could be applied to ships during the building stages and reapplied while at dry dock for maintenance operations throughout the life of the ship. Basically, two types of anti-fouling paints could be used: (1) a non-stick type, silicon-based paint that would prevent organisms from attaching to the surface of the tank, and (2) a biocidal anti-fouling paint that would release small amounts of biocide at the coating surface to kill attaching organisms. Unfortunately, paint coatings could only act on benthic organisms, leaving species in water columns unharmed. There are also questions regarding the durability of the coatings and how frequently reapplication would be needed to maintain an effective level of protection. In addition, biocidal coatings would ultimately release residual biocide

into receiving waters. The NRC (1996) did not consider this type of treatment to be suitable because the organisms that would be effectively controlled by this treatment method only represent a small portion of the total problem.

Findings and Evaluation of Ballast Water Treatment Alternatives



This report presents 13 different treatment technologies and procedures in five different evaluation considerations. The list of treatment technologies and procedures are by no means exhaustive. There are a number of other treatment options or different versions of some of the treatment options presented here that have not been discussed in this report. The evaluation and resulting findings are preliminary in nature because much of the information needed to complete a more conclusive assessment of the technologies is still being developed and not currently available. Nevertheless the information gathered so far may be sufficient to provide an idea regarding the status of development and application of the treatment options presented.

Table 6 presents a qualitative summary evaluation of the treatment technologies. First and foremost, it is important that in considering specific treatment options for application each treatment alternative be considered safe, biologically effective, and environmentally acceptable.

As mentioned previously, the evaluation is based on information gathered for each treatment alternative. The different treatment options are rated according to the following classifications:

- **Acceptable** – Considered to be safe, effective, environmentally acceptable or will be safe, effective and environmentally acceptable with minor technological modifications and refinements.
- **Partially acceptable** – Considered to be partially safe, effective or environmentally acceptable.
- **Unacceptable** - This rating does not mean that the treatment option should not be considered further. It simply means that the

technology may be considered too costly, or there are uncertainties regarding its safety, effectiveness, or environmental acceptability. It may also mean that the technology needs more design work, development, refinement, and research.

- **Unknown** ■ - Treatment technology is currently at the conceptual stage. Not enough information is available or gathered at the time this report was prepared to make a judgement regarding the specific evaluation consideration.

TABLE 6: PRELIMINARY BALLAST WATER TREATMENT TECHNOLOGY EVALUATION

Treatment Technology	Safety	Biological Effectiveness	Environmental Acceptability
Uptake/Release Practices			
Onshore Treatment			
Empty and refill exchange (ERE)			
Flow through exchange (FTE)			
Filtration			
Oxidizing Biocides			
Heat Treatment			
Ultraviolet			
Ultrasound			
Magnetic Fields			
Ozonation			
Pulse Plasma			
Deoxygenation			
Anti-fouling coatings			

 Acceptable
  Partially acceptable
  Unacceptable
  Unknown

Safety

- Ballast water uptake/release practices are moderately safe because they are subject to safety conditions during cargo loading and unloading. Ballasting operations may need to be carried out in port to maintain ship transverse stability, and to maintain both the clearances under cargo loading or cargo discharge facilities and under-keel clearance so the vessel remains safely afloat.
- Both BWE procedures are considered safe, although there appears to be still unresolved uncertainties with regard to ERE. ERE procedure has been reported to be potentially unsafe because it requires that ballast tanks be emptied before they are filled again. This procedure has been reported to compromise the stability and maneuverability of ships. It has been reported that this is most pronounced in ships larger than 40,000 dwt. Ships larger than 40,000 dwt have reported to have carried ERE without any perceivable deleterious effects. Hydrostatic analyses confirm this observation as long as ERE is not carried out during extremely high sea conditions. FTE is considered safe or safer because in this method ballast tanks are flushed out and filled in simultaneously during the voyage, and consequently the stability of the ship is not likely to be compromised.
- There are specific, unresolved concerns associated with biocide treatment. These concerns include handling and storing hazardous chemicals onboard as well as residual chemicals left onboard or in the ballast tanks after treatment causing corrosion problems. Further tests are necessary to evaluate the practicality of application for onboard treatment.
- Safety of heat, ultraviolet, ultrasound, magnetic field, pulse plasma, and deoxygenation treatments is unknown because some have not been shipboard tested, and there is not enough conclusive information available.

Biological Effectiveness

- Ballast water uptake/release practices can only be used as an initial avoidance strategy to control the uptake and discharge of aquatic organisms in specific areas under specific conditions.
- All BWE procedures were rated unacceptable because, although the operation is currently the most accepted practice in use today, it is widely recognized to be limited with regard to its effectiveness in reducing the discharge of non-indigenous organisms into receiving waters. The concept behind exchange procedures is that during a voyage nonindigenous organisms are replaced with mid-ocean organisms, which are then discharged at the port of destination. Mid-

ocean organisms are assumed to be killed upon being discharged to the new environment due to different environmental conditions of the receiving waters. At this point there are many uncertainties about the effectiveness of the operation. Biological effectiveness has been reported to range between 39 and 99 percent. There are currently ongoing studies intended to better determine the effectiveness of this procedure. In the mean time these practices should only be considered as an interim measure until more effective management alternatives are developed.

- Filtration and cyclonic separation was rated moderately acceptable. Studies have suggested that these systems could help reduce the intake of aquatic organisms into ballast tanks. However, it would be best to couple this treatment with a secondary system to ensure that more complete extraction of aquatic organisms is accomplished.
- Some biocides have demonstrated high level of effectiveness under laboratory conditions. Preliminary onboard studies have been conducted, but there is not enough conclusive information to perform an evaluation at this time.
- Much of the technology necessary to implement heat treatment is currently available. Preliminary studies have been carried out on its effectiveness, but further evaluation is needed.
- The effectiveness of UV was rated unknown because there are unresolved engineering and design questions associated with the installation and operation of the system. In addition, the exposure time and intensity of UV application to achieve adequate organism inactivation or elimination have not been well defined. The system is currently under further evaluation. Ultrasound has shown to achieve a high level of biological effectiveness on Zebra mussel veliger, nematodes, bacteria, and viruses, but the technology has not been tested on a large flow system capable of treating large volumes of ballast water onboard ship.
- Magnetic treatment effects would vary with the type and size of the organisms. Studies of fuel cleaning systems have indicated that high levels of biological effectiveness have been achieved against microbial organisms and fungi. At this time, no magnetic system has been developed for treating ballast water. Further tests aboard ship are necessary once the system is developed.
- Ozone treatment is another type of oxidizing biocide capable of causing direct oxidation and destruction of the cell walls of organisms. Preliminary studies indicate that the treatment is highly effective, but further investigation is needed.

- Studies on pulse plasma technology have indicated that the treatment is effective against the Zebra mussel, algae, and bacterial growth. It is presently being further tested with Zebra mussels for land-based applications. No system has been developed for shipboard testing.
- Deoxygenation treatment could be effective in killing larval, juvenile and adult oxygen consuming organisms but may be less effective on taxa adapted to low oxygen environments or with resistant stages such as cysts.
- Anti-fouling coat application inside ballast tanks would probably prevent benthic organisms from attaching to the tank's surfaces but would not affect organisms within the water column.

Environmental Acceptability

- Both ERE and FTE operations were rated as unacceptable because exchange operations result in an unpredictable combination of killing, removing, and adding organisms to a receiving aquatic environment. During exchange operations, some organisms in the original ballast water would be removed from the tanks as the water is replaced, but others could remain passively in the ballast tanks because of incomplete exchange process. When a ship arrives to the port of destination, the mix of mid-ocean as well as original estuarine organisms from the port of origin could be discharged during deballasting operations. The organisms that are discharged with ballast water are assumed killed by a change in salinity or other environmental factors. This assumption may not be valid because ballast tanks contain a wide range of organisms with a wide range of environmental tolerances. Consequently, the likelihood of any mid-ocean organism being able to tolerate coastal, estuarine, and freshwater environments when discharged with ballast water is not known.
- Biocide application to inactivate aquatic organisms in ballast water must be researched very carefully not only to determine effectiveness but to ensure that residual chemicals after treatment is neutralized or degraded into harmless byproducts before treated ballast water is discharged into receiving waters. Preliminary studies with specific biocides are promising. Any program designed to include application of any biocide should include a residual breakdown study phase to ensure active chemical ingredients are broken down into harmless compounds before being discharged into the environment.
- Ultraviolet, ultrasound, magnetic field, ozonation, and pulse plasma treatment technology are experimental, and their environmental acceptability is unknown.

- Deoxygenation technology can be accomplished through various ways; one of which binds available oxygen through the use of chemical additives. This procedure is also subject to the same constraints as biocides because the treatment could produce hydrogen sulfide when a significant amount of organic matter is present. This could create problems onboard ship as well as when treated ballast water is discharged into receiving water. Another concern would be the possible danger to native estuarine organisms when ballast water containing low oxygen is discharged to receiving water.
- Anti-fouling coatings, as with biocides, could ultimately release residual biocide into receiving waters.

Cost

Capital cost estimates for each treatment technology vary widely according to ship types and extent of modifications needed to install a specific system. Some estimates are conceptual, based on projected study costs. There are a number of cost estimates in the literature, but many are several years old and do not reflect current cost. Capital cost estimates for a shore-based treatment facility are substantially higher when compared with other types of treatment systems. Operation and maintenance cost also varies substantially, depending on power requirements or other peripheral equipment needed to operate the system.

Table 7 presents a rough estimate of capital costs and the costs to treat ballast water using the different options. Whenever possible, all values have been transformed into one general unit of measure in an effort to present all costs in a uniform manner. Capital costs are based on equipment cost estimates. Whenever available, treatment cost per MT of ballast water is also presented.

TABLE 7: CAPITAL AND TREATMENT COST ESTIMATES TO TREAT BALLAST WATER

Treatment Technology	Capital Cost	Treatment Cost
Ballast Water Uptake/Release Practices	No capital cost.	No Operating and Maintenance cost.
Onshore Treatment	\$8 million – \$50 million depending on the port. Further site specific work is needed.	Annual O&M \$150,000 – \$223,000/ year \$1.50 to \$8.29 /MT.
ERE	Depends on extent of piping modifications needed.	\$.02-\$.035 /MT.
FTE	Depends on extent of piping modifications needed.	\$.06-\$.08 /MT.
Filtration	\$40,000.	Unknown.
Biocides	\$400,000 - \$800,000 for electrolytic system. \$1,600 for dosing systems or negligible if a service company applies the biocide.	For some non-oxidizing biocides \$.16-\$.20 /MT. Less for oxidizing biocides.
Heat	\$28,000 – \$45,000 for heat exchangers. \$60,000 – \$600,000 for boiler systems not including piping system modifications.	\$.03 /MT.
UV	\$10,000-\$545,000 excluding installation. \$140,000 for a cyclonic separation and UV system (cost estimates estimated).	Undetermined but there are several combined systems presently being tested.
Ultrasound	\$500,000 estimated cost for two 600-gpm systems.	At \$.03 /kWh for 30,000 gpm unit power consumption, approximately \$18,144/month.
Magnetic	For a scale and hardness control system: 1. Non-electric – to treat 1000 gpm, \$10,000 excluding installation, 2. electromagnetic - 1000 gpm, up to \$1,000,000.	Unknown for onboard ship applications.
Ozonation	Oxygen gas unit and compressor system: \$245,000, destruct unit \$800 to \$1,200.	\$1,200, approximately 90 kw for power plus \$6,500 for filter replacement and etc.
Pulse Plasma	\$100,000 to \$200,000 not including installation.	\$150/hour excluding cost for electrical power.
Deoxygenation	Unknown.	Unknown.
Anti-fouling coatings	Unknown.	Unknown.

Conclusions



1. *At present there is not enough conclusive information to recommend a single treatment option or a combination of treatment options for certification in California.*

Most of the treatment technologies discussed in this report are under development or potentially available in the future. Some have been tested under laboratory conditions and only a few have undergone full-scale testing aboard ship. There are many fundamental scientific and engineering questions that need to be answered. Technologies such as filtration, biocides, heat, UV, ultrasound, magnetic, and ozone treatment either need further testing and refinement or are considered effective but systems have not as yet been designed and tested for shipboard application.

2. *Preliminary evaluation indicates that most of the technologies are either developing or in the conceptual stage.*

An initial assessment of the status of various treatment options using the information collected is presented in Table 8. Each treatment technology or procedure has been classified according to the following categories:

- Established – Technology or practice whose quality has been demonstrated through laboratory and shipboard tests.
- Developing – Technology or practice whose capabilities need to be brought to a more advanced and effective state.

- Emerging – New technology or practice in the conceptual stage, in the process of being developed, or not tested yet.

TABLE 8: INITIAL ASSESSMENT OF THE STATUS OF THE TREATMENT OPTIONS

Treatment Option	Category
Ballast Water Uptake/Release Practices	Established
BWE	Established
Filtration	Developing
Biocides	Developing
Heat	Developing
Ultraviolet	Developing
Ultrasound	Emerging
Magnetic	Emerging
Ozonation	Developing
Pulse Plasma	Emerging
Deoxygenation	Emerging
Anti-fouling coatings	Emerging

3. *Although BWE is considered an established practice, it should not be used to determine the biological effectiveness of technologies because its effectiveness has not been established and varies widely.*

California Public Resources Code section 71204(a)(3) requires that any alternative method of ballast water management be at least as effective as BWE in removing or killing nonindigenous organisms. Ballast water exchange procedures (ERE or FTE) have been established for some time and are recommended under IMO guidelines. However, there are many uncertainties associated with BWE procedures regarding the effectiveness and locations where exchange might be carried out. At the First International Ballast Water Treatment Research and Development Symposium and Standard

Workshop held on March 2001 at IMO headquarters in London, it was concluded that it was not appropriate to use equivalency to BWE as a standard for evaluating and approving new BWT technologies. BWE should be used as a temporary measure only to be replaced by a safer and more effective treatment alternative in the future.

Both BWE and BWT are intended to reduce the concentration of nonindigenous organisms in ballast water discharges to receiving waters. However, while all of the proposed technologies kill or remove organisms, BWE results in an unpredictable combination of killing, removing, and adding organisms. It is difficult to meaningfully compare BWE replacement results with BWT killing results because BWE assumes (1) a kill ratio effectiveness based on a volumetric exchange of ballast water, and (2) the likelihood of those organisms that are replaced and discharged to tolerate coastal, estuarine, and freshwater environments (Ballast Water News, GloBallast, 2001).

4. *Regardless of technology or methods used, the state should continue to require the use of ballast water uptake/release procedures as primary avoidance strategies whenever possible.*

These practices are presently recommended by IMO and required under California Public Resources Code section 71204 as long as ship safety is not compromised. However, the procedures should only serve as primary avoidance strategies to be used in combination with other treatment methods or technologies.

5. *Onshore treatment alternatives may be possible for smaller port facilities with a limited number of dedicated ship visits, or as an option for older vessels that are unable to retrofit because they are either nearing the end of their service life or it would be too costly to retrofit.*

This treatment alternative would require that ballast water be transferred to an onshore facility for treatment. Onshore treatment could be very effective in eliminating introduced species because the treatment process would be carried out in a full-scale treatment plant designed and fully capable to treat and dispose of ballast water. In some ports enough shore space could be available to establish shore-based facilities, or treatment could be accomplished in already existing facilities. It would be technically feasible to retrofit vessels and berths, develop transportation system to collect ballast from ships, build onshore storage tanks and treatment facilities, and dispose of the treated water in an environmentally safe manner.

Recommendation



As stated in the Conclusions, there is not enough conclusive information to recommend a single treatment option or a combination of treatment options for certification in the state. Further research and onboard testing are necessary to determine the effectiveness and feasibility of various technologies.

The increasing awareness of the problem of discharged ballast water, the stated limitations of BWE, and the lack of proven treatment alternatives to address the problem have caused various regulatory jurisdictions to adopt regulations requiring ballast water management. This has caused concerns in the shipping industry because the regulations adopted by different jurisdictions have oftentimes resulted in different and disparate responses to manage the ballast water problem.

There is no doubt that there is a strong demand for environmentally sound and effective ballast water treatment technologies. The shipping industry seems very interested in advancing these efforts and developing treatment alternatives that would be generally acceptable across those jurisdictional boundaries. However, the industry is understandably reluctant to fully invest large amounts of capital on partially tested, largely unproven technologies unless there are assurances that the technology will likely meet regulatory requirements now and for the reasonably foreseeable future.

In many cases, research efforts to test and establish treatment alternatives have been initiated by private companies that lack experience in dealing with technological effectiveness, environmental soundness, vessel and crew safety, engineering integration, operational and maintenance requirements, and cost. These fundamental scientific, engineering, and operational issues need to be addressed for each of the proposed systems.

The most efficient and practical way to assure that these fundamental scientific and engineering issues are appropriately addressed would be through the implementation of a well-designed research, development and certification program with built-in incentives for the shipping industry to promote the development of treatment options. Since the ballast water issue is an international concern, it should be addressed by the federal government in coordination with the state and the shipping industry.

Currently, CSLC is the lead state agency working with USCG on ballast water management issues. CSLC, in consultation with USCG, is implementing a detailed procedure to evaluate experimental or prototype ballast water treatment systems with demonstrated potential for effective destruction of nonindigenous aquatic organisms. This joint program approves installation and testing of experimental treatment systems and grants conditional approval for use in-lieu of BWE. The approval is granted for a determined period of time regardless of regulatory requirements for treatment that might be promulgated during the testing and evaluation period. The program requires demonstration tests contingent upon the implementation of a rigorous experimental study deemed appropriate by an independent panel of scientists. Participation in the advance approval program requires compliance with various review steps. The ship owner, operator, manufacturer, or developer is required to submit a study plan, accompanied by supporting documentation including environmental compliance, small-scale demonstration experiments, and a letter of commitment stating the intent to carry out all components of the study plan for which they are responsible. The eventual result of this program will provide the shipping industry a set of scientifically tested and certified treatment technologies that will comply with any international or local regulation.

Additional efforts that could be included in this joint program are:

- Focused research and engineering studies that would guide the development of promising treatment alternatives towards a working prototype. The research and development would incorporate the specific constraints and requirements of defined classes of vessels. This could include land-based testing where the technologies are

evaluated in an environmentally safe location that would facilitate objective testing using scientifically designed protocols for standardized land-based tests under controlled conditions.

- Shipboard installation and testing that would guide the research and development of a prototype system toward application onboard ship. This would include fitting and refining prototypes through shipboard trials over extended periods and under a broad range of operating conditions and biological testing to evaluate the effectiveness of the system.
- Tested technologies that are proven effective would subsequently be certified as suitable for use and implemented throughout the maritime industry.

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