EPA SAB Ballast Water Advisory Subgroup 1

Draft response to charge questions 1 and 2: Performance of shipboard systems with available effluent testing data

Question1a: For the shipboard systems with available test data, which types or categories have been evaluated with sufficient rigor to permit a credible assessment of performance capabilities in terms of effluent concentrations achieved (living organisms/unit of ballast water discharged or other metric)?

Question1b: For those types or categories of systems identified in, what are the discharge standards that the available data credibly demonstrate can be reliably achieved? Furthermore, do data indicate that certain systems (as tested) will not be able to reliably reach any or all of the discharge standards?

Answer:

The Science Advisory Board subgroup members evaluated the available information for existing shipboard ballast water management systems (BWMSs) to answer charge questions. Ultimately, the goal of this process was to determine the availability of existing Ballast Water Management Systems (BWMSs) to meet the IMO D-2 discharge standard and standards more stringent than D-2.

Data packages, reports, publications, certification documents, and other available information on the performance of BWMSs were compiled by the EPA through several means: solicitation of various Administrations that have granted Type Approval certifications, direct communication with developers and manufacturers of BWMSs, and searches for publically available sources (journal or conference publications and third-party reports provided through the internet). The SAB only considered information collected by the EPA. To maintain transparency and impartiality, group members then independently examined each data package. The amount of material in data packages varied, as some contained only a type approval certificate, while others included land-based and shipboard testing methods and data, documentation of G9 approval, a type approval certificate, and press releases describing the sale of systems for use on commercial vessels.

Next, a BWMS was scored as having 'reliable' or 'unreliable' data. At a minimum, the data package had to include methods and results from land-based or shipboard testing to earn a 'reliable' rating. A BWMS holding a certificate of type approval without supporting testing data was scored as having 'unreliable' data, as it was impossible to determine the validity of the testing procedures and, therefore, the data. If a BWMS's data package included one or more test reports, the data package was examined according to the following criteria:

- In general, is the operational type of system (e.g., deoxygenation + cavitation) appropriate for shipboard use (e.g., can it meet required flow capacities, size, power requirements, etc.)?

- Does the literature support the fundamental use of this approach (e.g., is it well known that using this approach in aquatic environments will safely and effectively remove, kill, or inactivate aquatic organisms)?
- Was laboratory testing conducted with 'reasonable and appropriate methods', i.e., methods commonly used in aquatic studies or alternative methods that appear rigorous and equivalent to a standard, common approach?
- Was land-based testing conducted with reasonable and appropriate methods; was sample size appropriately determined with statistical considerations in mind; was sample collection and handling appropriate and documented; did analytical facilities appear adequate; were IMO or ETV (v. 4.2) challenge conditions met; if necessary, were toxicological studies conducted; was a QA/QC policy followed? Did land-based testing produce credible results?
- Was shipboard testing conducted with the same considerations as land-based testing (as above)? Did shipboard testing produce credible results?
- If an active substance is included, does the BWMS have credible toxicity and chemistry data and G9 Basic approval or G9 Final Approval (which requires Basic approval)?
- Does it have Type Approval certification?
- Is it in operational use (not just for shipboard testing) on one or more active vessels? A BWTT without systems onboard vessels was not automatically categorized as having 'unreliable' data, but this information was useful.

Summing the answers from these questions, a BWMS was scored as having reliable or unreliable data.

Next, for BWMSs with reliable data, the system's ability to meet four discharge standards—IMO D-2/USCG Phase I (P-I) and 10x, 100x, 1000x more stringent than IMO D-2/USCG P-I—was determined. The following scores were assigned:

(A) Is demonstrated to meet the standard in accordance with the approach suggested in the IMO G8 guidelines (and G9 guidelines, if the BWMS employs an active substance)
(B) Is likely to meet the standard with reasonable scientific certainty[1]
(C) May have the potential to meet this standard
(D) Unlikely to or not possible to meet this standard

All of the BWMSs with reliable data were tested following the G8 guidelines, which suggest taking replicate samples with volumes of at least 1 m^3 for the size class of organisms ≥ 50 µm in minimum dimension (nominally zooplankton). Since the adoption of the G8 guidelines, however, it has been demonstrated that a time-integrated sampling approach with larger sample volumes will increase statistical confidence regarding whether zooplankton in sparse populations meet or exceed the D-2/P-I standard (Lemieux et al., in review; Miller et al.,

[1] Reasonable scientific certainty is defined as: (a) Rational basis built upon empirical scientific data that allows for drawing conclusions from data and (b) General acceptance by the relevant scientific community of the available data and methods, and the specific conclusions drawn from the data.

submitted; Lee et al., 2010). As such, some BWMSs were given a score of A/B. If the data showed they met the D-2/P-I standard by following the G8 guidance, they earned an 'A' (e.g., the BWMS was *demonstrated* to meet the standard using the G8 sampling approach). Those systems also received a 'B' if the number of living organisms was consistently low and it seemed very *likely* the BWMS would still meet the standard if larger, integrated sample were used.

Regarding the discharge standard 10x more stringent than the D-2/P-I, if the number of living organisms in all size classes was consistently low following testing (below the detection limit, often reported as zero, or not more than twice the standard), the BWMS was given a 'C'. The BWMS had *the potential* to meet the standard.

For the most stringent standards, 100x and 1000x more stringent than D-2/P-I, if any living organisms in any size class were found following treatment, a BWMS earned a 'D'. It seemed *extremely unlikely (or perhaps impossible)* the BWMS could meet a stricter standard, again because the detection limit of the test methods used provided resolution to D-2/P-I, at best. For example, if one zooplankter was found in testing using volumes of 1 m^3, the BWMS would be required to reduce the number of viable zooplankters to less than one in 100 m^3 or 1000 m^3 to meet the 100x and 1000x standards, respectively.

Next, group members collectively discussed their scores, reached consensus, and created Table 1. Rather than present the scores from individual, commercial BWMS units or models, the working group chose to categorize technologies by operation type (e.g., filtration + UV). The operation types were chosen from recently published, third-party data reports (Albert et al., 2010; Dobroski et al., 2010; Lloyd's List, 2010) to encompass all currently available operation types and to use standardized terminology. Thus, while the data packages from individual BWMSs were initially examined and scored, the results were collapsed to represent a top-order status of the field. For a given operation type, if reliable data were available for more than one commercial BWMS, the scores given to the operation type were the highest scores of any of the individual BWMS. In this manner, Table 1 represents the greatest potential of the operation types to meet various discharge standards.

Results of this assessment are presented in Table 1 and interpretations of the findings are provided below.

Question 1c: For those systems identified above, if any of the system tests detected "no living organisms" in any or all of their replicates, is it reasonable to assume the systems are able to reliably meet or closely approach a "no living organism" standard or other standards identified in Table 1 of the White Paper, based on their engineering design and treatment processes?

Answer:

To address this question, the Science Advisory Board agreed to define *reasonable scientific certainty* as: (a) rational basis built upon empirical scientific data that allows for drawing conclusions from data and (b) general acceptance by the relevant scientific community of the available data and methods, and the specific conclusions drawn from the data. The phrase *no living organisms* was also considered in two distinct ways: literally as the sterilization of ballast water and from a rational scientific perspective, as below method detection limits.

Based on the test data provided for several BWMSs, it is clear that numbers of live organisms in discharged ballast water are reduced dramatically. The performance of the five BWMS types is duly impressive since the organism disinfection or removal efficiency is often a 4 orders of magnitude reduction, which exceeds that typically required for the performance of drinking water treatments. However, levels of organism removal do not achieve sterilization or the complete removal of all living organisms. The identification of just one live organism would indicate non-sterile conditions, and all systems evaluated had at least one living organism in at least one treatment sample (and often more). Unfortunately, this low number of live organisms is not an unreasonable artifact that might result from contamination from scientific sampling gear (nets, buckets, etc.) or human counting error.

Alternatively, it is possible to establish specific detection limits (e.g., 100, 10, 1.0, 0.1, live organisms/m^3 or /ml) for the methods used to collect the current performance data available and conclude that if numbers of live organisms are below those detection limits, they are scientifically indistinguishable from zero or *no living organisms*. Efforts have been made to calculate the probabilities of meeting such a detection limit, using some assumptions, such as whether the organisms are randomly dispersed in space or spatially aggregated (see Lee et al. 2010 for details and examples). Not surprisingly, increased statistical power comes not only from increased sample size, but also from the difference between the set regulatory mean and the measured mean from a sample—the degree of compliance (or noncompliance).

Statistical power to assess samples against detection limits for testing and compliance monitoring also depends upon the sampling approach. When concentrations are close to the discharge standard, a single sample may require too large a volume of water to be logistically feasible. In that case, complete, continuous, time-integrated sampling (with the entire volume analyzed) and combining samples across multiple trials can improve resolution while maintaining statistical validity. As an example, conducting three trials of time integrated sampling of 7 m^3 (and analyzing the entire concentrated sample from the 21 m^3) from a ship's BW discharge can theoretically result in 80% or higher probability of detecting noncompliant discharge concentrations of 12 vs. 10 live organisms m^{-3} (Miller et al. 2010). Thus, pooling volumes from separate trials will allow lower concentrations to be differentiated from the discharge standard, although the practicability and economic costs of doing so have not been evaluated. Moreover, the practical limits of increased statistical sample sizes may already tax the capabilities of well-engineered ballast water test facilities.

In all statements (of meeting a regulatory standard) that are based upon statistical sampling, there is always a stated non-zero error probability (e.g., 0.1%, 1%, 5%) associated with a particular statistical conclusion. Thus, one can never claim to be 100% certain that, for example, the concentrations of live organisms > 50 μm is below (say) 10/m^3. More appropriate to statements about meeting a regulatory standard is the notion of *reasonable scientific certainty*. Based on available data, we can conclude with *reasonable scientific certainty* that several BWMSs can reliably perform to the IMO D-2 and USCG proposed Phase 1 discharge standard.

However, current BWMSs are unlikely to ever meet 100x D-2 or 1000x D-2, and complete sterilization is simply not possible. Furthermore, our current sampling and analytical methods do not, and may never, allow for the resolution to state with reasonable scientific and statistical certainty that ballast water discharge meets any of these stricter standards.

Question 2: Based on engineering design and treatment processes used, and shipboard conditions/constraints, what types of ballast water treatment systems can reasonably be expected to reliably achieve any of the standards, and by what dates? Based on engineering design and treatment processes used, are there types or categories of systems, which conceptually would have difficulty meeting any or all of the discharge standards?

Answer:

A diversity of system types are being considered for BWMS (Table 1). The data indicate that several different types of systems are proving reliable and effective, and Table 1 lists five different types that have been able to demonstrate that they have met the IMO D-2 standard. The five BWMS also appear to be mature technologies, with multiple active vessel installations, and are commercially available. Interestingly, four of the five systems include a filtration step, although the inclusion of filtration does not necessarily ensure that the BWMS will meet discharge standards.

Given the data available, it is also possible to assume that these same five systems have the potential to meet a 10X D-2/P-1 standard in the near future. As noted above, we make this prediction based upon available data that show viable organisms sampled as low (usually, below detection limits, see below). However, given the data available, it is highly unlikely that any of the systems listed in Table 1 could provide organism removal to the level of 100x or 1000x the standard because all systems showed at least one observation of a living organism within the sample volumes as specified in IMO D-2 guidelines, thus exceeding the hypothetically more stringent standards. No system reported zero living organism in all samples analyzed following treatment. We believe that ultimately different technologies, or treatment approaches or sampling strategies will need to be considered to achieve these higher levels of removal.

At this point in time, it is not possible to comment on the likelihood that the other system types listed will or will not be able to meet either the D-2/P-1 or more stringent standards. All the BWMS types listed in Table 1 have likely shown some potential for reducing the number of ballast water organisms, but the data available for examination were deemed either to be absent or unreliable. As such, predictions of eventual performance of these BWMS are difficult to make.

References:

Albert, R., Everett, R., Lishman, J., & Smith, D. 2010. Availability and efficacy of ballast water treatment technology: background and issue paper. White paper published by the U.S. Environmental Protection Agency, Washington D.C. [note that this document is available on the SAB website and provides citations to numerous documents used in its preparation which were shared with the Committee].

Dobroski, N., Scianni, C., Takata, L., & Falkner, M. 2009. October 2009 update: Ballast water treatment technologies for use in California waters. California State Lands Commission, Marine Invasive Species Program. Produced for the California State Legislature. Final Report available at: http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Reports_Presentations.html

Lee II, H., Reusser, D.A., Frazier, M., & Ruiz, G. 2010. Density matters: Review of approaches to setting organism-based discharge standards. U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Western Ecology Division. EPA/600/R-10/031.

Lemieux, E.J., Grant, J., Wier, T., Drake, L., Robbins, S., & Burns, K. In review. Generic Protocol for the Verification of Ballast Water Treatment Technologies, Version 5.0. Submitted to the EPA Environmental Technology Verification Program.

Lloyds's Register. 2010. Ballast water treatment technologies: current status, London. February, 2010.

Miller, A.W., M. Frazier, G.E. Smith, E.S. Perry, G.M. Ruiz, and M.N. Tamburri. Enumerating Sparse Organisms in Ships' Ballast Water: Why Counting to 10 is Difficult? Environmental Science and Technology, submitted.

Type or Category of BWMS	# of BWMSs	# with Type Approval Cert	# with Available / Reliable Data	D2/P1	10x	100x	1000
Deoxygenation	2	0	0				
Deoxygenation+cavitation	1	1	1	A/B	C	D	D
Deoxygenation+bioactive agent	1	0	0				
Electrochlorination	2	1	0				
Electric pulse	1	0	0				
Filtration	1	0	0				
Filtration+chlorine	2	0	0				
Filtration+chlorine dioxide	1	0	1	A/B	C	D	D
Filtration+coagulation	1	1	0				
Filtration+UV	10	3	3	A/B	C	D	D
Filtration+UV+TiO2	1	1	1	A/B	C	D	D
Filtration+ultrasound	1	0	0				
Filtration+ozone+ultrasound	1	0	0				
Filtration+UV+ozone	1	0	0				
Filtration+electrochlorination	5	0	2	A/B	C	D	D
Filtration+UV+ozone+ electrochlorination	1	0	0				
Filtration+electrochlorination+ advanced oxidation	1	0	0				
Filtration+cavitation+ electrochlorination	1	0	0				

Filtration+-electrochlorination+ ultrasound	1	0	0				
Filtration+cavitation+ozone+ electrochlorination	1	0	0				
Filtration+plasma+UV	1	0	0				
Filtration+cavitation+nitrogen+ electrochlorination	1	1	0				
Filtration+hydrocyclone+ electrochlorination	1	0	0				
Heat	1	0	0				
Hydrocyclone+filtration+peracetic acid*	1	1	1				
Hydrocyclone+electrochlorination	2	0	0				
Hydrodynamic shear+cavitation+ ozone	1	0	0				
Hydrocyclone+filtration+UV	1	0	0				
Menadione	1	0	0				
Mexel	1	0	0				
Ozone	1	1	0				
Ozone+cavitation	1	0	0				
Shear+cavitation+ozone	1	0	0				
Shear+cavitation+peracetic acid	1	0	0				
Based on one or more reliable data sets, the type of BWMS:							
(A) is demonstrated to meet this standard in accordance with G8/G9							
(B) is likely to meet this standard with reasonable confidence							

(C) may have the potential to meet this standard								
(D) unlikely or will not to meet this standard								
If 0 for available/reliable data leave blank								
*Not scored because the one manufacturer has withdrawn this BWMS from market								