Logistics of compliance assessment and enforcement of the 2004 ballast water convention

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When the 2004 Ballast Water Convention comes into force it is estimated that approximately 70 000 vessels will require functional certified Ballast Water Treatment Systems (BWTS). Certification testing to IMO D-2 regulations has involved both shipboard and land-based trials by a small number of test facilities world-wide. Compliance testing for enforcement purposes under the auspices of Port State Control, will include live/dead counts of residual organisms of different size classes in treated ballast water. However, technical problems in making counts of rare organisms, and difficulties in making live/dead assessment of smaller non-motile organisms mean that comprehensive testing for full D-2 compliance will be a complex, time-consuming operation. Given the large numbers of commercial ships visiting several hundred ports world-wide and the limited resources for comprehensive testing, it is inevitable that more limited tiered approach to compliance enforcement will be required.

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INTRODUCTION

Pending ratification of the 2004 IMO Ballast Water Management Convention has focused urgent attention on the criteria that will be used to enforce the statute relating to effective ballast water treatment once the Convention enters into force. This will occur twelve months after ratification by 30% of the world's flag states representing 35% of the world gross commercial tonnage.

The International Maritime Organization has acknowledged and approved ballast water treatment technologies that are capable of performing to the published IMO standard.[1] This has strengthened the likelihood of ratification of the convention by early 2012. When the Convention enters into force a tiered implementation timetable will be established, beginning with ships constructed before 2009 with a ballast water capacity of 1500–5000m^3. The installation timetable advances according to the year of construction and ballast capacity and includes an estimated 2000 new ships entering the world commercial fleet each year. Between 2012 and 2016 the equivalent of as many as thirty vessels per day will require ballast water treatment system (BWTS) installation. By 2017 it is estimated that all existing vessels over 400t will be in compliance and the BWTS market will comprise only newly-built ships. It is estimated that approximately 70 000 vessels will require to be outfitted with a functional certified BWTS by that time.

Certification testing has, thus far, been conducted at test centres based in several countries including Denmark, Germany, Japan, Netherlands, Norway, S Korea, Singapore, South Africa, USA and the UK, with the aim of obtaining both final approval from the IMO and Type Approval from various classification societies worldwide. Performances of BWTS have been tested almost exclusively against the published IMO D-2 standard and to-date have involved both land-based and shipboard components entailing a matrix of replicated trials in different water conditions and seasons. While shipboard conditions may not always be optimal for testing they have revealed constraints in terms of sampling, logistics, etc, and have provided useful information about specific BWTS effectiveness and its functional application. Shipboard testing for type approval has also revealed and informed numerous technical issues that may affect compliance testing. As a result of this, it seems likely that shipboard testing of some kind will remain a component of compliance assessment once the implementation timetable has been activated. As current certification testing will no doubt represent the model for compliance testing once the convention comes into force, it is important to review the current status of the testing process and its suitability for compliance assessment.

Enforcement of the convention will be the responsibility of individual port states, although it is clearly in the best interest of the commercial maritime industry to ensure that the enforcement process is as uniform as possible worldwide, particularly in the case of vessels that visit many different ports. It is therefore important to highlight any potential ambiguities in the international standard affecting its interpretation and the consistency of its implementation. The object of this paper is to provide a, hopefully, realistic appraisal of technical issues arising from current certification testing and to offer conclusions and recommendations for their resolution.

Although certification testing has become increasingly standardised world-wide, there remain several outstanding issues relating to test conditions, sampling strategies and endpoint determination. These, in turn have resulted in increasing complexity and sophistication of the methods used for BWTS performance evaluation. In this paper the implications of current performance testing are examined within the context of the logistical realities which will necessarily govern the enforcement of the Ballast Water Management Convention.

ISSUES RELATED TO SHIPBOARD TESTING

Performance vs compliance testing

Test water conditions

Guidelines for performance testing to the IMO D-2 standard include a requirement that untreated water taken up at ballasting (challenge water) should have a minimum density of organisms for the test to be valid. While this parameter is to some extent controllable at land-based facilities (most are located adjacent to productive water bodies), this is not the case in shipboard trials where the location and timing ballast water pick-up is dictated by the ships' schedules and routes. This has led to situations where challenge (pick-up) water conditions for the D-2 standard may not always be met. Ships' schedules are usually very rigid and not subject to alteration with the object of finding more productive water. While this has posed problems for certification testing and differences in interpretation of test data from unproductive water, it should be borne in mind that, while comparison of treated versus untreated water forms the basis for most performance (certification) testing, compliance (enforcement) testing will only be made on putative treated water, with no reference possible to challenge (untreated) water. This represents an important distinction between performance and compliance testing. Therefore, the productivity of the ballast water at uptake will not be a factor in compliance testing, where a single set of endpoints from treated water will be considered, irrespective of the productivity and source of the water at uptake. The focus of compliance testing will, therefore, be on appropriate sampling and analytical protocols based solely on the ballast water presented within the ship's tanks upon its arrival at the testing port, irrespective of the biological conditions prevailing at the geographical position where the ballast water was taken on board.

Sampling strategies

Sampling strategies for performance evaluation of BWTS have included both within tank collection of water samples and inline sampling, whereby a continuous sub-sample is obtained from the ballast stream either during ballasting or de-ballasting. Because of the patchiness of entrained organisms, particularly the larger, rarer organisms, an inline sampling technique is favoured, as it allows the possibility of collecting a continuous, integrated sample, over all or part of the ballasting/de-ballasting cycle. Often, this is split into sequential batch samples to facilitate their timely transfer to a counting station for examination while they are relatively fresh.

It is generally assumed that smaller, more numerous organisms, particularly bacteria, will have a more homogeneous distribution than larger, more sparsely distributed organisms such as zooplankton. In a recent EMSA report[2] it is suggested that a representative sample for the <50μm size category could be satisfactorily obtained from an integrated low volume 'split' collected over all or part of a ballasting/de-ballasting cycle. However, within-tank collections designed to examine patchiness have shown that the densities of even relatively small organisms, in the 10–50μm size range, may differ more than ten-fold among samples from the same tank.[3] Particularly where very low densities of organisms are encountered, concentration of the 10–50μm size fraction, using a 10μm filter, may be performed to enhance the reliability of the counts obtained, although such concentration has been contraindicated by the Netherlands Institute for Sea Research (NIOZ), through concern over possible damage to organisms resulting from the filtration process.

The biggest problem concerning the reliability of counts of entrained organisms relates to largest and least dense size category (>50μm). Because of the relative rarity of these organisms the largest possible volume of water must be filtered in order to obtain a representative sample. Section 6.2.2 of the G-2 guidelines states that:

'The sampling protocol should result in samples that are representative of the whole discharge of ballast water from any single tank or any combination of tanks being discharged'.

Citing a large body of research the 2010 ICES[4] report concluded that a sampling protocol that continuously sub-samples small amounts throughout a ballasting cycle significantly underestimates the number of larger organisms in the sample. Analysis of organisms is usually considered to conform to a Poisson distribution, with the consequence that the error associated with any count is inversely related to the total number of organisms counted and, therefore, the volume of water examined. Larger counts will result in greater precision. However, while continuous sub-sampling a ballast stream throughout a complete ballasting cycle best represents *'the whole discharge'* (above), time constraints and the need to process and examine fresh samples may render this process not feasible, particularly in the context of compliance assessment during a short port visit. An examination[5] of the statistical power associated with different sampling strategies concluded that 7m^3 time-integrated samples may provide a reasonable balance of statistical power and logistic achievability when applied to zooplankton discharge.

While the D-2 standard currently makes no mention of the error(s) associated with threshold limits, important questions facing regulators are:

(a) Should the error accompanying any count or set of counts be reported?
(b) Should the error be added to the mean organism count to create a standard that takes variance into account?

A corollary of this relates to results from replicated tests, and poses the question 'should *every* replicate count be at or below the D-2 standard, or can a BWTS be considered compliant if the *mean* of the replicates meets the standard?' Both the ICES (2010)[4] and Miller papers[5] address this problem, and recognise that sampling protocols that satisfy statistical requirements may present significant challenges within the context of compliance testing. Perhaps the most obvious conclusion to be drawn from this work is that it will be much easier to identify clearly non-compliant vessels requiring more detailed investigation than ships that comply with the international standard in every respect.

Endpoint determination

The current IMO D-2 standard states that treated ballast water should contain:

- Less than 10 viable organisms per 1m^3 greater than or equal to 50μm in minimum dimension;
- Less than 10 viable organisms per 1ml that are less than 50μm in minimum dimension and greater than or equal to 10μm in minimum dimension; and
- Less than the following concentrations of indicator microbes, as a human health standard:
  (a) toxicogenic *Vibrio cholerae* (serotypes O1 and O139) with less than 1 colony-forming unit (cfu) per 100ml,
  (b) *Escherichia coli* less than 250 cfu per 100 ml,
  (c) intestinal *Enterococci* less than 100cfu per 100 ml.

Up to x1000 more stringent standards have been proposed by the US as the second part of a two-tiered regulatory approach for that country, although the phase one standard currently adopted by the US essentially conforms to the IMO D-2 standards, with no set timetable for the introduction of phase two standard. While the D-2 standard will probably represent the universal standard when the convention comes into force it is not without problems or differences in interpretation.

Usually, the >50μm size category comprises motile zooplankton, allowing viability to be determined from movement of all or part of the organism with or without physical stimulation using a probe. Not all organisms in this size category are motile, however; fish and crustacean eggs are cases in point, and several biologists involved with sample examination have employed a variety of vital stains to enhance live/dead determination. However, not all organisms take up the stain.

Vital stains have also been increasingly used in examining viability of the 10–50μm size category which primarily comprises phytoplankton and protists, many of which are non-motile. Methods for determining live phytoplankton have included staining with fluorescein diacetate (FDA) and 5-chloromethyl fluorescein diacetate (CMFDA), as well as grow-out techniques which use growth potential as a determinant of viability. For FDA alone, different results have been obtained from the same species in different studies[6,7] and false negatives have been reported from dormant, but potentially viable cells retrieved from a dark ballast tank.[8] Results from a combination FDA/CMFDA combination study were variable among natural assemblages from different locations.[9] While vital stains have demonstrated utility in specific geographical areas[10] and have the potential of providing phytoplankton numbers that are compatible with the D-2 standard, overall, results have been mixed. The technique therefore remains speculative, particularly in view of the prospect of region-specific protocols for compliance testing with possible adverse legal consequences.

In grow-out studies growth is determined as an increase in phytoplankton biomass, which can be determined by cells counts or chlorophyll *a* measurement before and after a pre-determined culture period, although in neither case it is possible to interpret the results in the context of the standards themselves, which stipulate absolute numbers of live cells. An increase in overall cell numbers following grow-out can only indicate the presence of an unknown number of live cells among the phytoplankton community. Although taxon-specific cell counts following grow-out were undertaken[11] as part of a shipboard trial, data took several weeks to assemble and process. In contrast chlorophyll *a* can be determined rapidly, although will only provide an integrative figure with no relation to cell numbers. For example the chlorophyll *a* content of a single large cell may be the equivalent of several hundred smaller cells. In addition, false positives may result from the fact that the chlorophyll *a* molecule may remain intact within dead cells for as long as two weeks following cell death.

Any analytical method that eliminates cell culture or grow-out as a means of determining viability merits examination. For phytoplankton, pulse-amplitude modulated (PAM) fluorometry holds this promise. In measuring the photochemical efficiency of photosystem II (F_v/F_m) it provides a rapid measure of photosynthetic activity as an indicator of cell viability. However, results cannot be translated into cell numbers and are therefore incompatible with current standards. Similar problems of interpretation are also associated with several assays used to determine viable indicator bacteria. For example several commercial test-kits are available which measure the presence/absence of indicator bacteria including pathogenic *Vibrio* serotypes, enterococci and *E. coli*, although the quantification of colony forming units (cfus) is not apparent in many of these tests, and the detection limits, especially for *Vibrio cholerae* may be more appropriate for body fluids and sewage rather than open water applications. Several bacterial assays involve culture times that exceed the residence times of most ships in port, an obvious drawback in compliance testing.

A number of biologically important molecules have been used in aquatic studies to determine the presence of live material, although there are numerous drawbacks to their use. Ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) probes have both been used to indicate the presence/absence of live material, and RNA: DNA ratios have been used to quantify the growth rate of living organisms. Due to the refractory nature of RNA and DNA, both can persist following loss of cellular viability, thereby diminishing their predictive reliability of such tests for live material through the presence of false positives. However, the absence of these molecules will reliably indicate the complete absence of live material.

The nucleotide adenosine triphosphate (ATP) is the primary energy source in both prokaryote and eukaryote organisms and is involved in synthesis and trans-membrane transport of numerous macromolecules, structural integrity of living cells and muscle function. Present in high concentration in living cells it rapidly degrades after cell death and may, therefore, act as a broad spectrum indicator of living material. However, due to its ubiquity in living organisms, no relationship with any one taxonomic group can be determined. Analytical tools for free ATP rely primarily on light emission from the luciferin/luciferase interaction. As such they are highly sensitive, although contamination of samples from extraneous material following collection represents a possible source of error. A comprehensive assessment of the methodologies involved with a variety of biological endpoint determinations is documented.[2]

Further complications result from the rigid size ranges defining published standards and the enormous quantitative differences associated with those size categories. It has been observed[12] that the proportion of phytoplankton exceeding 50μm in ballast water samples could be greater than 20%, although it is recognised that this size category is implicitly 'reserved' for zooplankton. In localities where large dinoflagellates comprise a significant proportion of the plankton flora, phytoplankton cell numbers in this (>50μm) size range may exceed 10^7 per m^3. At this density a mortality rate of 99.9999999% would need to be recorded to comply with the >50μm standard. Another manifestation of the 'size problem' relates to marine nematodes, a group which is notoriously resistant to several treatment technologies, yet escapes inclusion in the >50μm, 'zooplankton' category because, while many exceed 1mm in length, most are <20μm 'in minimum dimension', as defined in the published standards. Thus, several million of these animals per m^3 could survive treatment, yet comply with the D-2 regulations.

IMPLICATIONS FOR COMPLIANCE ASSESSMENT AND TESTING

Scope of the regulatory task

In considering the prospect of world-wide compliance assessment, potentially involving hundreds of ports and perhaps thousands of ships daily it is important to examine the feasibility of performance testing as it might apply to compliance assessment, where a decision on whether a vessel is 'in compliance' would need to be reached during the relatively short period of time a vessel is in port. While many of the observations made during performance testing are relevant to compliance decisions, it is clear that performance trials as carried out by the few centres currently equipped to perform them world-wide are too lengthy and expensive for routine compliance assessment.

Problems fall into two areas; precision of sampling to D-2 standards, precision of live/dead determination to D-2 standards. It is estimated[16] that it costs between \$75 000–\$125 000/vessel for a single, non-replicated sampling event. Even within the precepts governing testing to the current D-2 standard, sampling requirements require several hours to days to accomplish, and biological endpoint determinations, several days to weeks to process and analyse. Furthermore, many of the foregoing issues related to sampling and endpoint determination remain unsettled within the scientific community. Thus, the time, effort and cost involved in sampling and analysing to D-2 standards would be difficult to achieve for routine compliance monitoring. A broad estimate of the world-wide scale of the issue illustrates this point.

While the world seaports catalogue recognises over 8000 ports in 222 countries,[13] from the enforcement standpoint it seems logical to restrict consideration of enforcement measures to the approximately 450 major seaports (including Great Lakes) that handle the great majority of international trade.[14] Any shipboard testing effort for compliance assessment needs to be considered within the context of total numbers of vessels requiring assessment and turnaround time in port, not all of which presents a truly dockside opportunity for a testing team. To provide this context it is necessary to make some broad generalisations.

For example the US National Ballast Information Clearinghouse (NBIC), located at the Smithsonian Environmental Research Center, Edgewater, Maryland, USA, provides data for qualifying vessels entering the USA, ie, ships discharging foreign ballast water, that may be used to make broader estimates. Between 2004 and 2005 a total of 8423 ships (32.7% bulker, 13.9% container, 10.5% general cargo, 3.8% 'other', 1.8% passenger, 4.1% reefer, 6.1% ro-ro, 26.5% tanker) discharged an annual average of 36 781 491 Mt foreign ballast water over 34 500 annual visits. Ignoring Great Lake ports, not in the NBIC database, we assume 40 major US seaports (12 East Coast; 11 West Coast; 17 Gulf Coast), and can make a rough calculation of 863 visits per port per year, or 2.4 per port per day. This ignores domestic ballast water from either domestic or foreign ships. Of course ship visits are not evenly distributed among ports. Nevertheless, even assuming only a relatively small percentage of ships would be tested, the primary logistical problem would relate to the coverage required to serve 49 major US ports, including the Great Lakes and Hawaii, given that analyses would need to begin within one hour of collection. Thus, for a large country (continent) such as the US, where major ports are separated by hundreds or thousands of miles, the highly specialised analytical expertise needed for full compliance assessment would be required locally and immediately if microscopic examination of fresh samples was to be performed.

Another consideration is the time a particular vessel is in port, a corollary being whether compliance assessment can be completed before the ship leaves the dock. Article 7 of the Ballast Water Convention states that a vessel should not be unduly delayed by the application of an extended survey process and it is thus of importance that any compliance testing regime follow some form of recognisable common standard with an expected time scale. The lack of such formalised protocols may result in the application of local or regional testing methodologies with disputes arising from unwarranted delays while compliance testing is carried out or results awaited. Times that vessels spend in port vary greatly according to vessel type and may take from less than 12 hours in the case of some tankers and container ships to several days for some bulkers. Turnaround times also vary enormously among different ports. The average turnaround time for ships in Singapore is between 6–8h, whereas other ports may take more than 10 times as long for a similar type of vessel.

In contrast to the US, Singapore receives over 70 000 per year commercial vessels in a single port, not including barges, tugs ferries and passenger vessels,[15] an average of more than 190 vessels per day. Unlike in the US, port and potential testing facilities in Singapore are relatively centralised, although in this case the impediment to full compliance testing relates to the sheer volume of traffic and the logistical difficulties involved with mounting the required sampling and analytical effort. In this regard, the problems facing testing facilities in other parts of the world fall between those illustrated by the US and Singapore. As it now stands, resources available for universal full compliance testing fall well short of those required.

CONCLUSIONS AND RECOMMENDATIONS

In view of the rapidly approaching need for standardised, world-wide compliance assessment it is critical to examine the feasibility of available alternative options to complete compliance testing. Where penalties for non-compliance are likely to be very high it is reasonable to assume that legal challenges are likely to ensue from ambiguities in the standard and their interpretation. In order to remediate this critical problem it is important to consider whether compliance assessment and enforcement should adopt a tiered approach. This could take several forms. An approach advocated by several authors[2] is the development of initial, rapid tests that provide compliance information for just a single group of organisms, ie, >50µm (zooplankton, >10µm <50µm (phytoplankton/protists) or bacteria. While D-2 compliance for one group does not always coincide with compliance for other groups,[2] results from initial screening tests may give a preliminary indication that a BWTS is not performing properly. Brazil (BLG 15/INF (2010) has suggested a target value of 1% for full 'representativeness' (compliance) testing against the D-2 standard, ie, 5% of the 20% of ships entering port that are routinely tested, but recommends an initial effort aimed at 4% 'representativeness' testing for the first two years of enforcement.

King and Tamburri[16] and Gollasch and David[2] conclude that it will be extremely difficult and costly to directly assess whether a vessel can meet all the numerical standards for viable organisms, as published in the current D-2 standard, and they advocate a tiered approach to assessment, eg, to start the compliance control sample processing with the 'easiest-to-prove' organism group. This strategy recognises that it will not be feasible to test more than a very small fraction of the world fleet at any given time. The proposed solution entails the use of reporting, inspections, and testing, involving a phased series of steps that increase the likelihood of detecting non-compliance but also increase cost and logistical challenges. Such a strategy is under development in the IMO

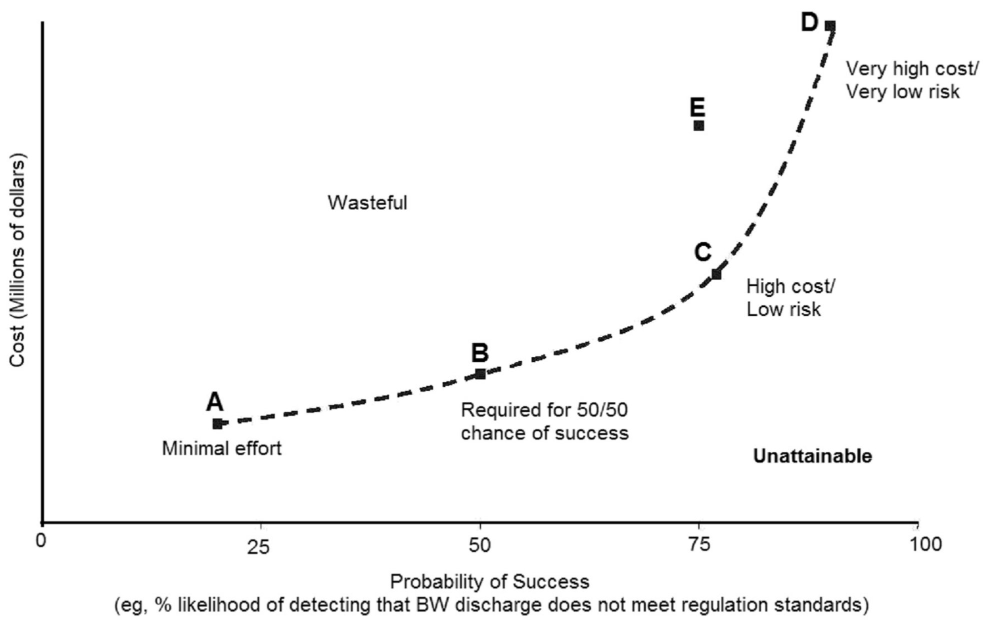

Fig 1: From King and Tamburri[16] (with permission).

Flag State Implementation (FSI) sub-committee. The rationale for such an approach is illustrated by the cost-effectiveness curve shown in Fig 1.

The most rudimentary step would take the form of reports submitted by vessel operators on the type of certified treatment system onboard and documentation indicating appropriate use and record of maintenance. This would be reinforced by onboard inspections by an enforcement official who would verify the certified treatment system's use and the attendant onboard records. Indirect or indicative water quality measures may be collected autonomously, or by inspectors, demonstrating appropriate treatment conditions have been achieved. As most BWTS include a filter, particulate profile analysis would provide a basic indication of effective BWTS use, although surrogate indicators of disinfection efficacy could include total residual oxidant [TRO] and/or oxidation reduction potential [ORP] sensors for chlorine and ozone treatments; dissolved oxygen and/or pH sensors for deoxygenation treatments; and radiometers or measures of power output + water transmittance for UV treatments. Indirect or indicative measures of abundances of live organisms may also be collected autonomously, or by inspectors, for indications of clear non-compliance (eg, ATP kits, *in-situ* chlorophyll fluorometers, vital stains + flow cytommetry, particle counting and imaging systems, and molecular and genomic probes). Some of these approaches are used in current performance testing of BWTS. Others are still in development, and all will require rigorous calibration to direct measures of live organism enumeration. Individually these methods only measure components or partial standards as discussed earlier. Verification of systems based on mandatory reporting and inspections of BWTS alone will not achieve acceptable levels of confidence that ballast water regulations are meeting their goals.

Verification of systems based on direct measurement (ballast water biological sampling) that are not comprehensive in terms of being both intensive (high volumes of ballast water sampled per vessel) and extensive (many vessels sampled) will not provide acceptable levels of confidence (Fig 1). Those that are comprehensive enough to provide acceptable levels of confidence will be very costly. It is concluded[16] that verification of systems based on indirect monitoring of ballast water using sensors offers the best alternative because they have the potential to provide a high level of confidence at a cost that is far lower than even the lowest cost and least reliable biological sampling strategies. The success of a verification system based on sensors will depend on the development of accurate, reliable sensors that generate data that are at least as capable of withstanding technical, statistical, and legal challenges as the results of any direct ballast water discharge measurement system that can meet the practicability test.

Whether any verification system for detecting violations will effectively deter violations will crucially depend on whether detected violations result in certain and meaningful penalties and sanctions; how they are shared by ship operators, shipowners, equipment vendors, insurance groups and clubs; how repeat offenders are treated; and other factors unrelated to expected detection rates. The fact that onboard ballast water sensors can predict likely violations prior to ballast water discharge means that they can be used to prevent as well as detect violations. This is another advantage of using sensors to detect imminent violations rather than relying on direct testing of ballast water at the time of discharge to validate violations. A comprehensive report intended as a guidance document for Port State Control is currently nearing completion under the auspices of the European Maritime Safety Agency which provides a detailed analysis of compliance assessment.[17]

The consequences of detecting imminent violations also need to be addressed. One consequence would be the refusal by the port authority to allow ballast water discharge. Another, possibly less expensive option would be the mandatory discharge to a land-based facility or barge. A land-based system reception facility that exempts ships from ballast water management under BWMC B3.6 would probably create extraordinarily difficult water treatment problems if tied into the municipal treatment system (neither G1 (sediment) nor G5 (ballast water) guidelines are intended to supersede local waste regulations). However, a dedicated system of ballast water receptacles, either land or barge-based and served by an approved BWTS could provide a more efficient option that obviates delays in cargo handling. Such a facility could handle 'suspect' ballast water and provide the opportunity for further testing in marginal cases. Clear violators would share the cost without the potentially even greater penalty of refused entry or re-routing. As an alternative or supplement to treatment, a system of barges could transit untreated or insufficiently treated ballast water to an approved dumping area. Any such facility would require access to, and piping compatible with high-volume pumps capable of pumping ballast via deck access ports if other means of off-loading to a barge or shore-based facility were otherwise unavailable.

The speed of detection of violations of the international standard represents a significant choke-point in the assessment process. As serious legal challenges may ensue from ambiguous interpretation of the existing standard, eg, issues of organism size, variance, viability assessment, it may be worthwhile to reinforce the D-2 standard to include a legally binding 'early warning system' that includes rapid endpoint detection. Such modifications would be seen as an addendum to, rather than a replacement of the current standard, and could include some of the autonomous measuring devices mentioned above. It is important to stress that such a strategy does not represent the repeal of the current standard, a move that would be counter-productive, particularly in view of the fact that it has yet to be ratified. However, any post-ratification process that streamlines and normalises compliance testing will result in a more even application of the Convention worldwide. Ship operators will also welcome a common and understandable approach by the Port State Control in verifying compliance.

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