REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*: 19-03-2014

2. REPORT TYPE: NRL Letter Report

3. DATES COVERED *(From - To)*: March 2013 - March 2014

4. TITLE AND SUBTITLE
Expert Workshop: Impacts of Ballast Water Management Systems on Ballast Tanks and Systems

5a. CONTRACT NUMBER: 2012-038

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER: 2

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER: 6130/1425

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Maritime Administration, Office of Environment, 1200 New Jersey Avenue SE, Washington, DC 20590
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10. SPONSOR/MONITOR'S ACRONYM(S): MARAD and MERC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release, distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In 2012, the United States Coast Guard published a final rule setting limits on the discharge of living organisms in ships' ballast water, and most commercial vessels will install a ballast water management system (BWMS) to meet the discharge standard to treat ballast water upon intake, discharge, during both of those operations, or by in-tank dosing. Currently, there are three main categories of treatment approaches used in BWMSs: (a) solid-liquid separation (e.g., filters and hydrocyclones), (b) physical treatment (e.g., deoxygenation and UV), and (c) chemical disinfection (e.g., oxidizing compound such as hypochlorite and ozone). Commonly, two or more of these treatment approaches are used in combination for a single BWMS. There is concern that some treatments—specifically those that use active substances—may affect the tank coatings, other components of ballast systems, or both, by altering rates of corrosion, wearing, pitting, cracking, etc. To address this concern, a workshop of subject mater experts was convened. The resulting discussions are summarized in this report.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	Unlimited	10	Edward Lemieux
					19b. TELEPHONE NUMBER *(Include area code)* 202-404-2123

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IN REPLY REFER TO

3900
Ser 6130/1425

25 MAR 2014

From: Commanding Officer, Naval Research Laboratory
To: Maritime Administrator, U.S. Department of Transportation Maritime Administration (Office of Environment C. Junemann)

Subj: EXPERT WORKSHOP: IMPACTS OF BALLAST WATER MANAGEMENT SYSTEMS ON BALLAST TANKS AND SYSTEMS

Encl: (1) Two copies of subject report

1. Enclosure (1), entitled "Expert Workshop: Impacts of Ballast Water Management Systems on Ballast Tanks and Systems," describes the findings from an expert workshop convened to consider approaches to assess the potential corrosive effects of ballast water management systems.

2. This work was sponsored by and guidance provided by the U.S. Maritime Administration and the Maritime Environmental Resource Center.

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6130/1425
31-Mar-14

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Center for Corrosion Science and Engineering

Expert Workshop: Impacts of Ballast Water Management Systems on Ballast Tanks and Systems

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Funded by the U.S. Maritime Administration and the
Maritime Environmental Resource Center, Agreement 2012-038, Task 2

Encl (1) to NRL Ltr Rpt
3900
6130/1425

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1. Introduction

Ballast water—and living organisms within it—is taken aboard ships to manage the draft, stability, trim, and stress on the vessel. As awareness grew that organisms in ballast water may become nuisance species in the waters into which they are discharged and potentially cause outsized ecological and economic harm, national and international attention became focused on the issue of ship-mediated biological invasions. To address this concern, in 2004, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments, which establishes standards for the discharge of living organisms in ballast water and has not yet been ratified to enter into force (IMO, 2004). Subsequently, the U.S. Coast Guard (USCG) issued a final rule (FR) with essentially the same criteria (USCG, 2012; Table 1).

Table 1. Ballast water discharge standards.

Organization	Living organisms ≥50 µm in minimum dimension[A]	Living organisms ≥10 µm and <50 µm in minimum dimension[B]	Toxigenic *Vibrio cholerae*[C]	*Escherichia coli*	Intestinal enterococci
IMO	<10 m^{-3}	<10 mL^{-1}	<1 cfu 100 mL^{-1} or <1 cfu g^{-1} (wet weight zoopl.)	<250 cfu 100 mL^{-1}	<100 cfu 100 mL^{-1}
USCG	<10 m^{-3}	<10 mL^{-1}	<1 cfu 100 mL^{-1}	<250 cfu 100 mL^{-1}	<100 cfu 100 mL^{-1}

[A]Nominally zooplankton. [B]Nominally protists. [C]Serotypes O1 and O139. cfu = colony forming unit, IMO = International Maritime Organization, USCG = U.S. Coast Guard, and zoopl. = zooplankton.

To meet these stringent standards, most commercial ships will install a ballast water management system (BWMS) to treat ballast water upon intake, upon discharge, by in-tank dosing, or using some combination of these approaches. Prior to obtaining flag state Type Approval to install BWMSs aboard vessels, they must undergo land-based and shipboard verification testing to determine their efficacy in removing or killing living organisms. Such testing will provide confidence to ship owners that an investment in given model of BWMS is sound, and it will allow the vessel to comply with the discharge standards. In the U.S., the Environmental Protection Agency (EPA), in concert with the USCG, and under the auspices of the EPA Environmental Technology Verification (ETV) program, developed a protocol for testing the efficacy of BWMSs, the *Environmental Technology Verification Program (ETV) Generic Protocol for the Verification of Ballast Water Treatment Technology, Version 5.1* (EPA, 2010). At present, the ETV Protocol encompasses only land-based testing, with the shipboard component currently under development.

Because some BWMSs employ chemical oxidative processes, or use deoxygenation, there is concern that installing and using a BWMS may accelerate corrosion of ballast tank materials, piping, and other components by damaging coating systems or other materials in ballast systems. To that end, a *laboratory* protocol for testing corrosive effects was developed under the auspices of NACE International (NACE, 2011). Because the ETV Protocol will include *shipboard* testing, a workshop was convened not only to explore the corrosion concerns associated with BWMSs but also to discuss the utility of incorporating corrosion testing during ETV shipboard testing. Since shipboard testing will proceed over a period of at least six months, it seemed to present an opportunity to evaluate potential corrosive effects using real-world platforms and over relatively long time scales.

2. Workshop

To address these issues, a workshop was convened on 14NOV2013 in Annapolis, Maryland. Attendees included experts in corrosion, ballast water researchers, and policy makers (Table 1). First, overviews of the types of BWMSs, the ETV Protocol, and the NACE Protocol (TM0122; NACE, 2012) were presented. Next, the group discussed charge questions (listed below). While they were intended to frame the issues, the discussion was not constrained to these topics.

Table 1. Participants at corrosion workshop.

Participant	**Organization**
Mike Bentkjaer	Sherwin-Williams
John Carter	Exova
Debra DiCianna	American Bureau of Shipping
James Ellor	Elzly.com
Richard Everett	U.S. Coast Guard
Ray Frederick	U.S. Environmental Protection Agency
Jonathan Grant	Battenkill Technologies, Inc.
Harvey Hack	Northrop Grumman
LCDR Kenneth Hettler	U.S. Coast Guard
John Hopewell	American Coating Association
Matthew Strom	U.S. Naval Research Laboratory
Paul Natishan	U.S. Naval Research Laboratory
Brad Shaw	Vision Point Systems
Lee Twombly	NACE.org
Organizers	**Organization**
Mario Tamburri	Maritime Environmental Resource Center
Lisa Drake	U.S. Naval Research Laboratory
Carolyn Junemann	U.S. Maritime Administration

3. Discussion

As the workshop unfolded, the following points were raised following the introductory presentations and to address the charge questions:

Introductory Presentations

1. Although the emphasis on potential corrosive effects of BWMSs tends to center on oxidative processes and deoxygenation, the community should also consider the corrosive effects of strong bases, such as sodium hydroxide, which is a treatment method used in the Great Lakes
2. The location where chemical dosing from a BWMS enters the ballast piping may be subject to high concentrations of treatment chemicals, as compared to most piping and tank walls, which will see much lower concentrations due to mixing with the ballast water.
3. Most ships are constructed of steel, but there are aluminum vessels in use, and they will employ different materials for various components; coatings for both tend to be epoxy and modified epoxy. Furthermore, the ballast water tanks in many aluminum vessels are not coated.
4. The American Bureau of Shipping (ABS) currently advises ship owners to consult their coating manufacturer when they install a BWMS and to consider the re-preservation of tanks at that time.
    a. While new buildings will have intact coatings (with a good record of the installation), existing vessels will likely have less intact coatings (with a potentially poor record of their coating material, application, maintenance, and repair).
5. When the results of a research study by NRL (Lysogorski et al., in prep.) were presented, the effects of chlorination were discussed. In the study design, four types of metal coupons in various configurations (coated, uncoated, coated and scribed, or coated and scribed with cathodic protection) and two gasket or seal materials were placed in freshwater and seawater in three environments (humid, alternate immersion or constant immersion), and they were subjected to simulated ballast water treatments (chlorine dioxide, sodium hypochlorite, and deoxygenation). After 180 days, corrosion was assessed by mass loss. In general, the trends were inconsistent among treatments, as no treatment consistently elicited the lowest corrosion rate. The group noted that corrosivity in chlorinated samples was sometimes much higher in the alternate immersion environment than in the other environments, particularly in specimens in freshwater environments. This result suggests that focusing solely on immersion environments may not be adequate, the effects of chlorinated water may extend beyond the tanks in which they reside, and tests should also be conducted on non-metallic materials, such as pump seals.
6. The NACE Protocol assesses only BWMSs' corrosion effects (e.g., changes in a coating system's color are not assessed). Testing occurs over six months using artificial seawater (therefore, no organic materials will reduce the total residual oxidant concentration, so this procedure represents the worst-case scenario with

respect to a treatment's realized dose). The method uses panels, and one has a U-bend to represent welds, but it might not address crevice corrosion.

a. On the behalf of the International Paint and Printing Ink Council (IPPIC), a testing company in the Netherlands evaluated four generic "new technology" coating types against chlorine (0, 10, 20, 50 ppm) replaced every 14 days. These tests resulted in no significant adhesion loss, gloss loss; the conclusion was that oxidants in concentrations ≤10 ppm are acceptable for BWMSs. Thus, the NACE Protocol tests all oxidants at 10 ppm.

b. This information will be included in the report by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) from their meeting in September 2013, which will be forwarded to the 66th meeting of the IMO Marine Environment Protection Committee (MEPC 66) in March 2014. Here, testing will be the responsibility of the BWMS vendor.

7. Concern: a huge number of ships will be required to install BWMSs, and many do not have PSPC coatings; the group's feeling was that BWMS-related corrosion will thus be more of an unknown issue on retrofitted vessels (which will not have PSPC coating systems) than new buildings.

Charge Question A - What are priority questions and concerns surrounding BWMS impacts on vessel ballast tanks, pipes, and systems that need to be addressed?

1. Corrosion is an issue that may be exacerbated by the action of BWMSs, and BWMS must be installed with materials compatible with existing ship systems.

2. There is no discussion in the IMO Performance Standard for Protective Coatings (PSPC; IMO, 2006) regarding ballast water treatment. Further, it is unclear if the coating manufacturer or the BWMS vendor would be responsible for repairing a coating damaged by ballast water treatment, and it is also unclear if the coating is insured. The coatings manufacturers believe the responsibility lies with the BWMS vendors.

Charge Question B - How can the potential impacts of BWMSs, identified in Charge Question A, be measured for different aspects of vessel ballast systems?

1. A different test for each ballast water system component (e.g., piping, valves, and tanks) might be needed, rather than different tests for each material. Component tests may need to assess corrosion under target environmental conditions, which would incorporate both the concentration of any active substance and flow conditions encountered by the component materials.

Charge Question C - Can some level of testing, for the concerns identified, occur under the current BWMS certification testing framework? [with a view toward shipboard testing]

1. Rather than shipboard trials, a flow-chart approach seems warranted. First, a literature search would be conducted to determine if existing studies show that laboratory assessments of ballast water treatments would be warranted. The literature

results would be evaluated for different parameters depending on the component of the ballast water system: coatings would need to have adhesion/cross linking determined, while metallic surfaces would have corrosion rate/potential or electrochemistry measured, and non-metallic surfaces would have other characteristics measured); if the literature search shows concerns, laboratory experimental testing would be conducted.

2. The group decided that shipboard experiments conducted in concert with ETV shipboard testing would *not* be useful because of the many variables (e.g., differences in vessels, seasons, source water communities, etc.) and the duration of testing (likely six months to one year). In particular, standard coupon type testing would likely not yield useful data from shipboard testing; this technique is more appropriate for the controlled conditions in a laboratory in order to assess dose-response parameters.

    a. The value of ETV shipboard testing will be to determine the variability in the ballast water treatment's real-world dose (e.g., how frequently does the dose exceed the target value and by what magnitude?) and conditions (temperature, etc.); collecting that data during land-based testing would also be helpful.

    b. Reviewing the parameters likely to be measured in ETV shipboard testing, what other parameters would be useful to measure to gain information about the variability of dose, etc., to inform laboratory-scale testing?

        i. Total residual oxidant (TRO) (dose) of treatment and through time
        ii. Treatment operations and BWMS parameters (e.g., variations in flow rate, dose)
        iii. Tank level (are tanks full or is there headspace?)
        iv. pH and dissolved oxygen (DO; the latter may be more difficult to measure than the former)
        v. Electrochemical potential (this measurement might be difficult and expensive, although corrosion sensors could be used)

    c. Additional measurements or approaches that would yield useful data from shipboard validation testing but may not be practicable:

        i. Wire ships to log corrosion data such as electrochemical potential, and if equipped with sacrificial anodes, anode current. Such systems would need to be approved by a class society for every installation.
        ii. Electrochemical impedance spectroscopy (EIS; for coated materials); while these measurements will document changes to coating, variations in film application may limit utility outside of a laboratory
        iii. Linear polarization resistance (to determine the corrosion rate), can only be measured under immersion.

3. Laboratory-scale trials—using the NACE Protocol as a basis, but with additional parameters—would yield the most informative data.
    a. Laboratory testing removes confounding issues of corrosion introduced by other factors (surface prep, coating application uniformity, physical damage).

Testing can occur for each oxidant type at a realistic dose (the maximum) and quantify impacts on coated, uncoated, and non-metallic materials.

b. It would be very informative to generate (in the laboratory) a dose response curve for each treatment against the four coatings used in the NACE Protocol), uncoated materials (various metals), and non–metallic materials (a list can be obtained from ABS).

c. For all coated, uncoated, and non-metallic materials, testing for flexibility should occur.

d. In tests conducted following the NACE Protocol, the dose that the BWMS actually uses should be tested, (not 10 ppm, as per the NACE Protocol)

e. The NACE protocol considers only coated materials (stainless steel, copper, brass, and fluoroelastomer), but the draft protocol considers uncoated and non-metallic materials

    i. It is recommended that uncoated and non-metallic materials are tested

        1. Materials of interest: steel, aluminum, copper nickel, bronze, Teflon, rubber (the most common type of rubber should be determined and tested), uncoated mild carbon steel

            a. For non-metallic materials, the literature will indicate what parameters should be measured following ballast water treatment, e.g., visual effects, swelling, brittleness, and standard methods to assess them are available (e.g., ASTM D1414)

    ii. Crevice testing should also be conducted (ASTM G44 is used for crevice corrosion of stainless steel), and the effects on sacrificial anodes should be assessed.

4. For deoxygenation-based systems, the same parameters should be measured as those measured for BWMSs using oxidants, but a different experimental design will be warranted.

    a. The following parameters should be measured: microbially influenced corrosion, stress corrosion cracking (C-ring testing per ASTM G38), and continuous measures of DO

    b. Deoxygenation has the potential to induce stress corrosion in stainless steel and passive alloys—such corrosion will cause failure of the base material (vs. the surface or coating) and can be catastrophic.

5. Acceptance criteria should be set.

4. Conclusions

The overarching conclusions from the workshop are summarized here:

1. A flow-chart approach to assessing the effects of BWMSs on ballast systems is recommended. Here, a literature search would be conducted to determine if existing studies indicate that laboratory assessments of ballast water treatments should be conducted. If so, the NACE Protocol should be followed, with additional parameters measured (as above).

2. No shipboard corrosion experiments carried out in concert with ETV shipboard testing are recommended. Instead, the value of shipboard testing will be to determine the variability in the BWMS operation (e.g., real-world dose and variations in dose), and conditions (temperature, etc.); in land-based testing, that data would also be desirable.

3. In the laboratory, a dose response curve should be conducted for each BWMS treatment against the coated materials, uncoated materials, and non–metallic materials.

5. Acknowledgements

This work was funded by the U.S. Maritime Administration (MARAD) through the Maritime Environmental Resource Center, under Agreement 2012-038, Task 2. We thank the workshop participants for their generosity with their time, ideas, and expertise; Carolyn Junemann (MARAD) for her advice and programmatic support; and Helen Cummings (MERC) for her efforts to organize the workshop. We also appreciate the support of Diane Lysogorski (Section Head, Naval Research Laboratory Code 6136 and Director, Center for Corrosion Science and Engineering, Key West, FL). This report was improved by reviews from the workshop participants, Tim Wier, Diane Lysogorski, and Richard Colton (Superintendent, Chemistry Division, Naval Research Laboratory)—thank you to all.

6. References

ASTM Standard D1414 (2008) "Standard Test Methods for Rubber O-Rings," ASTM International, West Conshohocken, PA www.astm.org

ASTM Standard G38-01 (2013) "Standard Practice for Making and Using C-Ring Stress-Corrosoin Test Specimens," ASTM International, West Conshohocken, PA www.astm.org

ASTM Standard G44-99 (2013) "Standard Practice for Exposure of Metals and Alloys by Alternate Immersion in Neutral 3.5% Sodium Chloride Solution," ASTM International, West Conshohocken, PA www.astm.org

International Maritime Organization (2004) Convention BWM/CONF/36 'International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004'

International Maritime Organization (2006) Annex 1 Resolution MSC.215(82) 'Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks in All Types of Ships and Double-Side Skin Spaces of Bulk Carriers'

NACE (2012) Test to Determing the Potential Corrosion Effects of Ballast Water Treatment Systems on Ballast Tanks. Standard Test Method TM0112-2012, NACE International, Houston, TX

U.S. Coast Guard (2012) Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters (Final Rule). Federal Register 77:17254-17304

U.S. Environmental Protection Agency (2010) Generic Protocol for the Verification of Ballast Water Treatment Technology, version 5.1. Report number EPA/600/R-10/146, United States Environmental Protection Agency, Washington, DC