Sodium Hydroxide (NaOH) Practicality Study

Prepared for
National Parks of Lake Superior Foundation

File No. 09129.01
19 February 2010
Rev. —

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

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Executive Summary

The practicality of sodium hydroxide (NaOH) as a ballast water treatment chemical for Great Lakes bulk carriers (Lakers) was reviewed for use on board the 1,000-foot *M/V Indiana Harbor*. Sodium hydroxide is used to treat ballast water by increasing its pH to a level toxic to aquatic organisms while the ballast is taken up into the ship. Various methods, particularly the use of carbon dioxide, are then used to neutralize the sodium hydroxide and reduce the pH to acceptable levels prior to ballast water discharge. Ballast water treatment is needed to prevent the transfer of potentially harmful aquatic species and pathogens from one port location to another.

Figure 1. Sister Ship during Winter Lay-Up

The *M/V Indiana Harbor* provides a test case to determine practicality, with typical ballasting rates of 20,000 gallons per minute, ballast water volumes of 11.4 million gallons, and the limited machinery space common to Lakers. Specific review findings include:

- **System Process Options**. It is practical to mix the chemicals into the ballast water, both on uptake and discharge. Additionally, there are opportunities to use the treated ballast water for scrubbing engine exhaust gas, which can reduce air emissions and lower the chemical demand for neutralizing treated ballast water prior to discharge.
- **Chemical Handling**. Special handling procedures are required for sodium hydroxide as a caustic solution, and carbon dioxide as a refrigerated liquid. These procedures are within the limits of good marine practice and regulatory requirements.
- **Material Compatibility**. Special materials and procedures are required for handling the chemicals in the concentrated form; however, once diluted into the ballast water,

no special materials considerations are required in terms of ballast water piping or tanks.

- **Shipboard Installation**. Piping system installation is reasonable and practical. Bulk chemical storage is a significant challenge requiring special solutions; for example, mounting carbon dioxide storage on a special platform above the main deck, and building an integral tank within an existing ballast water tank to hold the sodium hydroxide.
- **Costs**. A full installation would require carrying adequate chemicals for two ship round trips, the ability to treat the ballast water at full flow rates and volumes, and redundancy between the port and starboard ballast water mains. This installation cost is estimated at $2.0 million. The ship typically makes 45 trips per year, carrying 62,100 tons of cargo per trip. Chemical costs are currently estimated at $10,100 per trip, $475,000 annually, and between 16 and 19 cents per ton of cargo loaded. Alternative neutralization methods increase the capital cost, but lower the chemical costs. Should further efficacy testing determine that the assumed treatment level of pH 12.0 could be lowered to pH 11.5, then chemical costs could be reduced by up to 70%.
- **Marine Regulatory**. Comments considering marine regulations on the shipboard installations are pending from the U.S. Coast Guard and the American Bureau of Shipping.

Sodium hydroxide is practical to use as a ballast water treatment chemical within the parameters of logistics, handling, and costs outlined in this report. It is recommended that the effort to commercialize the treatment system move ahead by performance of the following tasks:

- **Ship Testing**. Demonstration and verification efforts should be performed to verify the arrangements and logistics developed in this report.
- **Land-based Testing.** Further land-based efficacy and toxicity testing to not only further confirm the system effectiveness, but also determine if a lower dose of the chemical might be effective.
- **Comparative Review.** The logistics, handling, and costs of other potentially effective ballast water treatment systems should be compared to this sodium hydroxide study.

Section 1 System Process Options

Sodium hydroxide is used to treat ballast water by increasing its pH to a level toxic to aquatic organisms while the ballast is taken up into the ship. Various methods, including the use of stored carbon dioxide and carbon dioxide from engine exhaust, are then used to neutralize the sodium hydroxide and reduce the pH to acceptable levels prior to ballast water discharge.

This section provides an overview of the study ship, and then reviews three process options for this ballast water treatment. Each of these options treats with sodium hydroxide, but uses various combinations of carbon dioxide and exhaust gas for neutralization prior to discharge. Subsequent sections consider other practical considerations such as safe handling and cost. Shipboard locations of major components and diagrams for each process can be seen in the drawings in Appendix A.

1.1 Ship Particulars and Operations

The *M/V Indiana Harbor,* the study ship for this report, is a Great Lakes bulker that typically transports iron ore and coal between Lake Superior and Lake Michigan ports. During an operating year spanning April through December, the ship will make an average of 45-50 round trips. Typically, the ship will carry cargo one direction and will return in ballast without cargo.

When transiting with cargo, the ship has a deadweight capacity of 80,900 gross tons to its summer load line draft of 34' 3/4". Due to navigational constraints, the average cargo load is 62,100 gross tons at a draft of 27' 6".

When transiting without cargo, ballast water is carried to maintain the ship's operational draft, reduce ship motions, and minimize stresses in the ship's hull. The *M/V Indiana Harbor* carries a typical load of 11,373,000 gallons of ballast water in up to 18 tanks. This total ballast load will vary, depending on weather conditions, from 10,000,000 to 15,200,000 gallons. The ballast tank pairs range from 211,000 gallons up to 1,300,000 gallons in capacity. The tanks are arranged in eight pairs, port and starboard, plus a forepeak and an aftpeak tank located on centerline.

A summary of the ship particulars includes the following:

Vessel Name	*M/V Indiana Harbor*
Owner	American Steamship Company
Length Overall	1000' 0"
Beam	105' 0"
Depth	56' 0"
Midsummer Draft (MS Draft)	34' 3/4"
Deadweight Capacity at MS Draft	80,900 Gross Tons
Deadweight Capacity at 27' 6" Draft	62,100 Gross Tons
Shaft Horsepower	14,000 HP
Main Engines (4) Horsepower	3500 HP each
Year Built	1979

1.2 Sodium Hydroxide Treatment

During shipboard tests, sodium hydroxide (NaOH, caustic soda) would be used to raise the pH of the ballast water to 12.0. This high pH has been shown to inactivate a wide range of aquatic organisms. A hold time of 48 hours is needed to inactivate some of the target organisms but many are inactivated at lower pH levels (Reference 2). In order to safely discharge the high pH ballast water, it must be neutralized with an acid to lower the pH below 9.0. Sodium hydroxide at 50% concentration by weight would be stored in integral tanks installed in ballast tanks No. 8, both port and starboard. The 50% solution would be drawn into a slipstream to lower the concentration to less than 4% by weight. The 4% solution would then be injected into the ballast main piping downstream of the main ballast pumps. A sparger would be used to deliver the solution across the width of the 30" diameter ballast main. A monitoring and control system would be used to maintain the pH of the treated water at 12.0.

A centrifugal pump (200 gpm, 60' TDH) would be used to provide the ballast water slipstream, through a piping loop in the main ballast line. This pump would also supply the slipstream needed for the carbon dioxide neutralization loop discussed later in this report. Downstream of the pump and located close to the sodium hydroxide storage tank, an eductor would be used to draw in the 50% solution. The eductor would be a bronze Schutte & Koerting Fig. 242 mixing eductor or similar. A solenoid operated metering valve would be used to control the amount of 50% solution drawn into the suction side of the eductor. A maximum flow of 10gpm of 50% solution is anticipated for treatment of the 10,000 gpm flow from each of two (2) ballast pumps. The resulting 4% solution would be injected into the 30" ballast main using a purpose-built sparger.

A centrifugal pump (10 gpm, 60' TDH) would be used to provide a separate slipstream of treated water to the monitoring and control system. The suction for this slipstream would be taken downstream from the 4% solution injection location to ensure that a mixed sample is taken. An additional suction to the metering slipstream pump would be used to monitor during discharge. The slipstream would pass through a control cabinet before being injected back into the main ballast line. The control cabinet would contain redundant pH meters and a Programmable Logic Controller (PLC) to control the various valves and pumps based on the pH readings.

Each full load of ballast will require 7,577 gallons (48.34 tons) of 50% concentration sodium hydroxide, based on an average ballast water load of 11,323,000 gallons and a dosing rate of 0.0006691 gallons of 50% sodium hydroxide per gallon of ballast water (Reference 9). To allow the ship to carry enough sodium hydroxide to make two full ballast evolutions between chemical deliveries, two ~8000 gallon storage tanks would be required.

Sodium hydroxide is a readily available industrial chemical used in many industrial processes. Dow Chemical is one of the largest manufacturers and distributors in the United States. Their cost for bulk sodium hydroxide is $125/ton (Reference 9), which results in a ballast water treatment cost for a typical ship voyage, or round trip, of approximately $6000.

1.3 Neutralizing With Stored Carbon Dioxide (CO_2)

Carbon dioxide is the preferred media for neutralizing the sodium hydroxide and lowering the pH after ballast water treatment is complete. For shipboard operations, carbon dioxide would be stored as a refrigerated liquid, at 300 psi and 0º F, in insulated pressure tanks installed in the weather on the main deck (see Figure 2). The liquid CO_2 would be heated and vaporized, and the pressure reduced to 125 psi before distribution. The gas would be injected into a slipstream using an inline sparger to create a solution of carbonic acid and dissolved CO_2. This solution would be injected downstream of the ballast pumps through an inline static mixer. A monitoring and control system would be used maintain the discharged water at less than a pH of 9.0, which is generally considered acceptable for an overboard discharge (Reference 10).

The centrifugal pump used to supply the slipstream water for the sodium hydroxide treatment would also be used for the CO_2 slipstream. The piping for this slipstream would pass into the conveyor tunnel, where a Mott Industrial GasSaver, or equal, would be used to sparge the gas into the slipstream. This type of sparger creates tiny bubbles of gas that are stripped away from the element to be mixed with the water. Incoming gas to the sparger would be controlled using a solenoid operated metering valve. The piping would pass back into the engineroom, where it would be injected into the ballast line through a 30" Westfall Model 2800, or equal, static mixer. The static mixer is required to ensure a complete mixing of the ballast water and CO_2 slipstream before the pH monitoring slipstream pickup point.

The monitoring system used during ballast uptake would also be used during discharge. The slipstream suction point during discharge would be located just forward of the seachest isolation valve. The neutralized water would be run through the control cabinet, before being injected back into the ballast line. The PLC would control the various valves and pumps based on the pH readings.

Based on an average ballast water load of 11,323,000 gallons, and a dosing rate of 0.004695 lbs of carbon dioxide per gallon of ballast water (Reference 9), each full load of ballast will require 53,200 lbs (6,300 gallons) of carbon dioxide.

Carbon dioxide is a readily available industrial chemical used in many industrial processes. The cost of bulk carbon dioxide is $0.07/lbs (Reference 9), which results in a neutralization cost for the average ballast water load of $3800.

1.4 Exhaust Gas Neutralization

Exhaust gases from the diesel engines contain high levels of carbon dioxide, along with sulfur and other chemical compounds. This carbon dioxide in the exhaust could be used to neutralize the sodium hydroxide in the ballast water. Two ways of extracting the carbon dioxide were examined, which include:

- Using a commercially available seawater type exhaust gas scrubber, and
- Developing a system to sparge cleaned exhaust gas through the ballast tanks.

A stored chemical neutralization system would be required with both options, either to allow discharge of residual treated water dockside, or in case of a malfunction of the exhaust gas system. The neutralization chemical storage volume would be reduced to save capital cost.

1.4.1 Commercial Exhaust Gas Scrubber

Hamworthy Krystallon produces a commercially-available seawater type exhaust gas scrubber that could use treated ballast water instead of seawater. The scrubber uses the alkalinity in the water (in this case provided by the sodium hydroxide) to absorb the carbon dioxide and sulfur compounds from the exhaust stream. The water is then treated to clean out residual pollutants and returned to the ballast tank. By circulating ballast water continually through this type of system, the pH could be lowered over a period of hours. The water flow rate through this system can neutralize ~1100 gpm of treated water from a pH of 12.0 to 8.0. Over a 36-hour period, roughly 20% of the treated ballast water could be neutralized; this also results in a similar reduction in the required neutralization chemical usage.

Commercial exhaust gas scrubbing requires significant space to install. Modifications to the ship's exhaust casings would be required (see Figure 2).

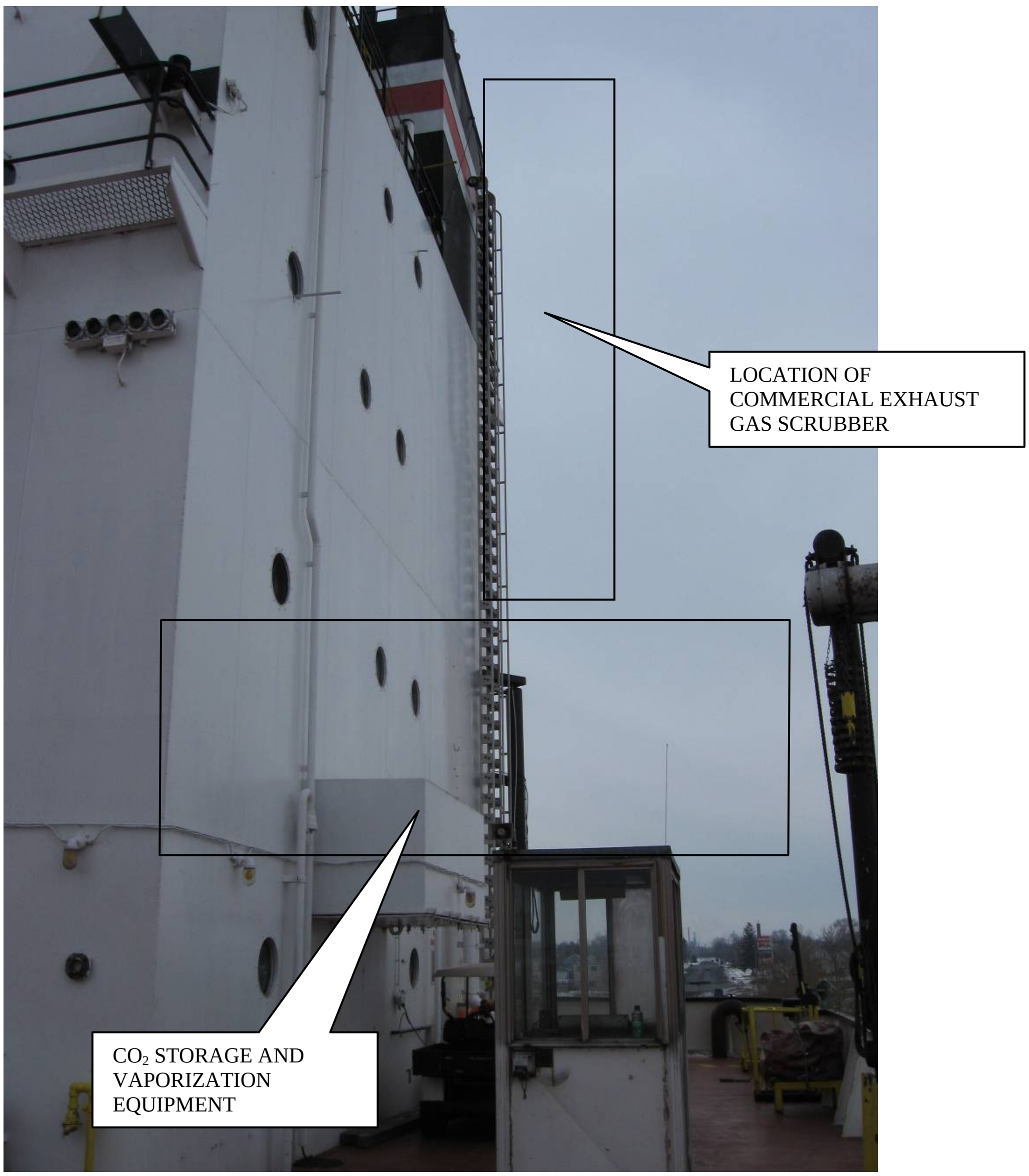

Figure 2. Locations of CO_2 Storage and Exhaust Gas Scrubbers

1.4.2 Sparging of Exhaust Gas into Ballast Tanks

Developing a way to sparge clean exhaust gas would require extensive development that is outside the scope of this project, but the basic concept was examined. An exhaust gas flow rate of 4600 cfm for 24 hours would be required to reduce the pH of an average treated load of ballast water from a pH of 12.0 to 11.4 (Reference 9). A pH below 11 greatly reduces the efficiency of the carbon dioxide transfer, and the neutralization slows considerably.

The exhaust from diesel engines contains soot and residual hydrocarbons that would require removal before the exhaust is introduced to the ballast water. A catalytic converter similar in design to that found on heavy mining equipment, Mine-X DC69.5-600 from DCL International Inc., may be able to remove the exhaust contaminants, although this needs further development.

Once the exhaust has been cleaned, it would require cooling and compressing for delivery to each of the ballast tanks. A cooling system would be required to reduce the temperature from ~600ºF to less than 100ºF. This system would require a heat exchanger, pump, and a cooling water loop to be installed. After the exhaust is cooled, it would be compressed to ~30psi so that it can be delivered to the bottom of the ballast tanks. It is estimated that a ~450 hp compressor would be required.

The 30 psi exhaust gas would then be piped to each of the tanks and dispersed using an in-tank sparging system. An 8" piping header would be required to supply the ballast tanks. Aero-Tube aeration tubing could be used to sparge the gas along the inboard bulkhead of the tank. The bubble wall created by the rising gas would also stimulate mixing of the water in the tank.

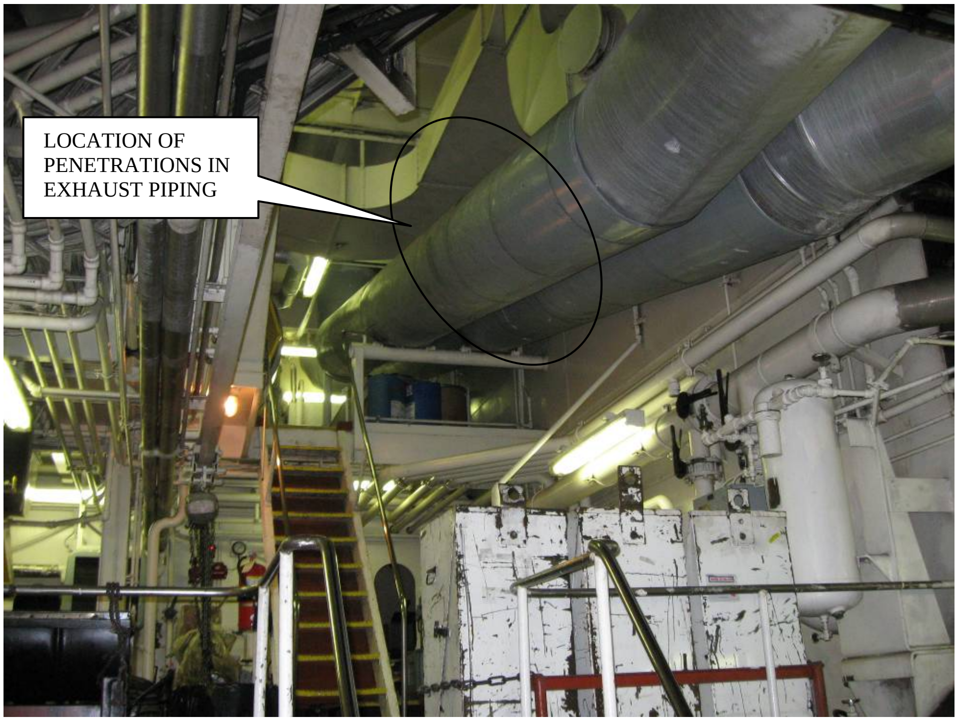

Figure 3. Main engine exhaust showing possible location for catalytic converter installation

1.5 Performing Lake Water Exchange

Lake water exchange was examined to see if it would be possible to reduce the pH of the treated water while in transit. The intent of ballast water treatment on the Great Lakes is to keep invasive species from being transplanted between lakes, and exchange would be required only after the ship's arrival at the destination lake.

A stored chemical neutralization system would be required to allow discharge of residual treated water dockside. The neutralization chemical storage could be reduced in size and cost by the percentage of exchanged water used.

This report did not investigate the environmental impacts of discharging higher pH water into the Great Lakes.

1.5.1 Discharge of Water below pH 9.0

This method would entail taking suction from a treated ballast tank using the stripping pump, while simultaneously filling the same tank with the main pump. The excess flow from the main pump would be combined with the discharge from the stripping pump to dilute it to a level safe for discharge. Diluting the pH12 sodium hydroxide ballast water enough to reach a pH of 9.0 would require 30 parts fresh water to 1 part treated water (Reference 6). Based on an average ballast water load of 11,323,000 gallons, the amount of clean water required would be 3.40×10^8 gallons. A reasonable time to complete the dilution would be less than 36 hours, based on the *M/V Indiana Harbor* sailing schedule. This would require a pumping rate of ~160,000 gpm to exchange 100% of the treated water, which is not feasible on these vessels. Based on the currently installed ballast pumps, roughly 7% of the treated water could be exchanged over 36 hours with no discharge of water with a pH greater than 9.0.

1.5.2 Discharge Higher pH Water with Dilution Assumed in Lake

This method would entail taking suction from a treated ballast tank using the stripping pump, while simultaneously filling the same tank with the main pump. The excess flow from the main pump would be combined with the discharge from the stripping pump to dilute it as much as possible. The combined flow of water would be discharged to the lake. A common practice is to assume that discharges from a moving ship will quickly dilute 200:1 in the surrounding water. With this assumption, the treated pH12 water could be discharged while the ship is moving and would quickly be diluted to pH 7.9 at a 200:1 dilution factor (Reference 6). Based on the currently installed ballast pumps, roughly 40% of the treated water could be exchanged over 36 hours.

Section 2 Chemical Handling and Feasibility

Chemical handling on board a vessel is of critical concern. The chemicals used in this ballast treatment system can cause injury to personnel and/or damage the ship if not handled properly. The approach taken in this report is to find the safest practical way to transfer, store, and distribute each of the chemicals used in this system.

2.1 General Philosophy

To help prevent injury, corrosive chemicals are stored at higher concentrations but are diluted significantly before they are injected into the ballast stream. In general, corrosive chemicals are not pressurized, but would be drawn into a slip steam using vacuum. Lengths of pipe containing concentrated chemicals would be as short as practical to minimize the possibility of hazardous leaks.

Gas detection systems would be used to warn personnel of hazardous situations, and piping would be designed such that it would not be pressurized unless the system is in use. Where cryogenic temperatures are possible, isolation systems would be used to protect ships structure as well as personnel. Gas storage would be in the weather to prevent flooding of occupied spaces with gas, or pressurization of confined spaces due to rapid release of pressurized gas.

2.2 Sodium Hydroxide

Sodium hydroxide (Caustic Soda, NaOH) can be used raise the pH of ballast water to a pH of 12.0. This high pH has been shown to inactivate a wide range of organisms. A hold time of 48 hours is needed to inactivate some of the target organisms, but many are inactivated at lower pH levels (Reference 2). In order to safely discharge the high pH ballast water, it must be neutralized with an acid to lower the pH below 9.0.

References 1, 3, 4, and 5 contain useful safe handling and storage information on sodium hydroxide.

Transfer:

Sodium hydroxide in a 50% aqueous solution would be transported to the ship in tanker trucks and loaded aboard through filling connections located on the main deck. The truck used to deliver the chemical would be offloaded either by pressurized air or by pumping. The fill stations would be located in the same area as the current fuel fill stations.

Safe handling procedures:

- The area around the fill and vent would be classified as a chemical handling area during loading of bulk chemical. This would thereby require personnel to wear special protective gear during loading operations.

- A suitable containment would be provided around the fill and vent connections to contain spills.

- To minimize risk of spilling and contact of the chemical with personnel, dry break couplings would be employed for the chemical transfer hose.

Storage:

The 50% sodium hydroxide solution would be stored in tanks built into ballast tanks No. 8 port and starboard before being injected into the ballast system during ballasting. The solution should be stored at temperatures between 65ºF and 115ºF. Below 65ºF the solution will solidify, and above 115ºF carbon steel needs special treatment to prevent stress corrosion cracking. Freezing of the solution does not affect its properties nor would it harm the ship. To melt frozen sodium hydroxide, heat is applied and the solution gradually warmed. A component of the storage system would be an electrical heating element in the bottom of the tank that would automatically maintain the temperature of the solution at 70ºF. The solution temperature is not expected to reach 115ºF, as most of the square footage of the tank sides will be cooled by water in the ballast tank.

The 50% sodium hydroxide solution stored on board should be considered hazardous ships' stores and is allowed by 46 CFR 147.15. The table in 49 CFR 172.101 designates aqueous sodium hydroxide solutions as Class No. 8 (Corrosive Material) with a Packing Group II, representing a moderate degree of danger. Containers for storage of the sodium hydroxide shall be constructed in accordance to the requirements of 49 CFR 172.101 and shall be labeled in accordance with 46 CFR 147.30

Distribution:

Piping would be routed out of the bottom of the storage tanks into ballast tanks No. 8 port and starboard, then would penetrate into the Engine Room below the deck grating. A slipstream of ballast water would be used to dilute the chemical as close to the Engine Room penetration as feasible. A dilution factor of 20 parts water to 1 part 50% solution would be the target dilution, resulting in a maximum 3.2% sodium hydroxide concentration prior to transport across the engine room and into the ballast main. According to the Screening Information Data Set (SIDS, Reference 1), a sodium hydroxide concentration below 4% is considered an irritant. An eductor would be used to draw the chemical into the slipstream downstream of the slipstream pump. The slipstream would then be injected back into the main ballast line and would mix with the main line just downstream of the forward pump connection to the main line. To obtain a pH of 12.0, the concentration of sodium hydroxide in the ballast tanks would be roughly 0.05% by weight.

A result of diluting sodium hydroxide with water is heat generation. Diluting 50% concentration NaOH to a 4% concentration results in a solution temperature rise of roughly 15ºF (Reference 5).

The eductor used to mix the 50% NaOH water would be constructed from 316L stainless steel. This material is resistant to any local high temperature 50% solutions during mixing

Venting:

Venting of the storage tank would be to the weather in the same general location as the chemical fill station and the fuel oil vent port and starboard. A separate spill coaming would be constructed around the vent outlet to capture any overflow. A floating ball check valve would be incorporated to prevent any water from entering the vent. Sodium hydroxide has a negligible vapor pressure and is rapidly neutralized by carbon dioxide in the air and therefore dust and vapor exposure are not expected (SIDS, Reference 1).

Materials:

Between 65ºF and 115ºF, NaOH can be stored in standard steel tanks without damage to the steel. Further investigation is required to determine if cooling and/or insulation would be required to maintain the solution below 115ºF. An alternative to prevent the solution from contacting the steel and possibly causing stress corrosion cracking would be to coat the interior of the tank. A coating system was not developed as part of this report.

Piping material should be ASTM A106 Gr B. Further investigation is required to determine if this grade of piping is susceptible to stress corrosion cracking with this solution.

Personnel:

The 50% sodium hydroxide solution is highly corrosive and can cause severe burns to eyes and skin. Appropriate eye and skin protection must be worn when handling this chemical. Full chemical suits should be available for use in emergency situations.

Depending on the concentration, solutions of NaOH are non-irritating, irritating or corrosive and they cause direct local effects on the skin, eyes and gastrointestinal tracts. Based on human data given in SIDS, Reference 1:

- Above 8% concentrations by weight (transfer, storage, and upstream of the eductor) are considered caustic.

- 0.5-4% concentrations by weight (downstream of the eductor) are considered an irritant.

- Less than 0.5% concentrations by weight (in the ballast piping and ballast tanks) are considered non-irritating.

Sodium hydroxide is non-flammable and poses no fire hazard.

Spill Response:

Reference 5 outlines the proper response to minor and major spills. The information in the handbook would need to be developed into vessel specific procedures for crew training.

In general small spills of sodium hydroxide can be carefully diluted with water, neutralized as needed and pumped overboard. Large spills would require special cleanup procedures, which may include bringing onboard trained personnel, or providing Hazardous Waste Operations and Emergency Response Standard (HAZWOPER) training and equipment for ship's personnel.

2.3 Neutralization

There are multiple ways to neutralize the sodium hydroxide treated ballast water and reduce the pH to below 9.0 for safe discharge. Neutralization with carbon dioxide gas to make carbonic acid and the use of sulfuric acid are discussed in this section.

2.3.1 Carbon Dioxide

Carbon dioxide can be used to neutralize the sodium hydroxide and lower the pH. Refrigerated carbon dioxide is maintained in liquid form at roughly 300 psi and 0ºF in pressurized tanks. The carbon dioxide is mixed with water under pressure to form carbonic acid which in turn reacts with sodium hydroxide to form sodium bicarbonate. Adequate quantities of carbonic acid will be generated to decrease the pH from 12.0 down to 9.0, making it safe for discharge. The sodium bicarbonate left in the water can be beneficial to aquatic systems (Reference 9).

Carbon dioxide gas is colorless, odorless, displaces air, and can be an asphyxiant at high concentrations. It is roughly 1.5 times heavier than air, so it will sink and fill any low enclosed areas. As such, special attention needs to be paid to ensure there is no place where the gas can get trapped if a leak occurs.

Transfer:

Liquid carbon dioxide is delivered by tanker truck and is discharged from the truck using pressurized gas or pumps. The fill station would be located on the port side in the same area as the current fuel fill station.

Safe Handling procedures:

- The area around the fill and vent would be classified as a chemical handling area during loading of bulk chemical. This would thereby require special protective gear during loading operations. This special gear would include protection from burns which can result from exposure to low temperature chemicals.

- A suitable containment area would be provided around the fill and vent connections to contain spills.

- To minimize risk of spilling and contact of the chemical with personnel, dry break couplings would be employed for the chemical transfer hose.

Storage:

One standard design tank would be mounted on the port side outboard of the house elevated roughly 8'. Tank location and arrangements will require further refinement.

A containment structure would be constructed around the tank to prevent any cryogenic carbon dioxide leaks from contacting the ships structural steel and to contain slow gas leaks. The containment would be sized to contain the full load of liquid carbon dioxide. The top would be open to prevent pressurization and for good ventilation. Drains would be located in each corner of the containment and led overboard to direct any leaks over the side.

The storage tank would have refrigeration units to maintain the temperature and pressure. As the tank warms up, more of the liquid evaporates into gas increasing the pressure in the storage tank. The refrigeration unit cools the gas condensing it and lowers the pressure.

46 CFR 147.60 requires that pressure vessels, other than cylinders used for containing ship stores that are compressed gases, must carry only nitrogen or air unless permission is granted by Commandant (CG-52) to do otherwise. In order to place the tanks onboard the ship, special approval would be required by the U.S. Coast Guard.

Distribution:

Carbon dioxide is used from the tank as a gas. The tanks would have vaporization units to warm the vapor in the tanks to roughly 70ºF and reduce the pressure to roughly 125 psi. The vaporization unit would be located inside the tank containment. The ambient temperature gas would be delivered to a sparger located in the pipe tunnel through steel piping. The piping would be run externally along the forward side of the house and would penetrate the deck into the conveyor tunnel.

The distribution system would have double shutoff and bleed valves to depressurize and vent the distribution piping located outside of the containment while not in use.

Venting:

Each of the tanks would have multiple factory installed pressure relief valves. The discharge from the relief valves would be directed overboard through the drain lines built into the containment.

Materials:

Tanks would be ABS classed and constructed to ASTM pressure vessel standards.

The containment would be ABS A-36 steel with scantlings to support a full containment of liquid.

Carbon dioxide piping would be ASTM A106 Grade B steel.

Personnel:

Carbon dioxide displaces air and can cause asphyxiation if allowed to accumulate. Carbon dioxide sensors would be installed in the containment, along the pipe run and in the conveyor tunnel. Elevated carbon dioxide levels would trigger alarms both local and in the control station.

Expanding carbon dioxide gas is endothermic and will draw heat from the surroundings. Leaks will cause temperatures to fall in the immediate area and could cause injury to people. Large leaks could cause the formation of dry ice around the leak and the pressure of the escaping gas could cause pieces of dry ice to be ejected forcefully. To reduce the chances of personnel coming in contact with super cooled carbon dioxide or dry ice all higher pressure piping would be isolated in the containment.

Spill Response:

Spills of carbon dioxide would be as a gas or as dry ice. If the spill is a slow leak, the gas would dissipate to the surroundings. As the gas is heavier than air, it could accumulate if it is in a confined space. A large leak would cause rapid depressurization of the storage tanks and any liquid inside the tank would freeze into dry ice. Dry ice is a solid at atmospheric pressure with a temperature of -109°F. If left alone, the resulting dry ice would slowly sublime from a solid to a gas as it warms up. Dry ice can be handled with tongs, shovels, or with adequately gloved hands, and can be discarded in the water where it will boil away into a gas. Adequate ventilation or supplied air is required while working with dry ice.

2.3.2 Carbonic Acid

Carbonic acid is made by dissolving carbon dioxide in water.

Carbonic acid is one of the ingredients in carbonated soft drinks. The carbonic acid used in this system is basically the same.

Transfer:

Carbonic acid would be generated on board the ship in the conveyor tunnel and would be reacted away in the ballast lines. As such there should not be any chance of contact with personnel.

Storage:

Carbonic acid would not be stored on the ship.

Distribution:

A slipstream of ballast water would be used to generate carbonic acid using a sparger inside the piping. The slipstream supply piping would penetrate the bulkhead between the Engine Room and the Conveyor Tunnel in the same area as the main ballast line. Carbon dioxide gas would be sparged into the slipstream in the conveyor tunnel to generate the carbonic acid. The slipstream piping would then penetrate the engineroom bulkhead and the carbonic acid solution would be injected into the ballast line under pressure using a static mixer installed in the main ballast line just aft of the aft ballast pump discharge tee into the main ballast line.

Venting:

A pressure relief valve would be installed on the main ballast line just downstream of the sparger to insure the ballast main does not over pressurize.

Materials:

The sparger would be a Mott Series 7100 Industrial GasSaver and is made from 316L stainless steel.

The slipstream piping loop would be ASTM A106 Grade B Schedule 40 steel pipe.

The static mixer would be a Westfall static mixer Model 2800 made of 316L stainless steel.

The solution of carbonic acid is roughly at pH 5 and is not expected to be corrosive to the ballast piping.

Personnel:

The carbonic acid would be contained from the time it is generated to the time it is consumed so personnel should not have any contact with the solution. If a leak would occur the solution is not expected to be more than an irritant.

2.3.3 Sulfuric Acid

Sulfuric acid is a strong acid used in industrial applications and could be used to neutralize the sodium hydroxide in ballast water. Sulfuric acid is highly corrosive to metals and contact with eyes or skin can cause severe burns. Dissolution of sulfuric acid in water is a highly exothermic reaction. Care must be taken to ensure the diluted solution does not boil due to the heat released.

To neutralize the average ballast water load of 11,323,000 gallons (Ballast Load Condition 6) would require 4026 gallons (30.9 ton) of concentrated sulfuric acid at a cost of $100/ton or $3090 per load (Reference 9).

The table in 49 CFR 172.101 designates sulfuric acid as class No. 8 (Corrosive Material) with a Packing Group II, representing a moderate degree of danger, the vessel storage requirements state solutions with more than 51% acid must be carried on deck.

Based on the highly corrosive nature of concentrated sulfuric acid to the ship's structure and the USCG requirement that the material must be carried on deck, sulfuric acid would not be recommended for sodium hydroxide neutralization.

Section 3 Material Compatibility

The structural steel, piping, gaskets, pumps and coatings currently used on the subject vessel are appropriate for the existing operational conditions. Taking into account the proposed chemical concentrations, the suitability of these materials was investigated and is summarized in Table 1.

Table 1 Material Compatibility

	Chemical Compatibility					
Material	**NaOH (50%)**	**NaOH (4%)**	**NaOH (.05%)**	**Carbonic Acid**	**Water**	**Source**
Garlock Gylon type 3510	A	A	A	A	A	Garlock
SBR "red rubber" gasket	B	A	A	-	A	West American Rubber Company (WARCO)
Neoprene manhole gaskets	A	A	A	A	A	Nibco for operational temperature
Teflon valve packing	A	A	A	A	A	Nibco for operational temperature
Pump Seal John Crane Type I or II	-	-	A	A	A	John Crane
Steel (A-36)	A	A	A	-	A	For operational temperature
Steel (High Strength)	A	A	A	-	A	For operational temperature

A = Suitable at operational temperatures

B = Depends on Conditions

C = Unsuitable

- = No data

3.1 Existing Structure and Piping

The majority of the ships structure on the subject vessel is high strength steel (ABS Grades AH32, AH34 and AH36). Existing ballast piping is steel ASTM A53. At 50% concentrations and less, and at temperatures less than 120° F, sodium hydroxide does not negatively affect carbon steel (Reference 3). Steel structures and ballast piping materials are acceptable for the proposed service.

3.2 Gaskets

Typical piping gasket material used on the subject vessel is Styrene Butadiene (SBR, Buna-S, “red rubber”). This material is a general service rubber compound commonly used for water service. West American Rubber, LLC (WARCO) rates the chemical compatibility of SBR and sodium hydroxide <10% solution as “little or no chemical attack”. West American Rubber, LLC (WARCO) rates the chemical compatibility of SBR and sodium hydroxide 100% solution to 200°F as “little or no chemical attack to minor chemical attack”. The gaskets used on the vessel are acceptable for the ballast piping where the sodium hydroxide concentration is below 1%.

Typical manhole gasket material used on the subject vessel is cloth inserted neoprene. This material is a common shipboard gasket material for manholes and bolted access covers. Nibco valves rates neoprene and sodium hydroxide at <10% solution as acceptable up to 170ºF. The manhole gasket material used on the vessel is acceptable for the ballast tanks where the sodium hydroxide concentration will be below 1%.

Garlock recommends Gylon style 3510 gaskets for piping joints in systems containing sodium hydroxide at above 4% concentrations.

3.3 Pumps and Pump Seals

During discharge the main ballast pumps would be subjected to a 0.05% sodium hydroxide concentration in the ballast water resulting in a pH 12.0.

The pump casing is malleable iron or cast steel. Both of these materials are acceptable for the proposed service.

The seals used in the main ballast pumps on the subject vessel are John Crane Type 1 or Type 2. The standard construction of this type of seal uses a carbon face/primary ring, 18-8 stainless steel retainer, drive band, disc, spring holder and spring, and Buna-N bellows. Per a John Crane technical representative these materials are acceptable for the proposed service but stated that EPDM bellows would be more appropriate. If this ballast treatment system is permanently installed it would be recommended to switch to EPDM bellows during the next overhaul of seals.

3.4 Coatings

The current coating system in the ballast tanks is in poor condition, see Figure 4. There are large areas of damaged and missing coatings. A Sherwin Williams marine coatings representative confirmed that common tank coatings, such as zinc primers and epoxy coatings, would not be damaged by the low concentration (0.05% by weight) sodium hydroxide in the treated ballast water.

Figure 4. Ballast Tank showing coatings

A recommended coating system to be used during routine application in ballast tanks containing treated water was given as Sherwin Williams Seaguard 6000 first full coat at 5-6 mils Dry Film Thickness (DFT), second coat stripe coat edges and welds and third finish coat at 5-6 mils DFT.

Section 4 Shipboard Installation

This section provides guidance and design for full-scale shipboard demonstration testing, and full-scale shipboard prototype installation of the complete 100% capacity system. This two-step approach has been developed to show that such testing can be practically conducted, and to support efficacy testing of a ship installation of the system.

4.1 Installation to Support Efficacy Testing

For efficacy trials piping penetrations are installed at key locations in the engine room ballast lines. These locations will allow sodium hydroxide dosing of a single tank or any combination of tanks, neutralization of any tank during discharge, and drawing of samples during dosing and discharge.

Portable chemical dosing and neutralization equipment would be temporarily installed on the deck and in the engineroom. The portable equipment would be connected to the installed penetrations for supplying chemicals. A portable sampling system would be temporarily installed in the engineroom to monitor the pH during all operations. Water samples would be taken just before the water is discharged from the ship, and possibly other locations, for testing to determine the condition of aquatic species.

4.1.1 Ballast Piping Modifications

In order to conduct efficacy testing of a NaOH treatment system various piping modifications are required. Reference 8 details the required piping penetrations.

4.1.2 Portable Dosing and Sampling Equipment

The design and construction of the portable dosing and sampling equipment is not covered in this report. The envisioned process is given in the following paragraphs. All the processes would be manually operated and controlled.

Dosing would use a skid mounted pump installed in the engineroom to provide a slipstream of water to dilute the sodium hydroxide and inject it back into the ballast system. The slipstream supply would be from a new penetration in the main ballast line located between the conveyor tunnel bulkhead and the pump suction isolation valve in the forward end of the engineroom. The sodium hydroxide would be metered into the slipstream from a tank mounted on the main deck using an eductor in the engineroom. Hoses would be used to distribute the sodium hydroxide from the tank to the slipstream. The slipstream would be reintroduced to the main ballast line through a sparger. The sparger would be located in the main ballast line just forward of the tee from the forward pump discharge pipe.

Neutralization would be conducted in the ballast tanks using a gas sparging system to be developed. A fitting is included in the ballast piping modifications to allow CO_2 dosed water to be injected into the ballast line between the pumps and the seachest. This fitting can be used if a CO_2 slipstream delivery system is developed for efficacy trials.

Sampling and pH monitoring would be conducted in the engine room using the various sampling ports installed.

4.2 Future Modifications to Support Full Installation

4.2.1 Tanks

Sodium hydroxide at a 50% solution would be stored in integral tanks build into Ballast Tanks No. 8 port and starboard between Frame 112 and Frame 114. The bottom of the new tank would be ~16' above the engineroom grating (23' above baseline) and the top of the tanks would be the cargo hold bottom. The outboard bulkhead would be 5' outboard of the engineroom bulkhead. This would result in two 16' long x 5' wide x 15'10" high tanks with a total capacity of 9,300 gallons. A recommended loading to 90% of full capacity would result in a usable capacity of 8,300 gallons. The existing structure of the ballast tanks would require modifications to accommodate the NaOH tanks.

The structure of the existing ballast tanks was designed based on a specific weight of water of 62.4 lbs/ft^3 (SG 1.0) while the specific weight of sodium hydroxide is 93.6 lbs/ft^3 (SG 1.5). The higher specific weight of the sodium hydroxide will require heavier plate and stiffeners than are currently installed. A summary of the required scantlings can be seen in Tables 2 and 3 a conceptual sketch can be seen in Figure 5. Details of the structural calculations can be found in Appendix C.

Table 2. Minimum Plate Thickness (ABS Rules)

MEMBER		tACT (in)	tREQ'D (in)	Achieved
Tank Top (EXISTING)	-	0.375	0.321	117%
Tank Bottom (NEW)	-	0.500	0.440	114%
Outboard Bulkhead (NEW)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%
Inboard Bulkhead (MOD)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%
Fwd Bulkhead (MOD)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%
Aft Bulkhead (MOD)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%

Table 3. Minimum Scantlings (ABS Rules)

MEMBER	SCANTLING		SMACTUAL (in3)	SMREQ'D (in3)	Achieved
Top plate stiffeners (EXISTING)	7x4x3/8 L on 3/8 PL	-	14.79	9.47	156%
Bottom plate stiffeners (NEW)	8x6x1/2 L on 1/2 PL	-	30.59	22.26	137%
Outboard stiffeners (NEW)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%
Inboard stiffeners (MOD)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%
Fwd Stiffeners (MOD)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%
Aft Stiffeners (MOD)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%

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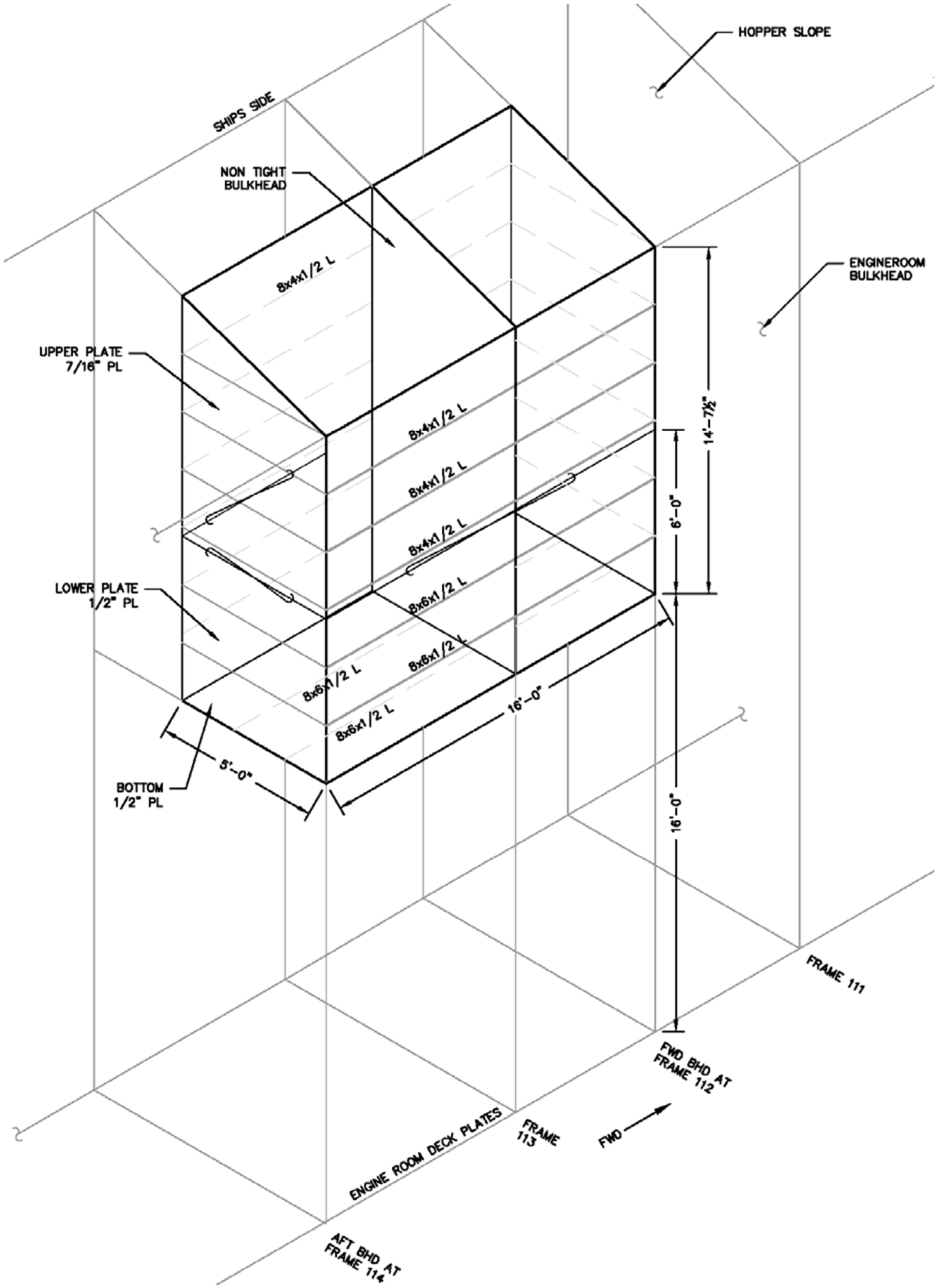

Figure 5. NaOH Tanks Starboard shown Port Opposite

Carbon dioxide would be stored in an ASME certified free-standing pressure vessel installed on the port side outboard of the house, roughly 8' above the main deck (see Figure 6). An open top containment would be provided beneath the tanks to prevent any spills from contacting the deck. A design of the containment has not been included in this report, but a weight and cost margin have been included in the calculations.

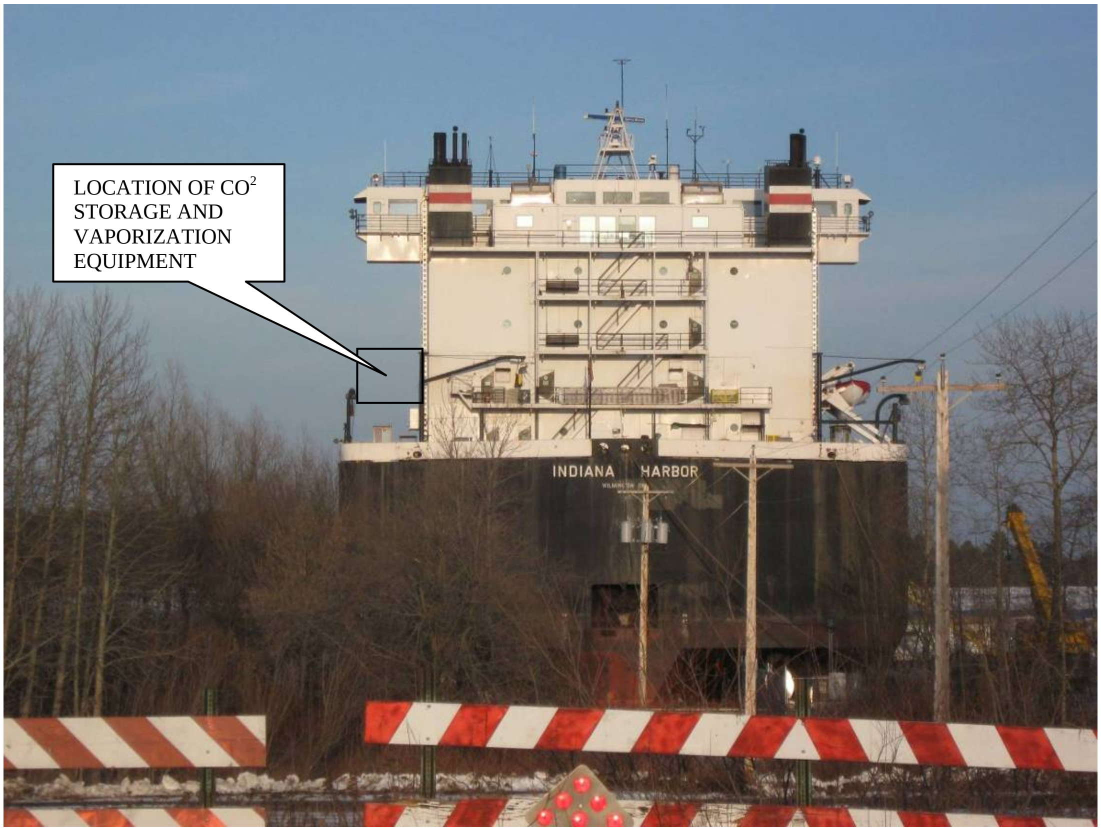

Figure 6. *M/V Indiana Harbor* showing location of CO_2 storage

4.2.2 Piping and Pumps

Piping and pumps would be installed to suit the selected process option. There would be identical pumps and piping systems installed in both the port and starboard enginerooms.

The slipstream pumps would be installed in the forward inboard corner of each engineroom below the deck grating. Suction for each pump would be taken from the ballast line on the suction side of the ballast pumps between the pipe tunnel bulkhead and the ballast pump suction isolation valve (installed for efficacy testing). The discharge of each pump would supply both the sodium hydroxide and the carbon dioxide slipstreams for that side of the ship.

Sodium hydroxide 50% solution supply piping would run inside containment piping from the bottom of the new NaOH tank to the slipstream eductor. The containment piping would be located in the No. 8 ballast tank and would be open to the containment in the engineroom. Any leaks in the supply line would drain into the containment. A solenoid operated valve in the 50% NaOH line at the slipstream eductor would control the amount of chemical added.

Sodium hydroxide slipstream piping would pass outboard below the deck grating in the forward end of each engineroom. Along the outboard engineroom bulkhead the piping would enter a covered containment at grating level where an eductor would draw in the 50% NaOH solution. The resulting maximum 4% NaOH solution would pass below the grating inboard then vertically to inject the solution into the ballast piping between the pumps and the main supply header through a sparger (installed for efficacy testing).

Carbon dioxide gas supply piping would run from the tanks located on the main deck to the sparging devices located in the conveyor tunnel. The piping would run in the weather as far as practical and would penetrate the main deck into the conveyor tunnel. The supply pipe would tee near the bottom of the conveyer tunnel to supply both the port and starboard sparging systems. Solenoid operated valves at each end of the supply piping would close automatically when the system is not operating. A valve in the weather would automatically bleed off any pressure and gas in the supply lines.

Carbon dioxide slipstream piping would penetrate the bulkhead into the conveyor tunnel where the CO_2 gas would be sparged directly into the line. The slipstream piping would then penetrate through the bulkhead into the engineroom again farther aft. The water-CO_2 solution would be injected into the ballast piping between the ballast pumps and the seachest through a static mixer that is required to achieve the rapid mixing needed.

Section 5 Costs

A full scale installation of a sodium hydroxide treatment system on a 1,000 foot Laker is estimated at between $2 million and $5 million depending on neutralization system approach, with the higher cost solutions target (a) reduced operating costs and (b) secondary benefits of reduced engine exhaust emissions. Operating costs are estimated between 13 cents and 19 cents per ton of cargo including amortization of capital expenditures. Table 4 outlines these results. Appendix B provides detail cost estimates and notes.

Table 4. Cost Summary

Process	Capital cost	Annual Operating Cost	Cost per trip	Cost per ton
NaOH Treatment/Stored CO2 neutralization	$ 1,981,000	$ 474,513	$ 10,105	$ 0.16
NaOH Treatment/Exhaust Gas Scrubbing	$ 6,060,400	$ 631,191	$ 12,680	$ 0.20
NaOH Treatment/In Tank Exhaust Gas Sparging	$ 4,319,000	$ 422,896	$ 8,438	$ 0.14

5.1 Capital Installation Cost

Capital costs were calculated for the three process options. Equipment cost was based on manufacturer supplied ROM quotes where possible. Structural steel installation was estimated at $8/lb of installed steel for complicated and below deck structure, and $6/lb for on deck and simple structures.

5.2 Annual Operating and Cost per Ton of Cargo

Annual operating costs were calculated for the three process options. The energy cost to run new equipment used was $0.15 per kilowatt-hour. Equipment maintenance was estimated to be 1% of original capital cost. The cost of CO_2 used was $0.07 per pound. The cost of NaOH 50% concentration by weight used was $125 per ton. Additional personnel required to run the system was included at a rate of $40/person/hour.

Additional costs per ton of cargo carried were calculated for the three process options. The number of trips completed per year used was 45 trips per year. The average cargo carried per trip was estimated at 62,100 gross tons.

Section 6 Recommendations for Future Work

Continued review of whole effluent toxicology of the chemical discharges discussed in this report is recommended. This report focused on the shipboard installation of the systems and does not address the environmental impacts.

Continued study of process efficacy at varying pH levels is recommended. A reduction in required pH from 12.0 to 11.5 would reduce treatment and neutralization chemical requirements by up to 70%. This reduction would have significant impact on equipment size, and capital and operational costs of the full system. Annual cost savings could be approximately $330,000 at the lower 11.5 pH treatment level.

Further investigation would be required to develop exhaust gas neutralization methods. A broad look was taken in this report, and further refinement of both options is advised.

Regulatory review of the system components will be required during the design of the subject systems. The subject vessel would require both ABS and USCG review of the systems before installation.

Development of shipboard-specific operational procedures to implement the handling procedures outlined in this report is required before full scale installation. The ship's crew would also require training to become familiar with these procedures.

Section 7 References

1. *Sodium Hydroxide*, SIDS Initial Assessment Report for SIAM 14, CAS N° 1310-73-2, Organization for Economic Cooperation and Development (OECD), published by the United Nations Environment Programme (UNEP), March 2002.
2. *Great Ships Initiative Bench-Scale Findings,* Technical Report – Public, Sodium Hydroxide (NaOH), dated 7 July 2009.
3. *Sodium Hydroxide Solution and Potassium Hydroxide Solution (Caustic) Storage Equipment and Piping System*, The Chlorine Institute Inc., Pamphlet 94, Edition 3, May 2007.
4. *Caustic Soda Suggested Safety Evaluation Guidelines*, DOW Chemical Company, Form No. 102-00469-0905.
5. *Caustic Soda Solutions Handbook*, DOW Chemical Company, Form No. 102-00011-104AMS, January 2004.
6. *Hydroxide Stabilization of Ballast or NOBOB Residuals*, Presentation by Barnaby Watten, USGS, Fall 2009.
7. *Safe Transfer of Liquefied Carbon Dioxide in Insulated Cargo Tanks, Tank Cars, and Portable Containers,* Compressed Gas Association, Inc., Third Edition, CGA G-6.4 - 2008.
8. *Ballast Piping Modifications,* The Glosten Associates, Inc., Drawing 09129-1, dated 12 February 2010.
9. Project Correspondence, Barnaby Watten emails dated 11 December 2009 to 18 February 2010.
10. *Guidelines for Exhaust Gas Cleaning Systems,* International Maritime Organization, 4 April 2008.

Appendix A NaOH Diagrams

PIPING SYMBOL LIST

SYMBOL	DESCRIPTION
X"	DIRECTION OF FLOW ARROW WITH PIPE SIZE
	EXISTING PIPING
	NEW DOSING PIPING
	NEW SAMPLE PIPING
	ELBOW, TURNED DOWN
	ELBOW, TURNED UP
	PUMP, CENTRIFUGAL
P	GAGE, PRESSURE, LOCAL READING
	VALVE, GLOBE
R	VALVE, REMOTELY OPERATED
B	VALVE, BUTTERFLY
	VALVE, SWING CHECK
	VALVE, GATE
	VALVE, BALL
	STATIC MIXER/SPARGER
	EDUCTOR
	AIR ESCAPE TERMINAL WITH SCREEN
	VALVE, ANGLE, PRESSURE RELIEF (SELF ACTUATED)
E	VALVE, ELECTRIC MOTOR OPERATED, TWO POSITIONS

SHEET INDEX

GENERAL NOTES

GENERAL NOTES

1. THIS DRAWING PROVIDES A CONCEPT ARRANGEMENT AND DIAGRAM OF THE SUBJECT BALLAST WATER TREATMENT PROCESS, PROVIDING A BASIS FOR ANALYZING INSTALLATION PRACTICALITY.
2. PRACTICALITY REVIEW CONSIDERS MATERIALS COMPATIBILITY, TANK SIZING AND ARRANGEMENT, EQUIPMENT SIZING AND ARRANGEMENT, PIPING SYSTEM INTEGRATION, AND SAFE CHEMICAL HANDLING.
3. IT IS THE INTENT THAT AN INSTALLED SYSTEM WILL COMPLY WITH ABS AND USCG REQUIREMENTS.
4. THIS DRAWING SHALL NOT BE USED FOR CONSTRUCTION.

OPERATIONAL NOTES

1. THIS DRAWING PROVIDES A CONCEPT ARRANGEMENT AND DIAGRAM OF A BALLAST WATER TREATMENT SYSTEM.
   A. SODIUM HYDROXIDE IS MIXED INTO THE SHIP'S BALLAST WATER ON UPTAKE TO RAISE THE BALLAST WATER BASICITY, WITH THE INTENT OF KILLING ORGANISMS AND PATHOGENS. TARGET P[H] LEVEL BETWEEN 11 AND 12.
   B. CARBON DIOXIDE IS MIXED INTO THE SHIP'S BALLAST WATER EITHER IN TANK OR UPON DISCHARGE TO LOWER THE BALLAST WATER BASICITY TO A LEVEL WHICH IS NOT TOXIC TO AMBIENT WATER (HARBOR OR LAKE). TARGET P[H] LEVEL OF LESS THAN 9.
   C. THE SHIP HAS SEPARATE PORT AND STARBOARD BALLAST WATER PUMPING SYSTEMS, EACH WITH TWO MAIN PUMPS AND ONE STRIPPING PUMP. TREATMENT SYSTEM ARRANGEMENT MATCHES THIS REDUNDANCY, WITH SEPARATE PORT AND STARBOARD SYSTEMS. ONE EXCEPTION IS THE USE OF A SINGLE CARBON DIOXIDE STORAGE TANK.
2. PRIMARY SYSTEM – SHEET 2. (DESCRIBES ONE PUMPING SYSTEM – PORT OR STARBOARD)
   A. BALLAST WATER UPTAKE USES ONE MAIN BALLAST PUMP.
   B. SLIP STREAM PUMP CIRCULATES BALLAST WATER WITHIN THE BALLAST MAIN, METERING SODIUM HYDROXIDE INTO SLIP STREAM TO ACHIEVE TARGET BASICITY.
   C. BALLAST WATER DISCHARGE USES ONE MAIN BALLAST PUMP OR THE STRIPPING PUMP.
   D. SLIP STREAM PUMP CIRCULATES WITHIN THE BALLAST MAIN. VAPORIZATION UNITS METER CARBON DIOXIDE INTO THE SLIP STREAM TO ACHIEVE TARGET BASICITY.
3. EXHAUST GAS CLEANING SYSTEM NEUTRALIZATION – SHEET 5. DURING ENGINE OPERATIONS, ENGINE STACK GASES CAN BE USED TO SCRUB PARTICULATE, AND NEUTRALIZE SULFUR AND CARBON DIOXIDE EMISSIONS. ADDITIONALLY, THIS PROCESS CAN NEUTRALIZE A PORTION OF THE TREATED BALLAST WATER.
   A. DEDICATED PUMP MOVES BALLAST WATER FROM ONE BALLAST TANK INTO AN EXHAUST GAS SCRUBBER VIA BALLAST STRIPPING LINE.
   B. DEDICATED PUMP MOVES WASH WATER FROM EXHAUST GAS SCRUBBER THROUGH WASTE HANDLING SYSTEM AND RETURNS TO THE SAME BALLAST TANK VIA THE BALLAST MAIN.
   C. PROCESS UNTIL DESIRED BASICITY IS REACHED, AND CYCLE TO NEXT TANK.
4. LAKE WATER DILUTION – SHEET 6. DURING TRANSIT, TREATED BALLAST WATER CAN BE DILUTED TO ACCEPTABLE BASICITY BY MIXING WITH LAKE WATER. SYSTEM DIAGRAM NOTES EXPLAIN MODE OF OPERATION FOR BOTH ON BOARD MIXING AND DISCHARGE MIXING.

MATERIAL SCHEDULE

PIPING SYSTEM	PIPE SIZE	PIPE MATERIAL	TAKEDOWN JOINTS MATERIAL	TAKEDOWN JOINTS GASKETS	TAKEDOWN JOINTS BOLTING	VALVES BODY	VALVES TRIM	FLEX CONN'S	FITTINGS TYPE & MATERIAL	MAX WORKING CONDITIONS SYSTEM	MAX WORKING CONDITIONS PRESSURE	MAX WORKING CONDITIONS TEMP	REMARKS
WATER BALLAST **(ABS CLASS III PIPING)**	2" & BELOW	CARBON STEEL, ASTM A53 OR ASTM A106, GR B, SCH XS, ANSI B36.10, SEAMLESS	STEEL, UNION, ASTM A105 MSS-SP-83, CLASS 3000, NPT	GARLOCK BLUEGUARD 3000 FULL FACE, ANSI B16.21	STEEL ASTM A307 ANSI B18.2.1 GR B	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34, NPT, CLASS 150,	MONEL OR 316 STAINLESS STEEL	NONE	STEEL, ASTM A105 OR A234, GR WPB, ANSI B16.11, CLASS 3000, NPT	BALLAST	50 PSIG	90 °F	
	2-1/2" & ABOVE		STEEL, FLANGE, ASTM A105 OR A216, GR WCB, ANSI B16.5, CLASS 150, SLIP-ON OR WELD NECK		STEEL ASTM A563 ANSI B18.2.2 GR A	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34 FLANGED, CLASS 150, MSS-SP-67, WAFER OR LUG	MONEL OR 316 STAINLESS STEEL, RENEWABLE		STEEL, ASTM A234, GR WPB, ANSI B16.9 & B16.28, SCH XS, BUTTWELD				
NaOH PIPING <4% SOLUTION **(ABS CLASS III PIPING)**	2" & BELOW	CARBON STEEL, ASTM A53 OR ASTM A106, GR B, SCH XS, ANSI B36.10, SEAMLESS	STEEL, UNION, ASTM A105 MSS-SP-83, CLASS 3000, NPT	GARLOCK GYLON 3510 FULL FACE, ANSI B16.21	STEEL ASTM A307 ANSI B18.2.1 GR B	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34, NPT, CLASS 150,	MONEL OR 316 STAINLESS STEEL	NONE	STEEL, ASTM A105 OR A234, GR WPB, ANSI B16.11, CLASS 3000, NPT	BALLAST	60 PSIG	90 °F	
	2-1/2" & ABOVE		STEEL, FLANGE, ASTM A105 OR A216, GR WCB, ANSI B16.5, CLASS 150, SLIP-ON OR WELD NECK		STEEL ASTM A563 ANSI B18.2.2 GR A	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34 FLANGED, CLASS 150, MSS-SP-67, WAFER OR LUG	MONEL OR 316 STAINLESS STEEL, RENEWABLE		STEEL, ASTM A234, GR WPB, ANSI B16.9 & B16.28, SCH XS, BUTTWELD				
NaOH PIPING >4% SOLUTION **(ABS CLASS I PIPING)**	2" & BELOW	CARBON STEEL, ASTM A53 OR ASTM A106, GR B, SCH XS, ANSI B36.10, SEAMLESS	STEEL, UNION, ASTM A105 MSS-SP-83, CLASS 3000, SOCKET WELD	GARLOCK GYLON 3510 FULL FACE, ANSI B16.21	STEEL ASTM A307 ANSI B18.2.1 GR B	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34 FLANGED, CLASS 150, MSS-SP-67, WAFER OR LUG	MONEL OR 316 STAINLESS STEEL	NONE	STEEL, ASTM A105 OR A234, GR WPB, ANSI B16.11, CLASS 3000, SOCKET WELD	NaOH SUPPLY	15 PSIG	90 °F	
	2-1/2" & ABOVE		STEEL, FLANGE, ASTM A105 OR A216, GR WCB, ANSI B16.5, CLASS 150, SLIP-ON OR WELD NECK		STEEL ASTM A563 ANSI B18.2.2 GR A		MONEL OR 316 STAINLESS STEEL, RENEWABLE		STEEL, ASTM A234, GR WPB, ANSI B16.9 & B16.28, SCH XS, BUTTWELD				
NaOH >4% SOLUTION VENTS, FILLS & SOUNDING TUBES **(ABS CLASS I PIPING)**	2" & BELOW	CARBON STEEL, ASTM A53 OR ASTM A106, GR B, SCH XS, ANSI B36.10, SEAMLESS	STEEL, UNION, ASTM A105 MSS-SP-83, CLASS 3000, SOCKET WELD	GARLOCK GYLON 3510 FULL FACE, ANSI B16.21	STEEL, ASTM A307 ANSI B18.2.1 GR B	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34 FLANGED, CLASS 150, MSS-SP-67, WAFER OR LUG	MONEL OR 316 STAINLESS STEEL	NONE	STEEL, ASTM A105 OR A234, GR WPB, ANSI B16.11, CLASS 3000, SOCKET WELD	VENTS FILLS SOUNDING	0 PSIG 15 PSIG 15 PSIG	120 °F 120 °F 120 °F	
	2-1/2" & ABOVE		STEEL, FLANGE, ASTM A105 OR A216, GR WCB, ANSI B16.5, CLASS 150, SLIP-ON OR WELD NECK		STEEL ASTM A563 ANSI B18.2.2 GR A		MONEL OR 316 STAINLESS STEEL, RENEWABLE		STEEL, ASTM A234, GR WPB, ANSI B16.9 & B16.28, SCH XS, BUTTWELD				
COMPRESSED CO2 **(ABS CLASS III PIPING)**	2" & BELOW	CARBON STEEL, ASTM A53 OR ASTM A106, GR B, SCH 40, ANSI B36.10, SEAMLESS	STEEL, UNION, ASTM A105 MSS-SP-83, CLASS 3000, SOCKET WELD	NITRILE FULL FACE, ANSI B16.21	STEEL, ASTM A307 ANSI B18.2.1 GR B STEEL ASTM A563 ANSI B18.2.2 GR A	STEEL, ASTM A105, OR A216, GR WCB, ANSI B16.34, SOCKET WELD, CLASS 150, MSS-SP-72, FLANGED, REGULAR PORTED	MONEL OR 316 STAINLESS STEEL	NONE	STEEL, ASTM A105 OR A234, GR WPB, ANSI B16.11, CLASS 3000, SOCKET WELD	COMPRESSED CO2	125 PSIG	120 °F	

REFERENCES

1. BAY SHIPBUILDING CORPORATION, DWG NO. 47329, BALLAST & STRIPPING SYSTEM PIPING DIAGRAM, 2/10/78

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPD

SIGNED ORIGINAL ON FILE

NATIONAL PARKS OF LAKE SUPERIOR FOUNDATION
HOUGHTON, MI

M/V INDIANA HARBOR
NaOH BALLAST WATER TREATMENT SYSTEM CONCEPT
PROCESS DIAGRAMS

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community
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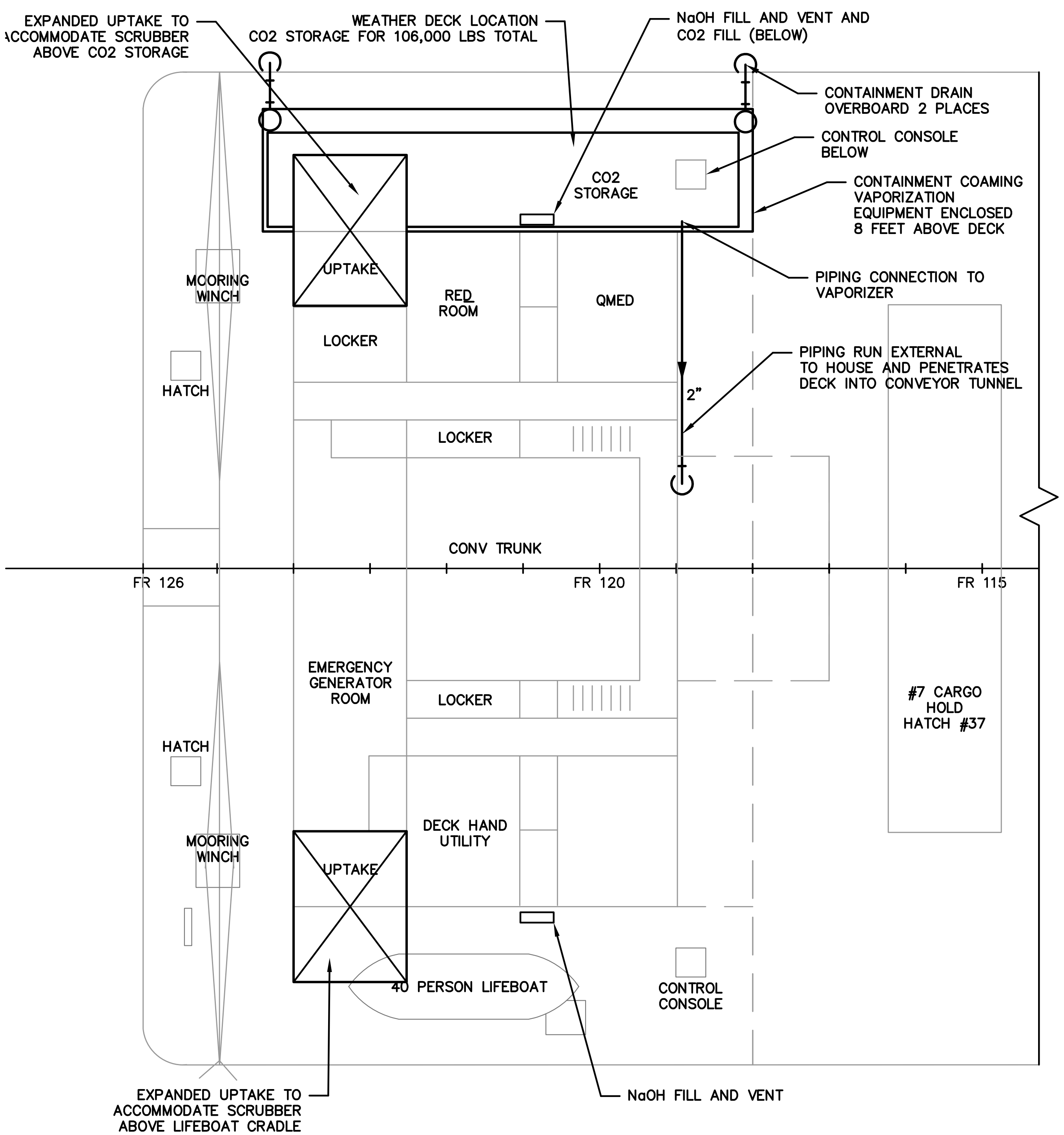
WEB www.glosten.com

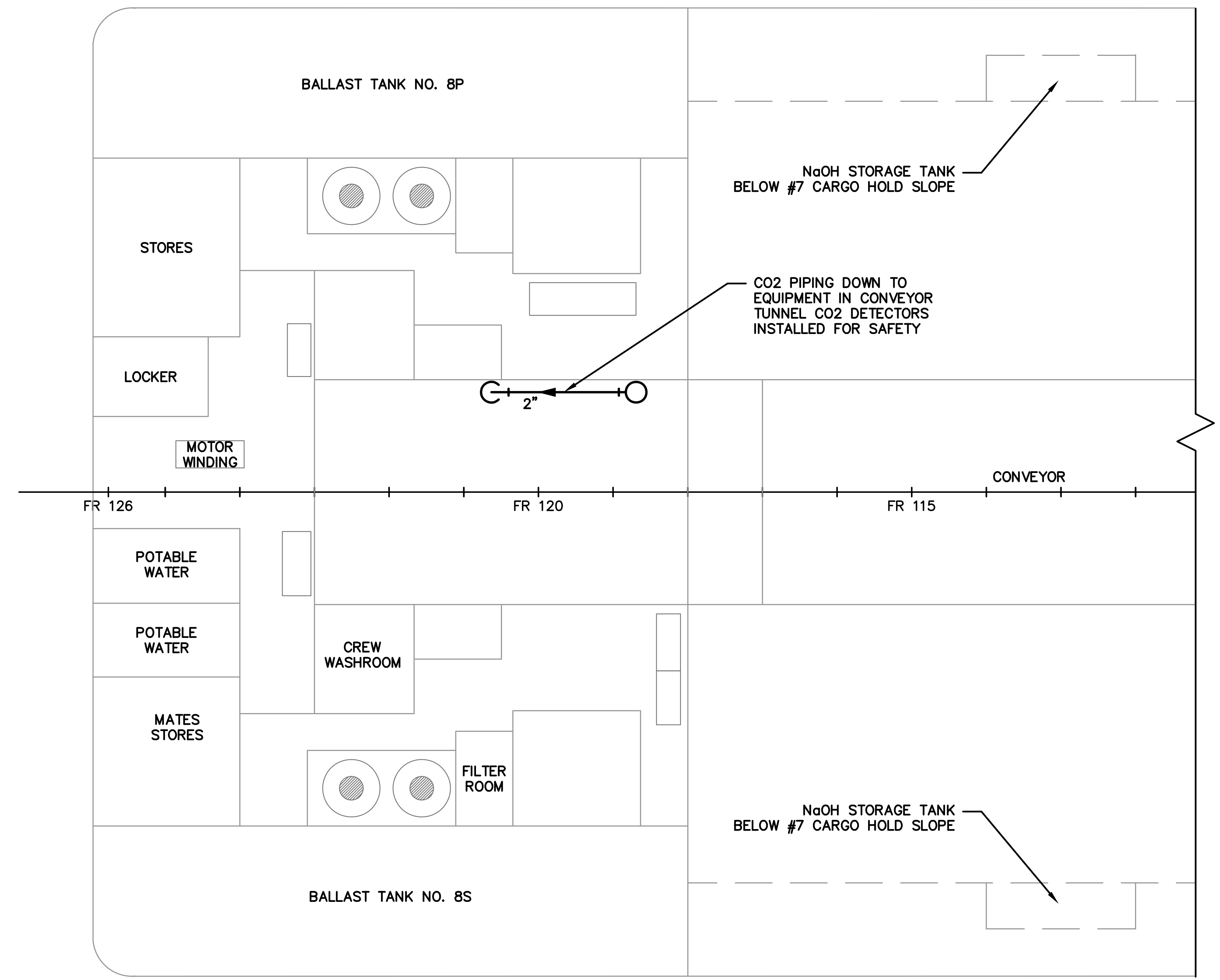
Drawn	Checked	Approved	Date
JKM	KJR	DWL	2/12/10

Scale	Drawing Number	Sheet	Revision
AS NOTED	09129-2	1 of 6	–



PLAN 4-5A

MAIN DECK, (57 FT ABV BL)



PLAN 4-7A

2ND DECK, (35 FT ABV BL)

SIGNED ORIGINAL ON FILE

NATIONAL PARKS OF LAKE SUPERIOR FOUNDATION
HOUGHTON, MI

M/V INDIANA HARBOR
NaOH BALLAST WATER TREATMENT SYSTEM CONCEPT
MAIN DECK AND 2ND DECK PLANS

THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community
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Scale	Drawing Number	Sheet	of	Revision
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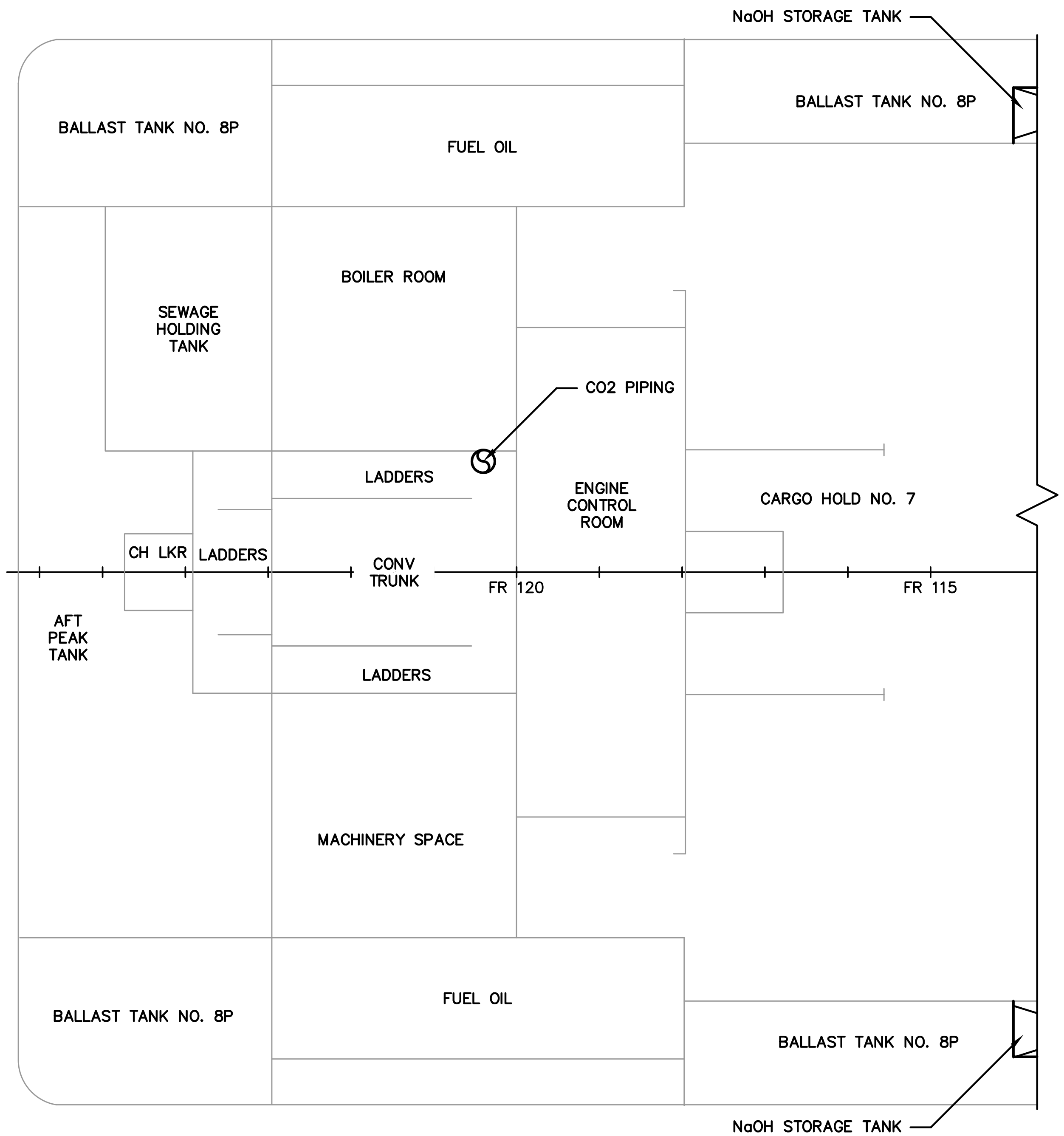
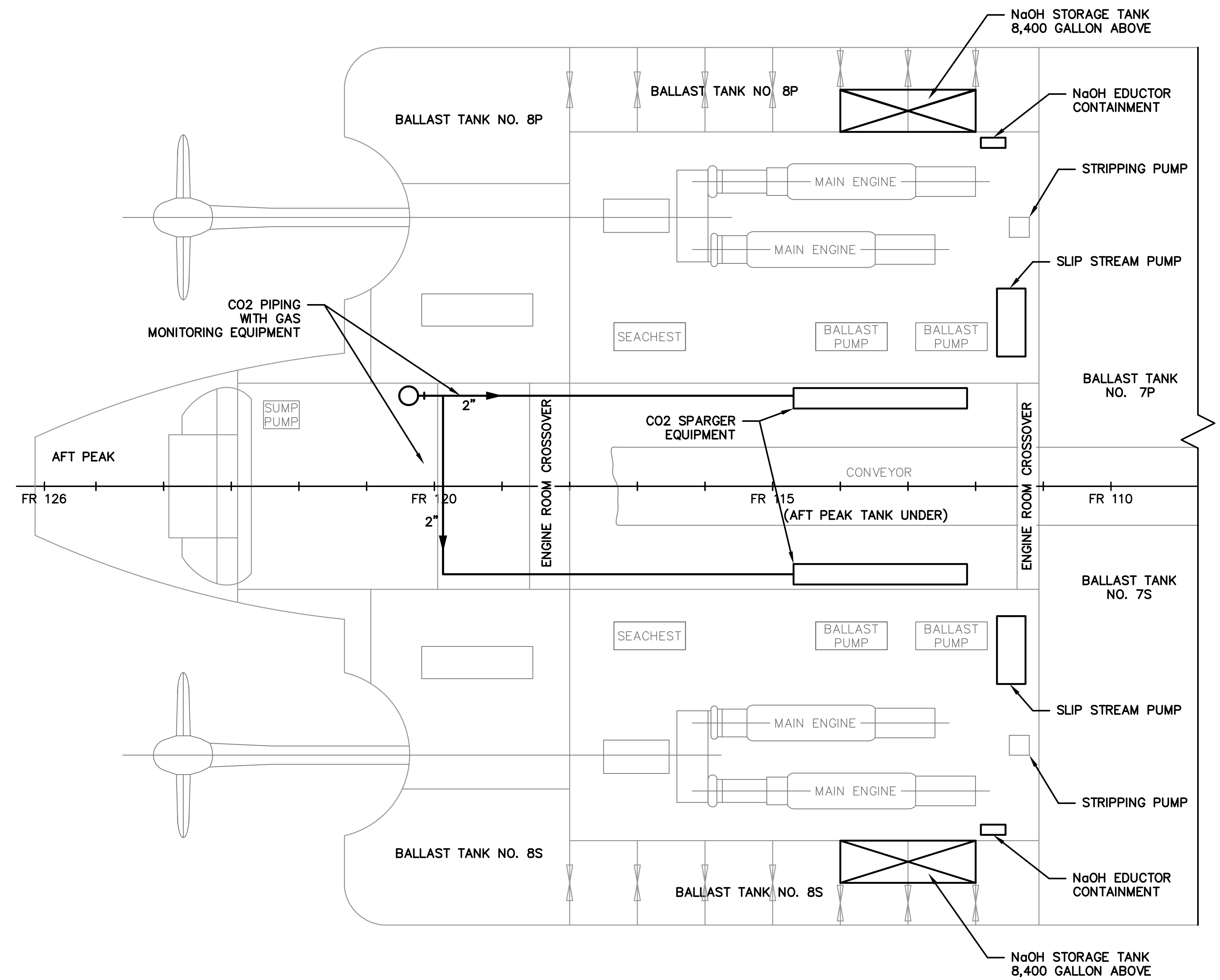


PLAN 3-7A
4TH DECK, (23 FT ABV BL)



PLAN 3-5A
ENGINE ROOM FLOOR

SIGNED ORIGINAL ON FILE

NATIONAL PARKS OF LAKE SUPERIOR FOUNDATION
HOUGHTON, MI

M/V INDIANA HARBOR
NaOH BALLAST WATER TREATMENT SYSTEM CONCEPT
3RD DECK AND ENGINE ROOM PLANS

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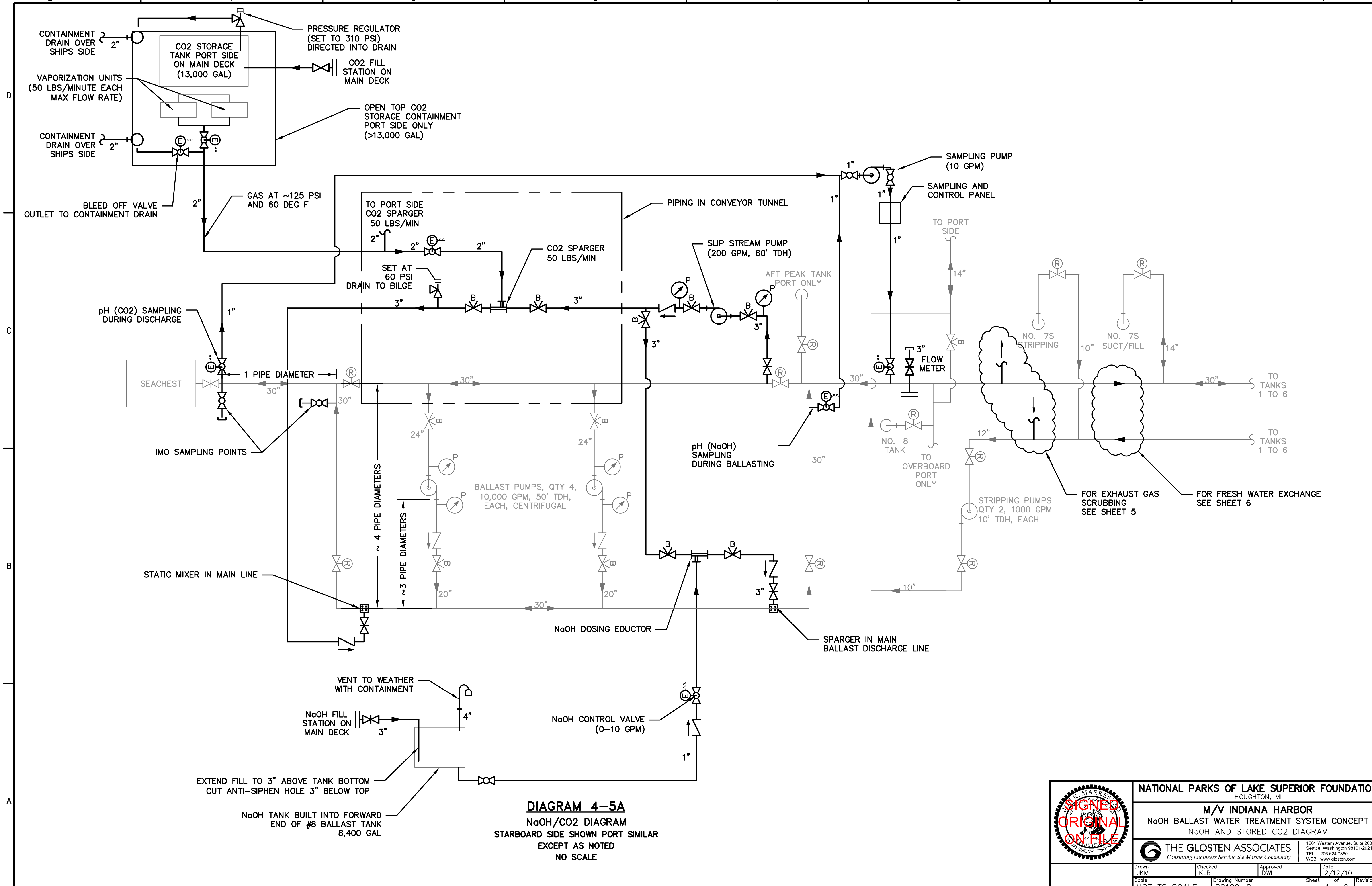

DIAGRAM 4-5A
NaOH/CO2 DIAGRAM
STARBOARD SIDE SHOWN PORT SIMILAR
EXCEPT AS NOTED
NO SCALE

NATIONAL PARKS OF LAKE SUPERIOR FOUNDATION
HOUGHTON, MI
M/V INDIANA HARBOR
NaOH BALLAST WATER TREATMENT SYSTEM CONCEPT
NaOH AND STORED CO2 DIAGRAM
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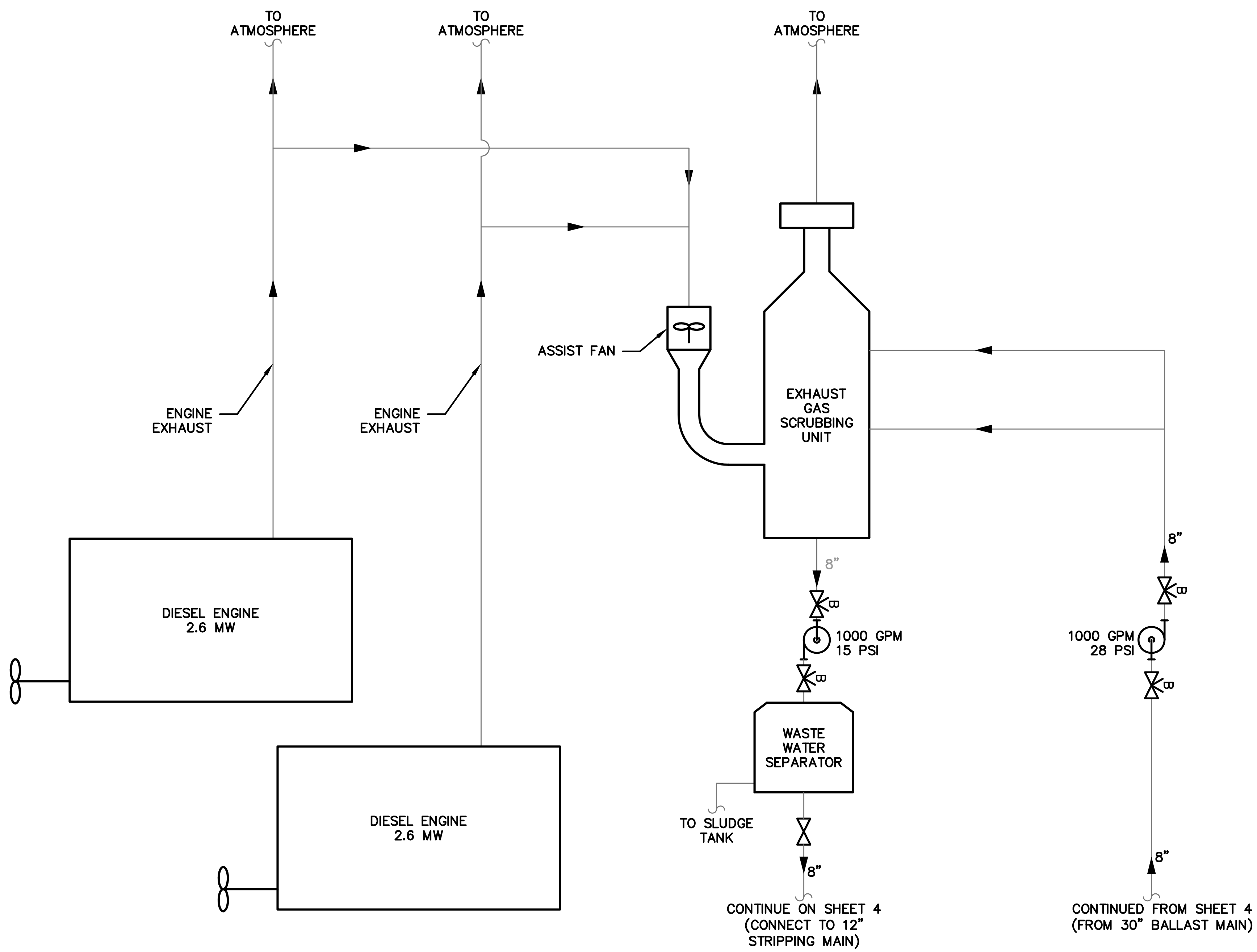

DIAGRAM 5–5A

EXHAUST GAS SCRUBBING SYSTEM

STARBOARD SIDE SHOWN PORT SIMILAR

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NATIONAL PARKS OF LAKE SUPERIOR FOUNDATION
HOUGHTON, MI

M/V INDIANA HARBOR
NaOH BALLAST WATER TREATMENT SYSTEM CONCEPT
EXHAUST GAS SCRUBBING DIAGRAM

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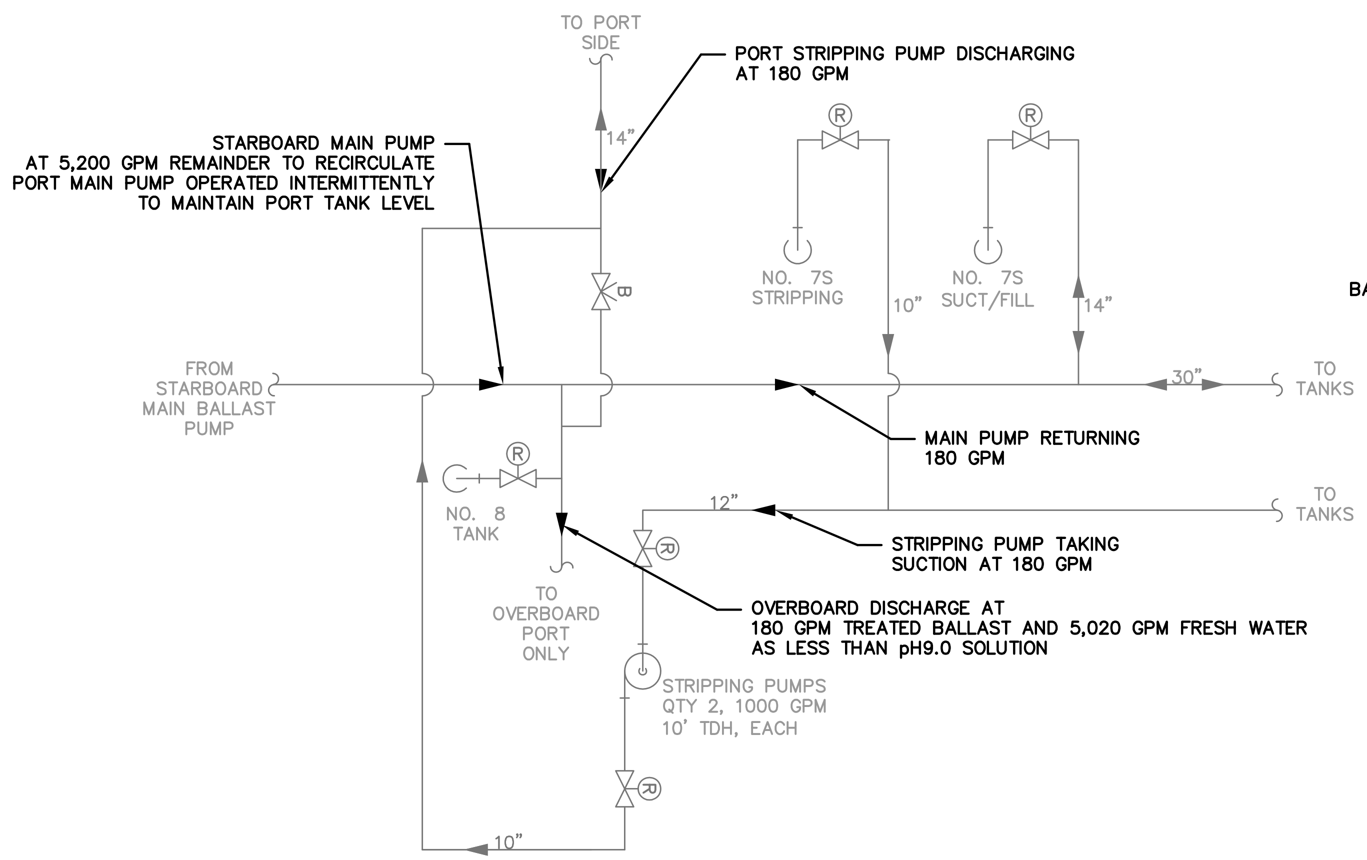
ASSUMING NO DILUTION EXTERNAL TO SHIP
OPERATIONAL PROCEDURE:

1. DOSE ALL TANKS WITH NaOH TO pH 12
2. RETAIN WATER REQUIRED TIME TO DEACTIVATE ALL ORGANISMS AND UNTIL SHIP IS IN WATER KNOWN TO BE FREE OF UNWANTED SPECIES.
3. START MAIN BALLAST PUMPS AT REDUCED FLOW WITH DISCHARGE DIRECTED OVERBOARD THROUGH SIDE SHELL.
4. START STRIPPING PUMPS WITH SUCTION FROM DESIRED TANK AND DIRECTED OVERBOARD.
5. OPEN MAIN BALLAST LINE VALVE TO DESIRED TANK AND BALANCE FILLING FROM MAIN PUMP AND DISCHARGE FROM STRIPPING PUMP.
6. CONTINUE EXCHANGE OF WATER UNTIL pH IN DESIRED TANK IS BELOW pH9.0.
7. REALIGN VALVES TO EXCHANGE FROM NEXT DESIRED TANK.
8. WHEN SHIP REQUIRES DISCHARGE OF BALLAST DISCHARGE BALLAST USING CO2 NEUTRALIZATION AS NEEDED TO ENSURE pH OF DISCHARGED WATER IS BELOW pH9.0.
9. DUE TO 14" PIPE SIZE FOR OVERBOARD ONLY 5,500 GPM CAN BE PUMPED AT A TIME. BASED ON A 30:1 DILUTION TO DILUTE pH 12 SOLUTION TO pH 9.0 ONLY 180 GPM CAN BE EXCHANGED AT A TIME.
10. A NEUTRALIZATION SYSTEM WOULD BE REQUIRED TO ENSURE DISCHARGE CAN OCCUR WHEN REQUIRED.
11. WITH THE FLOW RATES ABOVE IT IS ESTIMATED THAT LESS THAN 10% OF THE WATER CARRIED IN AN AVERAGE BALLAST LOAD COULD BE EXCHANGED IN 36 HOURS.



PLAN 6–5A

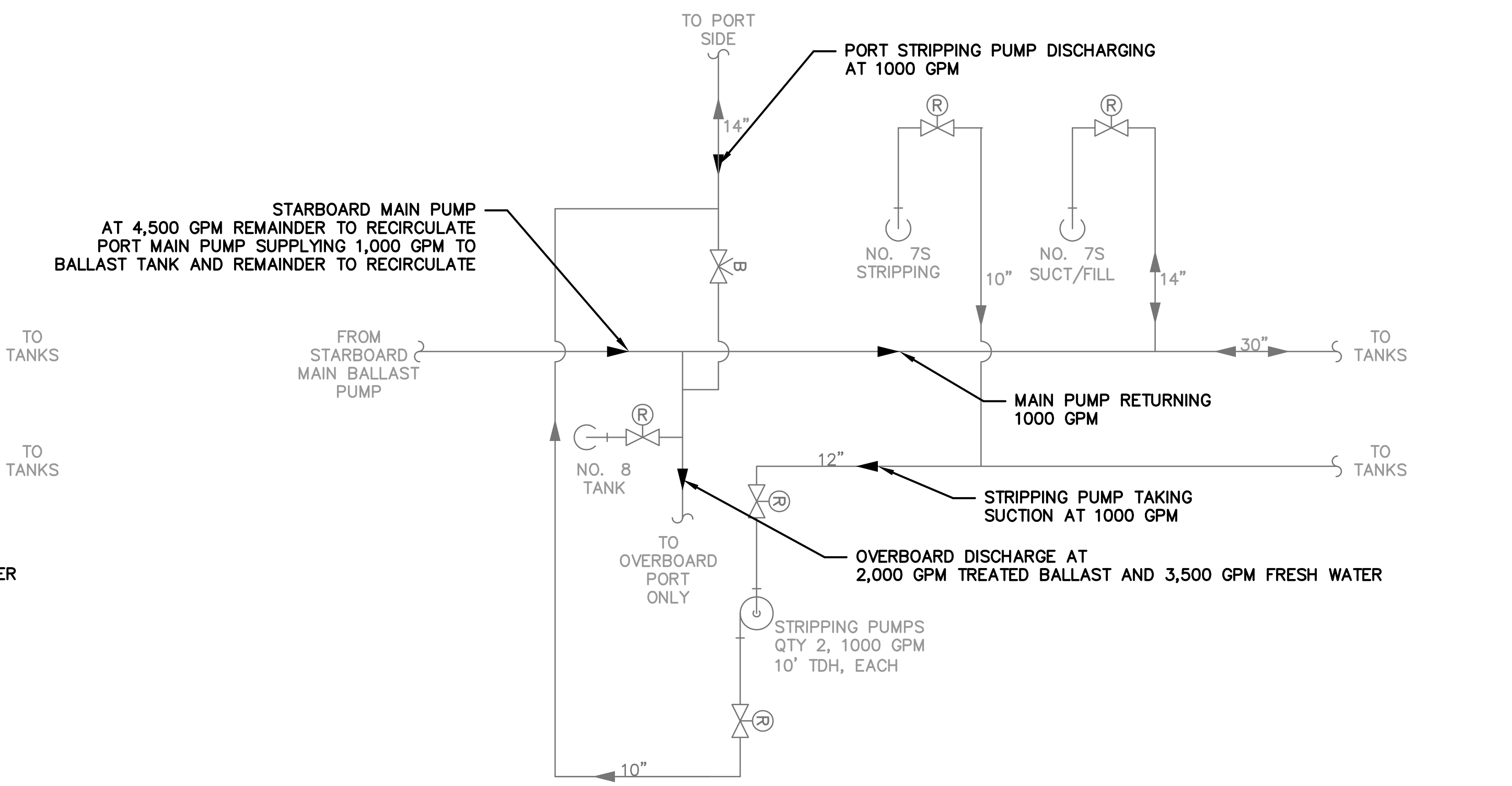
FRESH WATER DILUTION ASSUMING DISCHARGED BALLAST MUST BE DILUTED TO LESS THAN pH 9.0

STARBOARD SIDE SHOWN PORT SIMILAR

NO SCALE

ASSUMING 200 TO 1 DILUTION EXTERNAL TO SHIP
OPERATIONAL PROCEDURE:

1. DOSE ALL TANKS WITH NaOH TO pH 12
2. RETAIN WATER REQUIRED TIME TO DEACTIVATE ALL ORGANISMS AND UNTIL SHIP IS IN WATER KNOWN TO BE FREE OF UNWANTED SPECIES.
3. START MAIN BALLAST PUMPS AT REDUCED FLOW WITH DISCHARGE DIRECTED OVERBOARD THROUGH SIDE SHELL.
4. START STRIPPING PUMPS WITH SUCTION FROM DESIRED TANK AND DIRECTED OVERBOARD.
5. OPEN MAIN BALLAST LINE VALVE TO DESIRED TANK AND BALANCE FILLING FROM MAIN PUMP AND DISCHARGE FROM STRIPPING PUMP.
6. CONTINUE EXCHANGE OF WATER UNTIL pH IN DESIRED TANK IS BELOW pH9.0.
7. REALIGN VALVES TO EXCHANGE FROM NEXT DESIRED TANK.
8. WHEN SHIP REQUIRES DISCHARGE OF BALLAST DISCHARGE BALLAST USING CO2 NEUTRALIZATION AS NEEDED TO ENSURE pH OF DISCHARGED WATER IS BELOW pH9.0.
9. DUE TO 14" PIPE SIZE FOR OVERBOARD ONLY 5,500 GPM CAN BE PUMPED THROUGH THE OVERBOARD AT A TIME. THE SOLUTION DISCHARGED OVER THE SIDE IS ESTIMATED TO HAVE A pH OF 11.7.
10. AFTER DISCHARGE THE SOLUTION MIXES WITH LAKE WATER. BASED ON COMMON PRACTICE DISCHARGE FROM A MOVING SHIP WILL DILUTE BY 200:1 SOON AFTER DISCHARGE. THIS DILUTION FACTOR WOULD LOWER THE SOLUTION pH TO BELOW 9.0.
11. A NEUTRALIZATION SYSTEM WOULD BE REQUIRED TO ENSURE DISCHARGE CAN OCCUR WHEN REQUIRED.
12. WITH THE FLOW RATES ABOVE IT IS ESTIMATED THAT ~40% OF THE WATER CARRIED IN AN AVERAGE BALLAST LOAD COULD BE EXCHANGED IN 36 HOURS. THIS WOULD REDUCE THE REQUIRED CO2 STORAGE ON BOARD BY THE SAME PERCENTAGE.



PLAN 6–2A

FRESH WATER DILUTION ASSUMING DISCHARGED BALLAST DILUTES AFTER IT IS RELEASED TO pH 9.0

STARBOARD SIDE SHOWN PORT SIMILAR

NO SCALE

SIGNED ORIGINAL ON FILE

NATIONAL PARKS OF LAKE SUPERIOR FOUNDATION
HOUGHTON, MI

M/V INDIANA HARBOR
NaOH BALLAST WATER TREATMENT SYSTEM CONCEPT
P&ID NaOH AND LAKE WATER EXCHANGE

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JKM	KJR	DWL	2/12/10

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Appendix B Cost Estimates

JOB NO:	09129
CLIENT:	National Parks of Lake Superior Foundation
VESSEL:	M/V Indiana Harbor
TASK:	SODIUM HYDROXIDE TREATMENT SYSTEM - BASELINE AND OPTIONS
DATE:	02/19/10
BY:	JKM CHECKED: KJR

ITEM	DESCRIPTION	LABOR (HOURS)	MATERIALS ($)	SUB-TOTAL ($)	MATERIAL MARKUP	CONTINGENCY	TOTAL ($)
1	STRUCTURE	140	595,900	605,000	0	121,000	726,000
2	PROPULSION	0	0	0	0	0	0
3	ELECTRICAL	850	3,000	58,300	0	11,700	70,000
4	ELECTRONICS	660	107,000	149,900	0	30,000	179,900
5	AUXILIARY SYSTEMS	2,608	498,100	667,600	0	133,500	801,100
6	OUTFITTING ITEMS	0	0	0	0	0	0
7	DECK MACHINERY	0	0	0	0	0	0
8	SHPYD ENGR/MNGMENT	0	18,000	18,000	0	3,600	21,600
9	OWNER ENGR/MNGMENT	0	152,000	152,000	0	30,400	182,400
10	OPTION 1 - ADDITIONS	6,900	3,204,056	3,652,556	0	730,500	4,383,100
11	OPTION 1 - DEDUCTIONS	(400)	(227,144)	(253,144)	0	(50,600)	(303,700)
12	OPTION 2 - ADDITIONS	21,992	771,920	2,201,400	0	440,300	2,641,700
13	OPTION 2 - DEDUCTIONS	(400)	(227,144)	(253,144)	0	(50,600)	(303,700)

CONSTRUCTION TOTALS	
BASELINE - NEUTRALIZATION WITH CO2 (ITEMS 1 - 9)	**$1,981,000**
OPTION 1 - NEURALIZATION WITH EXHAUST GAS SCRUBBING (ITEMS 1 - 11)	**$6,060,400**
OPTION 2 - NEUTRALIZATION W/ IN TANK EXHAUST GAS SPARGING (ITEMS 1 - 9, 12, 13)	**$4,319,000**

LABOR RATE PER HOUR	MATERIAL MARKUP	ESTIMATE CONTINGENCY	
$65	added at detail level	20%	

ID	DESCRIPTION	QTY	UNITS	UNIT LABOR (HRS)	UNIT MAT'L ($)	TOTAL LABOR (HRS)	TOTAL MAT'L ($)	TOTAL COST ($)	REMARKS
1	STRUCTURE								
	NaOH tank structure (2 @ 8,000gal)	56,762	lbs	0	8	0	454,093	454,093	
	CO2 foundation	5,000	lbs	0	6	0	30,000	30,000	
	CO2 Containment	18,096	lbs	0	6	0	108,576	108,576	
	Slip stream pump foundation	1	ea	40	500	40	500	3,100	
	Sampling pump foundation	1	ea	20	200	20	200	1,500	
	Bulkhead penetrations	20	ea	4	125	80	2,500	7,700	
						0	0	0	
						0	0	0	
	Sub-Total					140	595,869	604,969	
2	PROPULSION								
	NONE					0	0	0	
	Sub-Total					0	0	0	
3	ELECTRICAL								
	Power to sampling pump	100	ft	1	4	100	400	6,900	
	Power to slip stream pump	100	ft	1	4	100	400	6,900	
	Power to CO2 cooling and regas unit	250	ft	1	4	250	1,000	17,250	
	Control cabling	1,200	ft	0.33	1	400	1,200	27,200	
	Sub-Total					850	3,000	58,250	
4	ELECTRONICS								
	Control system	1	ea	400	75,000	400	75,000	101,000	Includes PID programming and verification logs.

ID	DESCRIPTION	QTY	UNITS	UNIT LABOR (HRS)	UNIT MAT'L ($)	TOTAL LABOR (HRS)	TOTAL MAT'L ($)	TOTAL COST ($)	REMARKS
	Flow meter	1	ea	120	12,000	120	12,000	19,800	Includes meter, display, and interface with controls.
	pH sensor	2	ea	20	2,500	40	5,000	7,600	
	NaOH tank level indicator	2	ea	20	2,500	40	5,000	7,600	
	Alarm system (CO2 or NaOH leak)	1	ea	60	10,000	60	10,000	13,900	
	Sub-Total					660	107,000	149,900	
5	AUXILIARY SYSTEMS								
	Ballast Pipe Penetration 3"	16	ea	4	250	64	4,000	8,160	
	sparger NaOH	4	ea	2	600	8	2,400	2,920	
	sampling sparger	8	ea	2	600	16	4,800	5,840	
	3" steel piping	140	ft	3	10	420	1,400	28,700	
	1" steel piping sampling	100	ft	1	3	100	250	6,750	
	1" steel piping CO2	200	ft	1	3	200	500	13,500	
						0	0	0	
	3" butterfly valves	2	ea	2	200	4	400	660	
	3" gate valves	6	ea	2	350	12	2,100	2,880	
	3" check valve	2	ea	2	200	4	400	660	
	1-1/2" ball valves	10	ea	1	75	10	750	1,400	
	1" globe valves	10	ea	1	100	10	1,000	1,650	
						0	0	0	
	4" NaOH vent	80	ft	4	14	320	1,120	21,920	
	3" NaOH fill	80	ft	3	10	240	800	16,400	
						0	0	0	
	Sampling pump (10gpm)	2	ea	40	1,600	80	3,200	8,400	Assume small peristalitic with VFD and motor.

ID	DESCRIPTION	QTY	UNITS	UNIT LABOR (HRS)	UNIT MAT'L ($)	TOTAL LABOR (HRS)	TOTAL MAT'L ($)	TOTAL COST ($)	REMARKS
	Slip stream pump (200gpm)	2	ea	80	9,164	160	18,328	28,728	Assume centrifugal, Goulds 3796 with 7.5 HP motor
						0	0	0	
	CO2 storage and vaporizing system	2	ea	400	220,000	800	440,000	492,000	Scaled from TOMCO $400k ea quote which included not req'd carborizor w/ 10% mark-up
	CO2 sparger (Mott Series 7100 GasSaver)	2	ea	20	3,960	40	7,920	10,520	Quoted by Mott metulurgical w/ 10% mark-up
	Static Mixer (Westfall model 2800)	2	ea	40	4,180	80	8,360	13,560	Quoted by Mott metulurgical w/ 10% mark-up
						0	0	0	
	Hydro Test	1	ea	40	400	40	400	3,000	
						0	0	0	
						0	0	0	
	Sub-Total					2,608	498,128	667,648	
6	OUTFITTING ITEMS								
	None					0	0	0	
	Sub-Total					0	0	0	
7	DECK MACHINERY								
	None					0	0	0	
	Sub-Total					0	0	0	
8	SHPYD ENGR/MNGMENT								
	Construction support	1	ea		18,000	0	18,000	18,000	
						0	0	0	
	Sub-Total					0	18,000	18,000	

ID	DESCRIPTION	QTY	UNITS	UNIT LABOR (HRS)	UNIT MAT'L ($)	TOTAL LABOR (HRS)	TOTAL MAT'L ($)	TOTAL COST ($)	REMARKS
9	OWNER ENGR/MNGMENT								
	Detail design	1	ea		120,000	0	120,000	120,000	
	Regulatory review	1	ea		32,000	0	32,000	32,000	
						0	0	0	
	Sub-Total					0	152,000	152,000	
10	OPTION 1 - ADDITIONS	(EXHAUST GAS SCRUBBING TO REDUCE CO2 NEUTRALIZATION DEMAND)							
	Exhaust gas scrubber system	1	ea	2,000	2,299,055	2,000	2,299,055	2,429,055	Krystallon quote including 2 scrubbers, waste water plant, instrumentation w/ 10% mark-up
	Structural modifications	60,000	lbs	0	10	0	600,000	600,000	Extended stack areas to fit scrubber units
	Wash water pumps, 200 m3/hr at 2 bar	2	ea	400	55,000	800	110,000	162,000	Assume Goulds 3410 Series, Vertical Mount with Flow Meter and Drives
	Wash water piping (8")	200	ft	8	40	1,600	8,000	112,000	
	Exhaust piping	80	ft	20	100	1,600	8,000	112,000	Rework of Four Engine Exhaust Lines
	Controls Integration	1	ea	200	25,000	200	25,000	38,000	Console installed in Control Room
	Waste System Management	1	ea	200	10,000	200	10,000	23,000	Small waste holding tank, and pumping system.
	Test and trials	1	ea	500	1	500	1	32,501	
	Detail design	1	ea		120,000	0	120,000	120,000	
	Regulatory review	1	ea		24,000	0	24,000	24,000	
						0	0	0	

ID	DESCRIPTION	QTY	UNITS	UNIT LABOR (HRS)	UNIT MAT'L ($)	TOTAL LABOR (HRS)	TOTAL MAT'L ($)	TOTAL COST ($)	REMARKS
	Sub-Total					6,900	3,204,056	3,652,556	
11	OPTION 1 - DEDUCTIONS	(EXHAUST GAS SCRUBBING TO REDUCE CO2 NEUTRALIZATION DEMAND)							
	CO2 storage and vaporizing system	(1)	ea	400	200,000	(400)	(200,000)	(226,000)	50% of Full System Required
	CO2 Containment	(4,524)	lbs	0	6	0	(27,144)	(27,144)	75% of Full System Required
						0	0	0	
	Sub-Total					(400)	(227,144)	(253,144)	
12	OPTION 2 - ADDITIONS	(EXHAUST GAS **IN TANK SPARGING** TO REDUCE CO2 NEUTRALIZATION DEMAND)							
	Catalytic Converter for Single Engine Exhaust	1	each	200	25,300	200	25,300	38,300	Material from vendor quote w/ 10% mark-up
	Gas cooling system	1	each	400	100,000	400	100,000	126,000	ROM - Includes pump and heat exchanger
	Gas compression system	1	each	400	150,000	400	150,000	176,000	ROM
	Gas distribution piping (8" SS pipe)	1,520	feet	8	150	12,160	228,000	1,018,400	Stack through Tunnel 800 Feet, 18 Tanks at 40 Feet Each
	Gas isolation valves (8" SS)	18	ea	16	1,200	288	21,600	40,320	One valve per tank with remote actuator
	Control Cabling for valves	7,200	feet	0.22	1	1,584	7,200	110,160	18 Valves at Avg 400 feet
	In tank gas sparging (Airotube 660'/tank)	11,880	feet	0.50	1.5	5,940	17,820	403,920	USGS estimate including manifolds
	Exhaust piping	20	ft	20	100	400	2,000	28,000	Rework of One Engine Exhaust Line
	Controls Integration	1	ea	120	20,000	120	20,000	27,800	Console installed in Control Room (Valves and pH)
	Test and trials	1	ea	500		500	0	32,500	
	Detail design	1	ea		160,000	0	160,000	160,000	

ID	DESCRIPTION	QTY	UNITS	UNIT LABOR (HRS)	UNIT MAT'L ($)	TOTAL LABOR (HRS)	TOTAL MAT'L ($)	TOTAL COST ($)	REMARKS
	Regulatory review	1	ea		40,000	0	40,000	40,000	
						0	0	0	
	Sub-Total					21,992	771,920	2,201,400	
13	OPTION 2 - DEDUCTIONS	(EXHAUST GAS **IN TANK SPARGING** TO REDUCE CO2 NEUTRALIZATION DEMAND)							
	CO2 storage and vaporizing system	(1)	ea	400	200,000	(400)	(200,000)	(226,000)	50% of Full System Required
	CO2 Containment	(4,524)	lbs	0	6	0	(27,144)	(27,144)	75% of Full System Required
						0	0	0	
	Sub-Total					(400)	(227,144)	(253,144)	

Number of trips per year	45	
Average cargo capacity	62,100	tons
Energy Cost	$0.15	per kilowatt-hour
CO2 cost	$0.07	per lbs
NaOH cost	$125	per ton 50% solution
Maintenance cost	1%	capital cost
Shipboard labor rate	$40	per hour
Baseline Capital Cost	$1,981,000	
Option 1 Capital Cost	$6,060,400	
Option 2 Capital Cost	$4,319,000	

BASELINE - NEUTRALIZATION WITH CO2			
Item	**trip**	**extended**	**Notes**
NaOH	$6,043	$271,913	48.34 tons of 50% solution
CO2	$3,724	$167,580	53,200 lbs
Annual Maintenance		$19,810	As % of capital cost
Additional Personnel	$320	$14,400	2 persons 4 hours
Operation (Dosing)	$18	$810	10hp (7.5kW) for 16 hours
Total	**$10,105**	**$474,513**	
Cost per ton of cargo	$0.163		
Annual Depreciation		$66,033	Assuming constant depreciation over 30 years
Annualized total cost		$540,546	
Annualized cost per ton of cargo		$0.193	

OPTION 1 - NEURALIZATION WITH EXHAUST GAS SCRUBBING			
Item	**trip**	**extended**	**Notes**
NaOH	$6,043	$271,913	48.34 tons of 50% solution
CO2	$2,979	$134,064	42,560 lbs (80% of Baseline)
Annual Maintenance		$60,604	As % of capital cost
Additional Personnel	$320	$14,400	2 persons 4 hours
Operation (Dosing)	$18	$810	10hp (7.5kW) for 16 hours
Additional Personnel (Exhaust System)	$80	$3,600	1 persons 2 hours
Operation (Exhaust System)	$3,240	$145,800	240hp (180kW) full time
Total	**$12,680**	**$631,191**	
Cost per ton of cargo	$0.204		
Annual Depreciation		$202,013	Assuming constant depreciation over 30 years
Annualized total cost		$833,204	
Annualized cost per ton of cargo		$0.298	
Cost of Exhaust Gas Scrubbing System	$4,079,400		
CO2 Savings	($745)	($33,516)	Compared to Baseline System
Additional Exhaust system costs		$190,194	Including maintenance of exhaust gas system
Actual savings		$156,678	per year
Payback Period		NA	**years**

OPTION 2 - NEUTRALIZATION W/ IN TANK EXHAUST GAS SPARGING			
Item	**trip**	**extended**	**Notes**
NaOH	$6,043	$271,913	48.34 tons of 50% solution
CO2	$931	$41,895	13,300 lbs (25% of Baseline)
Annual Maintenance		$43,190	As % of capital cost
Additional Personnel (Dosing)	$320	$14,400	2 persons 4 hours
Operation (Dosing)	$18	$810	10hp (7.5kW) for 16 hours
Additional Personnel (Exhaust System)	$320	$14,400	1 persons 8 hours
Operation (Exhaust System)	$806	$36,288	300hp (224kW) 24 hours
Total	**$8,438**	**$422,896**	
Cost per ton of cargo	$0.136		
Annual Depreciation		$143,967	Assuming constant depreciation over 30 years
Annualized total cost		$566,862	
Annualized cost per ton of cargo		$0.203	
Cost of Exhaust Gas Sparging System	$2,338,000		
CO2 Savings	($2,793)	($125,685)	Compared to Baseline System
Additional Exhaust system costs		$74,068	Including maintenance of exhaust gas system
Actual savings		($51,617)	per year
Payback Period		45	**years**

Appendix C Structural Calculations

ABS RULES FOR BUILDING AND CLASSING STEEL VESSELS 2010

Calcs:	CCE	4 Feb 2010
Checked:	JKM	9 Feb 2010

PRINCIPAL CHARACTERISTICS

Length Overall	1000.00	ft
Length between Perpendiculars	990.00	ft
Breadth (mld)	105.00	ft
Depth at side (mld)	56.00	ft
Draft, Design (mld)	27.50	ft
Draft, Scantling (mld)	38.00	ft

EXISTING MATERIALS	**YIELD STRENGTH**	
Plating, ABS Grade AH36	51,000	psi
Scantlings, ABS Grade G AH36	51,000	psi
or ASTM A572	50,000	psi

NEW MATERIALS	**YIELD STRENGTH**	
ABS Grade A	34,000	psi

ABS MINIMUM PLATE THICKNESS

MEMBER		t_{ACT} (in)	$t_{REQ'D}$ (in)	Achieved
Tank Top (EXISTING)	-	0.375	0.321	117%
Tank Bottom (NEW)	-	0.500	0.440	114%
Outboard Bulkhead (NEW)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%
Inboard Bulkhead (MOD)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%
Fwd Bulkhead (MOD)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%
Aft Bulkhead (MOD)	Upper	0.438	0.404	108%
	Lower	0.500	0.440	114%

ABS MINIMUM SCANTLINGS

MEMBER	SCANTLING		SM_{ACTUAL} (in^3)	$SM_{REQ'D}$ (in^3)	Achieved
Top plate stiffeners (EXISTING)	7x4x3/8 L on 3/8 PL	-	14.79	9.47	156%
Bottom plate stiffeners (NEW)	8x6x1/2 L on 1/2 PL	-	30.59	22.26	137%
Outboard stiffeners (NEW)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%
Inboard stiffeners (MOD)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%
Fwd Stiffeners (MOD)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%
Aft Stiffeners (MOD)	8x4x1/2 L on 7/16 PL	Upper	23.00	17.76	130%
	8x6x1/2 L on 1/2 PL	Lower	30.59	22.26	137%

Part 3
Chapter 2 Hull Structures and Arrangements
Section 10 Deep Tanks

3-2-10/3 Construction of Deep Tank Bulkheads

Where the specific gravity of the liquid exceeds 1.05, the design head, h, in this section is to be increased by the ratio of the specific gravity of the liquid to be carried, to 1.05.

SG = 1.5 specific gravity of NaOH

SG factor = 1.43 = 1.5 / 1.05

3.1 Plating

t =	(s k √ (q h (SG factor)) / 460) + 0.10 in	no less than 0.25 in or s/150 + 0.10 in
t_{BOTTOM} =	0.440 in	thickness of bottom plate (ordinary steel)
t_{TOP} =	0.281 in (see correction below)	thickness of tank top (high strength steel)
$t_{UPPER\ BHD\ NEW}$ =	0.404 in	thickness of upper bhds (ordinary steel)
$t_{LOWER\ BHD\ NEW}$ =	0.440 in	thickness of lower bhds (ordinary steel)

s =	24 in	stiffener spacing
k =	1.0	plate aspect ratio factor
q_{EXIST} =	0.7	34,000 / Y psi; high strength steel
q_{NEW} =	1.0	34,000 / Y psi; ordinary steel
Y_{EXIST} =	51,000 psi	existing yield strength; high strength steel
Y_{NEW} =	34,000 psi	new yield strength; ordinary steel
h_{BOTTOM} =	29.69 ft	design head; tank bottom
h_{TOP} =	12.63 ft	design head; tank top
$h_{UPPER\ BHD}$	23.69 ft	design head; upper bhd, 6 ft abv tank bottom)
$h_{LOWER\ BHD}$	29.69 ft	design head; lower bhd

Calculate Design Head

56.0 ft	vessel depth at side
40.06 ft	distance from BL to outboard tank top
23.0 ft	distance from BL to tank bottom
17.06 ft	outboard tank height
34.0 ft	load line, GN 6 on midship dwg.
3.0 ft	height of tank overflow

h = distance from the bottom of plate to the max of the following:

12.625 ft	2/3 distance from top of tank to top of overflow
4.25 ft	(e) 3-2-7 Table 1
-6.06 ft	load line
10.63 ft	2/3 distance to bulkhead of freeboard deck

3.3 Stiffeners

SM =	$0.0041\ c\ h\ (\text{SG factor})\ s\ l^2$ in^3	section modulus
SM_{BOTTOM} =	22.3 in^3	
SM_{TOP} =	9.5 in^3	
$SM_{UPPER\ BHD}$ =	17.8 in^3	
$SM_{LOWER\ BHD}$ =	22.3 in^3	

c =	1.0	end attachment factor
h =	see above	design head
s =	2.0 ft	stiffener spacing
l =	8.0 ft	unsupported span

3.5 Tank-top Plating

Tops of tanks are to have plating 0.04 in thicker than would be required for vertical plating at the same level.

t_{TOP} = t + 0.04 in

t_{TOP} = 0.32 in thickness of tank top (high strength steel)

TANK BOTTOM and LOWER BULKHEADS
8" x 6" x 1/2" L on 1/2" PL

SMyy for Vertical Bending

Item	Base in	Height in	VCG in	Area in^2	Moment in^3	M*y in^4	I in^4
Deck	24.00	0.500	8.25	12.00	99.00	816.75	0.25
Web	0.50	7.50	4.25	3.75	15.94	67.73	17.58
Flange	6.00	0.50	0.25	3.00	0.75	0.19	0.06
Totals	*	*	*	18.75	115.69	884.67	17.89

Total Height	8.50	in
NA (From Bottom)	6.17	in
Moment of Inertia	188.77	in^4
SM (Bottom)	**30.59**	**in^3**
SM (Top)	81.02	in^3

UPPER BULKHEADS
8" x 4" x 1/2" L on 7/16" PL

SMyy for Vertical Bending

Item	Base in	Height in	VCG in	Area in^2	Moment in^3	M*y in^4	I in^4
Deck	24.00	0.44	8.22	10.50	86.30	709.25	0.17
Web	0.500	7.500	4.25	3.75	15.94	67.73	17.58
Flange	4.00	0.500	0.25	2.00	0.50	0.13	0.04
Totals	*	*	*	16.25	102.73	777.11	17.79

Total Height	8.44	in
NA (From Bottom)	6.32	in
Moment of Inertia	145.40	in^4
SM (Bottom)	**23.00**	**in^3**
SM (Top)	68.73	in^3

TANK TOP
7" x 4" x 3/8" L on 3/8" PL

SMyy for Vertical Bending

Item	Base in	Height in	VCG in	Area in^2	Moment in^3	M*y in^4	I in^4
Deck	22.50	0.375	7.19	8.44	60.64	435.88	0.10
Web	0.375	6.625	3.69	2.48	9.16	33.78	9.09
Flange	4.00	0.375	0.19	1.50	0.28	0.05	0.02
Totals	*	*	*	12.42	70.09	469.72	9.20

Total Height	7.38	in
NA (From Bottom)	5.64	in
Moment of Inertia	83.47	in^4
SM (Bottom)	**14.79**	**in^3**
SM (Top)	48.17	in^3