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Contract Designs for Ballast Water Treatment Systems on Containership *R.J. Pfeiffer* and Tanker *Polar Endeavor*

ABSTRACT

The Great Lakes Ballast Technology Demonstration Project is a joint U.S. and Canadian cooperative project which recently funded three 6-month, full-scale design studies of promising ballast water treatment systems. The intent of each study is to fully develop, for a specified "target" vessel, the contract design and life-cycle cost of a reliable, optimized flow-through, on-board treatment system that effectively removes living organisms from the ship's ballast water before it is discharged into an ecosystem other than its original source. The authors address two of these three studies, selecting two different kinds of target vessels. These ships represent classes of vessels typically involved in ballast water discharge in the ports and waterways of the U.S. West Coast, Hawaii and Alaska. This is one of the first efforts devoted to developing contract design level technical solutions, quantifying life-cycle costs and assessing actual vessel operational impacts on effective ecosystem maintenance.

INTRODUCTION

Introduction of nonindigenous species to new environments is one of the greatest threats to the world's coastal waters. Ballast water is a major contributor to the transfer of harmful organisms and pathogens. Potential economic impacts and impacts on human health and the ecology are very significant and cannot be ignored.

A substantial amount of scientific study has been devoted to the problem of invading species that are carried in ships' ballast water. The solutions to the problem are simple in concept, but complex in execution. These solutions are illustrated in Figure 1 below. Most maritime professionals agree that ballast water exchange, which is currently the only officially recommended method for limiting the transfer of organisms in ballast water, has many limitations and is not the long-term answer. Effective ballast water treatment methods must, therefore, be developed and their efficacy established. The installation engineering of these systems as applied to specific ships is the focus of this paper and will be part of a larger project report.

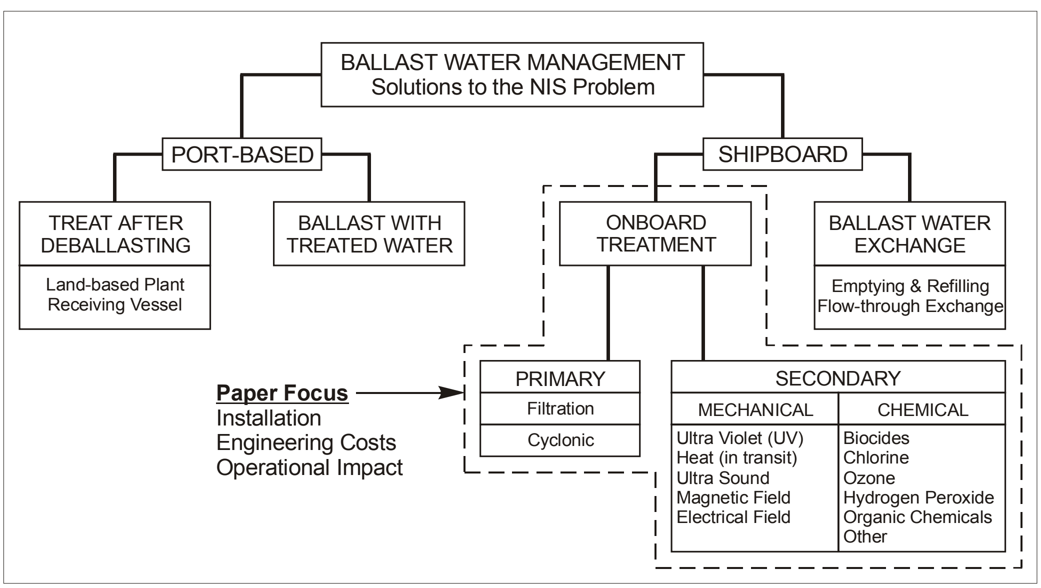

Figure 1. Paper Focus (Chart Originated in [1])

Table 1. Summary of Studies					
Target Vessel				Treatment System	
Ship Name, Type and Owner	Ballast Rate	Ballast Capacity	Route	Primary Treatment	Secondary Treatment
M/V Polar Endeavor (Millennium Class), Polar Tankers, Inc.	Two (2) @ 2,860 m^3/hr (12,600 gpm); (main system)	60,700 m^3	TAPS Trade – Alaska & U.S. West Coast	Cyclonic Separator*	Ultraviolet Radiation*
M/V R. J. Pfeiffer 2,420 TEU Containership, Matson Navigation	Two (2) @; 350 m^3/hr. (1540 gpm); (Only one pump is used for ballasting)	14,600 m^3	U.S. West Coast and Hawaii	Cyclonic Separator**	Ultraviolet Radiation
*Treatment System for *Polar Endeavor* includes a chemical treatment option.					
**Primary Treatment System for *R.J. Pfeiffer* includes MicroKill filters with automatic backflush as an alternate.					

The Great Lakes Ballast Technology Demonstration Project (GLBTDP) [2, 3], led by the Northeast Midwest Institute and the Lake Carriers' Association, has made an important step in the process of moving toward control of invasive species. It seeks operationally sound and biologically effective ballast water treatment solutions, going from the science and study stage to the engineering stage by applying the science to specific, full-scale installations – with the objective of assessing engineering practicalities and cost.

GLBTDP contracted with Herbert Engineering and The Glosten Associates – two leading Naval Architecture and Marine Engineering design firms experienced in conducting design studies, developing contract plans, and preparing packages for regulatory review and approval. Hyde Marine supported the studies with equipment definition. Ship owners Polar Tankers, Inc., (previously ARCO Marine, Inc.) and Matson Navigation supported the effort at no cost. These ship owners have a real interest in installing treatment systems in their vessels. Addressing owner preferences was a very important part of the study.

Two design studies addressed the application of specifically selected systems to target vessels by retrofitting ballast water treatment systems into these existing ships. It is anticipated that designing treatment systems for new construction will be significantly less expensive than the retrofits presented in this study.

Although generic treatment system types were selected for the study, specific equipment was identified and integrated into the ship systems' designs, and firm equipment prices were used in the cost estimates. System performance data presented in this paper are based on manufacturer claims, but some of the systems have been previously tested and evaluated.

Table 1 briefly describes the primary treatment systems and targeted vessels selected for each of the two studies. Complete details of the treatment systems and vessels can be found in the following sections.

TREATMENT SYSTEM REQUIREMENTS

Goals

Each design study provides a reliable on-board treatment system that "effectively" removes living organisms from shipboard ballast water before it is discharged into an ecosystem other than its original source. Moreover, each design study develops a treatment system that aims towards the optimization of the following GLBTDP goals:

- Maximizes killing and/or inactivation of living organisms from the target vessel's ballast water.
- Meets demands of the shipboard marine environment.
- Minimizes operational changes to the vessel's existing ballast management processes.
- Fits within normal and existing operational procedures of shipboard personnel and imposes minimal additional workload.
- Minimizes adverse effects on environment.

- Minimizes extent and physical impact of modification to the vessel.
- Minimizes initial capital as well as life-cycle and long-term operational costs.
- Meets the existing safety standards of the industry, regulatory bodies and the target vessel operating company.

Biological Sampling and Equipment Monitoring

The systems must be designed to provide the following sampling and monitoring features:

- Routine monitoring and sampling to ensure proper system operation.
- Initial extensive sampling for biological evaluation to verify installation.
- Automated operation and alarm.
- Reporting and data logging features.

SELECTED TREATMENT SYSTEMS

There is currently a wide variety of possible treatment options for ballast water [4]. Treatment systems were selected for this study that have either undergone testing and evaluation and have some documented results, or were requested for investigation by the ship owner.

Cyclonic Separator

An in-line flow-through cyclonic separator (CS) separates and removes suspended sediment from ballast water passing through the system. Past studies and testing have shown that cyclonic separation will remove entrained particles that are heavier than seawater [5].

Cyclonic separators are passive devices that allow the separation and removal of larger and heavier solids with some associated pressure drop added to the system. A major advantage of a CS is that there are no moving parts, and it is therefore highly reliable. There are some disadvantages as well. The CS will not remove materials with densities less than or equal to the ballast water. It also cannot handle significant differences in flow rate and will lose its effectiveness if the flow rate is reduced and the vortex collapses.

The CS requires a backpressure valve to build pressure to force the solids to discharge overboard against the static head of the ship during ballasting.

These separators are particularly suitable on the ballast intake cycle where the separated particles can be discharged back into the harbor of origin with an estimated 5 to 10% of the pumped water.

Cyclonic separators can be scaled in size to even the largest ballast pumping rates of ships.

Ultraviolet (UV) Light Treatment

The second stage treatment irradiates the "clean" ballast water processed through the cyclonic separator via application of UV light to the water stream. UV irradiation is currently available and has been demonstrated to kill or deactivate biological organisms, viruses and bacteria. The irradiation can be accomplished during both ballasting and deballasting. A UV unit has been installed on a ship specifically to treat ballast water, and UV units have undergone study and a full scale evaluation [5].

New units are under development with increased irradiation intensity to increase effectiveness in turbid water with transmittances as low as 30%.

The UV light units have the following positive attributes:

- Long history in marine industry with proven use in other shipboard applications.
- Readily available on the market.
- Low maintenance, easy lamp replacement.
- High and low flow rates available.
- Small pressure drop and simple piping modifications allow treatment in both ballast and deballasting operations.
- Capable of electronic monitoring/alarms.
- Compact size – 3,500 m^3/hr flow rate unit is about 2 meters long by 1 meter in diameter.

Filtration with Backflush

In-line filters have been tested and results and efficacy are reported in references [3] and [5]. Key technical issues and conclusions are:

- A 5 mm prescreen should be used upstream to protect finer filter screens.
- Automatic backwash is required and should be implemented during ballasting.
- A screen size of 50 microns is necessary; however, up to 100 microns size may be satisfactory if used with UV treatment.
- Filtration improves ballast water clarity.

Filtration with backflush may be a necessary component in the system if the ecosystems contain organisms that are known to be resistant to the UV irradiation levels selected. It is also a viable alternate to the cyclonic separator, and is particularly advantageous in vessels with lower ballast rates (less than 500 m^3/hr). In this regard, we reviewed current filtration technology being evaluated by the GLBTDP, plus at least two other filter technologies. Of these, the MicroKill filter was identified for this study.

Backflush filtration requires high pressure and flow capability to overcome filter resistance on existing ships. This design feature could require changing ballast pumps, or reducing the overall throughput rate due to the nature of the backflush action.

To retain the ballast throughput rate, external sources such as the ship's firemain or seawater service system, perhaps backed up by compressed air, could be used to backflush the filters. The backflush liquid, which should be minimal, can be pumped directly overboard during ballasting, or at the end of the ballasting period, using a separate pump or eductor. Backflush collection tanks and independent pumps can be provided.

On larger vessels, backflush filters are much more expensive than cyclonic separators, both for first cost and in operation.

Chemical Treatment

Chemical treatment is a potential secondary, tertiary or stand-alone treatment system that could be used in conditions where the primary and secondary systems of separators with UV or filters with UV are not effective. Chemical treatment does carry with it potentially onerous hurdles such as storing, handling and dosing the material on board ship, and gaining approvals for use and application.

Chemicals proposed for ballast water treatment include SeaKleen, glutaraldehyde, acrolein, hypochlorite and ozone, among other candidate treatments. Chemicals can be added using existing injection technology.

Chemical treatment considerations that need to be addressed include, among others: toxicity implications, efficacy, product availability, ecosystem damage and political acceptance. This study looks at equipment and materials compatibility and practical application of the technology with minimal cost.

TARGET VESSELS

Two ship types were selected to represent major vessel types and operations on the West Coast: the TAPS trade tanker and the containership. The new Polar Tankers' *Polar Endeavor* (Fig. 2), the first delivery of the Millennium Class, was selected as the tanker for the study, and the existing Matson containership *R.J. Pfeiffer* (Fig. 3) was selected as the containership.

Ship owners Polar Tankers, Inc., and Matson Navigation supported this project. Their ships call at U.S. ports including some of the most sensitive areas such as San Francisco, Puget Sound and Valdez, Alaska.

Polar Tankers, Inc., is currently operating a fleet of tankers in the U.S. domestic trade between Alaska and the U.S. West Coast.

Matson Navigation is a U.S. domestic carrier operating a fleet of containerships between the West Coast and Hawaii.

Design Study #1 – "Other Vessel of 10,000 MT Displacement or Greater"

Vessel Name	*M/V Polar Endeavor*
Vessel Type	125,000 DWT Crude Oil Carrier
Year Delivered	2001 (new building)
Owner/Operator	Polar Tankers, Inc.
Length Overall	272.69 m
Beam	46.20 m
Depth	25.30 m
Draft	16.31m
Deadweight	127,005 MT
Ballast Capacity	60,700 m^3 (55,000 m^3 used for heavy ballast condition)
Number of Ballast Tanks	6 pairs main tanks + 1 focsle tank + 4 aft tanks
Ballast Pumping Capacity	2 at 2,860 m^3/hr, main pumps 2 at 1,000 m^3/hr, aft pumps

Characteristics of *Polar Endeavor*:

1. Large volume of ballast and large pumping capacity with both pumps typically in use for ballast operations. Excellent comparison with other target ship types with lower ballast pumping requirements.
2. Dependence on gravity feed for loading and discharging ballast for operational efficiency.
3. Because of its trade routes between Puget Sound and other West Coast ports and Prince William Sound (PWS), it ballasts and deballasts in environmentally sensitive ports.
4. Could be a candidate for incentives (from the California State Lands Commission and the State of Washington Aquatic Nuisance Species Coordinator) to install the proposed system.

Figure 2. ***M/V Polar Endeavor***

Figure 3. ***M/V R.J. Pfeiffer***

Design Study #2 – "2000 TEU or Greater Containership Regularly Calling at U.S. Port"

Vessel Name	*M/V R.J. Pfeiffer*
Vessel Type	2,420 TEU Containership
Year Delivered	1992
Owner/ Operator	Matson Navigation Company
Length Overall	217.47 m
Beam	32.21 m
Depth	20.27 m
Draft	11.58 m
Deadweight	28,758 MT
Container Capacity	2420 TEU
Ballast Capacity	14,600 m^3
Ballast Tanks	26
Ballast Pumping Capacity	2 at 350 m^3/hr

Characteristics of *R.J. Pfeiffer*:

1. This vessel is a typical Panamax containership with ballast in the double bottom and wings used to maintain stability as well as control trim and list. It was selected over post-Panamax sized vessels because the larger vessels have much more flexible ballasting options and can often avoid port discharge through careful planning.
2. Only one ballast pump is used at a time providing a flow rate of 350 m^3 per hour.
3. The required system capacity is essentially identical to the system installed on the GLBTDP barge [2, 3].
4. Because of its trade routes on the U.S. West Coast and in Hawaii, it ballasts and deballasts in environmentally sensitive ports. Biological data for these ports are readily available.
5. Could be a candidate for incentives (from the California State Lands Commission and the State of Washington Aquatic Nuisance Species Coordinator) to install the proposed system.

DESIGN SUMMARY – *POLAR ENDEAVOR*

Vessel Ballast System Characteristics, Ballasting Practices and Common Port Calls

Polar Endeavor is entering service this year in the Trans-Alaska Pipeline System (TAPS) trade on the West Coast. The ship is designed to deliver North Slope crude oil from Valdez, AK, to the U.S. West Coast ports in Puget Sound, San Francisco, Long Beach (CA) and Hawaii.

There are two ballast systems on the vessel: the primary system consisting of two 2,860 m^3/hr (12,600 gpm) pumps serving the six pairs of forebody tanks and a single forepeak tank (both main pumps are typically used simultaneously); and the aft ballast system consisting of two smaller pumps serving four small tanks in the aft end of the vessel. The primary system also has an eductor system for stripping the forebody ballast system, and the aft ballast system is used to control trim and list.

Tanker ballasting operations are characterized by moving large volumes of ballast each trip. The ship must have a minimum draft when not carrying cargo to control hull stresses, provide good seakeeping and maneuvering, and provide propeller submergence.

Deck officers, or mates, perform the ballasting operations from the cargo control room. Pumps and valves are controlled by the ballast control system, which is part of cargo control.

"Gravitating" ballast is an important component of the ship's ballasting operations. Gravitating is allowing water to flow into or out of the tanks using the head differential between the tank level and the outside water level, and not using pumps. The ability to gravitate reduces the owner's cost because of reduced pump operating time, and provides simpler and more efficient operations for the crew.

The timeline (Table 2) roughly describes the anticipated operations of the vessel, without consideration of ballast water treatment.

Gravitating ballast is not possible in a treatment system using a cyclonic separator. The head differential used to gain the flow is not adequate to overcome the additional resistance imposed by the separator. Without gravitating, additional pump time is necessary. Additionally, pumping time is extended further due to the added resistance in the system and reduced flow rate, as well as the lost 5 to 10% capacity due to the sludge return from the cyclonic separator.

Table 3 summarizes the impact on ballast pump times. These data were developed using a piping system flow model of the *Polar Endeavor*'s ballast system that accounts for the changing tank levels during the pumping operation, the resistance of each component and the actual pump performance curve.

Increased pump usage is accounted for in the life cycle cost study in terms of pump maintenance increase and fuel cost associated with the additional electrical power generation.

One could presume that overall ship operation timelines would not be affected because pumping ballast will always be faster than gravitating ballast; however, because of ship's generator power limitations, ballast pumps cannot operate simultaneously with full output of cargo pumps. If the CS and UV were installed, the 5 hour increase in ballast pumping time would have to occur during the 8 hours of transit time outbound from the refinery to the sea buoy. There is potential for the vessel schedule to be affected. Arriving in Prince William Sound, the vessel could still gravitate on the ballast discharge, as the water was treated on the intake. However, as the system is currently designed, this operation would bypass the second UV treatment on the discharge.

Table 2. Vessel Operations Timeline – Anticipated

Time	Event
Day 1 Hour 0	Enter Puget Sound at Cape Flattery with 125,000 dwt tons of oil at a 44 foot draft, no ballast on board.
Day 1 Hour 8	Dockside, at the Puget Sound refinery, ballast is allowed to free-flood into the forebody tanks as cargo discharge begins.
Day 1 Hour 18	The free-flood rate diminishes as the ship draft decreases, and ballasting operations are suspended. 29,000 tons of ballast is taken on by gravitating in this 10 hour period.
Day 2 Hour 2	Cargo discharge is completed in a total of 18 hours of pumping. With power available for ballast pumps, they are started in order to finish ballasting.
Day 2 Hour 10	After 8 hours of pumping, main ballast tanks are loaded to the *normal ballast condition*. Ship departs with 50,300 tons of main ballast on board. Aft ballast tanks are empty.

Time	Event
Day 2 Hour 18	Ship clears Cape Flattery buoy heading northbound.
Day 3 Hour 12	Ship encounters heavy weather and mates take on 3,300 tons of ballast in the aft tanks, 2,200 in the focsle tank and 4,300 in the #6's to get to the *heavy ballast condition*, with a total of 60,100 tons of ballast.
Day 6 Hour 6	Ship arrives at Cape Hinchinbrook, entrance to Prince William Sound, and with a low sea state is able to gravity-drain ballast.
Day 6 Hour 12	Vessel arrives at Valdez, and begins taking on crude oil. Both main ballast pumps are started to discharge ballast. 21,750 tons are discharged by gravitating.
Day 6 Hour 20	Ballast tanks are empty, cargo loading continues. 38,350 tons are discharged by the main ballast pumps.
Day 6 Hour 22	Cargo tanks full, ship departs southbound to Puget Sound.
Day 10 Hour 10	Enter Puget Sound at Cape Flattery.

Table 3. Ballast Pumping Time Comparison Filling Tanks with Cargo Discharge at Puget Sound Refinery – *Polar Endeavor*

Procedure	Gravitating Time (Free Flooding)	Pumping Time	Total Ballasting Time
Gravitating and Pumping, no Separator / UV treatment	10.2 hours	7.5 hours	17.7 hours
Pumping Only, no Separator / UV Treatment	–	10 hours	10 hours
Pumping Only, with Separator / UV Treatment	–	12.3 hours	12.3 hours

Polar Endeavor Treatment Philosophy and Functionality

We have selected treatment systems that either have demonstrated effectiveness (or look to be the most promising of the existing treatments) and that have the capacity to support the vessel's large ballast system with minimal impact on operations. For example, we are using cyclonic separators instead of filters because the ballast system rate is high for fine filtration applications.

To provide design and operational flexibility and so that various water contamination problems can be treated, we have also specified redundant systems and different types of systems. These different treatment systems have been estimated and engineered separately, but can be combined in a number of ways depending on:

- Final rulings from the regulatory bodies on acceptability of equipment.
- New efficacy information that comes available.
- New regulations that come into force.
- Owner preferences.

The main and aft ballast system primary treatment is in three stages. The first stage is to treat the ballast as it is taken aboard by separating heavier particles with a cyclonic separator unit. The sludge is immediately discharged back into the harbor of origin. The secondary treatment irradiates the cleaned water with ultraviolet light to kill or inactivate the organisms in the water. Interference with UV irradiation is reduced by separating solid particles before entering the UV unit. Since surviving organisms may multiply while in the ballast tank during the voyage, the third stage irradiates the water again when discharged in the receiving harbor.

An optional chemical treatment system is provided as either a fourth stage, an alternate secondary treatment, or a stand-alone alternate treatment. Incoming ballast water can run through the cyclonic separator and the UV, and then also be treated chemically, or the cyclonic separator and UV can be bypassed and the water only treated chemically.

If incoming ballast water is clean and without solids, the cyclonic separator can be bypassed and water run only through the UV. It is not possible in this system design, however, to run water through the separator and bypass the UV unit, although the UV can be de-energized and water flow through without irradiation.

Both the main and aft ballast systems will have this functionality. Each of the four pumps has an associated separator and UV unit; however, one chemical tank serves the four possible ballast supply lines with four separate dosing pumps. The aft system is smaller in scale and capacity than the main system, matching the aft ballast pump capacity.

An eductor system has the capability to strip the ballast tanks and pump directly overboard. Hence a fifth UV unit is provided in that discharge line to provide the third stage treatment – irradiating water flowing through that system as it may be discharged in the receiving harbor.

Description of *Polar Endeavor* System Equipment

The following treatment equipment was selected for installation in the *Polar Endeavor*:

<u>Main Ballast System, Capacity 2860 m^3/hr x 2 pumps</u>

- Cyclonic Separators (2): MicroKill Model 3000 (Capacity 2,700 to 3,200 m^3/hr)
- UV Light Treatment (2): MicroKill UV Model MP600-08-7300 (Capacity 3,000 m^3/hr @ 120mWs/cm^2)

<u>Eductor System, Capacity 500 m^3/hr</u>

- UV Light Treatment (1): MicroKill UV Model MP300-02-2500 (Capacity 500 m^3/hr @ 50mWs/cm^2)

<u>Aft Ballast System, Capacity 1000 m^3/hr x 2 pumps</u>

- Cyclonic Separators (2): MicroKill Sep Model 1000 (Capacity 800 to 1200 m^3/hr)
- UV Light Treatment (2): MicroKill UV Model MP300-04-2500 (Capacity 1000 m^3/hr @ 50mWs/cm^2)

<u>Chemical Treatment, Capacity to treat 60,000 tons ballast at 5,720 m^3/hr ballast rate.</u>

- SeaKleen Chemical Treatment System: One 200 gallon tank with four feed pumps, each sized for 30 liters per hour. Tank's 200 gallon capacity is sized for chemical volume required to treat full 60,000 m^3 ballast volume of ship.

Polar Endeavor Equipment Installation Issues

Equipment installation in *Polar Endeavor*, and potentially in all tankers, is complicated because the ballast piping, pumps and valving are all located in the pump room, which is a hazardous area. The pump room also happens to be the most crowded, densely packed space on the vessel.

In addition, it is probably not possible to install a UV unit in that space because it would introduce electrical equipment and its wiring in a hazardous area. Electrical equipment in hazardous areas is not allowed unless "essential for operation purposes." The electrical equipment that can be allowed in the pump room must be intrinsically safe, and so far an intrinsically safe UV unit is not available.

There are three potential solutions to the problem: 1) Route the ballast piping out of the pump room up into a small UV unit compartment accessible from the engine room and install the UV unit in that space. 2) Continue in the development of an intrinsically safe unit and also gain acceptance from the regulatory bodies that the unit is essential for operation purposes. (OptiMarin has applied to DNV for certification as explosionproof and intrinsically safe).
3) Drop the UV unit and proceed with other alternatives.

Option 1 would be the best choice, but it is not easy to accomplish given the pump room space arrangements and physical size of the piping. Also, there are still potential regulatory problems as the ballast piping could be considered to pass through spaces where sources of ignition are present. This alternative is shown in Figure 4.

Additionally, although the lamps are isolated from the internal volume of the ballast piping with quartz sleeves, the internal piping may also have oil vapors when dry. This problem can be addressed by installing a flow sensor on the piping that does not allow the UV unit to be energized unless the pipe is full of flowing ballast water.

We have proceeded with developing the contract plans for the installation, and the UV unit is included in the drawings pending approval from the American Bureau of Shipping (ABS) and the U.S. Coast Guard and pending development of a unit that can be approved for use in pump rooms.

The aft ballast systems are much easier to install because the components can all be in the spacious enginerooms, and not be subject to the space and hazardous location constraints of the pump room. System diagrams are provided and the arrangement of the aft ballast system in the enginerooms can be developed and detailed by the shipyard.

The chemical treatment system is the simplest and least-cost installation and requires very minor storage facilities and tank volume. However, before discharge of the chemical is accepted, approval of all regulatory bodies (federal, state and local) is required. The regulatory approval process may be long, and may not be resolved by completion of this study – hence the optional nature of this chemical treatment system.

SeaKleen is the chemical identified for this study; the following engineering, design and cost information is used in this report:

- The chemical is a water-soluble powder. One kg of powder is mixed with 10 kg of water, which treats 1,000 metric tons of seawater.
- To treat 60,000 metric tons of ballast we would need 60 kg (132 lb) of powder mixed in 600 kg (1,322 lb or 160 gal) of fresh water.

- SeaKleen is a natural biocide, relatively safe compared with other chemicals. It has no particular storage or handling problems or unusual safety concerns.
- Toxicity diminishes over time so that it is relatively benign by the time the vessel reaches the ballast water receiving port and is ready to discharge ballast.
- Current cost estimates from SeaKleen indicate about $0.20 per ton of seawater treated, based on laboratory production of the chemical. This equates to about $200/kg of dry chemical. The final cost may be as low as one-half this cost, which is addressed later in life cycle cost estimates.

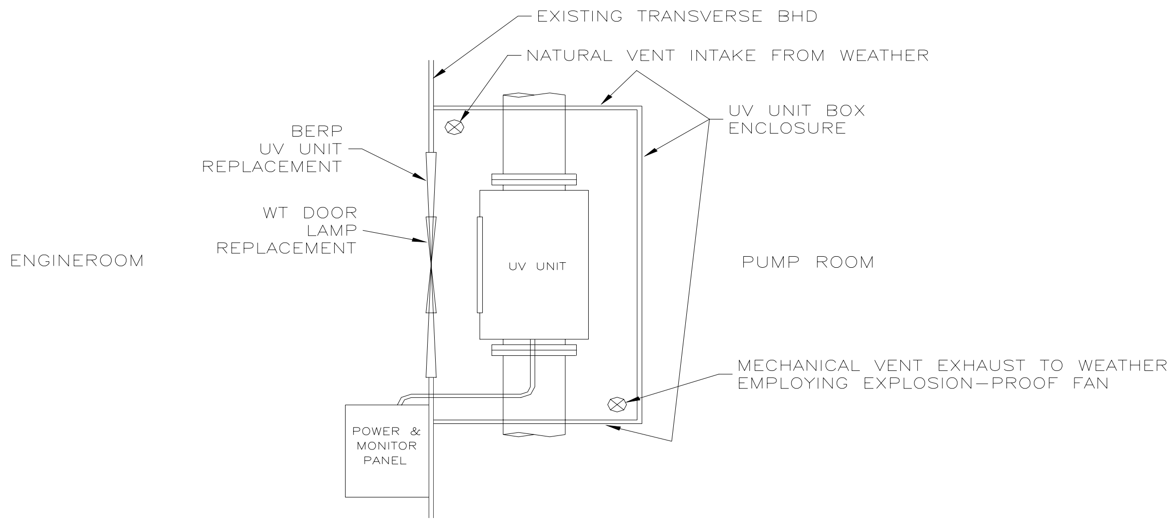

Figure 4. Alternate UV Unit Location

The chemical must be mixed just before ballasting, as degradation of the biocide begins as soon as it is mixed with water. A 200 gallon tank is specified because the chemical is mixed for each trip. A storage area is required, suitable for 900 kg (2,000 lb) of dry, powdered SeaKleen, which is adequate for about 15 trips. The entire system will be installed on one or two of the flats in the vertical access above the pump room.

SeaKleen may be manufactured in pellets, which would make it easier to store and use.

System Setup, Operation and Equipment Monitoring

Ballasting operations will become significantly more complex for the ship's crew, although nothing that cannot be accommodated. Ballasting operations and monitoring would include:

Operation of the cyclonic separator: Exit pressure is automatically monitored and the backflow pressure valve automatically adjusted with the changing draft of the ship. The sludge line will have a flow meter, and much of the other monitoring can be done with the automatic control and monitoring system.

Operation of the UV unit: Operation of the UV unit is set up to be automatic. Initial energizing of the unit at the controller will be linked to the ballast pump startup, and final energizing will be linked to the flow meter in the piping. The light transmittance is monitored and recorded, along with temperature. The unit control panel logs the data, and a summary alarm is added to the ship's machinery monitoring system to indicate if ballast is flowing but transmittance level is below threshold.

Operation of the chemical treatment system: Operation of the system is relatively automatic, with most of the impact on the crew occurring in the setup of the system and mixing of the chemical. The proportioning pumps will be energized in conjunction with the corresponding ballast pump. Chemical flow will be monitored and again alarmed if the flow rate is below specification.

Mixing of the chemical in the nurse tank, although relatively simple, will be a new operation for most crews. First, approximately 0.6 m^3 (160 gal.) of fresh water is metered into the tank. The chemical tank will have a sight glass for level indication. Then 60 kg (132 lb) of powder (or pellets) is added through a hatch in the top of the tank. The dry chemical will be stored in an expanded metal cage adjacent to the tank. Access platforms and fixtures to aid in the pouring of the chemical will be provided.

Given the sensitivity of the chemical dosage and short duration of its effectiveness, a dry chemical dispensing system should be developed, to dispense 10 kg at a time with a coordinated metering of 100 kg (27 gal) of water.

For automatic dispensing of the chemical into the ballast tanks when gravitating, a second dispensing rate will need to be determined so that, at the end of the gravity fill, the proper amount of chemical will have been added.

Sampling and Treatment Performance Monitoring

Means must be provided to sample the ballast water on board to determine treatment effectiveness. It is intended that the ship's crew will perform this function, but on occasion a trained science technician will come aboard to test the efficacy of the system. Sampling ports are provided in three places: incoming ballast before the cyclonic separator, outgoing ballast after the UV treatment, and at the sludge discharge.

A simple test kit will have to be developed and supplied to ships' crews, and they must be trained in its use.

System Maintenance

Maintenance of the ballast water treatment systems specified is relatively low. There is no maintenance on the cyclonic separator, and the UV unit only needs lamp replacement and occasional calibration of the light intensity monitoring equipment. The chemical treatment system also may require little maintenance.

A section that follows on life-cycle costs includes the effect of the system on ballast pump maintenance (from increased usage).

Personnel Training and Safety

The proposed systems do not present any particularly problematic training or safety issue. The systems are much less complex than many of the other systems on the vessel. Safety issues relating to the handling and storage of the chemical are minor. Coveralls, gloves and face masks will be all that is necessary.

Polar Endeavor Shipyard Scope of Work

The treatment systems on the *Polar Endeavor* are divided into four areas of work. The owner can select these components for implementation either individually or collectively. They are:

1) *Main ballast system cyclonic separators*. The ballast system piping will be modified to install the cyclonic separators (two, one for each ballast pump) as shown on the drawing, including its foundation, sludge lines and new dedicated overboard discharge. New hydraulic actuated valves will be installed with control integrated into the ship's ballast valve control system.
2) *Main ballast system UV light treatment units*. The ballast system piping will be modified to install the UV units (three total), as shown on the drawing, including foundation, control panel and power panel. Electrical power (480 VAC 60 kW each for the two main units and 5 kW for the eductor unit) will be fed from an auxiliary machinery power panel, and control and monitoring wiring will interconnect the equipment with the ship's alarm system. New hydraulic actuated valves will be installed with control integrated into the ship's ballast valve control system.
3) *Aft ballast system cyclonic separators and UV units*. The aft ballast system piping will be modified to install cyclonic separators (two) and UV units (two), as shown on the drawing, including foundations, sludge lines, and new dedicated overboard discharge line. All equipment will be installed in the two main enginerooms, port and starboard. The new hydraulic valves will be remotely controlled by the cargo control system. Alarm and monitoring systems will be modified to allow the new inputs.
4) *Chemical treatment system*. The fresh water system will be extended to a flat in the vertical access above the pump room, where a 200 gallon fabricated tank will be installed. The fresh water piping will be arranged to meter into the tank (an air gap must be provided). On the level above the tank the dry chemical storage area will be fabricated of expanded metal cage. The tank will have a hinged hatch in the top for adding the chemical. Independent supply piping will run to each of four air-powered

diaphragm pumps for injecting the chemical, and chemical feed piping will run to the designated ballast mains.

Installation Cost Estimating Assumptions and Data

A budgetary cost estimate was developed for this study, which is intended to be confirmed by a shipyard quotation. An in-house historical cost database was used to generate the estimate. Typical estimating assumptions were made as follows:

- Shipyard labor rate of $50/hr.
- Shipyard engineering cost about 15% of the installation cost.
- Material markup of 15%. This is a fairly standard value among most yards.
- Estimating contingency of 12%. This value is appropriate for this contract design level, particularly since we have firm quotations for the treatment equipment.

A summary of the estimate is provided in Table 4.

Life Cycle Cost Analysis Assumptions and Data

The method for calculating life cycle costs is presented as follows:

Life Cycle Cost is the overall estimated cost for the particular modification over the assumed remaining life of the ship, including direct and indirect initial non-recurring costs plus any periodic or recurring costs of operation and maintenance. Life cycle cost is simply the sum of the projected cash flow over the life of the ship, including assumed inflation rates that vary with the cost components.

Present Value of the Life Cycle Cost is the present worth or value of the projected cash flow assuming a discount rate.

Discount Rate is the nominal interest rate that the owner may expect to obtain if he were to invest the same money at t=0 in an income producing venture, either in other internal company projects or in external investments. This is a highly variable number. It will vary among owners, as well as depend on prime interest rates at the time, projected profit margins for the company, and target corporate rate of return.

Uniform Equivalent Annual Cost is the present value of the life cycle cost distributed over the life of the ship using the same discount rate, so that each year has a equal cost. This is also known as the average annual cost (AAC).

The following assumptions were applied in the life cycle cost analysis for the *Polar Endeavor*:

- Life of the ship: 30 years
- Hypothetical discount rate: 8%
- Shipboard crew labor rate,
  direct + indirect: $50/hr
- Inflation rates
  Fuel and Chemicals: 3.0%
  Labor: 5.5%
  UV lamps and parts: 4.0%
- Increased ballast pump usage was calculated as described earlier, including: the effect of non-gravitating, the increased head in the system from the CS's, a 5% increase in total pump volume required to fill the tanks due to the sludge discharge of the CS, the increase in pump maintenance and the increased fuel consumption for generating electrical power to drive the pumps.
- UV lamps have a 1000 hour life, and their material cost as well as the labor cost of replacing the lamps is included. UV units are energized for both the ballasting and deballasting operations.
- The increased fuel consumption for generating UV unit electrical power is included.
- The cost of the chemical additive is included on a per-ton basis, assuming 2 hours of labor each trip to handle and mix the chemical.
- Polar Tankers reports they have no significant problems with the accumulation of mud in the ballast tanks of TAPS trade tankers, so there is no cost savings associated with reducing mud in the tanks.

The results of life cycle cost analysis for the *Polar Endeavor* are presented in Table 5.

Table 4. Installed Cost Data – *Polar Endeavor*					
Item	**Material Cost**	**Labor Cost**	**Material Markup**	**Contingency**	**Total**
1. Main Ballast System Cyclonic Separators	$321,000	$83,000	$48,000	$39,000	$491,000
2. Main Ballast System UV Light Treatment Units	$427,000	$181,000	$64,000	$73,000	$745,000
3. Aft Ballast System Cyclonic Separators and UV Units	$474,000	$135,000	$71,000	$73,000	$753,000
4. Chemical Treatment	$38,000	$22,000	$6,000	$5,000	$71,000

Table 5. Life Cycle Cost Data – *Polar Endeavor*			
Item	**Life Cycle (LC) Cost**	**Present Value of LC Cost**	**Uniform Equivalent Annual Cost (AAC)**
1. Main Ballast System Cyclonic Separators	$726,000	$561,000	$50,000
2. Main Ballast System UV Light Treatment Units	$1,530,000	$815,000	$72,000
3. Aft Ballast System Cyclonic Separators and UV Units	$1,049,000	$832,000	$74,000
4a. Chemical Treatment @ $0.20 / ton	$10,233,000	$3,583,000	$318,000
4b. Chemical Treatment @ $0.10 / ton	$5,353,000	$1,884,000	$167,000

Cost Scenarios

The life cycle cost data can be combined in various ways, depending on final owner decisions on implementation, and in consideration of the latest data on treatment effectiveness of the various systems. For example purposes, we assume the following hypothetical scenario:

- Install the cyclonic separators in the main ballast system as primary treatment.
- Do not install the UV units in the main ballast system because regulatory acceptance for the installation is not in place.
- Install the chemical treatment system for use in the main ballast system. Assume that the regulatory agencies have approved its use and cost is $0.10 / ton ballast water.
- Install the aft ballast system – separator and UV units, because installation is simpler and relatively cost effective.

Table 6 presents the cost data for this scenario. While *present value cost* in $/ton is one cost measure, it is important to note that this cost will vary greatly among ships even when the same system type is installed in the same ship type. Economic factors such as life of the ship and the owner's particular discount rate have a significant impact on the resulting number.

Table 6. Hypothetical Scenario Cost Summary – *Polar Endeavor*			
Item	**Installation Cost**	**Present Value of Life Cycle Cost**	**Uniform Equivalent Annual Cost (AAC)**
1. Cyclonic Separators in Main Ballast System	$491,000	$561,000	$50,000
4b. Chemical Treatment System (@$0.10/ton)	$71,000	$1,884,000	$167,000
3. Aft Ballast System	$753,000	$832,000	$74,000
Totals		$3,277,000	$291,000
Tons of Ballast Pumped (Life Cycle and AAC)		43,056,000	1,435,200
Cost/Ton (Life Cycle and AAC)		$0.08	$0.20

DESIGN SUMMARY – *R.J. PFEIFFER*

Pfeiffer Ballast System Characteristics, Ballasting Practices and Common Port Calls

R.J. Pfeiffer trades on the U.S. West Coast and in Hawaii, ballasting and deballasting to maintain stability and control trim and list. Typical port calls include Long Beach, Oakland, Seattle and Honolulu. *Pfeiffer* has a total ballast capacity of 14,300 m^3 as compared with the 60,000 m^3 of *Polar Endeavor*, but the ballast can be loaded into 26 different tanks compared with 17 in *Endeavor*. The *Pfeiffer* is outfitted with a separate heeling pump and two dedicated wing tanks, one port and one starboard, to adjust for adverse heel associated with unbalanced cargo loading conditions.

Pfeiffer carries ballast in the full-load condition for stability and in a partial load condition for trim. Currently, the ship's ballast system does not have the capability to transfer ballast between tanks. As a result, ballast water is discharged to the sea when tanks are deballasted even though new ballast water may be brought into other tanks to reach the desired load condition. If possible, ballast adjustments are made at sea prior to arriving, in anticipation of the expected loads, or after departing the port. Some ballasting may be necessary during container loading and unloading operations. A review of previous voyages indicates that a total of about 400 to 500 tons may be loaded in multiple ports during a typical round-trip voyage. Most ballast discharged in port is deep ocean water.

Unlike the *Polar Endeavor*, *Pfeiffer* does not utilize gravity flow ballasting, and the added pump energy to overcome the added pressure losses is negligible in this size range, particularly given the smaller quantities pumped. Increase in ballasting time is only the amount to make up for the sludge discharge, which is accounted for in the life cycle costs (there is a minor amount of added fuel for the added power generation) but has no impact on the ballast operations.

Treatment Philosophy and Functionality

We have selected treatment systems that have demonstrated effectiveness for this study. The initial plan, based on the results from the Great Lakes testing [3, 5] was to pursue a filter system with automatic backflush as the primary treatment and a UV light unit as the secondary system. However, the cyclonic separator was chosen as the preferred primary treatment because of the mechanical simplicity of the separator as compared to the filters. The actual shipboard maintenance costs for the filters are also not yet fully understood. The separator also fits better into the engineroom arrangement.

Normal ballasting operations require the use of only one pump, so only one treatment system, consisting of separator and UV unit, is needed.

Both the separator and the UV system are sized to the 350 m^3/hour (1,500 gpm) capacity. The system is designed so that ballast water flows through both the separator and the UV unit when loaded, but only through the UV unit on the discharge. The cross connection to permit transfer of ballast forward and aft (and only forward and aft) would be made on the port side.

While both options are studied, only one is intended for installation.

Chemical treatment is not desired or considered at this time for this vessel.

Description of System Equipment

The following treatment equipment was selected for installation in the *R.J. Pfeiffer*.

- Option 1 (preferred)
  Primary Treatment: Cyclonic Separator, MicroKill Sep, Model SKX350
  Secondary Treatment: UV Light Treatment, MicroKill UV, Model MP300-04-2500
- Option 2
  Primary Treatment: MicroKill Filter, Model 6 x 4" with backflush unit
  Secondary Treatment: UV Light Treatment, MicroKill UV, Model MP300-04-2500

Equipment Installation Issues

Equipment installation on *R.J. Pfeiffer* is relatively simple compared with the *Polar Endeavor*. There are no hazardous space complications, and the engineroom (although not spacious) has available room for the machinery. There are no significant equipment installation issues.

System Setup, Operation and Equipment Monitoring

Ballast operations and monitoring of the cyclonic separator and UV unit are similar to those discussed for *Polar Endeavor,* but the setup, operation and monitoring of the filter system is unique to the *R.J. Pfeiffer*.

The equipment provider has proposed that the *Pfeiffer* filtration unit be continually backflushed as required during the ballasting operation. The backflush process is begun by securing the valves on the input and output side of one filtration element. A separate backflushing pump with a hydrophore tank will be activated and used to manually backflush that element of the filtration unit. The backflush water will be collected in a separate tank and then discharged using a newly installed line to the suction side of the existing bilge/ballast eductor. The actual discharge process could be accomplished either in port or at sea after leaving port. Alternatively, the tank could be emptied automatically using a float activated switch controlling a dedicated pump and a separate discharge pipe line with a hull penetration and appropriate valving.

Particular to the *R.J. Pfeiffer*, and possibly other vessels, it will not be simple to add to the existing alarm and monitoring system. The system is a custom, one-off design that is difficult to change because of lack of vendor support. It will probably be necessary to install independent alarms and monitoring for the ballast treatment system, keeping the monitoring system independent of the main ship system.

Sampling and Treatment Performance Monitoring

Sampling ports will be provided to sample ballast water on board to determine treatment effectiveness, in the same manner discussed for *Polar Endeavor*. See an earlier *Polar Endeavor* section on sampling.

System Maintenance

Maintenance issues are manageable for both options. Issues of UV light intensity calibration and lamp replacement will be the same as on *Polar Endeavor*, with added maintenance imposed by the filter unit. The section on life cycle costs, below, includes the effect of maintenance on ship's crew costs.

Personnel Training and Safety

Training and safety issues are also manageable. See the discussion for *Polar Endeavor*.

Shipyard Scope of Work

The two options for treatment systems on *R.J. Pfeiffer* have separate shipyard work scopes.

Option 1 – Cyclonic separator with UV light treatment unit serving the starboard side ballast pump.

The ballast system piping will be modified to install the cyclonic separator as shown on the drawing, including its foundation, sludge line and new dedicated overboard discharge. New motor operated valves will be installed.

The ballast system piping will be modified to install the UV unit as shown on the drawing, including foundation, control panel and power panel.

Electrical power (approximately 5 kW) will be fed from an auxiliary machinery power panel.

Control and monitoring wiring will interconnect the equipment to the control panel installed in the machinery control room and to the ballast control station in the ship's office on the main deck.

Option 2 – Filter system with UV light treatment unit serving the starboard side ballast pump.

The ballast system piping will be modified to install an Arkal filter system with a separate manual backflush pump and hydrophore tank. The unit will be configured to best fit into the space, providing access to all components.

The backflush holding tank will be installed complete with level indicator signaling automatic startup of the backflush discharge pump. A dedicated overboard discharge piping line with hull valves will be installed.

Power for the solenoid valves will be fed to the unit control panel from a local 120V power panel.

Installation Cost Estimating Assumptions and Data

We applied the same cost estimating assumptions to *R.J. Pfeiffer* as we did to *Polar Endeavor*. A summary of the estimate is provided in Table 7.

Life Cycle Cost Analysis Assumptions & Data

Life cycle cost estimating methods for *R.J. Pfeiffer* are the same as for *Polar Endeavor*, but there are a few differences in the assumptions:

- Remaining life of the ship: 20 years
- Hypothetical discount rate: 8%
- Shipboard crew labor rate, direct and indirect: $50/hr
- Inflation rates
  - Fuel: 3%
  - Labor: 5.5%
  - UV lamps and filter parts: 4%
- UV lamps have a 1000 hour life. Material cost, as well as the labor cost of replacing the lamps, is included.
- The increased fuel consumption for generating electrical power for the UV units is included.
- Cost savings for reduced mud in tanks is considered insignificant in the *Pfeiffer* and is not addressed.

The results of the life cycle cost analysis for *R.J. Pfeiffer* are presented in Table 8. Table 9 gives a summary of cost.

Table 7. Installed Cost Data – *R.J. Pfeiffer*

Option	Material Cost	Labor Cost	Material Markup	Contingency	Total
1. Cyclonic Separator and UV Light Treatment Unit	$159,000	$35,000	$24,000	$19,000	$237,000
OR					
2. Arkal Filter and UV Light Treatment Unit	$179,000	$54,000	$27,000	$28,000	$288,000

Table 8. Life Cycle Cost Data – *R.J. Pfeiffer*			
Option	**Life Cycle (LC) Cost**	**Present Value of LC Cost**	**Uniform Equivalent Annual Cost (AAC)**
1. Cyclonic Separator with UV Light Treatment	$304,000	$257,000	$26,000
2. Filter with UV Light Treatment	$427,000	$330,000	$34,000

Table 9. Cost Summary – *R.J. Pfeiffer*			
Option	**Installation Cost**	**Present Value of Life Cycle Cost**	**Uniform Equivalent Annual Cost (AAC)**
1. Cyclonic Separator with UV Light Treatment	$237,000	$257,000	$26,000
Tons of Ballast Pumped, Remaining Life of Ship & /year	---	260,000	13,000
Life Cycle and AAC in $ per ton	---	$1.00	$2.00
2. Filter with UV Light Treatment	$288,000	$330,000	$34,000
Tons of Ballast Pumped over Remaining Life of Ship	---	260,000	13,000
Life Cycle and AAC in $ per ton	---	$1.26	$2.60

CONCLUSIONS

Ballast water treatment technologies are advancing beyond the scientific investigation stage to the engineering stage, where potential ship systems can be evaluated, designed and installed. Nonetheless, continued scientific bench testing and additional full-scale testing of treatment solutions are needed.

Ship owners must know that their treatment installation will have long term acceptance by the regulatory bodies in order to confidently proceed with installations. They want assurance that, after initial approvals, regulations do not immediately change and become more stringent. The owners recognize their responsibility to maintain and monitor the equipment over the life of the vessel, but the initial installation must promise acceptable results.

Selection of appropriate methods of cost analysis are also important to properly assess the treatment systems. The *present value* in $/ton of ballast pumped is one measure of economic merit that sounds simple, as does increase in *required freight rate*. However, these measures are difficult to use across various ship types. Methods of evaluating treatment system cost must be specific to each type of vessel (volume of ballast handled varies), to each individual ship within a type (remaining ship life varies) and to each owner (economic models vary).

Further discussion and evaluation of appropriate economic measures is needed. It may then be possible to tabulate expected life cycle costs against varying vessel type, remaining ship life and owner economic model. However, the economic assessment is complex and we anticipate that each individual ship will need its own installation evaluation.

For a given ship, a rough evaluation can be made by following the approaches presented in this paper. The ship owner, along with their naval architect/marine engineer, will look at (in order):

1) Ballast system operational changes that do not affect ship operations.
2) Piping modifications.
3) Installation of new treatment equipment.

Selection of this equipment and the associated treatment method will be based not only on life cycle cost, but also on simplicity of changes and owner preferences and judgment. Elements of the system installation design and equipment selection processes will vary from ship to ship.

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ACKNOWLEDGEMENTS

The Great Lakes Ballast Demonstration Project has made another important step in addressing the problems associated with the introduction of non-indigenous species (NIS) into marine ecosystems. The marine engineering represented in this paper addresses two ships or ship classes. More importantly, two major U.S. ship owners participated in the process, and they are much closer to getting viable ballast treatment systems installed in ships.

Polar Tankers, Inc., and Matson Navigation Company are acknowledged for their input, enthusiasm and support for this project and this paper.

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Appendix

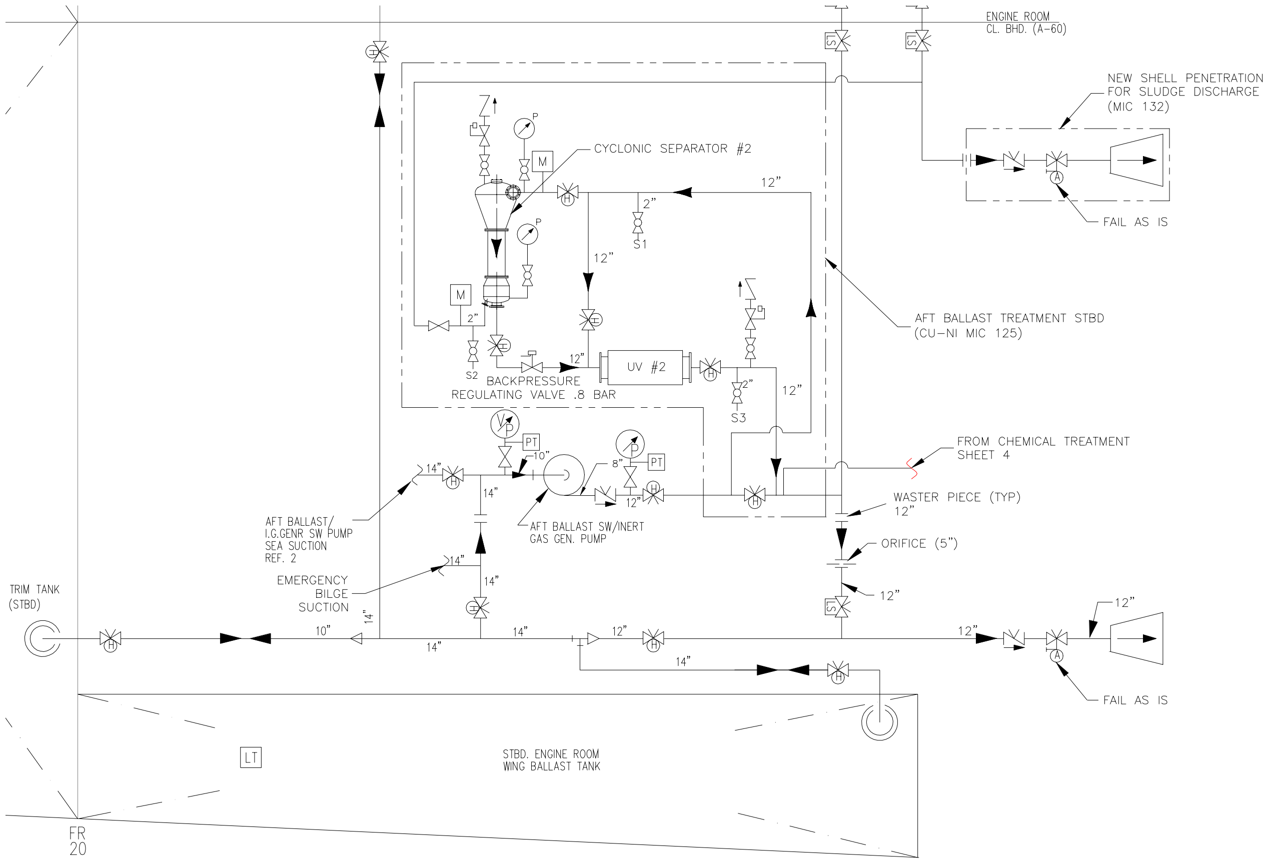

Figure A-1. ***Polar Endeavor*** **Aft Ballast Treatment System (starboard side shown, port side similar)**

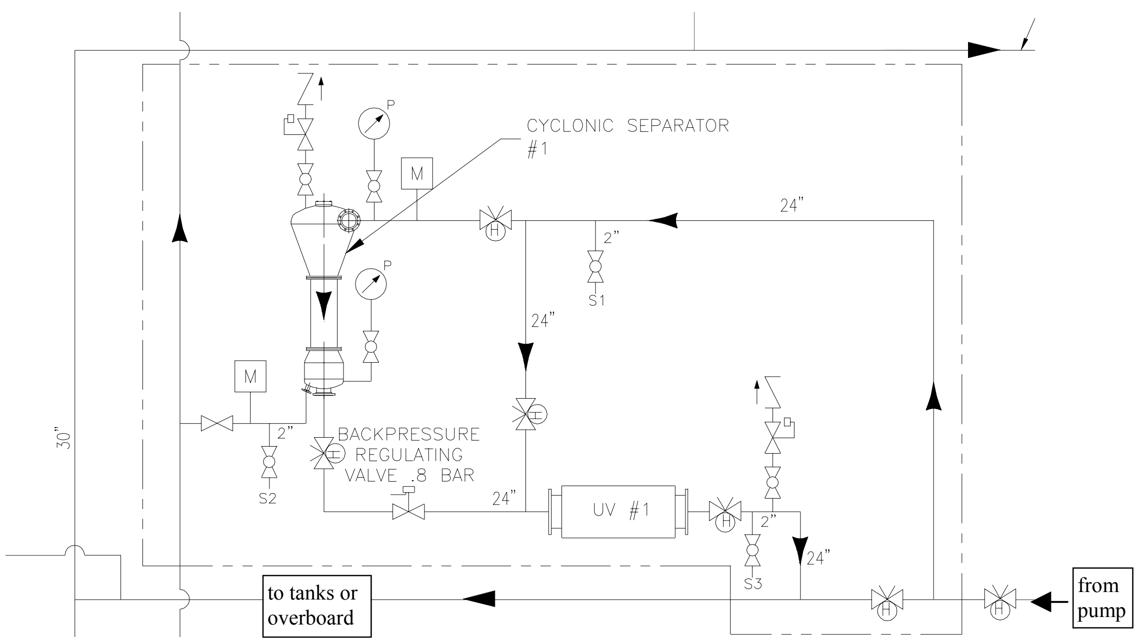

Figure A-2. ***Polar Endeavor*** **Main Ballast Treatment System, CS Detail and UV (one side shown, other side similar)**

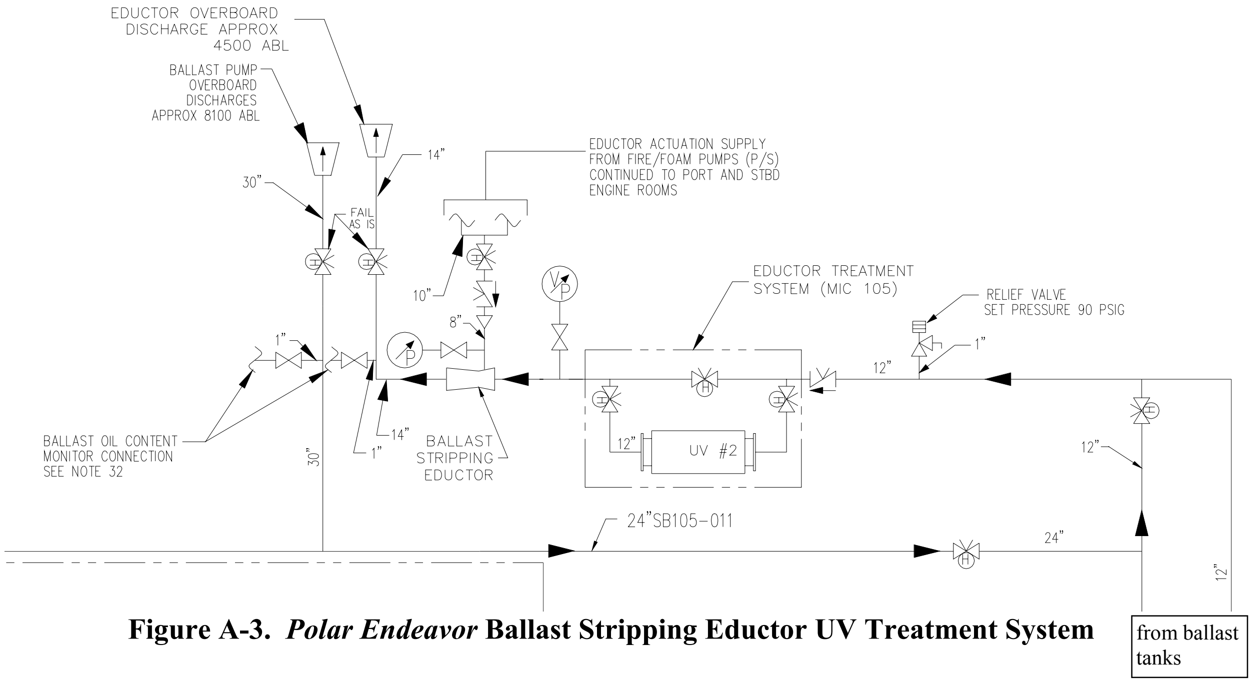

Figure A-3. ***Polar Endeavor*** **Ballast Stripping Eductor UV Treatment System**

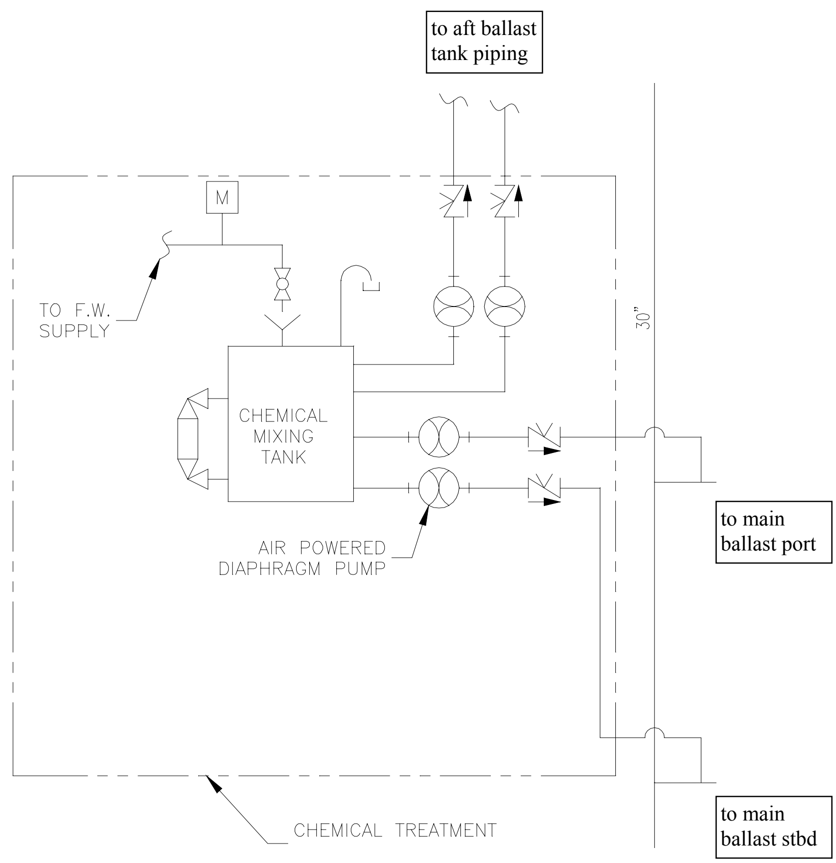

Figure A-4. ***Polar Endeavor*** **Chemical Treatment System Detail**

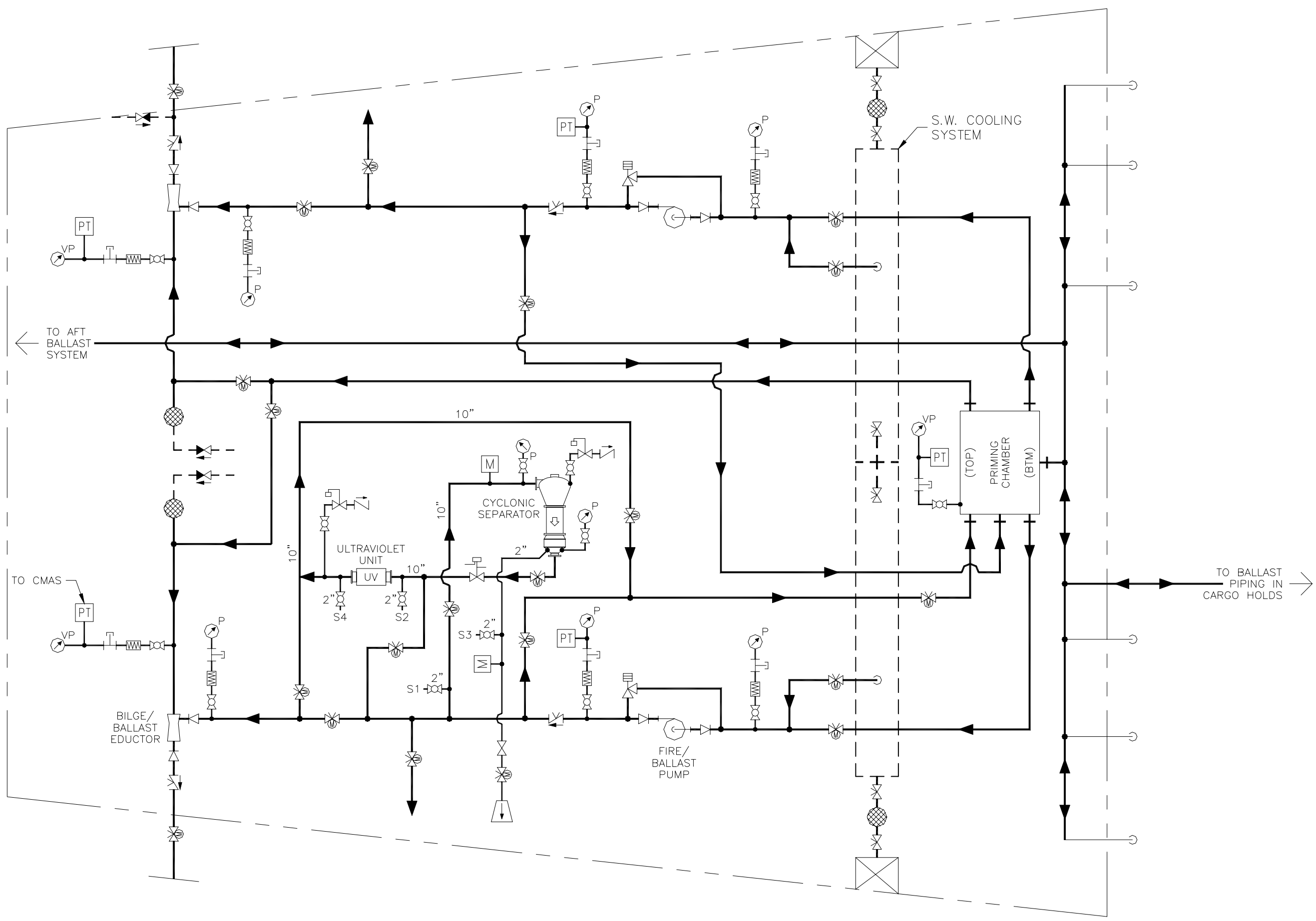

Figure A-5. *R.J. Pfeiffer* Ballast System Modifications