Ballast Water Treatment Technology: Design, Risk Assessment, and Installation on a Tank Ship

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This paper outlines the design, assessment, and installation of a prototype ballast water treatment system for a double-hull tank ship. The IMO has established a timetable by which vessels must be equipped with ballast water treatment systems that meet a prescribed performance standard. Tank ship installations are particularly challenging because ballast piping is typically located in spaces defined by classification society rules as hazardous. These same rules do not readily allow the treatment equipment and piping to communicate with these spaces. The treatment system described in this paper has been demonstrated, through a risk assessment, to meet applicable classification society rules. Planned full-scale testing intends to show the operational safety, efficiency, and biological efficacy of this promising technology.

Figure 1. Ballast water treatment module on the *S/R AMERICAN PROGRESS*

KEYWORDS: ballast water treatment; ballast water management; aquatic nuisance species (ANS); non-indigenous species (NIS); tank ship; risk assessment; hazardous area; ship operations.

INTRODUCTION AND BACKGROUND

Worldwide concern for the unintentional migration of non-indigenous species (NIS) by all vessel types is well documented. In 2004, the International Maritime Organization (IMO) adopted the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (Convention) for the "prevention, reduction, or elimination of the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments."

Upon ratification of the Convention, vessels that need to discharge while in port must either exchange ballast water at sea or treat ballast water. However, timelines in the Convention and Application Resolution A.1005(25) phase out the acceptance of ballast water exchange, and require the installation of ballast treatment systems on all newly-built and existing vessels that discharge ballast water in port (see Table 1). These ballast treatment systems will need to meet a prescribed performance standard as established by Regulation D-2 of the Convention.

Additionally, various national, regional, and local regulatory bodies are establishing requirements for ballast water treatment prior to discharge in local waters. For example, in California, this phase-in schedule is more aggressive than the Convention, with treatment requirements starting in 2010.

Table 1. IMO Ballast Exchange Phase-Out Schedule

Vessel Ballast Capacity (cubic meters)	Vessel Construction/ Conversion Date	Exchange Phase-Out (Treatment or Retention Only)
Less than 1500	Before 2009	First Survey starting **01-Jan-2016**
	On or after 2009	2nd Annual Survey no later than **01-Jan-2012**
1500 to 5000	Before 2009	First Survey starting **01-Jan-2014**
	On or after 2009	2nd Annual Survey no later than **01-Jan-2012**
Greater than 5000	Before 2009	First Survey starting **01-Jan-2016**
	2009 through 2011	Immediately starting **01-Jan-2016**
	On or after 2012	Immediately starting **01-Jan-2012**

In 2004, the US Coast Guard unveiled the Shipboard Technology Assessment Program (STEP), recognizing the need for ship prototype installations to facilitate the development of effective ballast water treatment technologies. The National Oceanic and Atmospheric Administration (NOAA) has also supported the need for shipboard experience, with the Ballast Water Technology Demonstration Program. Support from such programs, along with industry investment, has accelerated ballast water treatment research, development, and testing efforts. These efforts include testing of prototype systems on a variety of oceangoing vessels and shore-moored barges.

Despite these advances, there has not been sufficient prototype testing of practical systems for tank ships. Tank ship ballast water systems handle higher volumes and flow rates than many other vessel types. These higher flow rates require larger and more powerful equipment, and accessibility for routine maintenance and repair. As tank ships are designed to carry hydrocarbons, equipment installations must meet classification society hazardous area rules. These establish additional requirements on the type of electrical equipment and place restrictions on piping connections to areas where hydrocarbons may be present.

This paper examines the design and installation of a promising ballast water treatment technology. It includes a review of a risk assessment that demonstrates that the design and installation on a tank ship maintains an equivalent level of safety as other already-approved, comparable systems.

DESIGN CONSIDERATIONS

For a number of years now, the recognized method of ballast water management for non-indigenous species (NIS) has been ballast water exchange. Although simple in concept, the additional handling of ballast water, either through the pump-out and refill method or the three times overflow method, is inefficient and time consuming. Furthermore, ballast water exchange was recognized as insufficient for the effective elimination of NIS and led the IMO in 2004 to start phasing in "safer and more effective Ballast Water Management options."

It was realized that a treatment system that minimized the handling of ballast water would be preferred. Recognizing the common use of hypochlorite systems to control fouling in seawater systems and the widespread use of hypochlorite in water treatment systems worldwide as a low-cost, effective system, manufacturers were encouraged to develop a ballast water treatment system that would inject hypochlorite during loading of ballast.

Numerous issues needed to be addressed, including the preliminary design and sizing, impact of hypochlorite on piping and coating materials, and potential environmental concerns over the use of a chlorine-based solution. A prototype design by Severn Trent De Nora proved promising after testing the efficiency, efficacy, and suitability of hypochlorite. With the help of The Glosten Associates, Inc., and support from SeaRiver Maritime, Inc., a detailed design was developed for installation on the *S/R AMERICAN PROGRESS*, a 46,000 deadweight ton, double-hull product tanker. The American Bureau of Shipping (ABS) provided the classification society oversight and acceptance role for this prototype installation.

The ship was selected as it is of a typical double-hull tank arrangement. The vessel has 14 cargo tanks and 2 slop tanks. The double-hull, segregated ballast capacity is 19,000 cubic meters. The ballast is handled by two ballast pumps, each rated at 975 cubic meters per hour. The cargo and ballast pumps are located in a traditional pump room just aft of the cargo tanks and forward of the machinery space. The vessel's normal voyage, with a round-trip duration of 8 to 10 days, was deemed suitable to support testing efforts.

Figure 2. Main Control Panel for Hypochlorite Generator

Hypochlorite Ballast Water Treatment System

The BalPure™ hypochlorite Ballast Water Treatment System used in this prototype installation is based on the injection of hypochlorite into the ballast piping lines, downstream of the pumps, at a concentration of ~5-8 parts per million (ppm), to inactivate all marine organisms. As the hypochlorite reacts with the organisms, the concentration of hypochlorite falls to ~1-3 ppm, where it remains in the ballast tank until discharge. During discharge, sodium bisulfite ($NaHSO_3$) is injected into the ballast lines, upstream of the pumps, to neutralize the remaining hypochlorite and render the ballast water safe to discharge. The treatment system includes a monitoring system that measures the concentrations of hypochlorite during ballasting, the residual hypochlorite in the tanks, and the sodium bisulfite at discharge. The injection flow rates of hypochlorite and sodium bisulfite are regulated by electronics, using the ballast water flow rate and the detected concentrations of these two substances. Rates and concentrations are logged electronically for subsequent reporting.

REQUIREMENTS FOR TANK SHIPS

Tank ships are designed to carry hydrocarbons in bulk. The cargo tanks carrying the hydrocarbons are by definition hazardous areas. While not intended to contain hydrocarbon gases or liquids, adjacent spaces to these tanks, including ballast tanks and the pump room, must be designed to meet the requirements for a hazardous area.

The detailed rules applicable to hazardous areas are developed by classification societies to comply with the *International Convention for the Safety of Life at Sea* (SOLAS). ABS provides the following definition.

> *Areas where flammable or explosive gases or vapors are normally present or likely to be present are known as Hazardous Areas. The flammable or explosive atmosphere may be expected to exist continuously or intermittently.*

ABS Rules for Building and Classing Steel Vessels, Part 5, Chapters 1 and 2, set limitations on how piping can be run between hazardous and non-hazardous compartments. Specifically, application of ABS 5.1.7/1.7.2 requires segregated bilge/ballast systems for any tanks that have a common bulkhead with cargo tanks. This segregation is designed to prevent the potential release of hydrocarbon liquids or vapors in non-hazardous spaces.

These regulations imply that all ballast water treatment system components must be placed in hazardous areas only. This is often both impractical and inefficient. Given the system's electrical power requirements, the need for accessibility to carryout routine maintenance and repair, as well as other factors, it is preferable to install the components in a non-hazardous area such as the engine room or an auxiliary machinery space.

There are a number of exceptions to ABS rules concerning the interface between hazardous and non-hazardous areas as they apply to the delivery or recirculation of fluids between machinery spaces and the cargo block. These exceptions include:

- the transfer of machinery space bilge liquids to a holding "slop" tank,
- gas sampling installations,
- thermal oil and steam heating systems,
- the fire main/ballast system crossover, and
- inert gas systems.

In each case, specific rules have been developed by classification societies to eliminate or mitigate potential hazards.

In the absence of specific rules governing communication between hazardous and non-hazardous spaces for a ballast treatment system, the analysis team conducted a comprehensive risk assessment and compared their results to the requirements established for transferring machinery space bilge liquids into a holding "slop" tank. This theoretical approach would allow the team to compare its preliminary results to the rules that govern other systems that involve like conditions.

Figure 3. Ballast water discharge line in the pump room.

RISK ASSESSMENT

Objective

The objective of the risk assessment was to demonstrate that the installation of the BalPure™ hypochlorite Ballast Water Treatment System meets or exceeds comparable safety standards established for other systems that permit communication between hazardous and non-hazardous spaces. The ABS *Guide for Risk Assessment for the Classification of Marine-Related Facilities* provides an approval process for such a situation:

> *....where a design is being proposed on the premise that it provides equivalent protection against the risks addressed by the ABS Class Rules, rather than by strict compliance with existing prescriptive classification Rules.*

Assessment

The primary issue associated with the installation of the proposed ballast water treatment system was that system piping failures in safe areas could compromise the separation of potential ignition sources in the engine room from hydrocarbons carried in the cargo block. Specifically, the two sub-systems of interest were:

- Hypochlorite dosing piping from the generation equipment in the engine room to the ballast piping main in the forward pipe tunnel, and
- Sodium bi-sulfite dosing piping from the storage tanks in the engine room to the ballast main in the forward pipe tunnel.

The risk assessment of the ballast treatment system was structured to demonstrate equivalency when compared to a baseline case already approved by the rules.

A fault tree was developed for the baseline arrangement and its protective features to identify failure modes and results.

The comparative methodology utilized an assessment metric; i.e., the number of sequential failures of protective features that would theoretically expose safe areas to hydrocarbon gases or liquid.

Comparative Risk Assessment

Of the aforementioned exceptions that permit the communication of piping systems between hazardous and safe areas, "Machinery Space Bilge Discharge to the Cargo Slop Tank," Section 5.1.7/7.7, provided a suitable baseline. The isolation components required by this section of the rules, including a loop seal and non-return device, were found by the assessment team to be comparable and applicable to the ballast treatment system dosing lines.

A piping schematic was prepared for the two dosing systems based on the design concept and the isolation devices required by the baseline. In this way, the proposed new application could be compared to an application already accepted by ABS.

Protective features utilized in the baseline system were incorporated into the ballast treatment system wherever possible. In those cases where a direct match was not possible, the analysis team qualitatively identified alternate means that offered a like or greater level of protection (see Table 2).

Table 2. Protective Features for Risk Assessment

Protective Feature	Bilges to Slop Tank Description	Ballast System Dosing Description	More	Same	Less	Note
1	None	Oil Tight Bulkhead	X			a
2	None	Ballast Vent	X			b
3	Non-Return Valve	Non-Return Valve	X			c
4	Piping to Weather Deck	None			x	d
5	Loop Seal	Loop Seal		x		
6	Engineroom Bulkhead Flange	Engineroom Bulkhead Flange		x		
7	Stop-Check Valve	Stop-Check Valve	X			c
8	None	Welded Pipe	X			e
9	None	Fail-Safe Stop Valve	X			d
10	Piping Systems	Piping Systems		x		

Notes:

a. An oil-tight bulkhead separates the segregated ballast tank from cargo tanks (a source of hydrocarbons). By comparison, existing rules for the bilge slop line permit the line to terminate directly into a holding "slop" tank. This holding tank is designed to carry hydrocarbon gases and liquids.

b. In the unlikely event hydrocarbon vapors enter a ballast tank, they are vented to atmosphere by design. Should the vent fail, e.g., become plugged, gases could accumulate and become pressurized up to the pressure/vacuum valve setting of the adjacent cargo tank (generally 3.0 psig), allowing hydrocarbon vapors to unintentionally enter the ballast piping system.

c. The non-return and the stop-check valves for the ballast treatment piping have bubble-tight ratings. These valves are more effective at preventing gases from passing when compared to standard valves required for the bilge slop line.

d. The bilge slop line runs to the weather deck to prevent the back-flow of liquids into the engine room. The dosing lines utilize fail-safe stop valves that shut upon detection of reverse flow or loss of power. Such devices are designed to withstand potential pressure from the ballast system pumps.

e. The welded pipe of the dosing system, when compared to a flanged pipe of the bilge line, is generally recognized as a superior means of containing potential piping contamination up to the fail-safe stop valve.

Fault Tree - Baseline: A fault tree was developed for the baseline case (Appendix A, Machinery Space Bilges into Slop Tank). The fault tree, which appears below the baseline case schematic, lists the protective features required by the rules for the baseline case. Below the listed devices, the fault tree evaluates potential failures of the protective features based on the initiating events shown on the left.

This fault tree results set the metric of sequential failures for the assessment.

- An initiation event and three sequential failures for hydrocarbon gas passing into a safe area as follows:
  - (Initiation) Slop tank becomes pressurized.
  - Failure of the non-return valve.
  - Gas pressure overcomes the loop seal.
  - Flange or piping failure in the engine room.
- An initiation event and three sequential failures for hydrocarbon liquid passing into a safe area as follows:
  - (Initiation) Slop tank liquid level overflow.
  - Failure of non-return valve.
  - Liquid pressure overcomes the height of the weather deck piping.
  - Flange or piping failure in the engine room.

Fault Tree – Dosing Lines: Fault trees similar to the baseline were developed for both the sodium hypochlorite and sodium bisulfite dosing lines. The protective features for each of these are listed in Table 2. The arrangements for each are somewhat different and can be seen in Appendices B and C, respectively.

The team's assessment of the two ballast treatment systems found the same result. Using the metric of number of sequential failures, the proposed systems compared favorably to the baseline.

- An initiation event and **<u>five sequential failures for hydrocarbon gas</u>** passing into a safe area as follows:
  - (Initiation) Adjacent cargo tank pressurized with hydrocarbon gases.
  - Failure of the oil tight bulkhead between the cargo and ballast tanks.
  - Failure of the ballast tank atmospheric vent to relieve the hydrocarbon gas pressure.
  - Failure of the non-return valve to contain the gases.
  - Gas pressure overcomes the loop seal.
  - Flange or piping failure in the engine room.
- An initiation event and **<u>three sequential failures for hydrocarbon liquid</u>** passing into a safe area as follows:
  - (Initiation) Adjacent cargo tank filled with hydrocarbon liquid.
  - Failure of the oil tight bulkhead between the cargo and ballast tanks.
  - Failure of non-return valve.
  - Flange or piping failure in the engine room.

Further protection is provided by welding the piping from the engine room/pump room bulkhead, where it is connected to the stop-check and fail-safe stop valves in the engine room. By welding the connections, the possible leaks from flanges are eliminated. The two subsequent devices then increase the count to seven sequential failures for hydrocarbon gas and five sequential failures for hydrocarbon liquids to reach a safe area.

Comparative Risk Assessment Conclusion: The assessment was evaluated by an ABS technical review team, and circulated for comment to ABS technical offices world-wide. It was concluded that the proposed arrangement provided an equivalent level of safety and was suitable for classification.

DESIGN AND INSTALLATION LESSONS LEARNED

After receiving ABS approval of the risk assessment, the design and installation teams faced several key challenges for installing a prototype ballast water treatment system. Challenges and corresponding solutions are presented here for general interest.

Corrosive Liquids and Dissimilar Metals

Sodium hypochlorite at less than 1% concentration is pumped from the engine room, through the cargo pump room, and into the pipe tunnel, at a rate of 60 gallons per minute. Sodium hypochlorite, even at this low concentration, is corrosive to traditional shipboard piping materials such as carbon steel, galvanized steel, and copper nickel alloys. A further complication arises as piping systems that pass through hazardous areas must be conductive to prevent the buildup of static charges.

Hastelloy™ C was identified as both conductive and compatible with the hypochlorite, but was considered an impractical selection given the materials handling restraints of the shipyard and the high cost of the material. ABS-approved, glass-reinforced epoxy and electrically-conductive Bondstrand 7000M™ piping were used in the hazardous areas. In safe, non-critical areas, ASTM-certified PVC piping was used.

Sodium bisulfite at 38% concentration is pumped from storage tanks in the engine room, through the cargo pump room, and to the pipe tunnel, at rates less than 1 gallon per minute. This fluid has excellent compatibility with grade 316L stainless steel. Tubing of this material was selected given its availability and corrosive liquid handling characteristics.

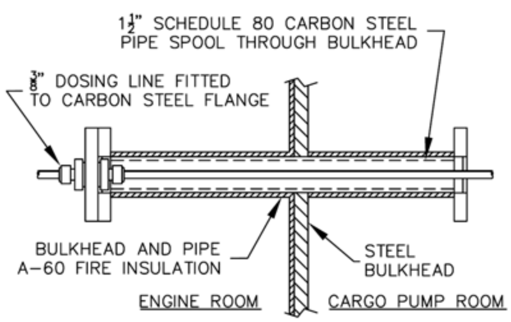

Figure 4. Bisulfite line penetration of engine room bulkhead.

Figure 5. Bisulfite and hypochlorite penetrations of the engine room bulkhead.

Dissimilar Metals: Figure 4 addresses the issue of corrosive fluids passing through non-compatible materials by utilizing an approved method of passing the sodium bisulfite line through a bulkhead, without exposing the bulkhead or carbon steel materials to the fluid. The stainless steel tubing containing the bisulfite is passed through an epoxy–coated, steel bulkhead penetration. For the hypochlorite line, the penetration is an epoxy–coated, steel bulkhead penetration flanged to the Bondstrand™ piping on each side of the bulkhead. Both penetrations are shown in Figure 5.

When the fluids reach the injection points in the ballast piping, potential contact between dissimilar metals is prevented by the design illustrated in Figure 6 and Figure 7 below.

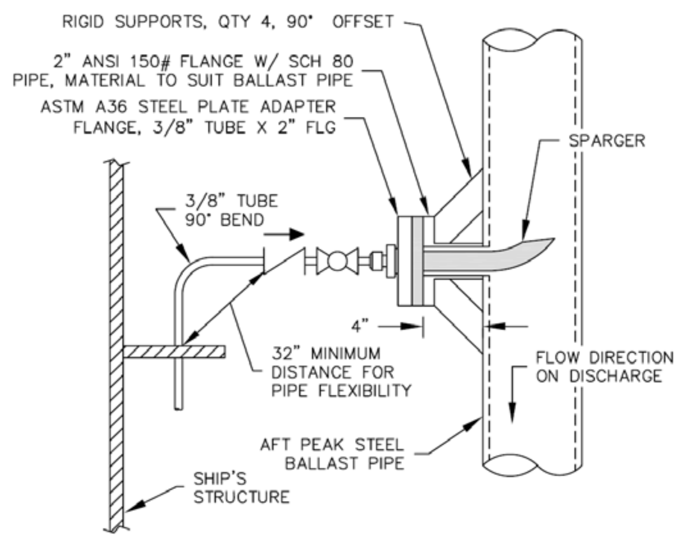

Figure 6. Bisulfite line injection into ballast piping.

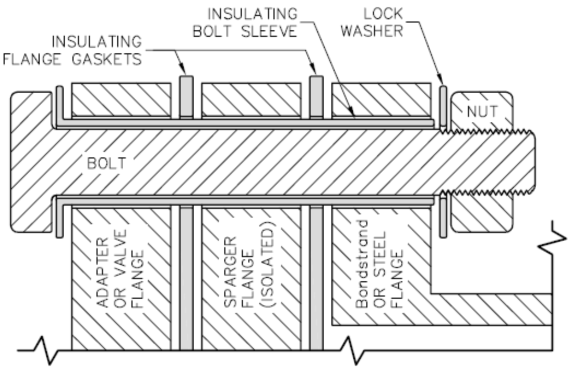

Figure 7. Electrical isolation of dissimilar metals.

Injection and Sampling Points

Dosing Injection Points Design Criteria:

- Robust design virtually eliminating any chance of piping material breaking off into the ballast piping.
- Readily replaceable unit should the first design not perform.
- Optimal mixing into the ballast stream to avoid concentrations from causing local corrosion in the ballast piping at the point of injection.

A robust Hastelloy™ sparger was developed to meet these specifications. To further address concerns that this highly noble metal would have galvanic effects on steel piping and components in the ballast system, the spargers were epoxy coated to provide electrical isolation.

IMO Sampling Port: Since the passage of the Convention in 2004, the Marine Environmental Protection Committee (MEPC) has prepared numerous guidance documents. One such document, currently in draft form, is the *Guidelines for Ballast Water Sampling*. Despite detailed guidance in this document, it appears that additional research is necessary before agreement can be reached regarding standards for sampling ports.

Recognizing that specifications for sampling ports will continue to evolve, the design team focused its attention on providing an adaptable access point. Figure 8 shows a sparger that can take a mid-stream sample from the ballast water discharge line. This sparger is designed so that it can be easily removed and replaced with an upgraded design.

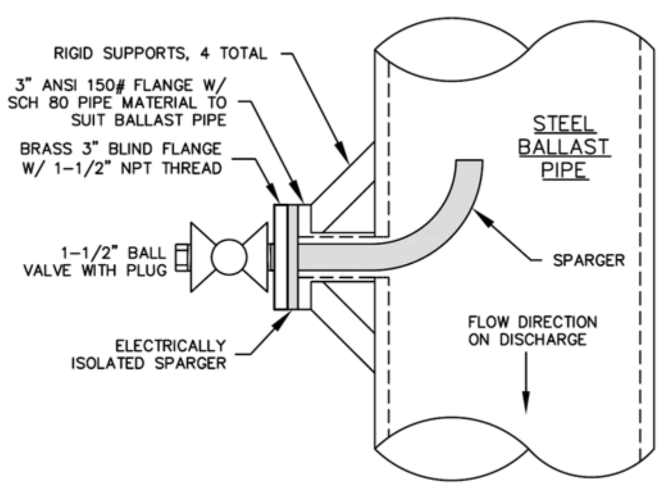

Figure 8. Ballast water sample port design.

Compact Modular Design for Refits

Installing a system on board an existing vessel requires a compact, modular design. The system was designed to minimize the rearrangement of existing shipboard equipment and to ensure system components were readily accessible for operation and maintenance. For this installation, the system was separated into five components and installed in available space.

Figure 9. Sodium bisulfite tanks located in engine room.

GENERATION OF HYPOCHLORITE

This section provides a brief overview of the generation of hypochlorite through electro-oxidation and its status for becoming a viable ballast water treatment technology. An understanding of electro-oxidation is critical for integrating such an installation with ship systems. Further understanding of the completed and planned testing efforts is critical to properly locating the sample testing equipment.

Background

Seawater (normally between 15 and 35 grams/liter) or other water containing sodium chloride (NaCl) may be used to generate a disinfecting solution containing oxidants by passing a direct electrical current through the solution. On-site generation of hypochlorite from seawater has been used for over 25 years. These systems can be purchased as completely skid-mounted systems that generate sodium hypochlorite from seawater. These systems are used by numerous shore-based facilities, offshore drilling platforms, and marine applications around the world. Systems can be scaled to the appropriate size depending on the quantity of hypochlorite required.

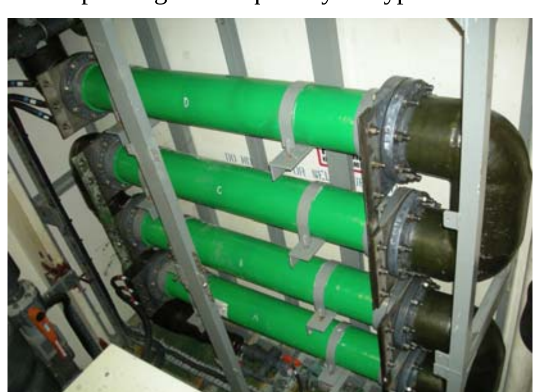

Figure 10. Electro-chlorination cells.

The type of electrolytic cell commonly used in existing marine and offshore applications is a "tube within a tube." A cell consists of one anode, one cathode, and one bipolar tube, with the necessary ancillary hardware to facilitate assembly. The outer anode and cathode are manufactured from seamless titanium pipe. The anode surface is coated with proprietary precious metal oxides, primarily ruthenium and iridium. Seawater enters one end of the cell and passes between the cathode, the anode, and bipolar tube annular spaces. When direct current is applied to the cell, sodium hypochlorite is generated. One cell can produce up to 5.5 kg/day, and a maximum of 12 cells can be connected in series for a capacity of 65 kg/day per train.

In some applications, such as ballast water treatment, a neutralization step can be added to the process. This requires the addition of a reducing agent, such as sodium bisulfite, to the end of the system to neutralize any Total Residual Oxidant (TRO) at the point of discharge. The end result is a non-toxic stream with no TRO.

Commercial, Land-Based Testing

Tests were conducted at the Naval Research Labs (NRL) from July 2006 through January 2007. System capacity was treatment of a seawater ballast test volume of 282 cubic meters at a flow rate of 300 cubic meters per hour. A second tank served as the control tank, with a capacity of 150 cubic meters. The ambient water from the Gulf of Mexico exhibited low concentrations of dissolved organics, particulates, zooplankton, and phytoplankton, so supplemental organisms and bacteria were added to the test (challenge) ballast water stream. Test conditions are listed in Table 3.

Table 3. Test Conditions - Naval Research Labs (NRL), from July 2006 through January 2007

Parameters	*Nominal Value*	*Range*	*Units*
Salinity	36	33-38	PSU
Ambient Water Temperature	20	10-30	Degree C
Dissolved Organic Carbon (DOC)	5	4-6	mg/l
Particulate Organic Material (POM)	5	4-6	mg/l
Mineral Matter (MM)	20	16-22	mg/l
Total Suspended Solids (TSS)	24	20-28	mg/l
Surrogate Biological Organisms			
Artemia (organisms/l)	120	100-300	75% viability
Rotifers (organisms/l)	120	100-400	75% viability
Tetraselmis (organisms/l)	1.1X10^4	10^4-10^5	90% viability
Thalassioira (organisms/l)	1.1X10^4	10^4-10^5	90% viability
Indigenous Bacteria (organisms/l)	1.2X10^5	10^5-10^6	80% viability

Biological Efficacy Test Protocol: The support system was started with a seawater flow established at 300 cubic meters per hour (1320 gpm), with the organisms and other constituents added at the desired rate to maintain the concentration listed above. This water was added first to the control tank, with no treatment. Once filled, the water was diverted to the test tank and the BalPure™ treatment unit was used to treat the stream to the test tank. The treatment unit removed a slip stream (approximately 20 gpm) of the ballast stream, made the required hypochlorite oxidant, and injected the disinfecting solution back into the main ballast line prior to entering the test tank. The production rate was matched to the ballast stream flow rate to maintain an oxidant concentration of 18 ppm when entering the ballast test tank.

During the fill cycle, samples were taken at the beginning, middle, and end of the fill cycle for each tank, respectively. The control and ballast tanks were allowed to sit full and idle for a minimum of 24 hours, with an average of 48 hours. Each tank was then emptied (deballasted) at a rate similar to the fill rate; the control tank first, followed by the test ballast tank. The BalPure™ system had an Oxidation–Reduction Potential (ORP) probe in the discharge line at the test ballast tank, followed by an injection point for bisulfite using metering pumps, followed by another ORP probe. The second ORP probe was used to monitor oxidant neutralization and control sulfite addition. During deballasting, three separate 3-cubic-meter samples were taken at the beginning, middle, and end of the cycle; this was to obtain significant volumes and to facilitate organism analysis.

Mechanical Test Results: The oxidant-generating unit maintained an initial concentration of 16–19 ppm Total Residual Oxidant (TRO). The TRO concentration in the ballast tank was 4-6 ppm, 24 hours after filling. The TRO concentration in the ballast tank averaged 1-2 ppm at the time of discharge. The neutralization was somewhat erratic during the initial minutes of the deballast segment of each efficiency test. For all tests, however, over 90% of all volumes deballasted had an ORP value of <200 mV, indicating no TRO and a residual sulfite amount.

Biological Efficacy Results: The average mortality rate for zooplankton organisms was 99.6%. All the ambient zooplankton were killed, and the only few survivors were from the injected Artemia. No living rotifers were found in the treated discharge. The treated water effluent, after incubation in the ballast tank, resulted in 100% phytoplankton mortality in all cases. Moreover, in none of the samples taken was a living phytoplankton identified. During the first two efficacy tests, greater than 99.9% of all bacteria were eliminated prior to discharge.

Commercial Shipboard Testing

The BalPure™ unit installed on the *S/R AMERICAN PROGRESS*, once fully commissioned, will be used during standard ballasting and deballasting operations. This US flagged, double-hull tanker typically transports cargoes from Texas to Florida. After discharging its cargo in Florida, the ship loads ballast water for its return transit across the Gulf of Mexico. The duration of each sea leg is approximately four days.

SeaRiver Maritime, Inc., the vessel owner and operator, has applied to the USCG for acceptance into the STEP. Once regulatory permission to proceed is granted, the University of Washington will conduct efficacy tests of the installed ballast water treatment system. Testing protocol guidelines issued with the Convention will be applied during the ballast segment of the vessel's voyage. Three separate, one-cubic-meter samples will be taken from a control ballast tank whose contents are not treated; six separate, one-cubic-meter samples will be taken for treated ballast water (two replicates of three samples). The respective samples of each set will be filled at the beginning, middle, and end of the ballasting cycle. During the ballast leg of the voyage, TRO will be tracked, along with organism destruction. During deballasting, the same sampling protocol will be followed for the control and treated tanks. Final organism and bacteria elimination efficacy will be determined from the 9 separate samples. The discharge samples will also be used to determine disinfection by-products, along with instantaneous and chronic toxicology studies.

With the design and installation phases now complete, Severn Trent and SeaRiver look forward to receiving regulatory permission to commence testing by the University of Washington.

CONCLUSION

The IMO has established a timetable by which vessels must be equipped with ballast water treatment systems. This paper describes the design, assessment, and installation of a ballast water treatment system on board a tank ship. Planned full-scale testing intends to show the operational safety, efficiency, and biological efficacy of this promising technology.

ACKNOWLEDGMENTS

The authors wish to acknowledge the generous support of the American Bureau of Shipping, SeaRiver Maritime, Inc., Severn Trent De Nora, and The Glosten Associates, Inc., for the development of this paper, as well as the cooperation of the mariners onboard the *S/R AMERICAN PROGRESS*. The authors also wish to acknowledge the generous support of the NOAA SeaGrant Ballast Water Technology Demonstration Project, whose grant made, in part, this project possible.

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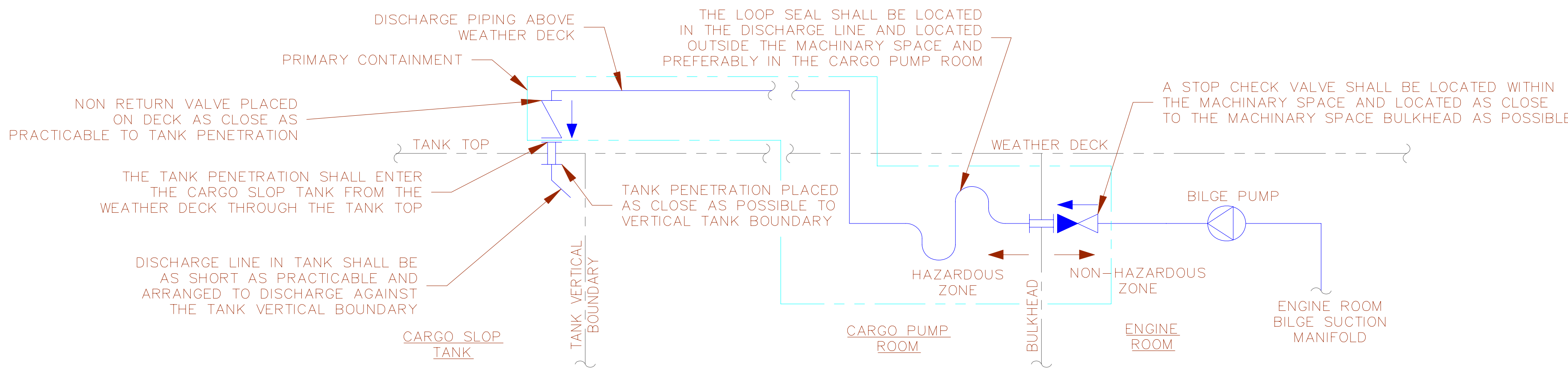
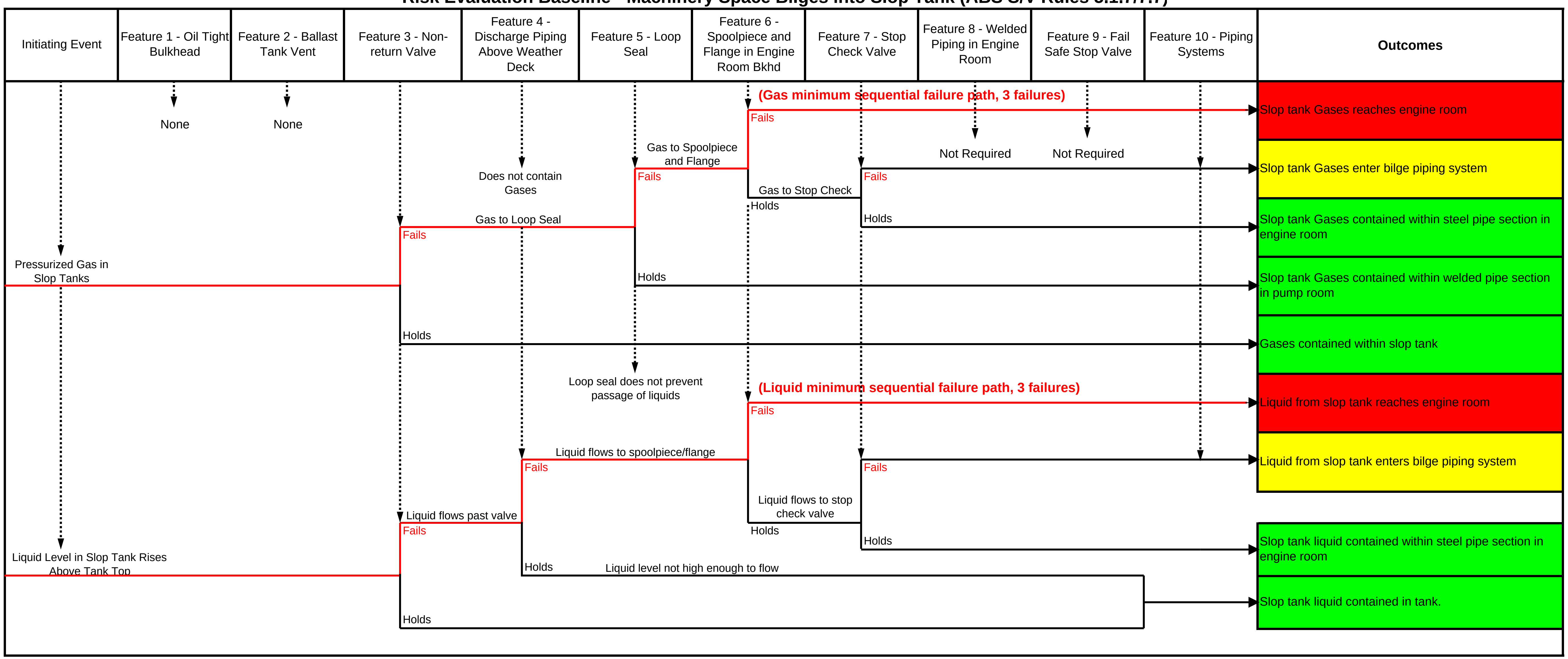
APPENDICES

A. Machinery Space Bilges into Slop Tank
B. Sodium Hypochlorite Dosing System
C. Sodium Bisulfite Dosing System

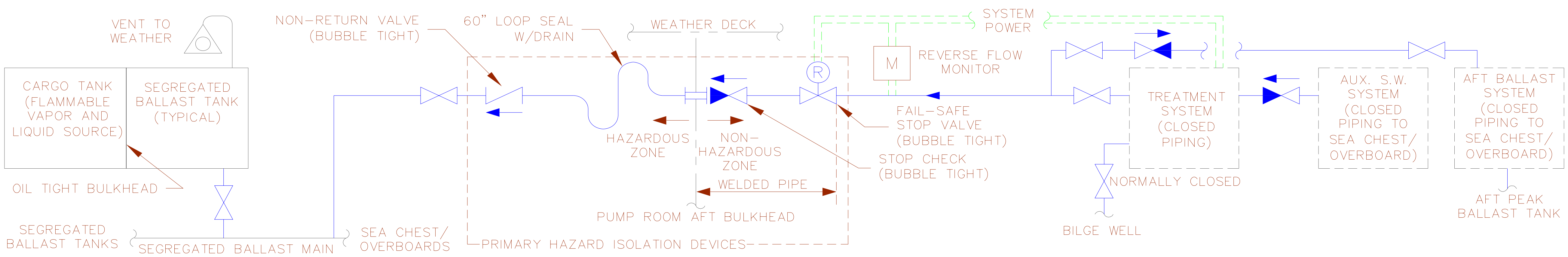
Appendix A - Machinery Spaces Bilges Into Slop Tank



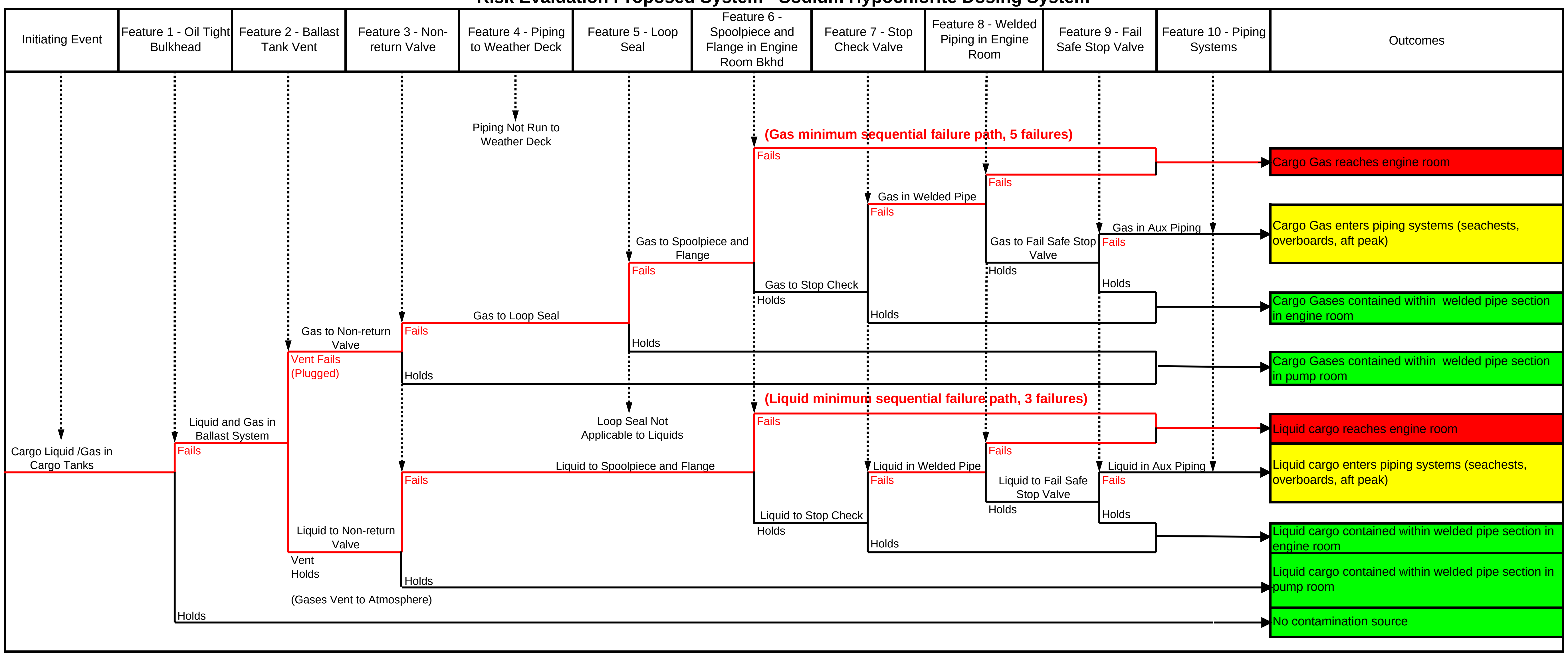
Risk Evaluation Baseline - Machinery Space Bilges into Slop Tank (ABS S/V Rules 5.1.7/7.7)



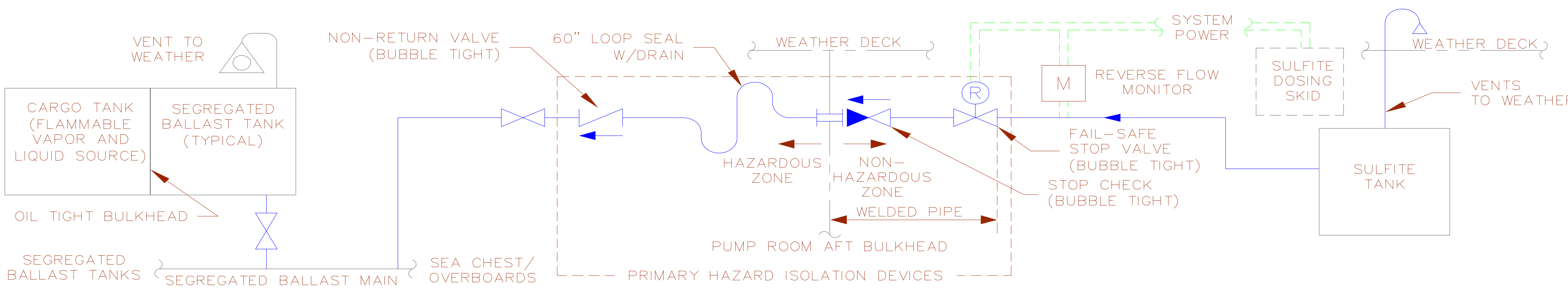
Appendix B - Sodium Hypochlorite Dosing System



Risk Evaluation Proposed System - Sodium Hypochlorite Dosing System



Appendix C - Sodium Bisulfite Dosing System



Risk Evaluation Proposed System - Sodium Bisulfite Dosing System