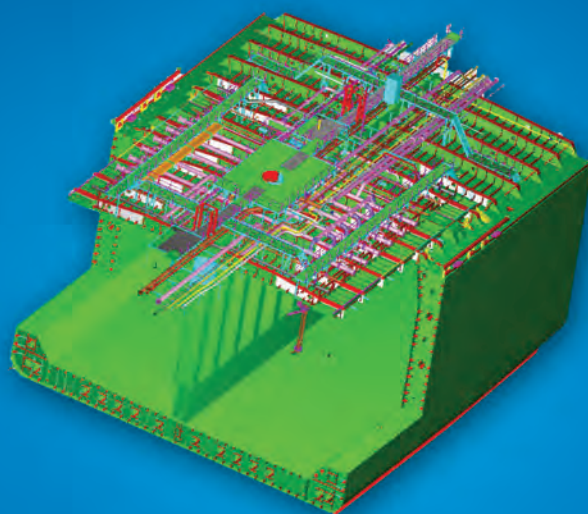
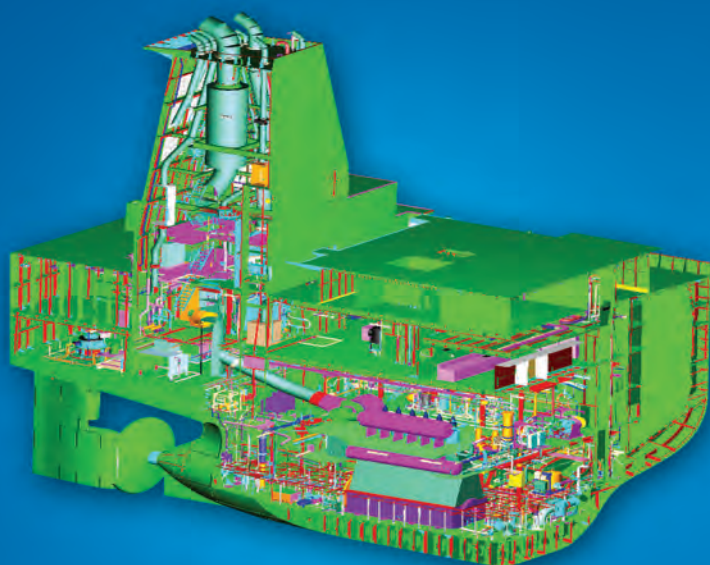


Establishing equivalency in the performance testing and compliance monitoring of emerging alternative Ballast Water Management Systems

A Technical Review



GloBallast Monograph Series No. 20
GESAMP Reports and Studies No. 83



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FAO



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The GloBallast Partnerships Programme is a co-operative initiative of the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and the International Maritime Organization (IMO) to assist developing countries to reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water and sediments, and to assist the countries in implementing the International Convention on Ballast Water Management. For more information, please visit <http://globallast.imo.org>

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Executive summary

Regulation B-3.7 of the Ballast Water Management (BWM) Convention allows for the development and approval of alternative BWM methods, provided they are deemed as giving *equivalent protection to the environment* as other approved methods. Approved methods currently include Ballast Water Exchange (BWE: Regulation D-1) and Ballast Water Treatment (BWT: Regulation D-2), with the former (D-1) to be phased out.

This independent technical review has the following objectives:

- (a) to provide a detailed background and appraisal, based on available published information, of the current range, features and status of EABWM concepts and research projects including the commonalities and divergencies of each method with respect to its approach to BWM;
- (b) to form the basis of technical presentations that would facilitate discussion on the approaches and methods for testing and approving alternative methods by participants at the workshop on *Emerging Alternatives to Ballast Water Management* (EABWMS) held at the World Maritime University (Malmö) in January 2010;
- (c) to stimulate further discussion on how the various alternative methods identified by this review might be Type Approved by developing test criteria and standards that, through appropriate risk-based evaluation, will be accepted as equivalent to the discharge benchmarks set by Regulation D-2.

With respect to (c), it is important to recognize that for any alternative method identifying what performance criteria are suitably equivalent to the benchmarks provided by D-2 is a prerequisite for determining its Type Approval testing regime and compliance monitoring needs.

There is currently much interest within the shipping industry in finding new ways of meeting the aims of the BWM Convention. On-board treatment systems designed to ensure that discharged ballast water complies with the Convention's D-2 standard may be costly to install and operate. This document describes new concepts in ship design (Section 3), as well as modifications to existing vessels, that to a greater or lesser extent dispense with the need to uplift or discharge water from ports and approach channels.

These 'alternative' methods of ballasting and trimming fall into two categories:

- (a) **No ballast/Zero discharge** methods; and
- (b) **Continuous flow** methods.

(a) No ballast/Zero discharge methods

As the name suggests, ships in this category may include those that are specially designed not to require liquid ballast (i.e. novel hull designs) and others ranging from those that carry ballast temporarily (e.g. during storms), to those carrying freshwater that is shifted from tank to tank and seldom discharged, to those that carry drinking water that can be discharged in port if necessary. Clearly, ships that do not discharge any ballast water are not covered by the Convention.

(b) Continuous flow methods

These designs (new and retrofitted) dispense with closed tanks and accelerate flushing rate to the point where >99.99% of the ballast water volume is fully exchanged within 10 to 500 nautical miles of steaming, depending on the particular method and circumstances of the ship. Such systems embrace various engineering concepts including the replacement of ballast tanks by longitudinal trunks, modified free-

flow ballast tanks and tanks that allow for enhanced exchange by pumping in the open ocean. All readily exceed the D-1 exchange standard.

Section 4 of this document addresses the question of how alternative methods may be evaluated and tested in accordance with Regulation B-3.7 of the Convention, which essentially requires the evaluation process to use the criteria of the D-2 performance standard for ballast water discharges as a baseline or ‘benchmark’ for reducing the risk of transferring unwanted species and pathogens. Where an alternative method does not involve treatment, the options are either to seek approval for individual ships on specified voyages or to develop new performance benchmarks that can be demonstrated as equivalent to D-2. These benchmarks are not only required for approval purposes, they will also be needed for performance testing and routine monitoring. The performance criteria of D-2 reduce, but do not eliminate, a bioinvasion risk because they are based on achieving a Log-4 reduction (99.99% dilution) of the maximum likely concentrations of planktonic biota that a ship may uplift from shelf-sea waters.

It is argued that of the three levels of risk reduction recognized by the Convention, risk ‘*elimination*’ would apply to No ballast/Zero discharge systems, risk ‘*prevention*’ to systems that preclude any discharge to coastal waters (including those that discharge to reception facilities) and risk ‘*minimization*’ to both continuous flow systems and treatment technologies. One approach would be to employ comparative risk assessment to evaluate the equivalence of alternative BWMs to treatment methods that meet the D-2 criteria. The objective would be to determine if the alternative method will “*provide the same level of protection to the environment, human health, property or resources*” (Regulation B-3.7) as a D-2 compliant discharge of similar volume at the same location. The quantification of risk in a BWM context, however, remains problematic.

In order to gain approval for an alternative method a two-stage process is proposed. *Initial* approval would be sought from MEPC, based on an independent expert appraisal of the risk-based evaluation and supportive evidence submitted by the proponent with respect to equivalency with D-2, and the proposed benchmarks (criteria) to be used in performance testing and compliance monitoring. Feedback from this stage would help to guide the proponent and avoid any inordinate expenditure on research and development. The subsequent *Type Approval* stage, leading to an application for a Type Approval Certificate from IMO, would not be commenced until all evidence and results of the investigations, as proposed and accepted for *Initial Approval*, had been completed.

It is envisaged that the experimental and testing procedures for the Initial and Type Approval stages would need to include (but not be limited to):

- physical modelling, including hydrodynamic, engineering and design analyses;
- computerized fluid dynamics;
- other numerical modelling and simulations;
- biological modelling;
- tank testing and scale modelling;
- use of surrogates and substitutes (tracers and markers, etc.);
- turbulence modelling and tank testing;
- use of relevant statistical procedures (e.g. for sampling, scenario analyses);
- semi-scale, modular and/or full-scale operational testing.

Without modifications or additions to existing Regulations and Guidelines, the testing and evaluation of alternative methods of ballast water management must remain within the current provisions of these regulations and guidelines. The report outlines some of the issues that arise as a consequence.

There are currently various regulatory and technical impediments to gaining IMO approval for the use of alternative BWM methods. Whereas regulations and associated guidelines under the BWM Convention provide for new management methods, and exemptions from existing methods, these provisions are not easily applied to some innovative methods, especially those that avoid use of containerized ballast water. For example, the D-2 performance standard itself is aimed at a discrete body of water discharged from tanks in which it has been stored for a period and not to much larger volumes of water that are constantly changing in terms of their biological diversity and biomass.

Whereas exemptions from D-2 (under Regulation A-4) may be approved by MEPC for individual ships operating exclusively between specified ports and locations, the applicable G7 guidelines are based primarily on target species and bio-geographic criteria that are not applicable to methods aimed at minimization of organism size and density. Exemptions under Regulation A-4, that must be renewed every five years, may, however, be an option for certain ships using alternative BWT methods that have not yet achieved type approval. With respect to the process for approval of BWM systems generally, the associated G8 guidelines are aimed explicitly at systems for “*installation on board all ships required to comply with Regulation D-2*”, i.e. they are very much treatment orientated.

Special problems may be encountered with performance testing of continuous flow ballasting systems in that proper evaluation of different designs is likely to require full-scale prototypes operating under field conditions. In this context, the report notes that for purposes of evaluating alternative methods there is currently no equivalent within the Convention to Regulation D-4 that allows for testing of BW treatment prototypes on individual ships which do not then have to comply with D-2 for up to five years after the normal compliance date. A similar provision for alternative methods might facilitate the design and approval of more cost-effective BWM systems. In the context of freshwater discharges, other regulatory aspects that it would be helpful to clarify are the definition of the ‘high seas’ in the context of ballast water uptake and the possible significance of MARPOL Annex IV (prevention of pollution by sewage from ships) in the context of compliance with the microbe component of the D-2 performance standard.

Technical issues that need to be addressed include the environmental and human health significance of discharges of freshwater (including disinfected potable water) on the high seas, and, in the case of continuous flow systems, the possibility that fouling on internal surfaces open to the surrounding sea might increase the extent of species’ transfers by this means.

For each alternative BWM method under development, there exists a number of options with respect to both design and operational features of the ships concerned. Journey times and the proportions of shelf sea and oceanic waters on particular routes are of special relevance. The document explores the requirements and guidance, applicable to ships with different designs and use patterns, contained within the various regulations and guidelines of the Convention and shows how they might be used in demonstrating compliance with, or equivalence with, existing performance standards. Finally, preliminary advice is given on approaches to compliance monitoring of new BWM systems.

The document does not attempt to resolve the many issues raised by these important innovations in ballast water treatment but, by identifying key issues that affect the further development and certification of methods, should contribute to discussions between regulators and technical experts on the best ways forward.

*“To the uninformed there are many possibilities,
to the informed there are few.”*

*“Well-informed people know it’s impossible to transmit voice over wires
and that, were it possible to do so, the thing would be of no practical value.”*

(Boston Post Editorial, 1865)

Glossary of terms, acronyms and abbreviations

Air draught (<i>draft</i>)	Height of a ship from the waterline to its highest point, usually its mast top.
AIS	Aquatic Invasive Species
AUBAFLOW	Automatic ballast flow
BLG	Working Group (of MEPC) on Bulk Liquids and Gases
BOB	Ballast on board (pumpable)
BW	Ballast water
BWE	Ballast water exchange
BWM	Ballast water management
BWMP	Ballast Water Management Plan
BWRA	Ballast water risk assessment
BWRB	Ballast Water Record Book
BWRF	Ballast water reporting form
BWT	Ballast water treatment
cm	centimetre(s)
CBWF	Continuous blue-water flushing
Convention	<i>International Convention for the Control and Management of Ships' Ballast Water and Sediments</i>
DB	Double bottom
DNV	Det Norske Veritas (Oslo, Norway)
Draught	Distance from a vessel's waterline to its lowest point, usually the aft part of the keel if normally trimmed. See UKC.
DSME	Daewoo Shipbuilding & Marine Engineering (Korea)
DUT	Delft University of Technology (Netherlands)
DWT	Deadweight tonnage (largest weight of cargo, bunkers and stores a ship is permitted to carry – usually some 4–10% more than its payload tonnage of cargo). See GT.
EABWMS	Emerging alternative BWM system(s)
Euryhaline	Ability to acclimate to a wide range of salinities (opposite of <i>stenohaline</i>). Euryhaline biota are predominant in estuaries and many tide pools. Also includes migratory species, which move into rivers or the sea for spawning.
Freeboard	Vertical distance between lowest part of a vessel's main deck and the waterline.
GBP	GloBallast Partnerships programme (2008–2012)
GEF	Global Environment Facility of the World Bank
GHG	Greenhouse gas
GIA	Global Industry Alliance: the group of industry partners supporting GloBallast Partnerships, presently comprising BP, Daewoo and Vela Shipping.
GloBallast 1	First GEF/IMO/UNDP Global Ballast Water Management Programme (2000–2005).

GBP	GloBallast Partnerships: 2008–11 Global Ballast Water Management Programme, funded by GEF, IMO & UNDP and supported by the GIA.
GT	Gross tons: a measure of a ship's total enclosed internal volume available for cargo, stores and passengers (not a measure of mass). Used for manning regulations, safety rules, port dues and registration fees. See also NT.
HELCOM	Helsinki Commission
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
In ballast/ ballasted	When a ship contains any quantity of pumpable BW to help maintain its stability, trim, steerage and/or propulsion efficiency, or to reduce its <i>air draught</i> .
IOC	International Oceanographic Commission
km	kilometre(s)
km ²	square kilometre(s)
km/h	kilometres per hour
knot	1 nautical mile per hour (~1.852 km/h)
LME	Large Marine Ecosystem
LoBE	Loop ballast (water) exchange
m	metre(s)
m/s	metres per second
µm	Micrometer(s) (micron)
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee of the IMO
Moulded depth	Height of a ship's side, measured from the lower edge of the main deck
NT	Net tonnage: a volume measure of a ship's cargo spaces and used to calculate port dues. There is no fixed relationship between NT and displacement tonnage or DWT.
NIS	Non-indigenous species
nm	nanometer(s)
nM	nautical mile (the distance covering 1 second of latitude; 1 nM = ~1.852 km)
NOBS	No ballast (water) ship(s)
NOBOB	No (pumpable) ballast water on board
OSPAR	Oslo-Paris Commission
Potable water	Freshwater (<0.5 PSU) treated to a recognized standard for safe human consumption, such as the WHO (2008) <i>Guidelines for Drinking Water Quality</i>
PSC	Port State Control
PSU	Practical Salinity Unit: the conductivity ratio of seawater to a standard potassium chloride (KCl) solution. While ocean salinity metrics such as mg/L and ppt are generally close to PSU, PSU accounts for differing compositions of seawater (ion ratios vary between regional and enclosed seas such as the Caribbean, Gulf, Baltic, Caspian, Black and Mediterranean).
RA	Risk assessment
R&D	Research & Development
RO	Reverse osmosis (membrane ultra-filtration)
SB	Solid ballast
SBTs	Solid ballast TEUs (containers)
SRC	Ship Research Centre of Japan
TEU	Twenty (foot) equivalent unit: an imprecise measure of containerized cargo payload.

TS	Transverse stability: the ability of a ship to remain upright, and a measure of its resistance to either loll, take on a permanent list, or to capsize completely.
VLCC	Very large crude carrier (typically >200 000 DWT)
UKC	Under keel clearance
ULCC	Ultra large crude carrier (typically >300 000 DWT)
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNOPS	United Nations Office for Project Services
WHO	World Health Organization
WMU	World Maritime University (Malmö, Sweden)

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The report was compiled by two consultants, Dr. Robert Hilliard, InterMarine Consulting Pty Ltd, Australia, and Professor Peilin Zhou, Dept. of Naval Architecture and Marine Engineering, University of Strathclyde, Glasgow, Scotland.

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Following the completion of the full draft report, it was peer-reviewed by GESAMP. The peer-reviewed report was then amended to incorporate the comments from GESAMP and edited by Mr. Rick Boelens, independent consultant, before being published.

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DISCLAIMER

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1

Introduction

1.1 REPORT BACKGROUND AND PURPOSE

The International *Convention on the Control and Management Ships' Ballast Water and Sediments* was adopted by IMO member States in February 2004, and is commonly known as the Ballast Water Management (BWM) Convention.

The Convention's Regulations and Guidelines cover all facets of BWM, including the performance, safety and compliance testing requirements and procedures for ballast water exchange (BWE) and on-board ballast water treatment (BWT). The relevant standards for BWE and BWT, and certain other regulations relevant to alternative ballast water management systems, are shown in Table 1-1.

Table 1-1: Key regulations governing ballast water management

Basic provisions under Regulation B-3	Relevant considerations
<p>Regulation D-1</p> <p><i>Ballast Water Exchange Standard</i> – Ships performing ballast water exchange shall do so with an efficiency of 95 per cent volumetric exchange of Ballast Water. For ships exchanging ballast water by the pumping-through method, pumping through three times the volume of each ballast water tank shall be considered to meet the standard described. Pumping through less than three times the volume may be accepted provided the ship can demonstrate that at least 95 per cent volumetric exchange is met.</p> <p>Regulation D-2</p> <p><i>Ballast Water Performance Standard</i> – Ships conducting ballast water management shall discharge:</p> <ul style="list-style-type: none"> less than 10 viable organisms $\geq 50 \mu\text{m}$ (minimum dimension) per cubic metre; less than 10 viable organisms $< 50 \mu\text{m}$ and $\geq 10 \mu\text{m}$ (minimum dimension) per mL. <p>Discharge of indicator microbes, as a human health standard, shall not exceed:</p> <ul style="list-style-type: none"> < 1 cfu of toxigenic <i>Vibrio cholerae</i> (O1 and O139) per 100 mL, or per 1 g wet weight of zooplankton sample; < 250 cfu of <i>Escherichia coli</i> per 100 mL; < 100 cfu of intestinal <i>Enterococci</i> per 100 mL. 	<p>Ballast water exchange</p> <p>Ballast water exchange is being phased out (cessation dates depend on age of vessel and ballast water capacity) and will cease after 2015.</p> <p>Regulation A-4</p> <p>This allows for the granting of exemptions from the B-3 provisions (left column) where a ship operates exclusively between specified ports and locations, for a period of no more than five years, where the ship does not mix water or sediments other than those from the specified locations, and where the risk assessment (G7) guidelines have been taken into account.</p> <p>Regulation B-3.7</p> <p>Other methods of ballast water management may also be accepted as alternatives to the ballast water exchange standard and ballast water performance standard, provided that such methods ensure at least the same level of protection to the environment, human health, property or resources, and are approved in principle by IMO's Marine Environment Protection Committee (MEPC).</p>

Over the past decade the potential cost-effectiveness of alternatives to BWE and BWT has become increasingly recognized within the global shipping community, with a number of concepts involving innovative hull designs, modifications and other concepts being subject to appraisal, research and development activities.

Many of the alternatives have received labels such as 'No ballast', 'Zero discharge', 'Ballast-free' and 'Continuous flow' methods, and several are approaching the point where more formal guidance on their

safety evaluation, performance testing and compliance monitoring is needed. In fact, no alternative can become an accepted BWM method unless it can be tested, Type Approved and then compliance monitored in ways that are accepted as equivalent (if not directly comparable) to the short-term D-1 process standard for BWE, or the long-term D-2 performance standard for BWT, with the latter including the Convention's G8/G9 Guidelines and Procedures for testing, approving, installing and certifying an on-board BWM system.

In response to these developments, the GloBallast Partnerships (GBP) programme with support from its Global Industry Alliance (GIA) partners commissioned this independent technical review of emerging alternative methods. The immediate aim of the review was to facilitate discussion and ideas regarding the safety, performance testing and compliance monitoring of the alternatives at the workshop on *Emerging Alternative Ballast Water Management Systems* (EABWMS) held at the World Maritime University, Malmö, 26 January 2010. Discussion points and information provided by workshop participants were then incorporated into the preliminary review to finalize this document. A summary of the main topics discussed at the Malmö workshop is given in Annex 1.

1.2 REVIEW SCOPE AND OBJECTIVE

The main objective of the review is to stimulate discussion on how proposed alternative methods to BWM need to be evaluated, tested and monitored with respect to:

- (a) the present requirements of the Convention and its technical Guidelines; and
- (b) equivalency in their performance testing and compliance monitoring with respect to the BWE D-1 and BWT D-2 standards. As D-1 is a short-term process standard for BWE that is due to be phased out within eight years, the review focusses primarily on the long term D-2 performance standard for treated ballast discharge.

The scope and contents of this desktop technical review include the following:

- 1. identifying, grouping and describing the more advanced and/or publicized alternative methods;
- 2. evaluating what potential issues each method raises with respect to dockyard and port infrastructure, ship safety, crew health and the aquatic environment;
- 3. comparing its operational characteristics and potential efficacy with those of the current BWM options (i.e. 'conventional' BWE, shipboard BWT, discharge to a reception facility, disposal of ballast tank sediments); and
- 4. In the context of achieving adequate risk reduction to the spread of harmful species and pathogens, outlining the scientific basis for establishing performance equivalency between the alternative and existing methods, to help facilitate the resolution of:
 - (a) appropriate performance standard/s that relate to the D-1 or D-2 benchmarks;
 - (b) approaches to system performance testing and their type approval procedure;
 - (c) methods and potential technologies for compliance monitoring.

1.3 REVIEW CONTENT

1.3.1 Structure of this review

Section 2 introduces the topic of risk as it applies in BWM. This sets the scene for subsequent consideration of the efficacy of different BWM systems and how alternative ballasting methods might be compared with existing treatment and vessel/route based systems.

Section 3 summarizes the various types of alternative method that have been proposed to date, before describing and evaluating the key design and operational features of each method with respect to their technical feasibility, affordability and their potential to influence ship safety, crew health and the environment (including GHG emissions), when compared to installing and operating an on-board BWT system.

Section 4 addresses some key aspects of the evaluation and performance testing of the various alternative methods, with respect to the aim of the Convention and its requirements regarding equivalency with existing BWM methods and using the D-2 performance standard as a benchmark.

2

Efficacy and risk in ballast water management

In considering the development of ballast water management (BMW) systems, it is important from the beginning to have a clear view of what management is intended to achieve so that the efficacy of different techniques and approaches can be systematically evaluated. In the following sections of this report, various alternative BMW systems are described and their attributes are analysed with a view to assessing the *risks* they represent in comparison to BWT methods that meet the D-2 standard. This section provides a background on environmental risk assessment and is included early in the document so that the reader may be persuaded to consider the kinds and degrees of risk associated with the alternative BMW systems described and how these risks might be compared and assessed.

The potentially harmful consequences of transferring aquatic species to new environments where they can reproduce and flourish, and disrupt the local ecology, are well known within the shipping industry as well as to environmental managers. Ballast water is only one of a number of vectors for these ‘alien’ species but, because of the diversity of shipping routes, the frequency of voyages and the very large volumes of water that may be involved, it is arguably one of the most significant.

The BMW Convention is designed to ‘prevent, minimize, and ultimately eliminate’ the risks associated with species’ introductions via ballast water. In essence, the Convention seeks to prevent harm to the environment or human health due to such introductions. In this sense, therefore, *risk* is synonymous with *harm*. Risk management is typically based on a prior risk assessment that considers some form of hazard (e.g. substance, activity, organism) along with the environment in which the hazard occurs. That is very similar to the approach adopted by the Convention in its guidance (G7 Guidelines) on the assessment of risks associated with particular voyages (i.e. seaways traversed, BW uptake and discharge areas, etc.)

The dictionary defines *risk* as the ‘chance of loss or injury’ and the ‘degree or probability of such loss or injury’. In science, the term *risk* tends to be used more broadly and expressed quantitatively as the chance (e.g. 1:20 or 95%) that an event will or will not happen. Whereas the BMW Convention seeks to prevent, minimize and ultimately eliminate *risk*¹, it does not specifically define it. The regulations and guidelines promulgated under the Convention do, however, constitute a regulatory and technical framework against which the efficacy of alternative BMW procedures that do not comply with the current D-1 and D-2 standards² can be evaluated. They do this by requiring an assessment of the extent to which the procedures will achieve a level of risk reduction equivalent to, or better than, these standards. Thus, for purposes of the Convention, it may be said that *risk* is defined by a process rather than statistically or in a concise form of words.

Of the two management standards currently in operation, D-1 is an exchange performance standard requiring at least 95% volumetric replacement of ballast water which, at the time it was introduced and in the absence of either a treatment standard or suitable treatment technology, was seen as an attainable target affording a worthwhile degree of risk reduction. Because the degree of water replacement may not correspond with the extent of either organism reduction or risk reduction, the standard is temporary and will be withdrawn in 2016. Compliance with the D-2 standard, based on biological criteria and organism density, almost certainly affords a greater reduction in the risks associated with organism transfer and has the advantage of being measurable. This form of standard implicitly defines a degree of risk *acceptable* to the parties adopting it, although the actual risk can only be expressed in relative terms.

The G7 guidelines provide a basis for granting an exemption (primarily on bio-geographic grounds) from the D-1 or D-2 standards to a vessel that cannot meet those standards or for which the standards are

¹ See Section 4.1 for further consideration of risk/performance assessment for innovative BMW systems.

² Depending on vessel age and ballast water capacity.

not directly applicable; this would include ships fitted with some of the alternative BWM technologies described in this report. The G7 guidelines include a set of risk assessment principles (Annex 3), a set of risk assessment methodologies and associated technical considerations which, taken together, constitute a suite of criteria by which voyages between particular ports and along particular routes may be broadly classified as high-, medium – or low-risk. Such assessments rely heavily on available evidence (which may not always be adequate) and expert judgement.

The G7 guidelines are not directly applicable to assessments of alternative BWM systems designed for broad geographical use. Further guidance on the evaluation of alternative systems, including treatment technologies, is provided in Annex: Part 2 of the G8 guidelines; these are not risk-based but focus on tests that compare performance to the D-2 standard.

To date, there is little experience in applying either the G7 or G8 guidelines in assessing the performance of non-conventional BWM systems, such as those described in this report, that avoid or substantially reduce high-risk ballast water discharges at destination ports. Nevertheless, innovative systems that operate on the principle of flushing and water exchange might be evaluated using principles set forth in both these sets of guidelines and/or by a new guideline developed for the purpose that facilitates reasonable estimates of relative risk reduction.

The concept of an *acceptable level of risk*, as represented by the D-2 standard, is clearly important and points to the possibility that the basis of the D-2 standard – a minimum Log-4 reduction in the concentration of planktonic biota uplifted in ballast water at the start of a sea crossing – might be used as a benchmark for assessing the performance of alternative BWM systems (see Section 4).

3

Review of emerging alternative methods

3.1 OVERVIEW

Since the late 1990s various concepts have been emerging to enable ships to operate without having to uplift or discharge port or channel waters for their ballast and trimming needs³. Following adoption of the BWM Convention in 2004, interest in these alternatives to conventional BWM has increased since they offer ways to avoid, or substantially reduce, the operational issues and costs of either exchanging or treating compartmentalized BW to meet the Convention's respective D-1 or D-2 discharge standards, plus the cost of managing tank sediments.

Most of these concepts have been labelled 'ballast free', 'no ballast', 'continuous flow' or 'zero discharge' methods, sometimes confusingly. The most radical involve novel hull forms or substantial features that cannot be retrofitted to existing ships, while the most simple comprise a relatively simple installation or upgrade, such as the proposal to permit use of potable water from an on-board water maker or shore-side supplier. The present range of alternative methods can be placed in one of the following two groups:

1. **'No ballast'/'Zero discharge' methods:** These are design and/or operational concepts where a ship carries either:
 - (a) always zero BW;
 - (b) occasionally some storm BW (temporarily uplifted to provide additional stability when encountering exceptionally heavy seas);
 - (c) an amount of permanent internal BW (non-dischargeable but moved internally for adjusting trim/list, and usually freshwater to minimize corrosion); or
 - (d) potable BW that meets a drinking water standard.

Their key features are compared in Table 3-1.

2. **'Continuous flow' methods:** These include both new hull designs and retrofitting solutions aimed at de-compartmentalizing BW and accelerating its flushing rate to the point where >99.99% of its volume becomes fully exchanged within 10–500 nautical miles (nM) of steaming – the exact percentage or distance steamed depending on the particular method and circumstances of the ship. Whereas replacement times for flow-through systems are largely theoretical at present, all are aimed at readily achieving and frequently exceeding the D-1 process standard without the safety and performance issues surrounding the present deepwater 'empty/refill' or x3 tank volume flushing methods for BWE. Two of them are aimed at achieving equivalence with the higher D-2 discharge standard. The most radical is a hull design that externalizes all water to the 'outside' of the ship, thereby replacing conventional ballasting with a buoyancy control system, at least for the offshore sections of unladen voyages. Key features of the continuous flow concepts are also shown in Table 3-1.

Compared to conventional BWE and BWT, the practicality and cost-effectiveness of the other methods will vary according to ship type, size and duties. Ship owners and fleet operators are expected to become more incentivized to examine their pros and cons when the actual installation and operating costs of the different BWT systems now coming to market become clearer for the main ship types and sizes.

³ Ship operation, particularly in the case of dry-cargo vessels (non bulk carriers), requires ballast water for trimming purposes. Small capacity internal ballast tanks will be required when No Ballast/Zero Discharge methods are used. Discharge of BW used as internal ballast should not impose any additional risks of transferring species (*See Section 3.2.3.*)

Table 3-1: Key features of emerging alternative BWM methods

Alternative method <i>(potential equivalent BWM method)</i>	Feature/s	Benefits <i>(*includes fuel and GHG emission cost)</i>	Penalties	Suitable ship type/s
No ballast water: <ul style="list-style-type: none"> Zero ballast <i>(eliminates risk and avoids all BWM requirements)</i> 	(a) Novel hull designs; or (b) use of ‘solid ballast TEUs’ (SBTs) to provide unladen stability and trim without need for ballast water.	Avoids all costs* associated with BWM.	Higher hull build costs and/or operational costs from increased hull drag, or port turn-around costs from the logistics of handling additional SBTs.	(a) New ro-ro pax, car, container, livestock ships and other ‘high volume cargo’ ships; (b) existing box ships.
No or minimal discharge: <ul style="list-style-type: none"> Storm ballast <i>(must meet D-2 if any storm BW is discharged in PSC jurisdictional waters)</i> Internal ballast <i>(must meet D-2 if eventually discharged in PSC jurisdictional waters)</i> Potable water <i>(must meet D-2 if discharged in PSC jurisdictional waters)</i> 	Novel wide beam V-hull design needs only two tanks used for temporary storm BW that may not be discharged in port.* Freshwater that is shifted from tank to tank and not routinely discharged in port.* Only drinking water is added to clean tank/s, allowing it to be discharged in port.*	Avoids all costs* of installing and operating a large BWT system.* Avoids costs* of installing and operating a BWT system. Avoids costs* and loss of space for installing and operating a BWT on a small ship.	Higher hull build cost and possible berth access or shiploading constraints due to wider beam. Reduced cargo capacity, no capacity to make air-draught adjustments; how to discharge for a tank survey/inspection. Cost of potable water production/purchase, then maintaining D-2 or DWQ quality in tanks.	New bulk carriers (possibly more suited to liquid than dry bulk carriers) Existing and new container ships, ro-ro pax, liners, livestock carriers. Super yachts, CTVs, cruise liners, some livestock carriers, some pax and some military vessels.
Continuous flow: <ul style="list-style-type: none"> Longitudinal trunks <i>(meets D-1 and may approach equivalence to the D-2 standard)</i> 	Replaces ballast tanks with buoyancy trunks to enable continuous flushing without pumping.	Avoids costs* of installing and operating a large BWT system, and possible propeller efficiency gain/s.	Higher ship build + valve servicing costs, (may be offset by long term fuel saving), plus risk of biota /sediment accumulation prevent.	New Seaway-size and other large bulk carriers.

Alternative method (potential equivalent BWM method)	Feature/s	Benefits (*includes fuel and GHG emission cost)	Penalties	Suitable ship type/s
<ul style="list-style-type: none"> Ship buoyancy control (<i>meets D-1 and may approach equivalence to the D-2 standard</i>) 	Multiple below-waterline valves convert each BW tank into a free-flooding buoyancy compartment for continuous flushing without pumping.	Avoids costs* of BWE pumping to reach D-1, and may avoid costs* of installing and operating a very large BWT system for coping with the fast BW discharge rates of large tankers and large dry bulk carriers.	Costs of installing multiple valve and control system, plus valve servicing, coating and cleaning costs to maintain ship safety and avoid biofouling; potential for slight increase to hull drag. Any sediment and biota that settle or gather in a low-flow zone will impede equivalency to D-2 if no BWT is available.	Existing and new cargo ships.
<ul style="list-style-type: none"> AUBAFLOW (<i>exceeds D-1; seeks to place enhanced BWE as an alternative method that is specific to VLCCs</i>) 	Enhanced blue-water BWE by flushing without using pumps, for transoceanic voyages.			Existing and new VLCCs + ULCCs.
<ul style="list-style-type: none"> Loop ballast exchange (<i>above D-1; may approach D-2 equivalency for VLCCs</i>) 				
<ul style="list-style-type: none"> DynaBallast (<i>exceeds D-1; seeks to become an approved alternative method to D-2</i>) 	Enhanced blue-water BWE pumping, by adding specialized aerator-eductors to all BW tanks.	Avoids costs* of installing and operating a BWT system.	Any sediment/biota accumulating in a low-flow zone can impede equivalency to D-2.	Most types of existing and new cargo ship on transoceanic trade.

As noted in Table 3-1, each alternative brings particular benefits and penalties that influence overall transport efficiency. Penalties may include fuel use and CO₂ emitted per ton-mile of cargo moved. Also, apart from the increased capital outlay of the initial ship-build or a retrofit/installation, some methods may influence overall transport efficiency by reducing the amount of cargo capacity, or a voyaging cost such as higher fuel consumption from increased hull resistance, or the time and costs of managing units of solid ballast. Furthermore, depending on operational procedures (e.g. opening and closing of continuous flow compartments; need for freshwater treatment plant), some designs may not avoid all costs associated with BWT. Meaningful comparisons between two or more methods should therefore include a detailed cost-benefit analysis as well as an appraisal of the likely environmental benefits versus impacts.

In the case of meeting the equivalent D-1 and D-2 standards, alternative methods that will exceed the process-based D-1 standard for conventional BWE but face challenges in reaching equivalence with the D-2 discharge quality standard, may incur a substantially shortened lifespan penalty owing to the planned phase-out of D-1 by 2016.

In the case of ship safety considerations, and particularly for the more radical new-build and retrofit concepts (including those that replace compartmentalized ballast tanks with more contiguous buoyancy control compartments), it is important to recognize that the history of ship structural design is one of evolution rather than revolution. Designers learn from past experience and each new ship tends to be a development of a previous successful design. This is because of the very complex interaction of the many variables that affect the stresses in the structure of a large, double-hull cargo ship at sea. As noted by many reviewers^[e.g. 24,25], these variables stem from the:

- structural design, including plate thicknesses, local stress concentrations, stiffness and proper transmission of loads;
- construction quality, including alignments, local imperfections and the quality of steel and welding;
- cargo, fuel and ballast distributions within the ship, with the payload distribution potentially having many different permutations;

- the static and dynamic forces of the wind, wind-waves, swells and breaking waters that produce a range of stresses during heaving, pitching, rolling and slamming;
- vibrations from machinery;
- effects of potentially random corrosion; and
- the complex internal distribution of stresses between a ship's primary, secondary and tertiary structures.

It is impossible to calculate accurately the true in-service stress levels throughout a ship's structure entirely from first principles. This is why the 'design' or calculated stress levels for all elements of a ship routinely use safety factors and margins for error that are based on previous successful experience.

3.2 NO BALLAST/ZERO DISCHARGE METHODS

3.2.1 Zero ballast water concepts

Projects:

- '*Monomaran Hull*' – Delft University of Technology (DUT), Netherlands^[5];
- '*Volume Cargo Ship*' – Det Norske Veritas (DNV), Norway^[6];
- '*Solid Ballast Ship*' – Daewoo Shipbuilding & Marine Engineering (DSME), Korea^[14].

Description:

When a ship rolls during the unloaded condition, its stability without use of BW requires adequate returning buoyancy. Both the DUT and DNV concepts achieve this by widening the ship's beam and moving the displacement volume outward from the centreline. The DUT concept^[5] proposes a 'monomaran' hull by adopting a catamaran shape to the underside of a broad single hull (Figure 3-1), while the DNV concept (Figure 3-2) indicates a tri-hull concept similar to the cathedral hull that provides a high level of stability to tenders and other planing vessels. In the case of DSME's solid ballast (SB) concept, the conventional displacement hull is retained since the BW is replaced by 25 tonne SB TEU containers, and the method is applicable to container ships only.

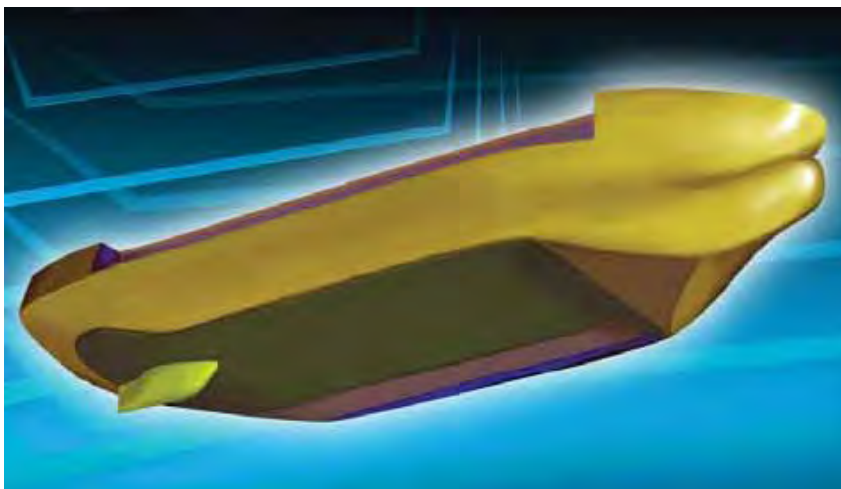


Figure 3-1: Monomaran hull form proposed by DUT for a zero ballast ship

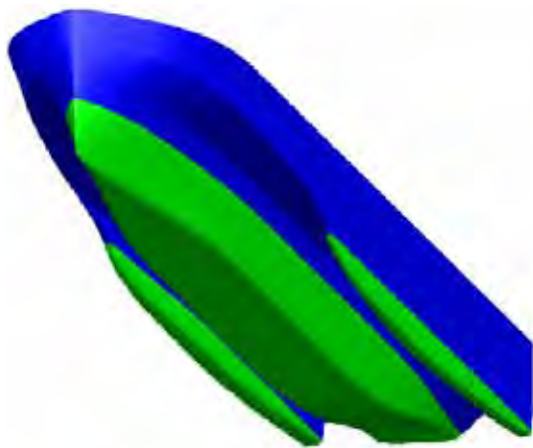


Figure 3-2: Cathedral hull form concept by DNV for zero ballast ‘high volume cargo’ ships

Significant drawbacks of the monomaran and cathedral hull concepts may include their high build costs and relatively large wetted surfaces when loaded. In the case of the increased build cost, the amount will vary according to the design cargo type and capacity, cargo loading/unloading requirements and other trading factors.

The larger wetted surfaces of both hull shapes could increase their frictional resistance (drag) compared to conventional ships of equal DWT. If propulsion efficiency remains unaltered, the additional drag causes higher fuel consumption, especially during the loaded condition. Any fuel efficiency gain that can be made when the monomaran or tri-hull is sailing in the unloaded or part-loaded condition is therefore critical.

Compared to a cathedral hull, the monomaran form appears more amenable to monopod or twin-pod propulsion options, and these offer ways to minimize drag-related performance losses through increased propulsion efficiency, superior manoeuvrability and the potential to reduce berthing costs (fewer or no tugs are needed). Because of their beamy hull and likelihood of higher fuel consumption when fully loaded, both the DUT and DNV concepts appear least suited to bulk carriers and most suited to smaller ‘high volume’ cargo ships, as also noted by DNV^[6]. A hull form that is suited to tankers and bulk carriers, but which minimizes rather than entirely removes the need for BW, is the ‘V-hull’ concept. This is addressed in Section 3.2.2, which also evaluates the ‘no-ballast’ hull types and the issues posed by wide and unusual hull forms with respect to costs, safety, health and environment.

In the case of replacing the BW of container ships with solid ballast (SB) TEUs⁴, this concept was put forward by DSME in early 2009^[14]. Before embarking on a light or completely unladen voyage, standard dimension containers with suitable weights are loaded, using the normal cranes at the container terminal. The concept would be more attractive for retrofits or new builds than unmodified container ships, since hull space previously designated to BW can be used to store additional containers during loaded voyages⁵ (Figure 3-3).

Table 3-2 shows data from DSME’s preliminary study^[14], where the notional mass of each SB container (25 tonnes) is just above the maximum allowable gross weight of a standard but untested TEU⁴. The table indicates that a 4,400 TEU ship would need 549 SB containers for any completely unladen voyage, reducing to 349 for its fully loaded voyages. Thus, 200 SB containers is the largest number that would need to be unloaded from a 4,400 TEU ship when visiting an export-oriented terminal.

⁴ A TEU (Twenty-foot Equivalent Unit) is an inexact measure of cargo volume and weight. A standard 20 ft (6.1 m) container is 20 ft (6.1 m) long, 8 ft (2.4 m) wide, 8.5 ft (2.6 m) high and 1,360 ft³ (39 m³) volume. Both 9.5 ft (2.9 m) tall ‘high cube’ and 4.25 ft (1.30 m) ‘half height’ containers are reckoned as 1 TEU, causing 1 TEU volume to range from 680 ft³ (19 m³) to 1,520 ft³ (43 m³). Maximum gross mass of a standard dry cargo TEU is 24 tonnes, comprising a 21.6 tonne payload and a 2.4 tonne tare ‘Heavy tested’ TEUs have a 28.1 tonne payload and maximum gross weight of 30.5 tonnes. The maximum gross mass of 40-foot (12 m) containers (2 TEU) is ~30.5 tonnes and they provide a payload of 26.5 tonnes.

⁵ Loss of torsional strength from removing the inner shell of a modern, double-sided container ship will require detailed design considerations because these wide-hatched ships rely on their double hull to minimize twisting^[24].

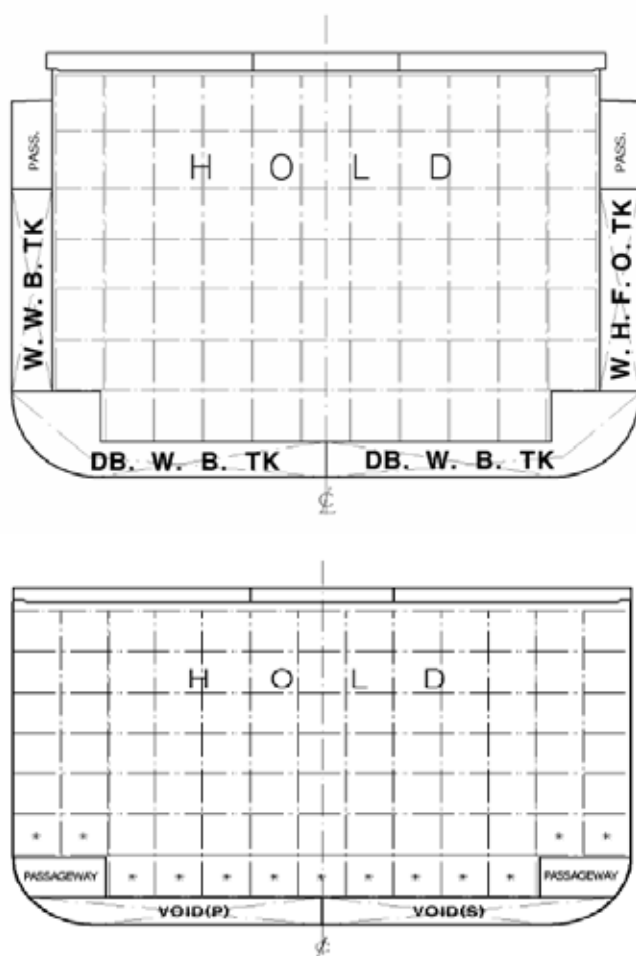


Figure 3-3 Conversion of container ship's BW tanks to provide additional hold space

It is unclear to the authors if DSME has examined the option for existing container ships to be retrofitted in a way that preserves their ability to store the permanent ballast as freshwater that is never discharged but can be transferred between internal compartments for trimming purposes. This option would appear to offer additional cargo volume since the density of a 25 tonne TEU that occupies some $\sim 40 \text{ m}^3$ is only 625 kg/m^3 .

Table 3-2: Estimated number of solid ballast TEU containers for different container ships

Ship size (TEU)	BW capacity (tonnes)			SB container weight (tonnes)	Number of SB containers required (TEU)	
	Total	Unloaded	Loaded		Unloaded	Loaded
4,400	14,128	13,705	8,704	25	549	349
8,400	28,495	22,721	7,857	25	909	315
14,000	48,859	40,807	12,803	25	1,633	513

The SB concept saves container ships the cost of BWM operations and maintenance, but the saving is offset by the need to handle the SB containers, including the planning, logistics and additional crane work to ensure:

- (a) correct on-board distribution; and
- (b) a sufficient number of SB containers are present at the terminals serviced by these ships.

SB container operations require all participating terminals to have the infrastructure and yard area capable of handling and managing the SB containers, so as to minimize in-port delays and avoid voyages that are below optimum cargo capacity. Unloaded SB containers may be held at the terminal until needed by another ship. Container imports/exports are rarely in close balance at any terminal, however, so the SB containers will tend to accumulate at the more export-oriented terminals and be scarce at the import-oriented ones. The problem may be solved in part if the SB containers accumulating at export terminals are emptied for cargo re-use and/or back-loading voyages. Nevertheless, long-term cargo efficiency penalties remain owing to the storage, handling and other logistical costs of the SB containers, including wharf-ship/ship-wharf transfers, transferring them to import-oriented terminals, and procuring, loading, unloading, storing or disposing the SB material itself.

Potential cost, safety, health and environment issues

By using SB containers that replace the side BW tanks, the DSME concept requires no external hull form changes, but alters the skinned hull to a single-side double-bottom (DB) hull. At least some of the smaller existing container ships may be refitted to attain this concept, provided their integrity to torsion stress can be retained. Thus, any retrofit involving replacement of the side tanks with additional container slots will need to consider hull strength and provide reinforcement options. While hull resistance, manoeuvring ability and propulsion efficiency will be unaffected, ship stability and trim become highly reliant on a modified container management system. This system must ensure and confirm that an adequate number of SB containers of known weight have been loaded and distributed correctly. The operational penalty of relying on SB TEUs is the need for additional handling at container terminals and resultant increases in berth time. The amount of TEU handling could be reduced if some, if not all, of the trimming need is achieved by providing a permanent (non-dischargeable) internal freshwater system (see *Internal Ballast Concept*, Section 3.2.3).

Conclusions

By eliminating the need for a ship to carry any dischargeable BW, whether by its hull form or use of solid ballast, the zero ballast methods remove any potential to introduce harmful species by this vector and place the vessel beyond any requirement of the Convention as it does not currently apply to ships not designed or constructed to carry BW (Article 3, Application). They have been included for completeness and are not addressed beyond the end of Section 3.

3.2.2 Storm ballast only concept

Project:

- *The Non-Ballast Water Ship (NOBS)*; Shipbuilding Research Centre of Japan (SRC).

Description

SRC has carried out R&D on NOBS designs since 2001 and mostly for tankers since 2003^[1]. The NOBS concept is based on a V-shaped hull. As with the DUT and DNV hull designs for zero ballast, the NOBS V-hull stems from new thinking about optimal hull shape and buoyancy distribution, and it represents another major design change away from the flat-bottom hull of conventional trading ships (Figures 3-4, 3-5). SRC has also applied for patents for the NOBS concept in several countries.

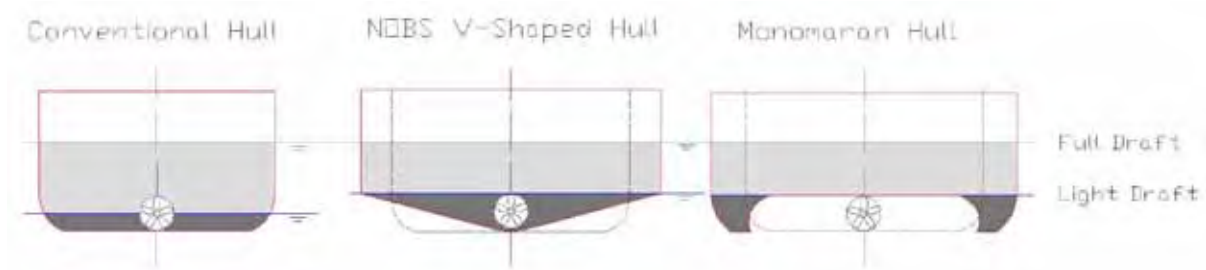


Figure 3-4: Hull concepts for no-ballast ships with the same DWT and loaded draught as their conventional counterpart (from^[1])

The V-hull alters the vertical distribution of hull buoyancy, causing a deeper draught in the light (unloaded) condition. By widening the beam by ~30%, displacement is kept at the same full load draught as that of an equivalent DWT conventional hull, while hull length is minimally altered (Figure 3-5; Table 3-1). In the case of a NOBS-equivalent to a conventional Suezmax tanker, the additional steel for the wider hull increases hull weight by roughly 4,500 tons^[2].

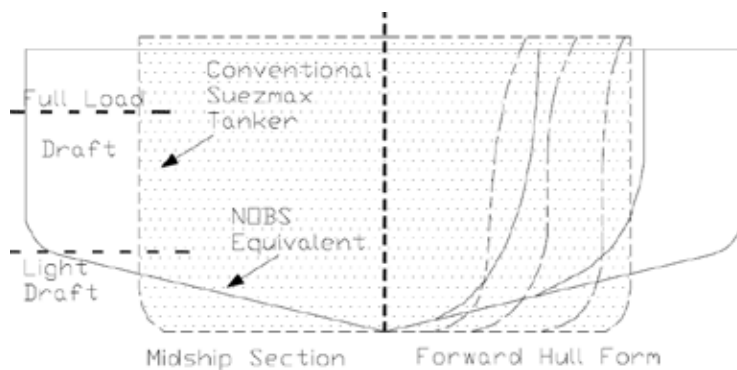


Figure 3-5: The NOBS concept uses the effect of a transversely raked hull bottom plus a wider beam to maintain equal displacement draught in the loaded condition

In the unloaded condition, the V-hull's centreline sits more deeply in the water than that of an equivalent DWT flat-bottom ship when unballasted (Figure 3-6). Since the moment of waterplane inertia increases as hull breadth is increased, and since the returning moment of a rolling ship is proportional to the moment of its waterplane inertia, the stability of a beamy V-hull is inherently higher than a flat-bottom ship.

This is the main purpose of adopting the V-shape cross-section, which is to maintain sufficient unloaded draught and stability and avoid bow slamming and propeller racing without needing any BW for the majority of sea conditions^[1]. In the unladen condition, the V-hull also provides the potential for better vessel control, reduced hull resistance and improved propulsion efficiency for most speeds and sea conditions.

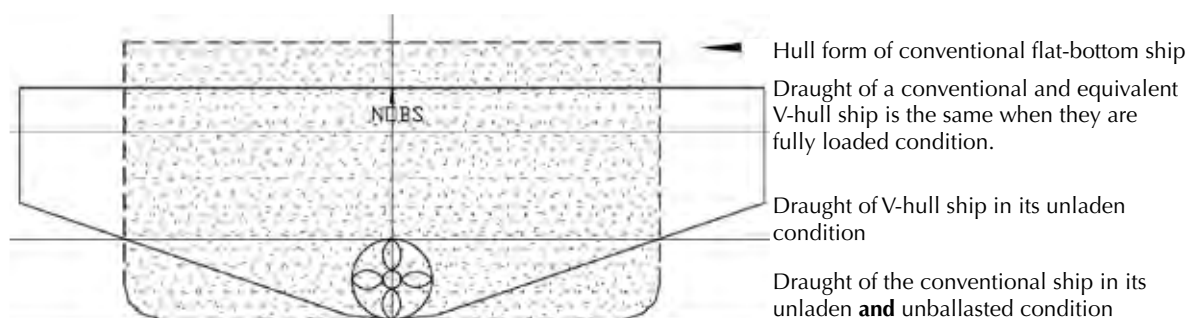


Figure 3-6: Deeper draught of V-hull in its unloaded condition than that of conventional hull

Potential Cost, Safety, Health and Environment Issues

The increased resistance of the V-hull when in its fully loaded condition is due to the wider beam and larger wetted surface, and this impost to propulsion efficiency and the likely increased fuel consumption (compared to a fully-loaded conventional ship) has been assessed by SRC for different ship types. The V-hull offers both advantages and disadvantages for each ship type so the challenge is to find the best compromise among a range of interrelated factors, including the amount of transverse rake and alterations to length, beam, draught and trim, and resultant changes to hull drag, propeller depth and propulsion efficiency, plus the additional steel and other construction costs associated with V-hull designs.

As shown in Figure 3-7, a case study conducted by one of the authors (P. Zhou) for a 54,000 DWT container ship indicated that hull resistance of a fully-loaded NOBS container ship would be some 20% higher than its conventional flat-bottom counterpart at speeds up to ~16 knots, rising rapidly to reach 40% by 20 knots, then 80% by 25 knots. This implies fuel consumption and GHG emissions of V-hulled container ships will be overly high because they undertake most voyages in the fully or at least part-loaded condition.

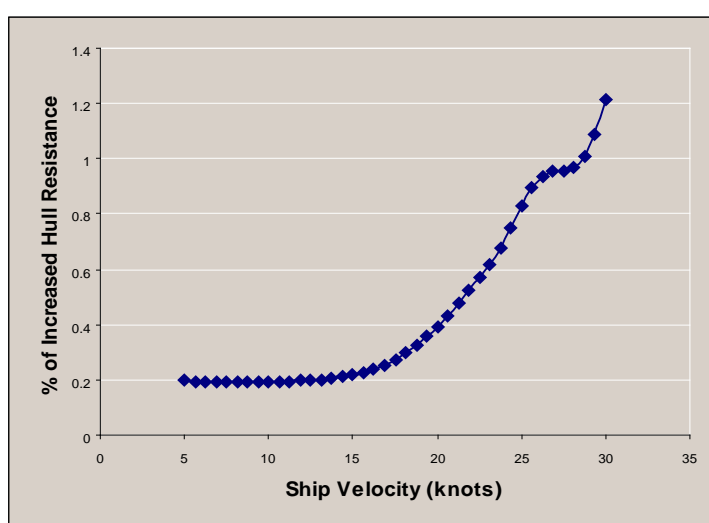


Figure 3-7: Increased resistance of a fully-loaded NOBS container ship versus a conventional container ship (reproduced from author case study [Peilin Zhou])

Comparisons like these support SRC's view that the NOBS V-hull concept is most suited to tankers and bulk carriers because they regularly alternate between fully loaded then fully unloaded passages. This allows them to take full advantage of the relatively large gain in hull performance and propulsion efficiency during every unloaded voyage. In fact, SRC has claimed the gain during unloaded passages should outweigh the increased hull drag and fuel consumption that is incurred during loaded voyages, yielding overall average gains of 5–7% for both NOBS Suezmax tankers and VLCCs^[1,6].

SRC^[6] has modelled the application of a V-shaped hull to a Suezmax tanker and a Very Large Crude Carrier (VLCC) to evaluate its technical feasibility, cost, safety, health and environmental aspects, including hull strength, structural integrity, forward visibility and rolling behaviour.

By eliminating the need to carry BW in the unloaded condition, operators of large NOBS tankers or bulk carriers may expect to avoid the capital equipment and operating costs to meet the BWM requirements of the Convention (especially the costs of a large BWT system for achieving the D-2 performance standard for large tank volumes and fast discharge rates above 5,000 tonnes per hour). However, two segregated heavy weather ballast tanks are incorporated in SRC's feasibility designs for both the VLCC and Suezmax tanker^[6] (Figure 3-8; Table 3-3).

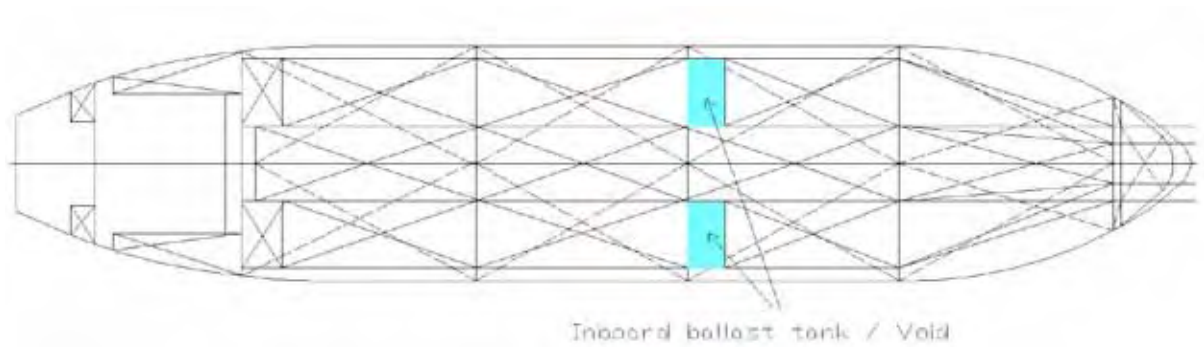


Figure 3-8: Location of the two BW tanks in the NOBS Suezmax design (from ^[6])

The purpose of these tanks is to deepen the relatively shallow forward draught, so as to reduce bow slamming and associated stresses when the ship encounters very rough seas (Figure 3-9). In both the NOBS VLCC and Suezmax designs the total capacity of the storm tanks is approximately 25% of the total BW capacity of their conventional counterparts (Table 3-3).



Figure 3-9: NOBS Suezmax tanker design, showing the waterlines in the laden condition and in the typical 'bow-up' unladen and storm ballasted conditions (modified from ^[6])

Table 3-3 compares the principal characteristics of a conventional versus NOBS Suezmax tanker. As noted earlier, the hull of the NOBS Suezmax tanker is some 4,500 tons heavier due to the additional mild steel but its total light displacement is much less owing to the complete absence of BW (Table 3-3).

Table 3-3: Comparison of the particulars of a conventional vs NOBS Suezmax tanker

Principal characteristics	Conventional Suezmax	NOBS Suezmax
Length of waterline	271 m	271 m
Length between perpendiculars	265 m	267 m
Breadth (beam)	43 m	56 m
Moulded depth	23.8 m	22.5 m
Bottom rake	0°	15.2°
Propeller diameter	8.6 m	7.7 m
Deadweight tonnage (DWT)	134,000 tonnes	136,500 tonnes
Loaded draught	16 m	16 m
Loaded (full) displacement	160,000 tonnes	162,500 tonnes
Total ballast tank capacity	55,000 m ³	13,800 m ³
BW requirement (normal light condition)	43,050 tonnes	0 tonnes
Unloaded (light) displacement	68,650 tonnes (inc BW)	28,100 tonnes
Light draught – forward	5.84 m	3.00 m
Light draught – aft	8.82 m	7.90 m
Additional heavy weather BW capacity	~22,000 m ³	13,800 m ³

Heavy weather conditions often occur on the high seas⁶ and other relatively deep offshore areas, so the storm ballast tanks of a NOBS ship may be filled with this ‘blue’ water which does not contain the levels of suspended material and coastal biota that occur near ports or on short-sea routes. If seawater uplifted from a high seas or shallower area is **not** discharged before a NOBS enters the jurisdictional waters of a Party to the Convention and approaches its destination, this water could be:

- discharged in line with the D-1 BWE standard (for uplifted high seas water) or in a designated BWE area (for uplifted shelfal water) – but only until the planned 2016 phase-out of D-1 BWE for >5000 m³ BW capacity ships laid before 2012;
- discharged slowly before and during port entry and cargo loading phase (if the ship has a small BWT system that achieves the D-2 standard, e.g. 36 hours at 400 m³/h for a NOBS Suezmax);
- retained on board until the NOBS completes loading and re-enters the high seas, potentially with a reduced loaded cargo capacity due to its increased draught versus departure channel depth, underkeel clearance (UKC) and/or reduced freeboard safety constraints;
- discharged without BWT if an Exemption is approved by the port State in accordance with the risk assessment requirements of Regulation A-4 of the Convention;
- discharged to an approved shore-based BW reception facility;
- pumped to a reception vessel that can either treat the BW on board to the D-2 performance standard or move it to an approved shore-based BW reception facility⁷.

Due to the increased breadth and bending moments of the NOBS hull there is a requirement for additional steel that causes a 4,500 tonne and 5,600 tonne increase in hull weight for the respective Suezmax and VLCC designs examined by SRC. The additional steel work is estimated to add USD 5.2 million to the price of a NOBS Suezmax and USD 6.5 million to the price of a NOBS VLCC (2006 pricing^[4,6]). Because of the claimed 5-7% gain in overall performance and associated fuel savings, the additional build cost is predicted to be recovered within ~15 years, a period that may reduce with further R&D to improve NOBS performance^[4,6].

Other potential cost issues are associated with the NOBS construction, dry-docking and operations phases as a result of the ~30% increased breadth and V-shape hull. Construction and subsequent dry-docking of exceptionally wide tankers or bulk carriers will require major modifications to many existing shipyards whose slips, dry-docks and equipment have been designed for accommodating conventional hulls. The exceptional width may also present access issues for the transport and assembly of hull sections and modules during NOBS construction. If the transverse dimensions exceed the limits of existing yard and dry-dock spaces, companies with relatively cramped facilities may be reluctant to remove or downgrade existing infrastructure to make room for constructing NOBS or accommodating their dry-docking needs. It can be expected that only the largest shipyards with access to sufficient space will be able to accommodate such ships without significant disruption and/or land acquisitions.

In the case of bulk cargo loading/unloading, the NOBS concept appears more suited to tankers than dry-bulk carriers, since the former can be readily designed to connect to existing pipe hose systems for liquid cargo handling. In contrast, the width of existing dry bulk carrier berth pockets and departure channels at tidally-influenced terminals plus the reach of their ship loading/unloading gear may limit safe access and/or routine loading by a NOBS dry bulk carrier.

Manoeuvrability of unladen NOBS in wind-exposed narrow channels may pose challenges with respect to the wide beam and markedly reduced forward draught, although the V-shape hull should improve directional control. Pilots, masters and deck officers will need sufficient access to bridge simulators to gain handling proficiency and experience in operating NOBS ships under a range of wind, tide and berthing scenarios. Another safety aspect may be the NOBS rolling pattern, which SRC has shown will have larger roll damping (reduced amplitude) than a conventional flat-bottom counterpart but shorter and stiffer rolling periods (higher frequency) owing to the larger metacentric height. The shorter but sharper rolling

⁶ The ‘High Seas’ are the open ocean waters beyond a nation’s jurisdiction including its exclusive economic zone (UNCLOS), and Thus, they are typically >200 m deep and do not start until 200 nM offshore.

⁷ A reception vessel cannot take any received and untreated BW back to the high seas as a ‘cargo’ for disposal, as this will probably require a formal assessment and Sea Dumping Permit under the London Convention.

on a rough voyage may pose an injury or sea sickness risk to a new crew member who is accustomed to the slower heave of flat-bottom ships.

The bridge layout and wings will require customisation to ensure adequate vision, voice communication and ship control across the longer width distances, and the height of the bridge will need to be higher than normal to overcome the more limited forward vision during the unladen voyage (the NOBS design trims bow high when empty; Figure 3-9). The need to provide higher superstructure and/or forward CCTV assistance to ensure adequate forward vision has been noted by SRC^[6].

It is possible the relatively lower freeboard during laden voyages through rough seas may allow a higher incidence of green water flow over the main deck. More breakwater and protective areas may be required to ensure deck safety is not reduced for crew access and deck work during transoceanic voyages.

Conclusions

The patented NOBS concept relies on a V-hull and increased beam to minimize but not completely remove the need for a trading ship to carry BW. SRC's work to date has focussed on large tankers, as these appear most suited to the concept with respect to berth access, cargo handling requirements, and avoiding increased fuel bills and associated GHG emissions.

The need to uplift BW to reduce bow slamming in heavy seas means the concept does represent a fully 'No Ballast/Zero Discharge' method. The presence of BW tanks for storm conditions means the NOBS will remain under the requirements of the Convention. If the BW is uplifted in a high seas area and all is returned to same once the rough weather has passed, it can be argued there is no pressing need for such oceanic discharge to meet the D-2 standard. However, if the BW is kept on board and/or uplifted in shelfal waters after the ship enters the jurisdictional waters of a Party to the Convention, then the NOBS will need to comply with the Convention's requirements for BWM. This may not be economically critical for a large NOBS tanker, as the amount of storm BW requiring BWT is relatively small and is not required to be kept on board for the port approach or berthing phases. Thus, only a relatively small on-board BWT plant would be needed to manage a steady pump-out, and this would not require completion until the end of the cargo-loading phase.

3.2.3 Internal ballast concept

Internal ballast methods are impractical for liquid or dry bulk carriers and more suited to ships that normally have cargo on board and which operate a regular liner service with predictable bunkering access. These include many feeder and transocean container ships, ro-ros and ro-ro/pax ferries, plus some cruise ships, livestock carriers, vehicle carriers, construction/accommodation barges. The internal method uses freshwater to avoid corrosion, which is shifted among a set of relatively small tanks to control trim and stability according to cargo distribution and loading/unloading patterns. Tanks need to be relatively small to avoid over-ballasting or part-filled water-slammings situations due to rolling, heaving and pitching in rough weather. A range of container ships are already using their ballast management system in this way to avoid discharging BW in port waters^[1].

A key penalty for a trading ship that operates a permanent internal ballast system is the potential for reduced cargo capacity on some voyages, although there are ways to minimize if not avoid a reduced payload voyage. For example, it has been proposed that a ship could discharge part of its freshwater into the high seas before entering jurisdictional waters and reaching port, with the remainder occupying <10–15% of total cargo capacity. The potential for reduced cargo carrying is smallest for ships that operate two-way or multi-port 'round-robin' services where cargo loading/unloading occurs at each port, including back-haul cargo.

It has also been suggested that improvements to the hull and main deck may allow some ship types to load fully and depart a port safely without discharging any BW until they reach offshore waters^[1]. This procedure requires sailing with deeper than normal draught and a smaller than normal freeboard until reaching the nearest discharge location such as a designated BWE area or nearest deep waters (>50 nM or >200 m). This 'overloaded' departure procedure would appear risky for many routes for ship safety and fuel efficiency reasons, particularly routes that experience rough inshore conditions in winter. The markedly increased sailing draught can pose steerage, UKC and deck access safety issues, while the increased drag (= higher fuel cost) may occupy a significant portion of the payload voyage, particularly for short-sea

routes. Accommodating unusually deep-draughted departing ships may also require the port or terminal to undertake expensive channel deepening and/or increased maintenance dredging.

Any ship with a permanent internal ballast system will eventually need to discharge this water for tank inspection and class survey purposes, either alongside a berth or before it enters dry-dock. As described in the WHO Guidelines for Drinking Water (2008), on-board water storage and pumping systems are readily contaminated by materials and pathogens from other sources, owing to pipework and tank ventilation complexity, vibrational wear/tear and fittings located in cramped, hard to access spaces (see Appendix A for relevant WHO 2008 excerpts).

The Convention's focus includes pathogens so the permanent BW will need to be tested to determine if it complies with the D-2 standard, since the origin/s of any potential pathogenic microbes will be unclear and Thus, not amenable to any risk assessment-based exemption under Regulation A-4 and the G7 Guidelines.

3.2.4 Potable ballast concepts

Usage and appraisal studies:

- *On-board drinking water makers* – Super-yachts, Royal Canadian Navy, Royal Australian Navy^[9-11];
- *Drinking water purchased from shore* – Livestock carriers in Asia-Pacific region^[12].

Description

As noted by URS in 2006^[11] and more recently by the United Kingdom in a 2009 submission to MEPC^[9], use of potable water in place of uplifting normal BW can provide small ships, where physical space may be limited, with an alternative to installing an approved BWT system for complying with the Convention. While the cost of producing potable water for ballasting purposes may be high on a simple tonne-for-tonne basis, producing small quantities to satisfy ballasting/trim requirements removes the costs (and loss of space) of investing and operating an additional system for treating uplifted seawater to meet the D-2 discharge standard. In fact, use of potable water for BW has already been adopted by some super-yachts and considered potentially viable for various naval ship and patrol vessel types^[9-12].

Potable water-makers for small ships generally use a modular and compact reverse osmosis (RO) system where the membranes are protected by two or three filtration stages (Figure 3-10). These compact units can generate from 2 to over 30 tonnes per day, depending on unit size and available power supply. Larger ships may use water condenser instead of RO units.



Figure 3-10: Examples of different sized RO potable water makers for small ships

The UK submission to MEPC^[9] noted that the potable water option could be useful to <3000 GT ships, and that the risk of discharging potable water would be no more than discharging freshwater uplifted from rivers for ballasting/trimming, then treated to meet the D-2 standard before discharge. As defined in Article 1.2 of the Convention, BW is “...water with its suspended matter taken on board a ship to control trim, list, draught, stability or stresses of the ship.” As noted by the UK^[9], this implies that potable

freshwater produced on board for primary purposes other than ballasting, could be construed as not having to comply with the Convention's D-2 discharge standard.

Evaluation of safety and environmental issues

Risks arising from discharging stored drinking water have not been formally quantified but the UK submission considered these would generally be negligible, including any salinity change due to the slight dilution effect in small ports or marinas^[9]. The possible effects of brine streams produced by Reverse Osmosis (RO) water makers in enclosed harbours were not noted, and the possibility of treatment chemical/s, by-products and/or pathogenic contamination of potable water during tanked storage before discharge was also not addressed. (The issues of making and storing potable water on ships are examined in some detail in the WHO (2008) *Guidelines for Drinking Water Standards*; see Appendix A.)

As a result of the UK's request for clarification on the use of potable water as an alternative BWM method^[9], the MEPC referred the question to its Ballast Water Review Group (BWRG) during MEPC 59 (July 2009)^[10]. MEPC subsequently agreed to the BWRG's recommendation that, irrespective of its source, any BW must comply with the Convention's requirements. Thus, if potable water is used for BW then this should be subject to Regulation D-2 when discharged owing to the potential presence of treatment chemicals and residuals^[10]. As such, there are options available under the G8/G9 Guidelines and Procedures^[10] to ensure an on-board production and storage system/s will allow the discharge to meet D-2.

A key issue relating to the G9 *Procedure for Active Substances* is the use of chlorine or other sterilising chemicals for achieving and maintaining drinking water quality. Residual chlorine or other by-products could therefore be discharged when the potable ballast is pumped out. Tables of the various disinfectants, by-products and other contaminants that can occur in drinking water supplies, as a result of the disinfecting steps and the materials used in the water distribution and storage circuits, are shown in Appendix A.

It was agreed at MEPC 59 that the approval procedures provided by the current G8/G9 Guidelines and/or the future "*Procedure for assessing other methods of ballast water management*" (presently under development by the BLG Sub-Committee) would be appropriate for assessing proposals that use potable water. However, the Committee could not agree on the way such proposals should be handled. Some delegations also raised the case where a ship takes on drinking water from a shoreline source for use as BW (a practice already used by some livestock carriers^[12]). Both matters are being addressed by the BLG sub-committee, and MEPC intends revisiting the issue after the "*Procedure for assessing other methods of ballast water management*" has been adopted.

3.3 CONTINUOUS FLOW METHODS

3.3.1 Buoyancy control concepts

3.3.1.1 Longitudinal trunks

Project:

- '*Ballast-free ship*' (US patent 6 694 908 B2; 24 Feb 2004^[13a]) and '*Variable Buoyancy Ship*'^[13b] – MG Parsons, University of Michigan (Ann Arbor).

Description

When a ship moves forward it produces regions of increased water pressure near its bow and reduced water pressure at its stern. The longitudinal trunk method uses this pressure differential to drive water through a set of these below-waterline corridors without the need for pumps^[13a,b]. The trunks, which occupy the double bottom (DB) space in place of the usual watertight DB ballast tanks of a conventional ship, are fed by a plenum near the bow and run almost to the stern of the ship (Figure 3-11). By opening the lower part of the hull to the sea rather than uplifting water into watertight tanks when not carrying cargo, the draught required for maintaining the ship's stability is achieved by reducing its buoyancy instead of increasing its displacement weight^[13a,14]. By externalising the seawater, which sweeps through the trunks as the ship moves forward, the ship is more 'immersed' in local waters instead of carrying tanks of it from one region to another.

The longitudinal trunk concept was conceived in 2001, patented in 2004^[13a] for new-vessel constructions (Figure 3-12) and emulates an ideal BWE procedure (continuous flow tank flushing). All water discharged after the trunks have been closed for cargo loading therefore comprises local waters rather than waters that have been tanked across large distances. The original ‘ballast-free’ label refers to the ship being free of ‘foreign’ BW^[15]. A key design goal is for all water entering the trunks to be flushed out as much as possible within 1–2 hours at normal unladen voyage speeds, plus minimal retention of sediment. Thus, organisms entrained into the trunks (including microbes attached to suspended particles as well as free-floating biota) should therefore be carried only a limited distance (~25 nM) before exiting the ship.

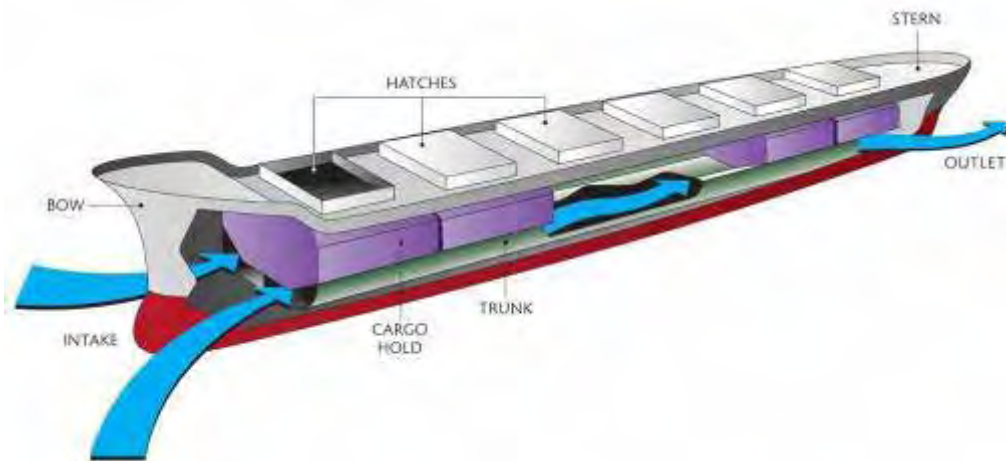


Figure 3-11: General schematic of the longitudinal trunk concept

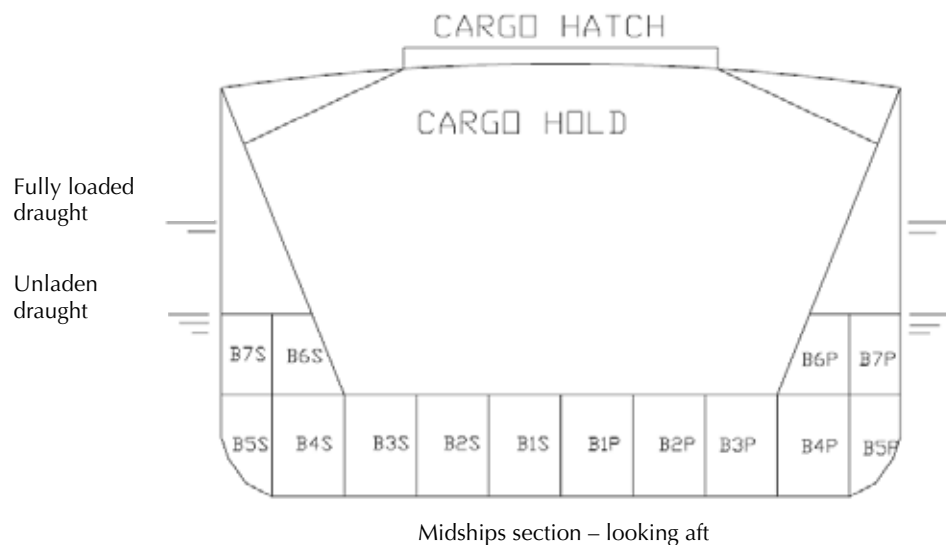


Figure 3-12: Cross-section initially conceived for a ‘ballast-free’ Seaway-size bulk carrier, (from the 2004 patent application^[13a])

Valves at the bow and near the stern control the ingress and exit of the water (Figures 3-13, 3-14). Opening the valves to flood the trunks during cargo unloading reduces the hull’s buoyancy to achieve a suitably deep draught in the light condition, thereby retaining stability and avoiding bow slamming and propeller emersion in heavy seas. The valves are kept open throughout the unladen voyage to ensure a continuous flow of seawater along and out the trunks, as ‘driven’ by the ship’s forward motion.



Figure 3-13: Locations of the bow inlet (left) and alternative outlet locations near the stern (right) studied by the University of Michigan project in 2007–08

At the end of an unladen voyage, the inlet and outlet valves are closed to isolate the trunks so the water can be pumped out. To minimise sediment ingress, trunk closure should occur before the ship enters shallow waters in the port approaches⁸. During cargo loading in ports, a conventional ballast pump system is used to pump out the water, thereby to restore the buoyancy required to support a full payload.

Following the initial 2002–2005 work and patent application, experimental and numerical hydrodynamic investigations during 2006–2008 were focussed on hull resistance and propulsion efficiency of a St. Lawrence Seaway-size bulk carrier (18,100 tonne total ballast capacity, including one heavy weather cargo hold), as sponsored by the Great Lakes Maritime Research Institute. In these studies, the pressure of the water flowing into the trunk was maximized by locating a single inlet at the centre of the bow bulb (Figure 3-13). To help resolve the effect of the exiting flow on wake resistance and propulsion efficiency, upper and lower locations for the pair of aft outlets were investigated (Figure 3-13).

The scale model experiments were conducted in the towing tank at the University of Michigan's Marine Hydrodynamic Laboratory using a 5 m long precision model built in 2006, based on Polstream's six-hold Seaway carrier *Isa* and a more modern design^[13b,15]. The associated numerical studies used several commercial fluid dynamics packages^[14]. Domain of the modelled internal flow comprised half the ship, i.e. three parallel trunks occupying the double bottom beneath the cargo holds, and connected via plenums with sluice gates near the bow entry and stern exit points (Figures 3-13, 3-14). This domain was used to calculate the times required to replace 95%, 99% and 99.9% of the water initially occupying the trunks.

⁸ Compared to transoceanic 'blue-water' routes, the trunk concept is far less suited to coastal or short-sea routes due to the frequent high levels of suspended fine sediment and organic particle ingress.

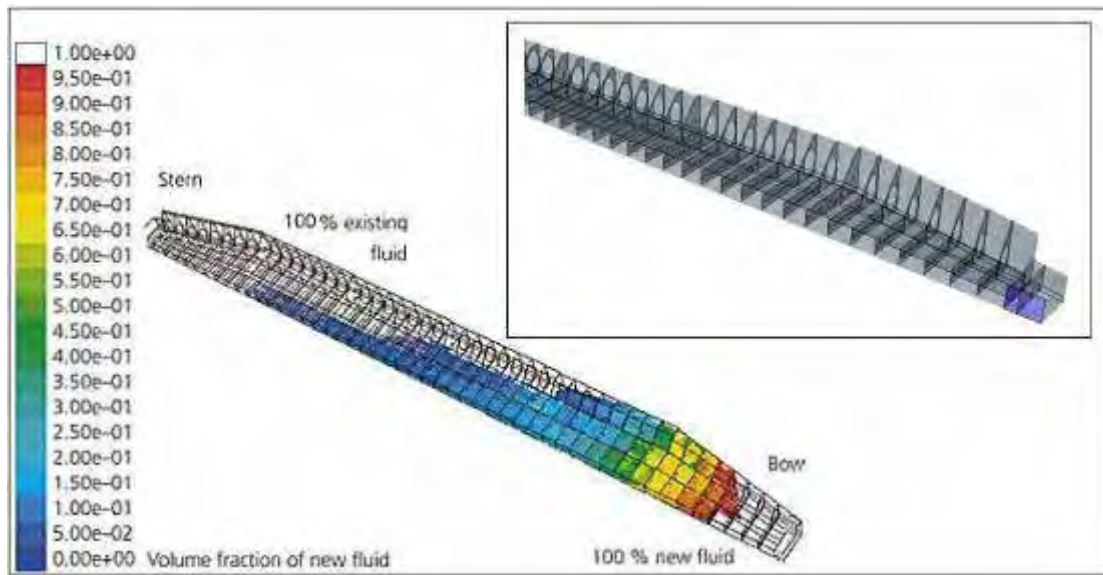


Figure 3-14: Output from the numerical analyses, showing replacement of the water occupying the three portside trunks, some 8.3 minutes after opening valves at 15.5 knots. Part of the modelled domain, from bow plenum to midships, is shown in the inset (composite from figures shown in ^[14] and ^[16])

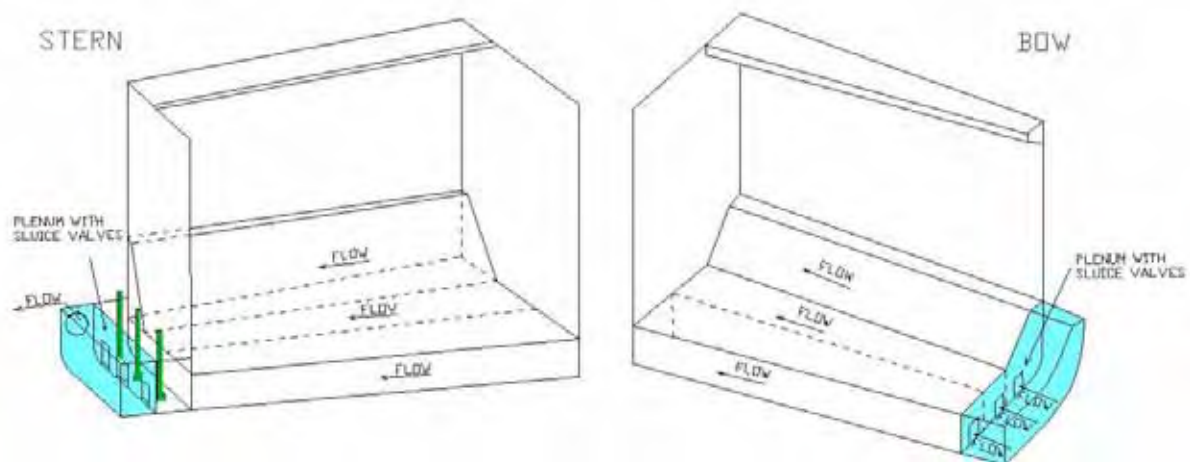


Figure 3-15: Arrangement of the bow (right) and stern (left) plenums that distribute flow into the three DB trunks on portside of 'ballast-free' Seaway-size carrier (adapted from figures in ^[16])

To locate enough trunk volume below the unladen waterline requires a higher tank top and, in the case of grain carriers, a greater hull depth (moulded height) than their conventional counterpart in order to keep the same capacity for carrying a full light cargo. The unladen draught is slightly deeper, in part because of the higher tank top. Figure 3-16 compares key features of a 'ballast-free' Seaway carrier with its conventional counterpart.

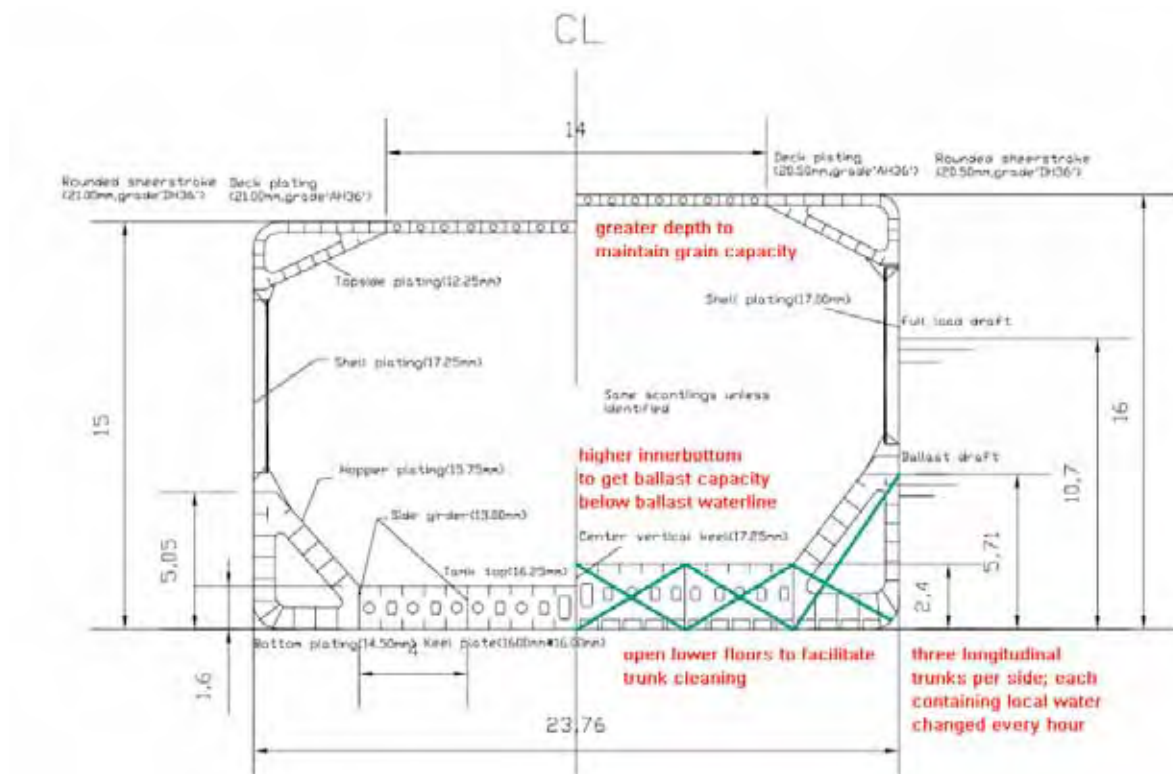


Figure 3-16: Midship cross-sections of a Seaway-size grain carrier (left) and its 'ballast-free' counterpart (right), with higher tank top to provide sufficient trunk volume and greater moulded hull depth to retain same light cargo capacity (from ^[17]).

The taller double bottom is claimed to facilitate trunk cleaning, for minimizing accumulation of sediments that can retain unwanted biota^[14,15,16]. The arrangement in Figure 3-16 also shows the cutaways (to the level of the bottom shell) that can be added to many of the transverse frames to help reduce sediment accumulation and facilitate trunk cleaning^[14,15,17].

Results published to date indicate that increased hull resistance from operating the trunks in a Seaway carrier design is mainly due to the flow discharge at the stern, with a more modest contribution from the inlet at the bulbous bow. Using the lower pair of stern outlets (Figure 3-13) at an assumed unladen speed of 15.5 knots produced a 4.61% increase in hull resistance in the towed model. A much lower increase (2.7%) occurred at the same speed when the higher pair of stern outlets was used, and it was concluded that further design of the outlet arrangement may overcome this remaining negative effect^[15].

It was also found that the upper exit stream option made a positive effect to the modelled carrier's unladen propulsion efficiency, which was increased by 6.34% compared to situations of no trunk flow. The improved propulsion efficiency was related to an improvement in water flow around the stern and consequential change to the propeller operating point, with the flow exiting the higher pair of outlets entering the boundary layer and Thus, increasing flow to the upper part of the propeller disc and reducing wake friction^[14]. The improvement was more than sufficient to offset the 4.61% rise in hull resistance as measured without the propeller, offering a net measured saving in propulsion power of 1.63%^[14]. The 2008 study also concluded that the trunk flow concept may be financially attractive not just to operators of Seaway-size grain carriers but also those of other new-build ships of different types and sizes^[14].

Efficacy in preventing the long distance transfer of marine species

If all water in the longitudinal trunks is fully exchanged every 1–2 hours then, theoretically, no marine species will be transferred more than ~25 nM. The actual distance will vary according to the unladen hull speed versus the average internal flow rate and path length. Theoretical transfer distances of ~25nM in open coastal waters, enclosed seas or oceans would not represent a significant breach between regional marine ecosystems or other biogeographical boundaries.

In the case of canals and internal waterways where locks are present, however, these can provide an abrupt biogeographical boundary, leading to the problem of how to achieve a complete exchange if the propagules, larvae or adults of unwanted harmful species occur on one side of the boundary but not the other. In the case of a seaway carrier voyaging to the freshwater Great Lakes to load grain or other bulk cargo, closing the trunks before it leaves the oceanic realm would resolve the issue⁹, unless the ship intends to trade between ports within the Lakes and/or upper (low salinity) Seaway before returning to the North Atlantic¹⁰.

A more significant issue is the problem of ensuring that the various biota and suspended particulate matter that enter the trunks during unladen voyages do not become trapped and accumulate inside them – particularly where the transverse frames and cargo hold bulkheads interrupt smooth longitudinal flow. Because the water has to pass through a series of man-holes and proposed cut-outs on these frames (Figure 3-16), the design challenge is to remove all zones where sternward flow may be reduced to zero (dead spaces) or even reversed by turbulence-induced eddies. As with BWE in conventional tanks, such areas provide nooks and niches where suspended particles and biota, including passively drifting and actively swimming organisms, will not be swept toward the aft outlets. Thus, unless the flow paths can be designed to eliminate all dead corners, many organisms may settle, accumulate and survive in the trunks until these are pumped out, at which time the altered flow regimes may be expected to sweep at least some of the trapped material and biota to the eductors. In this context, end-of-voyage biota survival rates in the trunks are likely to be higher than in ballast tanks, where declines in dissolved oxygen levels during a voyage cause significant mortalities.

It is also possible for fouling species to settle on the trunk surfaces, particularly during passages that transit shelf-sea waters near coastlines where a range of sessile suspension-feeders could settle and commence growing around valve edges and other sheltered niches within the trunks¹¹. Much of this biota would not survive the subsequent laden voyage as a result of their aerial exposure, unless the passage was quick and/or where water pools (unpumpable ballast) remained on parts of the trunk floors. If the ship waits at anchorage or is laid up before its next loaded voyage, the closed but filled trunks may allow a fouling assemblage to survive, with eventual mortality rates depending on the rate of dissolved oxygen decline.

The biota entrapment and potential fouling issues can be reduced if the trunks are always closed before the carrier enters shallow coastal waters, as these are the regions where the diversity and density of fouling species is greatest. Protecting all permanently wetted surfaces of the trunk system floor with an anti-fouling coating would inhibit settlement and growth of fouling species, although the application and upkeep of these coats will represent an additional cost as they are more expensive than the corrosion control coatings applied to ballast tanks.

Evaluation of costs, safety, health and environment

As noted by Parsons, further work is required to determine if and how much power saving can be achieved by a ship fitted with longitudinal trunks, as the 1.6–1.7% reduction values reported to date remain a model-based estimate^[13b,14]. Work is also required to resolve trunk segregation requirements for trimming needs and damage survivability^[13b]. This includes the location and operation of additional valves in the transverse bulkheads that separate the cargo holds, plus the use of butterfly valves in place of the initially-conceived sluice gates^[13b,17].

Reliable operation of all of the valves, including their ability to isolate perforated trunks following a collision or other damage, will be critical to ship safety whenever it is fully or part loaded. Regular valve inspection and servicing can therefore be expected to be an important maintenance feature of the operations budget.

Since the bulbous bow of unladen carriers can regularly project out of the water in rough seas, air entering the intake in bad weather will need to be vented from the trunk system to avoid uneven buoyancy/

⁹ Organisms entrained in the trunks at this point of closure will be those adapted to a pelagic oceanic realm, and thus, highly unlikely to survive or reproduce in a landlocked freshwater ecosystem.

¹⁰ For a Seaway carrier intending to trade within the Lakes and holding seawater in its longitudinal trunks, this risk would be removed if the sequence of its cargo loading/unloading cycles avoids the need to release low salinity trunk water into a different lake, following its first loading/unloading cycle.

¹¹ Most likely species would be the fauna that commonly colonize sea chests, seawater pipework, valves and sea strainers, including sessile hydroids, barnacles, mussels, oysters, bryozoans and ascidians.

displacement distributions. If adequate venting can be designed to occur in the forward plenum (Fig 3-15), the need for multiple vents along each trunk will be minimized.

Use of longitudinal trunks poses no direct threat to crew health. Application of the volatile and generally toxic antifouling coats to the surfaces of the confined trunk spaces will require an adequate air supply and protective clothing for dockyard painters, but this would not represent significantly different occupational health and safety procedures compared to those taken for coating the internal surfaces of conventional ballast tanks.

3.3.1.2 Buoyancy control compartments

Project:

- ‘Ship buoyancy control system’ Arai, Suzuki & Kora, Yokohama National University (Patent applications JP2007/073761, EP 07850335.6 ^[18]).

Description

The Yokohama concept converts conventional ballast tanks into a series of buoyancy control compartments. Each compartment is flooded to provide adequate draught in the unladen condition then continuously flushed at normal voyage speeds to ensure efficient exchange without the need for pumps. The concept is similar to the longitudinal trunk approach except it can be retrofitted to existing conventionally-ballasted ships, as well as installed for new builds.

In their patent application document^[18], the researchers point to the potential constraints of trunking designs that rely on the high pressure area at the bow for achieving adequate internal flow and compartment flushing. These include the size of a bow-positioned intake (large aperture(s) can affect seawater flow around the bow), resistance to water flow along the trunklines, and the ‘bow-up’ trim that is typical of unladen ships owing to the aft location of their machinery, fuel and superstructure¹².

The Yokohama concept seeks to avoid these problems by converting ballast tanks into multiple independent buoyancy compartments to achieve the required unladen draught and trim. Each compartment is fitted with intake and outlet valves that are optimally designed and positioned for each compartment so as to maximize its flushing rate during normal voyage speeds. The concept remains theoretical, with the patents based on numerical modelling of water flow and exchange for a series of inlet and outlet valve configurations for unspecified tanks, plus in-tank weirs to further improve tank flushing (Figure 3-17). No empirical investigations or specific testing, such as changes to hull resistance as a result of the multiple inlets and outlets, or the design and additional weight of fitting a weir inside each compartment have been reported.

As shown in Figure 3-17, seawater enters each compartment via a forward intake then exits via one or two valves positioned at the compartment’s aft end, while an air vent on the ceiling of each compartment ensures they can remain fully flooded.

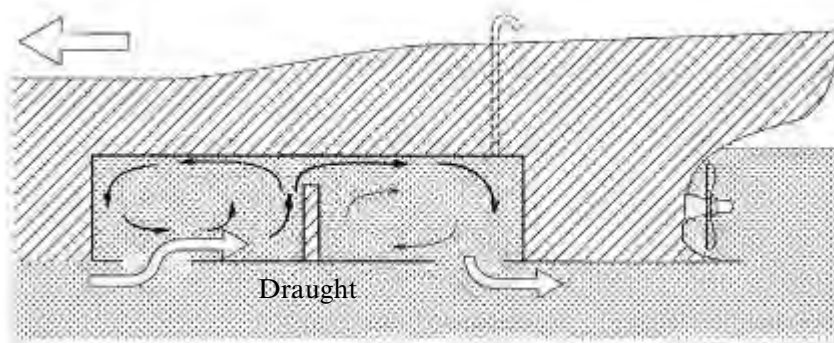


Figure 3-17: Concept diagram of the Yokohama system, showing how a flooded buoyancy compartment is flushed as the unladen ship moves forward (modified from ^[18])

¹² A shallow forward draught during unladen voyages lowers hull resistance and promotes fuel savings but can inhibit a consistent ‘drive’ of seawater into intakes on or near the bulb bow in rough weather.

Positioning the water intake near the centreline and outlets near the turn of the hull (Figure 3-18) maximizes the available water pressure differential to drive the flushing process as the ship moves forward. An internal weir is positioned within each compartment to reduce the tendency for plug flow ('short-cuts') and dead spaces (Figures 3-17, 3-18).

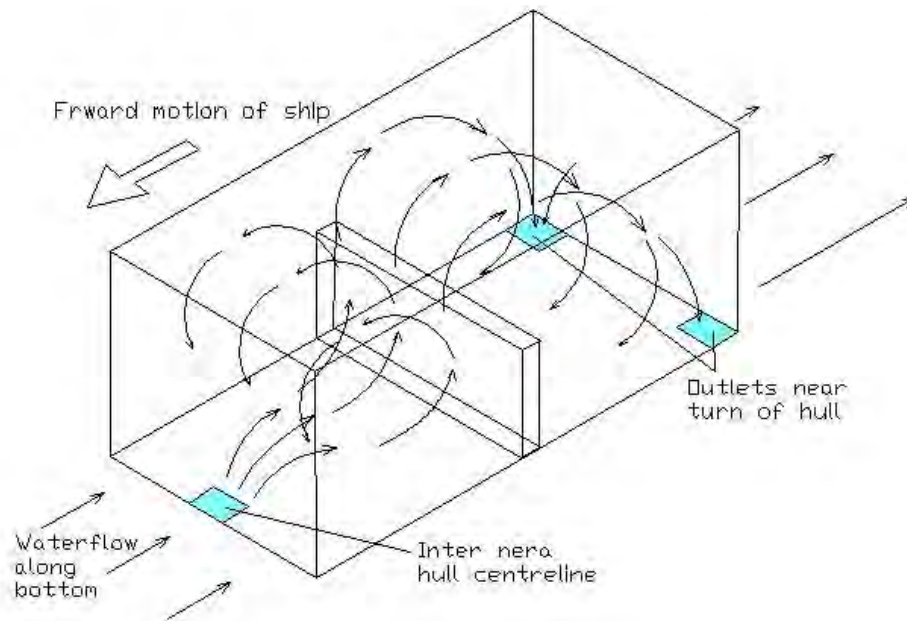


Figure 3-18: Locations of the inlet and exit valves in a buoyancy control compartment, fitted with a central weir to minimize plug flow and dead space areas (from ^[18])

Seawater inflow and exit from each compartment occurs due to the pattern of different under-hull water pressures that are produced by the moving ship. The patent notes the value of selecting the best inlet and exit port shapes, as well as their position for each compartment, so as to maximize its flushing rate without incurring excessive drag (Figure 3-19). The best arrangement of inlet and outlet geometry is determined by tank shape and location that, in turn, depend on the design of the system.

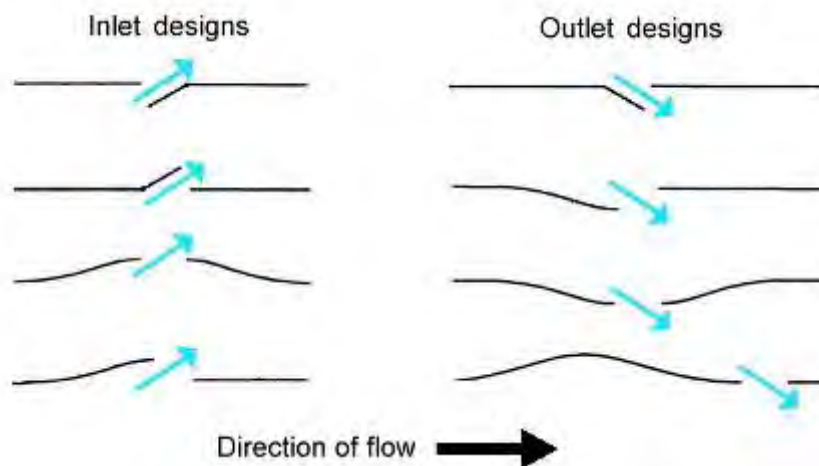


Figure 3-19: Range of inlet and exit valve design options shown in the patent application^[18]

Compartment flushing has the capacity to be more effective than that achieved by a longitudinal trunk system because of the much shorter entry-to-exit pathway in each compartment. If rapid seawater flushing can be achieved, none of the entrained water and biota should remain within a compartment for more than a few hours. Before cargo loading, and ideally before the unladen ship enters turbid coastal waters near its cargo-loading destination, all intake and exit ports are closed. Buoyancy required to carry a full payload is regained by pumping out the compartments using a conventional deballasting system.

A recent paper by the Yokohama authors^[19] indicates that the structure of the DB tanks of an existing ship can remain unaltered to form the lower buoyancy control compartments, while the bilge hopper and side tanks of a conventional cargo ship will need to be connected to form a set of buoyancy compartments on each side of the hull (Figure 3-20).

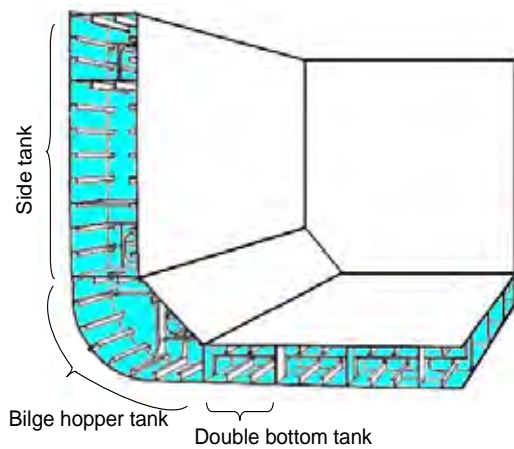


Figure 3-20: Layout of ballast tanks that are converted to buoyancy compartments

As noted earlier, the inlet and exit valve locations and geometry will be critical for ensuring adequate flow within each bottom and side compartment. Inlets to the bottom compartments need to be installed close to the ship's centreline where the static pressure is highest, while the exits are positioned on or near the turn of the hull where pressures are low (Figures 3-21, 3-22). In addition, the time required for 99.99% BW exchange at different speeds should be further investigated.

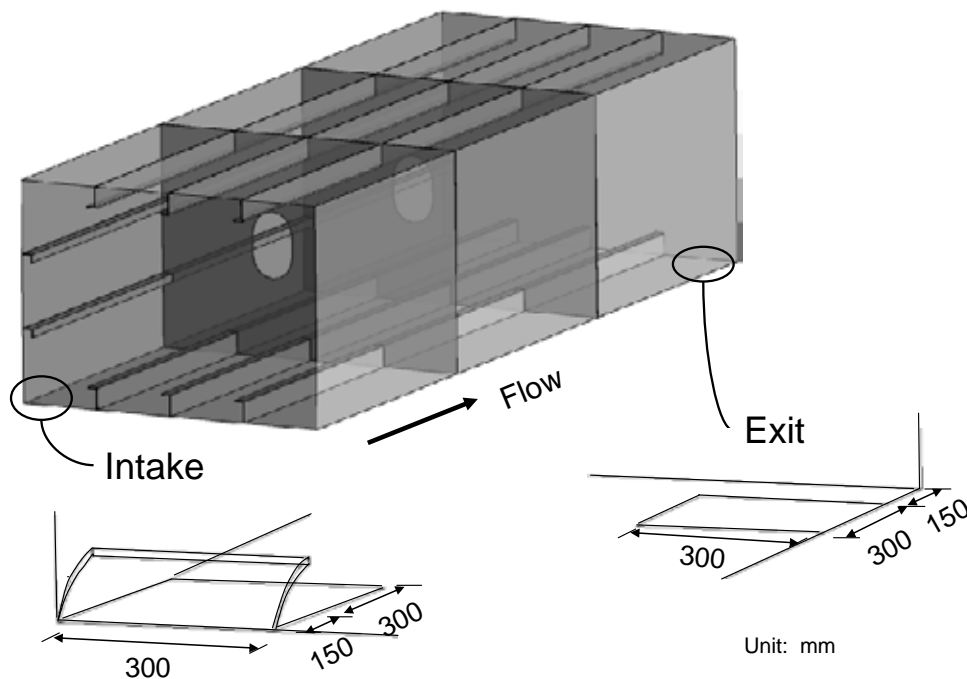


Figure 3-21: Model of the converted DB tank used in the simulation study^[19]

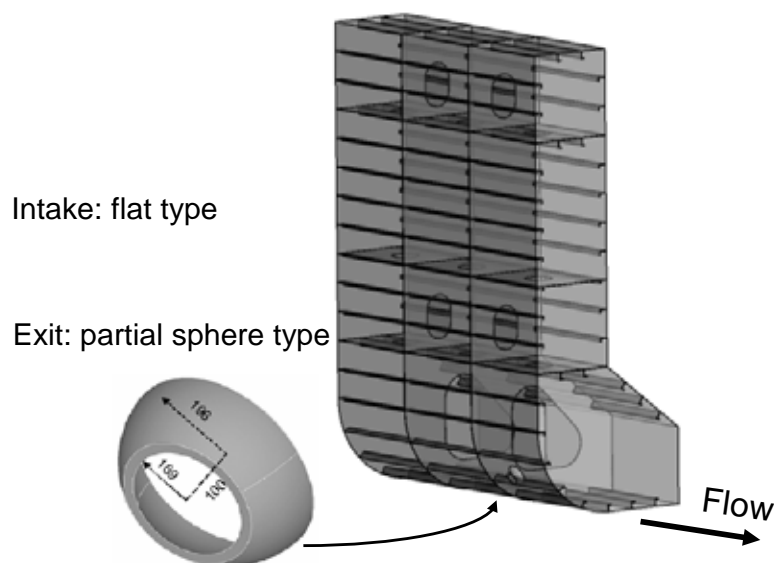


Figure 3-22: The converted bilge hopper and side tanks of the Yokohama simulation study^[19]

The simulations of water flow and exchange efficiency within the DB and lateral compartments were performed using routine computer fluid dynamic modelling. Experimental simulations indicated that a 99% exchange of a compartment's water volume could be achieved in just over 3 hours at a speed of 23.3 knots, which equates to a distance of 77 nM^[19]. However, such results may underestimate the actual time required to achieve a >99% exchange, owing to the array of framing inside conventional ballast tanks (transverse members, longitudinals, partitions, bulkheads, etc). Some redesign of the internal structures will therefore no doubt be needed for maximising the exchange rate and efficiency.

The results were used to evaluate the theoretical flushing efficiency of the compartment with respect to the first component of the D-2 performance standard, using the concentration of >50 µm (minimum dimension) plankton in Tokyo Bay as the baseline and a simple dilution ratio to determine the time required to achieve this part of the D-2 standard (i.e. <10 organisms that >50 µm (minimum dimension) per cubic metre).

The ratio was the volume of 'new' water flowing into the compartment versus the compartment's total volume, while the number of dilutions of the Tokyo Bay water required to reach the first part of the D-2 standard was 99.99%. As shown in Figure 3-23, this exercise found that a dilution to 99.99% could theoretically be reached by the time the ship had travelled 154 nM at a speed of 23.3 knots¹³ (6.6 hours). No attempt was made to estimate the number of dilutions required to reduce the concentrations of the smaller plankton (10-50 µm) or microbial pathogens in Tokyo Bay to reach the D-2 standard^[19].

¹³ By the end of the 154 nM, it is highly likely the compartment will still contain a concentration of **other** >50 µm plankton that is higher than the D-2 standard, owing to the presence of such plankton outside the Bay and its consequent entrainment into the compartment during the first 154 nM. Once the ship reaches the deep oceanic realm beyond the continental shelf, then the entrained concentration of >50 µm plankton is far more likely to remain below 10 per cubic metre.

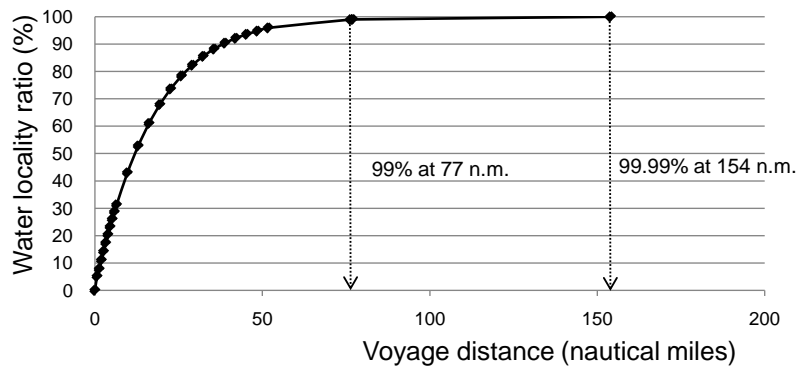


Figure 3-23: Output of the simulation showing distance travelled versus local seawater ratio

Potential safety, health and environment issues

A prime concern of the Yokohama buoyancy control concept will be ship safety, particularly in the loaded or part-loaded condition and damage survivability. Maintaining adequate buoyancy and trim will require the faultless operation of a large number of inlet and exit valves that must be installed below the waterline, including the bottom centreline region (on or near the garboard strakes) and along the turn of the hull. Considerable strengthening may be required around the apertures as these areas can experience considerable stress and potential fatigue as a result of the hull bending moments due to cargo load and sea conditions. The secure design and installation of these ports and their associated valves and control systems will pose design and cost challenges but are essential for ensuring compliance with international safety regulations and class requirements.

Maintenance and repairs to the various apertures and valves may also pose cost issues owing to dry-docking requirements. Use of a coffer box enabling external access to individual apertures below an undocked ship may provide a cheaper alternative unless multiple ports at different locations require attention. Reliable installation and operation of the inlet and exit apertures will therefore be crucial not only for ship safety but also for operating costs.

Experimental work for the Yokohama concept has not yet addressed the combined effect of the various apertures on the flow regimes that influence hull resistance and propulsion efficiency. As indicated by the University of Michigan studies (Section 3.3.1.1), the position of the exit ports and direction of the exit flows near the stern can cause significant changes to the propeller operating point and wake resistance.

Operating a series of mechanical ports and valves should not pose any direct hazard to crew health or the environment. In terms of preventing the transfer of harmful marine species, however, the Yokohama concept faces the same challenges faced by the longitudinal trunk method. Thus, the number of dead spaces, eddy zones and other niches that will promote the entrapment and accumulation of suspended particulates and biota within each compartment will need to be minimized, as well as the presence of water pools when in the loaded condition (unpumpable ballast).

3.3.2 Enhanced ballast water exchange concepts

Projects:

- *Automatic Ballast Flow (AUBAFLOW)* – Vela International Marine Ltd (patented October 2004/0039660 A2^[20a, 20b]);
- *Loop Ballast Exchange (LoBE)* – Vela International Marine Ltd (patented 2007^[23a,b]);
- *DynaBallast* – Dagin Marine technology Group/eL-Tec Elektrotechnologie^[26,27].

3.3.2.1 AUBAFLOW

The AUBAFLOW method was conceived by Vela International Marine Ltd (Vela) with the aim of improving BWE efficiency for very large crude carriers (VLCCs), with design and numerical modelling assistance from Marin^[20b]. AUBAFLOW uses bow pressure generated from the speed of a VLCC in its

ballasted condition to provide continuous tank flushing, which enhances BWE without using the ship's ballast pumps. Concept development used Vela's VLCC *Capricorn Star*, both for initial field tests that pumped BW to overboard outlets positioned on the main deck and sheer strake, and for modelling the continuous flushing of its L-shape DB and side tanks during unladen voyages (Figure 3-24). Numerical simulations of the flow pressures around the hull at 14 knots showed that pressure at the front of the bulbous bow is sufficient to force seawater through each DB tank, then high enough in the overlying side tank (wing tank) to reach exit points located just above the ballasted waterline on the outer shell.

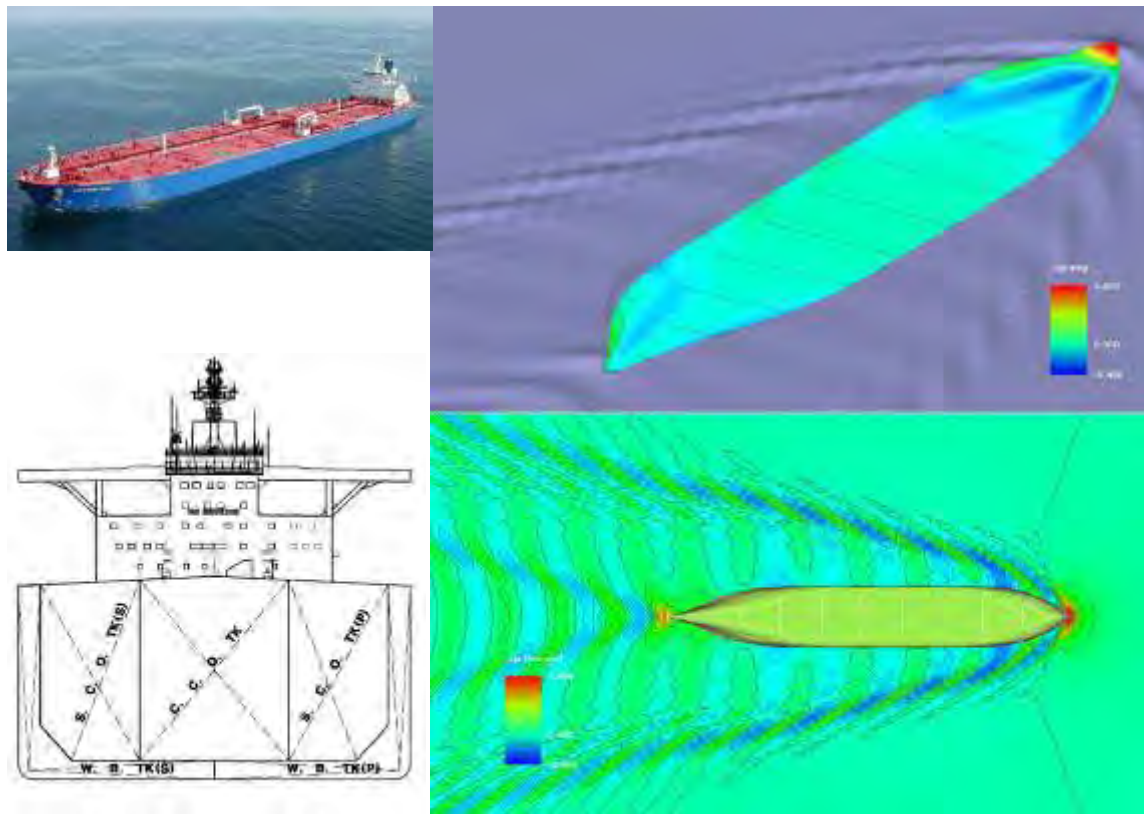


Figure 3-24: Vela's *Capricorn Star* and outputs from hull pressure modelling by Marin (from ^[20b])

To distribute this flow to flush each L-shape tank in turn, the AUBAFLOW concept requires the installation of a bow inlet and central trunkline that runs aft before splitting to connect with all port and starboard DB tanks (Figure 3-25). After the start of cargo unloading, both the bow and normal sea chest apertures are opened, allowing the hydrostatic pressure of the external water column to fill the DB tanks. The inflow of the local port water continues until the water level reaches a height in each wing that is roughly equal to the ship's unladen draught.

Prior to departure, the bow inlet(s) are closed and the main ballast pumps may be temporarily used to fill the side tanks further for final trimming, so as to achieve the required propeller immersion, forward vision, steerage or air draught during the VLCC's slow speed departure from the delivery terminal.

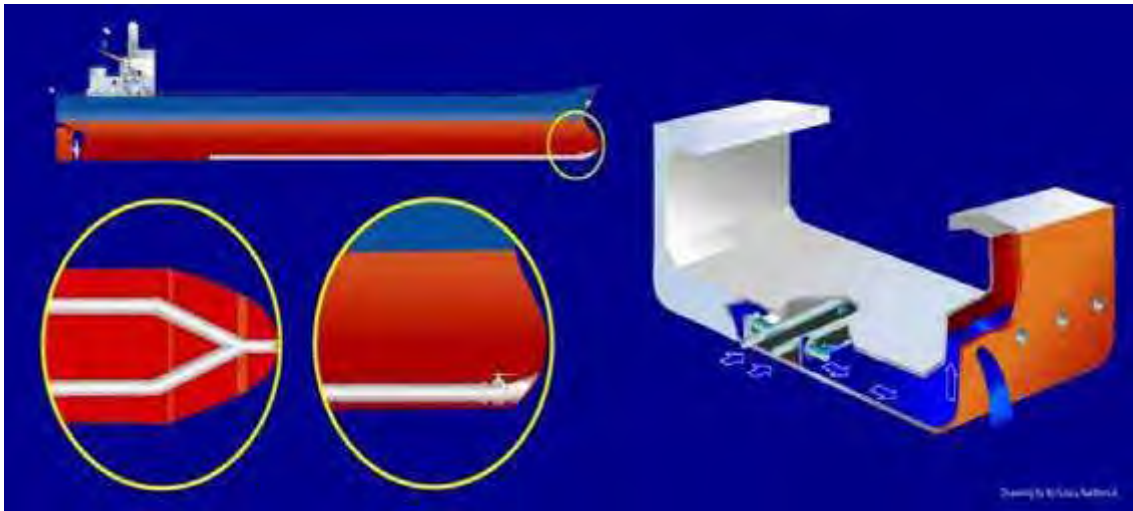


Figure 3-25: AUBAFLOW concept diagram, showing the central trunk running aft from a bow bulb aperture inside the double bottom (left), and the overflow outlets of the side tanks piercing the outer shell near the ballasted waterline (right).

After the ship reaches its normal ballasted speed in open waters, the bow aperture(s) can be re-opened to allow the system to perform BWE by continuous tank flushing without using the ship's pumps, with the pressure produced by the VLCC's forward motion driving the water into a DB tank then up the overlying side tank to the level of the overboard exits. While initial tests with *Capricorn Star* used its BW pumps to lift water to outlets on the sheer strake and main deck, Marin's numerical simulations have indicated that if these outlets are installed on the outer shell near the ballasted waterline, each tank could be exchanged to the D-1 standard (three times flushing of its tank volume) in ~12 hours at a VLCC's sailing speed of 14–16 knots.

Ship speed has to remain sufficiently high to generate enough bow pressure for overcoming flow resistance along the central distribution trunk, through a DB tank then up its wing tank and finally overboard via side exits just above the unladen waterline (Figures 3-25, 3-26). Unlike the buoyancy control concepts that have below-waterline exits (Section 3.3.1), the sequential overflowing of each L-shape tank does not alter the VLCC's displacement.

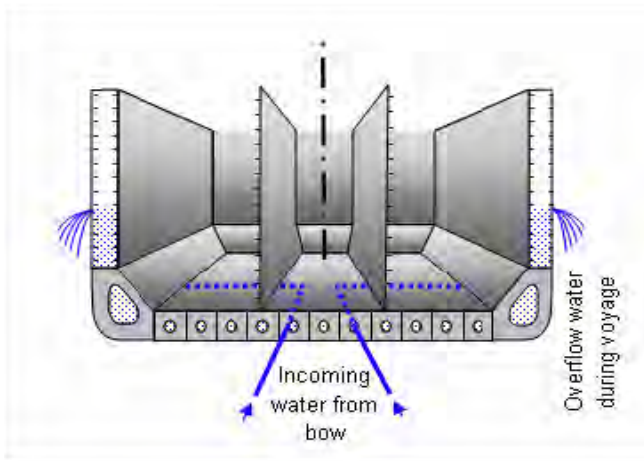


Figure 3-26: Cross-sectional view of the AUBAFLOW concept

Before the VLCC enters coastal waters near the loading terminal, the bow and side apertures are closed and its normal ballasting system is used to discharge the BW in concert with oil loading. Installation of the bow intake(s), the central trunk distribution system and the outlet valves to an existing or new VLCC has been estimated to cost in the order of USD 500,000^[20]. A formal study of the possible changes to hull

resistance when the AUBAFLOW system is operating has not been conducted but Marin considers there should be no significant increase^[20b].

Marin used the FREDYN package to model the flow inside the ship, including a defined geometry of the compartments, openings, pipes and bends, plus a non-linear time domain simulation of the flushing process that included ship motions^[20b]. The results indicate that AUBAFLOW improves an existing VLCC's ability to meet the BWE D-1 standard by the x3 tank volume flushing method, and it should readily exceed D-1 if flushing is continued long enough in deep oceanic waters. It is possible that complete tank exchanges may require longer times than implied by the modelling, owing to the numerous partitions, frames, girders and stringers that can impede the full mixing of incoming water with existing water. (Even a relatively fast water flow tends to take the shortest, least-resistant path from its entry to the nearest outlet.) On the other hand, there should still be ample time during a long transoceanic voyage for all tanks to be flushed to a level of dilution that is well above the 95% target of D-1.

While the studies to date suggest an ideal AUBAFLOW system can flush all VLCC ballast spaces to meet D-1 in a relatively short period, its ability to achieve a 99.99% BWE for all tanks during a blue-water passage (i.e. sufficient flushing for the concentration of any remaining coastal organisms to approach or exceed the D-2 performance standard) has not been examined. Approaching this standard would require the flushing process to remove the coastal particulate matter entrained with the BW that was uplifted during cargo discharge (Section 3.3.2.2).

Thus, the biggest potential drawback of the AUBAFLOW system is the problem of how to ensure all suspended particulates and biota that enter the tanks via the sea chests and bow aperture(s) during cargo unloading are removed by the flushing procedure. Some of this material is likely to settle and accumulate in any area where the in-tank flushing flows are relatively slow or variable. The rate of accumulation for any particular VLCC will vary according to the number and size of the 'dead-space' zones in each tank, and the amount and types of planktonic organisms and suspended particulate matter that are present at its most regularly-visited cargo unloading terminals.

Potential safety, health and environment issues

The AUBAFLOW system is a mechanical method that, in terms of crew health, enables a safer BWE than the present 'pump-through' method that cause BW streams, sprays and even fountains to exit from multiple small vents on the main deck. The hazards of tank over-pressurisation and icing on the main deck in winter are also removed by the use of side outlets. AUBAFLOW should not alter the hull strength or ballast tank integrity of existing VLCCs, but the arrangement of the bow aperture(s) and the installation and reliability of the outlet valves will merit close attention. In the case of the side valves, most – if not all – will lie several metres below the loaded waterline during every laden voyage. During the unladen (ballasted) passages, the bow aperture(s) may need to be closed during heavy seas if pitching is significant to cause sufficient bow emergence and consequent intake of air. Air entrained in the system would interrupt the flow and may accumulate in particular tanks to provide an uneven weight distribution that may adversely alter trim, stability and/or hull strain moments. Since the discharge openings are located halfway up the wing tanks, the space above the openings cannot be utilized for ballasting purposes under normal ship operations. This space may be used for BW in severe weather but the effect of this on overall exchange efficiency may need to be investigated to ensure that it continues to meet prevailing Convention requirements.

3.3.2.2 Loop ballast exchange system (LoBE)

Description

LoBE builds on Vela's AUBAFLOW principles of using VLCC speed and long transoceanic voyages to provide a more cost efficient and biologically effective BWE flushing process without using the VLCC's ballasting pumps^[20b,23a-c]. LoBE replaces the use of bow aperture(s) and central trunks with intake valves on the side wall of each L-tank to provide a more direct inflow.

The LoBE concept also provides additional pipework to the floor of each DB tank to minimize dead zone areas and increase flushing of particulates for improved BWE efficiency. Suction of the old water and associated loose particulate material from the tank floor zones is achieved by using the flow of incoming seawater to drive an ejector. The LoBE concept stemmed from the realisation that a side valve allows seawater to enter at sufficient velocity and pressure to drive such an ejector. A tank flushing layout was

then designed and evaluated on the premise that side valves can be positioned along the hull without significantly reducing a VLCC's speed by increasing hull resistance or reducing propulsion efficiency. The arrangement of pipework placed in each DB tank allows seawater to flow into the upper level and, via use of the suction ejector, back out of the tank from its lowest levels (Figure 3-27).



Figure 3-27: Conceptual layout of LoBE pipework in a VLCC ballast tank (from ^[23c])

Efficiency and efficacy in preventing transfer of marine species

Removal of 'old' seawater from the floor region of each DB tank is facilitated by an ejector that is primed and operated by the force of the incoming flow. The ejector helps draw the old water, together with loose particulates, from the tank bottom region, which is then directed to an angled outlet on the side of the ship. The greater the ship's forward speed, the greater the volumetric flow of water through the conduits and efficiency of the ejectors^[23]. Thus, LoBE further enhances the dilution efficiency of AUBAFLOW by providing a shorter flow path and use of a suction action that can be tailored to the near-floor region of each tank.

It has been claimed that a VLCC fitted with LoBE and moving at 14 knots could exchange its entire BW content by three tank volumes per tank in 36 hours^[23]. The distance travelled at this speed would be just over 500 nautical miles. On voyages along continental margins or across enclosed seas, this is long enough for biota to be carried across biogeographic boundaries but it has little biogeographical significance for a VLCC when traversing an oceanic realm^[21, 22].

Many long blue-water routes traverse areas of clear surface waters where the concentrations of planktonic biota can approach if not exceed the D-2 performance criteria (Section 1.1), particularly with respect to the densities of harmful species and pathogens^[28,29,30]. In this context, it has been considered that systems which enhance BWE, such as LoBE or AUBAFLOW, may merit acceptance as an alternative BWM method for VLCCs owing to their trading characteristics that involve regular transoceanic voyages^[20].

Compared to pumping three times the volume of each tank (totalling some 240,000–300,000 tonnes of seawater per unladen VLCC voyage to meet the BWE D-1 process standard), such continuous blue-water flushing (CBWF) methods offer cost and environmental advantages in terms of fuel savings and associated GHG reductions. If CBWF could be made to reach a level of risk reduction deemed equivalent to that achieved by D-2, it would also permit VLCCs to avoid the equipment, extra power and chemical generation needs of most BWT systems approved to date.

The fuel required by the world's merchant fleet for meeting the power needs of their BWT may exceed 500,000 tonnes per year¹⁴, a value representing ~0.5% of an annual ~200 million tonne maritime fuel

¹⁴ The total amount of fuel required each year by the world's merchant fleet for achieving D-2 by an on-board BWT system can be approximated by estimating the number of ships requiring BWM (~50,000, but likely to rise to ~60,000 by 2017), their average BW capacity (12,500 m³) and number of voyages requiring BWT per year (~20), an average BWT duration of ~30 hours (~400 m³ per hour), the mean power rating of present BWT systems (68kW per 1,000 m³^[32]), the electricity generation efficiency of marine gensets (~35%), and a fuel heating value of 42MJ/kg. This leads to a total annual fuel consumption in the order of 500,000–600,000 tonnes.

consumption. This provides a significant environmental incentive for developing NOBS, CBWF and other alternatives to ‘conventional’ on-board BWT.

Compared to BWE by conventional pumping or the installation of a buoyancy control system to a new VLCC (Section 3.3.1), the AUBAFLOW and LoBE concepts offer the following advantages:

- can be fitted to existing VLCCs as well as new builds;
- the side valves can be accessed for inspection, servicing and repair without dry-docking or need for coffer boxes (including possibly the bow aperture(s) of AUBAFLOW by maximising the bow-up trim when unloaded);
- sideboard discharge avoids the hazards of crew exposure to BW spray and streams on the main deck, plus no ice formation (as can occur by current tank flushing methods in winter);
- avoids tank over-pressurisation hazards (unlike conventional flushing that relies on relatively small vents, sounding pipes and/or the manual removal of inspection hatches to ensure there is adequate outflow to the main deck)¹⁵.

Compared to installing BWT system, achieving an effective CBWF would also offer the following advantages to existing VLCCs:

- no additional power requirements, with associated increased fuel consumption and GHG emissions;
- no generation or purchase of large quantities of chemicals and the risk of inadvertently discharging potentially toxic residuals or by-products;
- no alteration or constraints to the normal BWM control system for cargo loading/unloading operations.

Potential safety, health and environment issues

Ship safety issues posed by the LoBE system appear to be similar to those for AUBAFLOW, with respect to the position and operation of the side outlets, the latter being below the laden waterline. In the case of the lowermost inlets, however, these could pose additional access problems for inspection and servicing if placed inside the outer shell on the turn of the hull, particularly for the more aft DB tanks. Ship stability in scenarios involving single or multiple valve failure in the laden or part-laden condition will need formal analysis, although the LoBE concept will not remove the individual integrity of each DB-wing tank combination.

3.3.2.3 DynaBallast system

Description

The DynaBallast system was developed in 2006–2007 by Dagin Marine Technology, with design support from the Delft University of Technology (DUT), as a relatively simple method to enhance a conventional BWE using the ship’s existing ballast pumps^[26,27]. It is included here as an example of a tank flushing system that uses aeration as a principle method. By fitting eductor-aerators and air-vent heads in positions that are optimized for each ballast tank, the system is designed to improve the resuspension and flushing out of fine sediment and biota that can accumulate on tank floors, stringers and other horizontal surfaces. The ‘frothing’ produced by the aerators is used to help lift fine particulates and biota to the outlets. A control box that monitors the system, including the number of hours each tank is flushed and the ship’s GPS position during all stages of the procedure, provides a record that can be accessed by the engineer and transmitted to PSC, if required.

Development and testing of the system has included a shipboard programme using the 2,500 DWT multi-purpose cargo ship *Bravery*, operating between Duisburg and UK ports. Further shipboard testing was carried out in 2008, with the system installed on a 6500 DWT vessel built at Scheepswerf Peters (Netherlands). Dagin claims the system has been shown to remove 99% of all fine particulates (<50 µm) and 75–90% of the coarser material in the 50–100 µm range^[26,27]. This is achieved by installing eductor-

¹⁵ When LoBE system exit pipes are under water during heavy seas, back pressure may increase and affect water circulation. To minimize or eliminate back pressure caused by external waves, exit pipes could be designed to create a Venturi effect to promote exit flow when waves pass the outlets.

aerators in every tank, their number and location depending on the tank shape and size. DynaBallast can be retrofitted to most types of existing vessel as well as installed on new builds, but it is not suited for ships that trade only on short-sea routes that do not enter deep offshore areas.

By maintaining continuous flushing for the initial 200 nM sector of the unladen voyage, a distance enabling the ship to reach deep (>200 m) offshore waters, the concept of DynaBallast is to flush out all sediments and biota that had entered the tanks during cargo unloading in the same bioregion as the departure port. The fine sediment and any accumulated biota is resuspended into the tank water column by the aeration action, so it can be flushed out together with the 'old' BW from the source port. Dagin also suggests the tank flushing system can be restarted before the ship leaves deepwater and moves across the shelfal waters of the arrival port, but this would not provide an advantage unless the initial operation had not been operated long enough before it was shut down.

Efficiency and efficacy in preventing transfer of marine species

DynaBallast offers a method for improving the efficiency of a conventional BWE by vessels that use their ballast pumps for three times flushing. Dagin also promoted the system as a potentially suitable alternative to installing a BWT, but this does not appear to have gained much support following its initial 2007–2008 publicity. No information regarding system development and testing post-2008 has been found for this review, and the system was not included in the LR reviews of BWT systems in 2008 or 2010^[32].

Potential safety, health and environment issues

Ship safety and crew health would not be compromised by installation or operation of the DynaBallast system, and tank over-pressurisation hazards would be reduced by the presence of the air/water vents. Additional power is required to operate DynaBallast as a result of its need to continuously operate the ballasting pumps and aerators for achieving a level of flushing that exceeds D-1 and approaches D-2. Compared to 'normal' BWE, fuel consumption and associated GHG emissions will be increased, as would ballast pump servicing costs.

4

Equivalency in environment protection and performance testing

4.1 OVERVIEW

The objective of Section 4 is to help stimulate discussion on how the various alternative methods identified in Section 3 may be evaluated and tested in accordance with Regulation B-3.7, which essentially requires the evaluation process to use the criteria of the D-2 performance standard for BW discharges as a baseline or ‘benchmark’ for any BWM system designed to reduce the risk of transferring unwanted species and pathogens¹⁶.

It is therefore worth noting the Convention’s objectives and how the performance criteria of D-2 were identified as providing an acceptable reduction to the risk of a ballast-mediated bioinvasion or disease outbreak. In the Convention’s preamble, its Parties are resolved to:

“prevent, minimize and ultimately eliminate the risks to the environment, human health, property and resources arising from the transfer of Harmful Aquatic Organisms and Pathogens through the control and management of ship’s Ballast Water and Sediments, as well as to avoid unwanted side effects from that control and to encourage developments in related knowledge and technology.”

In evaluating the ability of an alternative method to provide a level of risk reduction commensurate with the aims of the Preamble and Regulation B-3.7 (Section 1.1), it is also worth bearing in mind the range of BWM procedures recognized by the Convention. For the purpose of this technical review, it is argued that:

risk ‘*elimination*’ may be attached only to the ‘Zero Ballast/Solid Ballast’ alternatives that remove the need for a ship to carry any BW (Section 3.2.1).

risk ‘*prevention*’ may be attached only to those alternatives that remove the need for a ship to discharge any BW when in port or coastal waters. This includes discharge to an approved BW Reception Facility (Regulation B-3.6 and G5 Guidelines) as well as the alternative methods described in Sections 3.2.2 and 3.2.3 (see Table 4-1);

- risk ‘*minimization*’ is appropriate for any method that reduces the risk of a BW discharge releasing viable organisms that have been moved to a port or region where they do not naturally occur but could survive, at a concentration where the number of survivors following dispersal in the receiving environment might enable their reproduction¹⁷. Discounting the interim D-1 standard for BWE¹², these methods include:
 - on-board BWT (Regulation D-2 and G8/G9 plus G2 for approval testing plus sampling);
 - Tank Sediment Management (Regulation B-5 and G12 Guideline);
 - ‘High Seas’ and ‘Same Place’ Exceptions for BWM (Regulations A-3.4 and A-3.5);
 - ship – and route-specific risk-based exemptions from BWM (A-4 and G7 Guidelines);
 - potable water and continuous flow alternative methods (this report: Sections 3.2.4 and 3.3).

¹⁶ All of the alternatives covered in Section 3 will readily attain, if not markedly exceed, equivalence with Regulation D-1. There is little incentive for a proponent to seek approval for an alternative based on equivalency to D-1 because this standard is due for complete phase out by 31 December 2016.

¹⁷ Release of a harmful species into a region where it does not naturally occur is often termed a ‘*biosecurity incursion*’. The process of introducing something to where it can grow and reproduce is also termed an *inoculation* (e.g. a suspension of bacteria or any other microorganisms that is added to a culture medium).

Table 4-1 summarizes aspects of the different types of alternative method described in Section 3 that pertain to those BWM options already recognized by the Convention.

The performance criteria of Regulation D-2 reduce but do not eliminate a bioinvasion risk because they were based on achieving a Log-4 reduction ($0.0001 \Rightarrow 99.99\%$ dilution)¹⁸ of the maximum-likely concentrations of planktonic biota that a ship may uplift from shelf-sea waters.

The establishment of a D-2 standard was discussed at length in the negotiations leading up to the adoption of the BWM Convention, not least in a global expert workshop on ballast water treatment standards, organized by the GloBallast project. At this workshop, various sets of standards were discussed; however, based on the average ambient concentration of marine organisms in coastal waters, there was a general opinion at that time, and with the technologies that could be foreseen, a Log-4 reduction of marine biota and a Log-6 reduction of pathogens would be in line with what the best available technologies can achieve, while at the same time representing a reasonable protection of the marine environment. It can only be assumed that the same reasoning was later incorporated into the discussions at MEPC.

It should therefore be noted that the absolute numbers in the D-2 standard, although based on extensive scientific debate, may not exactly correspond to a precise level of risk reduction number. However, compared to the ambient concentrations of source port biota, one could argue that what was eventually agreed for the final text of the Convention concerning the absolute numbers in the D-2 standards would, in principle, correspond to a Log-4 reduction (or 99.99%) in the concentration of marine biota (>10microns) and a Log-6 reduction of pathogens.

Existing BWT technologies are new and relatively few, and experience of their routine day-to-day on-board operation and reliability, as shown by sampling and testing programmes, remains very limited. This is another reason why the risk minimization approach is appropriate when evaluating the performance of an alternative method with respect to the D-2 standard.

It is therefore argued that the evaluation and approval process for a proposed alternative to BWT should use a risk-based approach for determining if it will “...provide the same level of protection to the environment, human health, property or resources” (Regulation B-3.7).

4.2 DETERMINING EQUIVALENCE TO THE D-2 PERFORMANCE CRITERIA

4.2.1 Objective and risk-based approach

When evaluating the equivalency of a proposed alternative method via comparison with the ‘benchmark’ provided by the D-2 criteria, the objective and scientific basis of this evaluation need to be clear and transparent.

The objective of the evaluation should be expressed concisely as well as comprehensively. It may, for example, be summarized as follows:

“To determine, to a level of reasonable certainty based on sound evidence and the balance of probabilities, if BW subjected to the proposed method will provide, at the point of its discharge, the same level of protection to the environment, human health, property and resources, as a discharge of similar volume and location that meets the criteria of Regulation D-2.”

The scientific basis of the evaluation needs to be risk-based, and should take into account advice and material in the G7 Guidelines (Annex 3), as these describe the risk assessment approach and methods for assessing an application for a BWM exemption for a specific ship or route.

¹⁸ Based on a proposal from the International Council for Exploration of the Sea (ICES) at an ad hoc Discussion Group of MEPC47^[32] ^[33].

Table 4-1: Relationship of the alternative methods described in Section 3 to risk management and relevant BWM procedure(s) of the Convention

Type of alternative method	Relationship to risk management and nearest applicable BWM procedure(s)	Requirements to confirm acceptable equivalent risk ^a	Other suggested requirements
No ballast/ Solid ballast	Risk elimination	(Design approved by a class society)	N/A
Storm BW only (for a V-hull ship)	<p>Risk Prevention – if uptake then discharge is completed on High Seas or Same Area, or is retained on board [with no mixing] until returned to Same Area, then no BWM is needed (<i>A-3.4/3.5 Exception</i>); or may be discharged to an approved BW Reception Facility (for mixed storm BW and/or no return to same area available).</p> <p>Otherwise Risk Minimization – by treating to D-2 using a small on-board BWT system.</p>	<p>Performance testing not required.</p> <p>Guidelines on bio-geographic extent of ‘High Seas’ and ‘Same Area’ will help a ship define boundaries and assess options for discharge of storm BW.</p>	Ship’s BWM Plan to specify permitted areas and non-mixing requirement for any unmanaged discharge of storm BW. All BW ops to be logged in the BWRB as per usual requirement.
Internal freshwater BW	<p>Risk prevention: Avoids all discharges and associated BWM, until a tank discharge is needed for inspection/ survey/dry-docking.</p> <p>If testing shows non-compliance to D-2, adopt risk minimization (= must treat to D-2, or discharge to an approved BW reception facility, or else discharge to High Seas).</p> <p>Before permanently stored FW ballast is to be discharged into the High Seas or a designated BWE area, without testing or treating for pathogens, it needs to be established that this an acceptable risk re. intention of the Convention and its Regulations.</p>	<p>D-2 treatment or performance testing needed when discharge eventually required.</p> <p>Where discharge of untested permanent FW ballast to the High Seas or other deep offshore area is planned, it will be necessary to clarify who decides if the ship should treat or test the concentration of the potential pathogens.</p>	Ship’s BWM Plan to specify sampling/testing before discharge in any port, coastal or inland waters, and to show treatment options if non-compliant.
Potable BW	<p>Risk minimization: Any discharge into PSC jurisdictional waters should meet D-2 standard. An approval procedure is therefore needed for the water-maker unit (or perhaps a certificate from the potable water vendor) plus for any on-board storage tank system and disinfection process.</p> <p>This might involve type Approval by the Administration using a ‘fast-track’ G8/G9 approach for the disinfecting step and its active substances.</p> <p>Also need to consider whether or not discharge of potable BW to High Seas is an acceptable equivalent to D-2, including risk of possible low quantity of active substance residuals or by-products.</p>	<p>One option might be to develop a fast track approval system with elements of G8/G9 e.g. Installer of on-board disinfection and storage system to provide data to Administration showing residuals, by-products and tank contamination risks are acceptable (G9 baseline).</p> <p>Water-maker vendor (or potable water supplier) may provide test certificate of installed unit (or purchased).</p>	<p>Consider developing Guidelines to help equipment vendors obtain approval for their Potable System/s, drawing on experience of G9 work re active substances and their by-products.</p> <p>Provide Guidelines to promote uniform type approval that is tailored to potable BW system.</p>

Type of alternative method	Relationship to risk management and nearest applicable BWM procedure(s)	Requirements to confirm acceptable equivalent risk ^a	Other suggested requirements
Continuous flushing by Buoyancy Control^b	<p>Risk minimization: Methods may approach D-2 on many blue-water routes. To avoid phytoplankton blooms or jellyfish swarms, no flushing in shelf waters or in well-known (listed) or satellite-detected areas of upwelling.</p> <p>May merit ship and route-specific risk-based Exemptions (A-4) for blue-water routes, using the G7 Risk Assessment Guidelines.</p> <p>May merit approval as an alternative method under B-3.7 for particular transoceanic routes and ship types.</p>	<p>Approval for these alternative methods should be risk-based, in line with approvals for specific ship and route Exemptions (A-4).</p> <p>To encourage development/investment, a two-step approval process may be useful, e.g. a ‘basic approval’, if application is supported by sound theoretical argument and results from computer simulations, numerical analyses and empirical evidence, and a proposed benchmark for performance testing and compliance testing. Ship safety, health and environmental side effects also to be covered.</p>	
Enhanced BWE by continuous blue-water flushing	<p>Risk minimization: Methods may be capable of approaching the D-2 criteria for the long-distance blue-water routes used by VLCCs.</p> <p>May merit VLCC and route-specific risk-based Exemptions (A-4) for long blue-water routes, using the G7 risk assessment Guidelines.</p> <p>May merit approval as an alternative method under B-3.7, for VLCCs operating particular transoceanic routes.</p>	<p>The G7 Guidelines show RA procedures to be followed for A-4 exemptions. They also help form the basis of the RA that compares the performance benchmark proposed for the alternative method against the quality of discharges treated to D-2, with respect to the concentrations and types of organisms and microbes predicted to occur in the discharge of BW subjected to the alternative method.</p> <p>Performance testing should include adequate numerical modelling and simulations, supported by pertinent empirical evidence wherever practical, such as tank tests, models and operational sampling and testing of existing BWE methods on same or similar ship type/s.</p> <p>Modify D-4, or else provide a similar Regulation, to allow full-scale prototypes to operate for approved sampling, testing and development programme/s.</p>	

^a Assumes the economic, ship safety, health and environmental aspects are feasible and practical.

^b Systems using multiple valves on lower hull may face challenges re ensuring ship safety.

To assist the proponent of an alternative method, as well as its evaluation and approval process, it would be useful to expand or modify some of the definitions and terms used in the Convention.

For example, the definition of BW may be extended to cover non-compartmentalized water associated with buoyancy control. For example, “...and water external to the hull that is temporarily entrained into buoyancy compartments or other free-flooding spaces for the purpose of adjusting draught or trim.”

Several of the alternative methods described in Section 3 are modified ship design and/or operational procedures that represent Risk Prevention strategies (Table 4-1).

In the case of internal freshwater BW systems and those that use potable BW (Section 3), these provide an option for a ship to discharge unmanaged but very low risk BW into a High Seas area or a deep offshore location under jurisdictional control (such as an area designated for BWE).

It will therefore be useful to confirm the meaning and boundaries of the ‘High Seas’ (c.f. the UNCLOS definition), and to provide guidance on the nature, size and intended difference (if any) between “location” that is noted for Exceptions (Regulation A-3.5) and “location” that is noted for Exemptions (Regulation A-4.1.1, A-4.1.3).

Comparison with pertinent MARPOL Annex regulations regarding the storage, management and disposal options of a ship’s grey water and sewage (black water) would also be illuminating and helpful to

the proponent of any internal BW system that uses freshwater or potable water. In this context, grey water is generally not considered to pose any significant hazard to the environment when discharged in open waters although it can on occasion contain some minor concentrations of potentially harmful substances such as detergent residues, hydrocarbons and various laundry bleaching agents.

4.2.2 Evaluation of alternative methods that involve continuous flushing

Methods involving continuous fast flushing (via buoyancy control) or continuous slow flushing (via enhanced BWE) in deep offshore waters can be argued to present a very low but sometimes variable risk with respect to the potential entrainment, transfer and eventual discharge of harmful species into a different bioregion. The total risk of a flushing method is therefore a composite of:

- entrainment of a harmful species (if present in the surface waters);
- transfer out of bioregion (via imperfect in-tank/in-compartment flushing due to dead spaces and nooks);
- voyage survival (darkness, plus temperature changes during voyage);
- survival and growth after discharge into the receiving environment (tolerates environmental conditions at the ballast discharge point of the cargo loading terminal, including habitats and local biocommunities in the direction of local currents);
- potential for fouling species to settle inside buoyancy control trunks or compartments, and to survive subsequent periodic air exposures during laden voyages if water pools (unpumpable ballast) remain on floor of compartment or trunk spaces; risk can be minimized by floor design, effective pumping and use of antifouling coating in permanently wet niches, valve assemblies, eductor sumps, etc.

Operational actions and design can reduce the likelihood of the first two and last of these factors, while on-board BWT to D-2 could be used against the remaining three factors.

A risk-based evaluation of a continuous flushing method will therefore be needed to address:

- (a) what types of harmful organism may be entrained and where during the unloaded/loaded voyage cycle;
- (b) what features of the method will minimize their entrapment within the ship for sufficiently long periods to be transferred into another bioregion; and
- (c) the ability of the most likely types of survivors to tolerate the environment following their eventual release into a different bioregion(s) of the voyage, including the bioregion at the cargo loading terminal. An assessment of bio-fouling potential may also be warranted (Box 4.1).

Some BWE studies have shown how diversity of species within tanks can increase following one or more exchanges, as an exchange can provide different species entrained into the tanks as well as a source of fresh oxygenated water. It is worth noting that any continuous flushing method faces the most challenge with respect to entrainment and accumulation of organisms and sediments if it is operated in shallow coastal waters or, to a much lesser extent, when operating in more offshore shelf waters (50–200 m deep).

Beyond the shelf break, blue ocean waters >200 nM from coastlines are generally devoid of suspended particulate matter of a size relevant to ballast tank sediment management. Human pathogens are absent (at routine detectable levels), as are larger marine species that could establish and spread in port, coastal or inland waters. In other words, species and microbes entrained into tanks or buoyancy compartments in the oceanic realm are unlikely to constitute the harmful species or pathogens that are spread by the BW vector.

Box 4.1: Assessing potential for fouling of continuous flow systems

The potential for continuous flow systems to increase the level of fouling on internal spaces exposed to ambient seawater warrants careful attention. Although the BWM Convention does not address the issue of hull fouling, studies by invasive species specialists in several parts of the world have shown that more harmful and unwanted species have been introduced to those areas attached to hulls and sea chests than via ballast water. It would therefore be counterproductive to develop and approve BWM systems that effectively reduced transfer of drifting organisms but enhanced transfer of sessile forms.

In this context, issues that need to be addressed are:

- the practicality of coating all internal surfaces exposed to flowing water with anti-fouling;
- the effectiveness and durability of such coatings;
- the feasibility and cost of inspecting the condition of these internal coated surface;
- the feasibility, cost and safety of cleaning and restoring these coated surfaces;
- rates and types of fouling in both coastal waters and on the high seas;
- the extent to which biofilms will form on internal surfaces with and without anti-fouling;
- the extent to which fouling organisms will survive in empty but damp compartments;
- possibilities for improving tank drainage through innovative floor designs.

These aspects of fouling should be investigated for each alternative method as part of the Type Approval process using prototype ships under a range of operational conditions.

One exception is the presence of a transient bloom of a potentially harmful phytoplankton species (HAB: harmful algae bloom). However, these tend to occur in well-defined and relatively limited geographical areas subject to upwelling and may often be detected by satellites fitted with ocean colour monitoring equipment.

It is difficult to quantify the precise transfer risk posed by a particular blue-water voyage, owing to a range of seasonal and other timing factors that influence upwelling events and associated concentrations of microalgae cells and zooplankton in offshore surface waters¹⁹. However, the size of this risk will depend mainly on a few key factors such as:

- the number of times the voyage route/s of interest traverse or parallel a shelf margin where upwelling events are common;
- whether or not the flushing system is temporarily shut down when the ship enters shelf waters (<200 m deep and/or <200 nM/50 nM from the nearest coast)²⁰;
- the particular tank flushing characteristics and design capabilities of the ship, in terms of the number of dead spaces and low-dilution zones where entrained biota may be able to accumulate within the tanks or free-flooding trunks and compartments;
- the presence of favourable environmental conditions in different bioregion(s) where eventual release or pump-out of entrapped harmful organisms occurs, Thus, enabling survival, growth and reproduction. (This includes proximity to suitable shallow seafloors and favourable water column characteristics for stimulating growth.)

With respect to tank and organism flushing efficiencies, it may be possible to test the performance of particular flow-through systems in relation to the D-2 standard (i.e. Log-4 reduction) (*see also Box 4.2*), although this still has to be evaluated from an engineering/modelling perspective.

¹⁹ For example, upwelling boundary currents may seasonally contain high surface concentrations of potentially toxic phytoplankton 25–100 nM from shore, such as in the Benguela and Agulhas Currents off southern Africa. As in other red-tide prone regions, satellite ocean colour monitoring can detect these concentrations and could be set up to provide a useful warning to ships that undertake BWE or continuous flushing in these areas.

²⁰ Too many shutdowns on short voyages will constrain achieving adequate flushing and dilutions.

4.3 POSSIBLE FRAMEWORK FOR APPROVING AN ALTERNATIVE METHOD

It is suggested that the approval framework for a proposed Alternative method should provide a two-step procedure, drawing from experience of the G8/G9 approvals process operated by MEPC (with assistance from GESAMP for systems with Active Substances), and the Type Approval procedure operated by Administrations also under the G8 Guidelines.

A staged approval framework for an Alternative method will help guide the proponent and avoid any inordinate upfront R&D investment requirements for the method warranting a step-wise development path.

A question that needs to be addressed is whether the proponent of an alternative method that has been used by a ship to help secure an Exemption from BWT (D-2), under the conditions of A-4.1, should be encouraged or required to seek approval under B-3.7. Exemptions under A-4 are temporary (no more than five years and subject to an intermediate review), and are specific to ships on voyages between specified ports or locations, or to a specific ship that operates exclusively between specified ports and locations. Multiple applications for this form of exemption may place a high load on an Administration, compared to a single Type Approval under B-3.7.

It is suggested the structure of the framework and the content of its approval steps should include the following:

1 Initial Approval. An in-principle approval, administered and granted by MEPC.

The application should be supported by a comprehensive description of the proposed method, including a preliminary risk evaluation using either the G7 guidelines (applying the low-risk criterion) or the D-2 criteria as the comparative baseline, or both, as appropriate.

The application should describe and justify any new benchmark(s) proposed by port States for performance testing for purposes of both Type Approval and compliance monitoring.

The application should also include an adequate assessment of the method with respect to ship safety (referring to pertinent annex of G8), human health and environmental side effects. For a method that uses or generates chemical/s (active substance/s) to achieve the proposed benchmark, this will also be subject to approval in accordance with the procedures of the G9 Guidelines.

Other environmental side effects should be evaluated in accordance with the G8 Guidelines. Effects such as GHG emissions²¹ should be quantified where practical, and may be assessed by comparison with the same or equivalent effect arising from a BWT system.

The application should identify what gap-filling information, investigations and other test results are to be obtained to provide a reasonable level of proof, based on sound supportive evidence and a balance of probabilities, that the alternative method will achieve its benchmark under all identified operational conditions and Thus, remain in equivalence with D-2.

The application should describe the remaining development pathway of the proposed method should Initial Approval be obtained. This should note if a testing programme involving a full-scale prototype is intended, and if this platform needs to operate under an exemption from compliance with the D-2 standard (similar to that provided for BWT in D-4).

The application for initial approval should include the results of an independent expert appraisal of the risk-based evaluation and supportive evidence submitted by the proponent with respect to performance equivalency with D-2 including the proposed performance standard(s) to be used for performance testing and compliance monitoring. The approval notice should provide advice or comment to clarify and help advise the proponent as to the scope and nature of the remaining data collection and performance-testing requirements.

2 Type Approval. This step and the subsequent notifications may be performed by an Administration in accordance with the G8 Guidelines for approvals of BWT systems.

An Administration should not commence a Type Approval process until all investigations have been completed, and evidence compiled and submitted by the proponent, as proposed and accepted for the Basic Approval.

²¹ Refer to International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), Annex VI.

With respect to achieving equivalency with D-2 under all of the operating conditions stated in the Type Approval application and Initial Approval documents, it is possible there may be a lack of scientific certainty that constrains a Type Approval decision based on a premise of *'beyond reasonable doubt'*, versus a decision made *'on the balance of probabilities'*.

The former is a level equivalent to being $\geq 95\%$ confident of something, with respect to quantitative statistical evidence used for scientific certainty. It is the chance of **not** making a Type I error (i.e. believing something has or will occur when actually it does not).

In contrast, the latter level is widely accepted as comparable to a $\geq 80\%$ chance of **not** making a Type II error (= believing something will not occur when actually it does). This is typically used for environmental monitoring programmes and pollution investigations, where it is important not to overlook an unwanted event. In the context of BWM, the unwanted event is the transfer of a potentially harmful species to a new bioregion, where environmental conditions may allow it to survive and grow, and in numbers that would allow the species to reproduce and establish a new population.

It is possible that some aspect of the proponent's supporting evidence or risk assessment procedure may require the Administration to refer the matter to MEPC for further expert consideration. In such cases the proponent should be notified of this action and the reasons for it.

4.4 PERFORMANCE TESTING METHODS AND TECHNOLOGIES

The G8 Guidelines for the approval of a BW treatment system identify various land-based performance testing procedures and standards. The guidelines are relevant to land-based testing of a ballasting system using potable water and particularly appropriate where the Initial Approval step identifies a need to examine the efficacy of disinfection following long-term storage. Questions regarding the types and decay rates of particular by-products or residuals may also arise via the G9 basic approval step.

In contrast, land-based methods are irrelevant and/or impractical for testing a continuous flow system because of its design and mode of operation. This is why the description of the alternative method submitted as part of the Initial Approval application should include a risk-based evaluation that demonstrates the equivalence of the method to D-2, as well as sufficient information to justify any new performance benchmark(s) to be used in performance testing.

In the case of continuous flow systems, it would be useful if part of the proposed performance standard comprised a set of direct (measured) and/or indirect (modelled) estimates of the mean and maximum concentrations of viable organisms and indicator microbes that may be transferred from one bioregion to another, in a form that provides equivalence to the three types of organism specified in the D-2 discharge criteria. (See Box 4.2.)

It may also be necessary to develop a series of such benchmarks, each covering a particular commonly used voyage route that traverses a particular set of bioregions with boundaries or overlapping (i.e. transition) zones that have been reasonably well demarcated by oceanographic studies and/or research on Large Marine Ecosystems (LMEs).

Until suitable benchmark(s) are identified and agreed, it will not be possible to determine the full extent or details of the performance testing programme, including its approach, methods, sampling requirements and sampling regimes, etc.

In the case of a proposed alternative method that involves purchase or production of potable water to be stored as BW, several parts of the G8 Guidelines are relevant, such as the procedure for evaluating the potential for environmental impacts of by-products formed by the desalination and sterilisation steps of the water-making equipment. The methods and results of these procedures also require appraisal by the Administration during the Type Approval procedure (G8 Guidelines: Annex Part 3).

Once accepted by MEPC as part of the Initial Approval stage, the proposed performance benchmark(s) will form the basis for the Type Approval testing requirements and eventually, perhaps in modified form, for compliance monitoring by port States. As noted earlier, the purpose of the benchmark(s) is not only for performance testing but also to show that a system using the Type Approved method is operating correctly and providing the same level of protection as predicted in the Initial Approval.

Box 4.2: Performance evaluation of continuous flow BWM systems

It has to be recognized in the context of evaluating continuous flow (CF) systems that the scheduled withdrawal of the D-1 standard presents significant difficulties. CF systems are designed to improve flushing and, thus, BW exchange. D-1 is an exchange standard and it is arguable that without an accepted criterion of this kind it will be very difficult to gain type approval for such technologies, so that their use may have to be restricted to individual ships and routes as specified under Regulation A-4.

At present, it is far from certain that performance benchmarks equivalent to the D-2 treatment standard can be devised for ships that use CF ballasting. Nevertheless, pending amendments to the Convention that recognize the existence and potential benefits of CF systems, this is the procedure proposed in this report.

Whereas water exchange rates may be closely approximated using hydrodynamic models, computerized fluid dynamics and related techniques, the efficiency with which entrained organisms are flushed from tanks and open compartments will need to be tested using partly or fully-fitted ships (prototypes) operating on the various routes, and under the various sea conditions, they will encounter when in service. All CF designs described in this document have the facility to close intakes and outlets thereby enclosing volumes of water that can, at least in principle, be sampled and tested for source-port organisms against the D-2 standard and G8 Guidelines. Thus, on a research (experimental) basis, it should be possible to measure and compare the densities of each D-2 organism group at various stages of a voyage.

A criterion that legitimately might be seen as a D-2 surrogate applicable to CF ballasting systems could be achieved by translating the absolute numbers of the D-2 standard to a comparable reduction in density for the three categories of D-2 organisms, e.g. a Log-4 reduction for marine biota and Log-6 reduction for pathogens, **as compared to the waters in the vessel's port of origin**. Even if it could be shown that a particular system consistently achieved these reductions between the point of departure and, for example, at the end of a blue-water crossing, under existing regulations it may still not qualify for Type Approval because of monitoring difficulties. On the other hand, if a ship were to proceed closer to the destination port and it could be shown that organism types and densities were either indistinguishable from, or superior to, the surrounding waters, it would be increasingly difficult to refute the efficacy of the system. The case would be even stronger if, in the course of performance testing, it could be shown that organism diversity and density at or near the destination, consistently showed low-risk status in accordance with the G7 guidelines.

In summary, a new framework for testing, approving and monitoring CF systems is required to facilitate development of these potentially beneficial ballasting systems. Such a framework may require amendments to regulations, guidelines and also perhaps definitions, under the BWM Convention. The framework would need to embrace performance criteria (such as those suggested above) as well as sampling strategies and locations for both performance testing and compliance monitoring.

Where possible and appropriate, the performance testing and system compliance benchmark(s), together with their sampling, modelling or other analytical procedures, should follow relevant international standards, such as the WHO Drinking Water Guidelines (Annex 2) and other recognized standards for modelling, sample handling and testing, etc.

Land-based testing will need to be replaced by a range of other procedures, while shipboard performance testing may require more complex and expensive hull and ship modifications than those used for Type Approval testing (often a relatively small modular unit, skid – or container-mounted).

In the case of ship-board testing of an alternative method there is presently no regulation in the Convention equivalent to Regulation D-4. D-4 allows a ship to be designated for Prototype BWT testing and not have to comply with D-2 up to five years after the normal compliance date. Such a regulation could be considered more valuable encouraging the development and Type Approval of some alternative methods than D-4 has been for BWT system approvals, as relatively small prototypes of some BWT systems have been installed on some ship types with minimal modifications or disruptions to sailing schedules.

To demonstrate that a proposed alternative method does consistently meet the agreed performance benchmark(s), and therefore is capable of providing a level of protection equivalent to D-2, the experimental and testing procedures for the Initial and Type Approval steps are likely to include (and not be limited to) the following:

- physical modelling, including hydrodynamic, engineering and design analyses;
- computerized fluid dynamics;
- other numerical modelling and simulations;
- biological modelling;
- tank testing and scale modelling;
- use of surrogates and substitutes (tracers and markers, etc);
- turbulence modelling and tank testing;
- use of relevant statistical procedures (e.g. for sampling, scenario analyses);
- semi-scale, modular and/or full-scale operational testing.

In the case of using prototypes for full-scale or part-scale testing, the continuous flow buoyancy control method requires more investment than continuous flow BWE. For trials of the latter, only one or two tanks of an existing ship would need to be modified. The installation of the additional pipework and valves would not require major structural changes requiring extensive design and engineering studies to ensure hull integrity, strength and ship safety is preserved.

4.5 APPROACHES TO COMPLIANCE MONITORING

The various alternative methods described in this review can be separated into three groups with respect to the different types of compliance monitoring that may be undertaken by port States.

In the case of the two types of continuous flushing method (fast flushing via free-flood buoyancy control compartments and slow flushing via enhanced BWE), all will require a compliance monitoring method that is based on the performance testing standard(s) that were selected and used during the Initial Approval and Type Approval stages.

In the case of the method that relies on the purchase or on-board production of potable water stored as BW, the compliance testing will be focussed on sampling for a limited number of criteria, as identified in the approval stages (e.g. the human pathogen component of D-2, plus possibly a key residual or by-product chemical depending on the nature of the sterilisation process used to achieve an appropriate standard of drinking water quality). Where potable water is obtained from an onshore vendor or public utility, any treatment process or chemical used on board to maintain the quality may also require some form of compliance check to ensure it is working correctly.

In the latter context, there may be a need to monitor stored water quality should it be accessed for domestic uses as well as for trimming purposes. In this case compliance monitoring by a port State should include checks of the ship's monitoring and sampling plan and associated record book. A related consideration is that concentrations of residuals allowable for drinking water can markedly exceed those considered acceptable for discharges to the aquatic environment (e.g. residual free chlorine). However, most modern on-board systems do not rely on chemical dosing to achieve disinfection, particularly those employing reverse osmosis (RO). Excerpts from WHO guidelines on drinking water quality, applicable to ships, are presented in Annex 2.

With respect to other alternative methods described in Section 3, compliance monitoring by port States will focus on ensuring the ship has been following the procedures and operations detailed in its on-board BWMP and the associated BWRB. For those methods where an option is to use a small BWT system, compliance monitoring will also examine the operation and discharge performance of the system, as with any ship fitted with an approved BWT system for routine treatment to the D-2 standard.

The key features of compliance monitoring for the different kinds of alternative BWM systems are summarized in Table 4-2.

Many port States are likely to circulate the findings of BWM compliance inspections, sampling and testing, according to their arrangements with regional protocols for port State control (Paris MOU, Tokyo MOU etc). As with port State inspections for SOLAS and MARPOL, the purpose of sharing information on inspections is to optimize the cost-effectiveness of compliance monitoring under the BWM Convention and so avoid unwanted over – or under-inspection of particular ships.

Table 4-2: Approaches and procedures to compliance monitoring by the alternative BWM methods identified in Section 3

Group	Type of alternative method	Compliance monitoring approach	Specific aspects
-	Zero BW	N/A	N/A
1	Storm BW	Confirm that ship BWM operations are being conducted according to the Ship's approved BWM Plan and logged in BW Record Book. If BWT system present, check correct operation and sample as/when necessary to check discharge meets D-2 criteria.	Ship's BWM Plan to specify the allowable areas (and the non-mixing requirement) for any discharge that is not treated to D-2 or discharged at an approved BW Reception facility.
	Internal freshwater BW	Procedures for tank sediment inspections, sediment avoidance measures and disposal arrangements follow B-5 requirements. All BW operations correctly logged in the BWRB	Ship's BWM Plan to specify sampling/testing before any discharge in port, coastal or inland waters, and treatment options if non-compliant.
2	Potable BW	Confirm source/s of potable water meet the approval requirements in terms of shipboard monitoring and servicing. Stored water may be sampled to check it meets D-2 standard, if intended to be discharged in port State control waters.	If approved on-board water-maker is present, any stored water intended for discharge may be sampled to test for by-products or residuals, according to advice in the type approval certificate relating to disinfection method.
3	Continuous flushing by buoyancy control	BW sampling to confirm water quality meets performance standards defined in the Type Approval certificate, using relevant sampling points and procedures as listed in the Installation Certificate and Ship's BWM Plan.	System may be approved for particular transoceanic routes and ship type, as detailed in Installation Certificate and listed in Ship's BWM Plan.
	Continuous dilution by enhanced BWE	If the approved system is approved for specific routes and terminals only, confirm from the BW Record Book, bridge/engineering logs and MOU/ port State control records that BW uptake and discharge operations correctly match the operational trading history of the vessel. If the approved system demarcates specific areas, depths or other locations where continuous flushing is to be shut down for minimising biota/sediment entrainment, compare BW Record Book, system operation logs and deck logs to confirm. Tank sediment monitoring, inspections and performance targets, as where stated, are meeting criteria for tank sediment management.	System may be approved for particular long transoceanic routes, loading/unloading terminals and ship type only, as noted in Ship's BWM Plan.

5

Conclusions

- 1 Certain innovations in ship design and engineering show good potential for improving the practicality, cost-efficiency and safety of ballasting operations, and may offer an alternative to conventional practices while meeting standards for discharged ballast water required under the BWM Convention. The practicality and cost-effectiveness of these alternative ballasting systems will vary according to ship type, size and usage.
- 2 The alternative systems can be categorized as either *No ballast/Zero discharge* systems or *Continuous flow* systems. To date, there is limited experience in evaluating the efficacy of these new technologies in reducing the transfer of harmful species in accordance with the goals of the BWM Convention. All continuous flow systems readily exceed the performance required by the D-1 exchange standard but this standard is to be withdrawn at the end of 2015.
- 3 Where neither the D-2 treatment standard nor the biologically-based exemption for individual ships on fixed routes (Regulation A-4) constitute a suitable basis for testing and assessing a new BWM system, Regulation B-3.7 affords an opportunity to use different criteria (performance benchmarks) providing they are shown to be at least as effective as the D-2 standard.
- 4 In accordance with the Preamble to the BWM Convention, new performance benchmarks for use in testing and assessing particular technologies should be risk based, taking into account the risk assessment procedures contained within the G7 guidelines. However, the quantification and assessment of risk in a BWM context remains problematic. Another approach might be to use the basis of the D-2 standard (a Log-4 reduction in the maximum-likely concentrations of planktonic biota that a ship may uplift from shelf-sea waters) as a benchmark for assessing alternative BWM systems.
- 5 This report, in line with the findings of the Malmö workshop to which it was submitted in January 2010 (*see Annex 1*), identifies technical and regulatory issues with regard to testing and approval of innovative BWM technologies that need to be addressed in order to clarify the process by which the efficacy of these technologies, in relation to existing performance standards, should be demonstrated.
- 6 The search for new benchmarks equivalent to the D-2 standard, as provided for under Regulation B-3.7, raises queries regarding Convention definitions, regulations and guidelines that may not have arisen at the time they were adopted. For example, it is unclear whether or not the definition of ballast water applies to non-compartmentalized water associated with buoyancy control (i.e. certain flow-through systems). With respect to shipboard testing, there is currently no regulation that allows a ship to be designated for prototype testing of alternative methods, as is the case for treatment methods under Regulation D-4. Concerning risk assessments, apart from some general principles the guidance provided by the G7 Guidelines is designed for exemptions based on biogeographic grounds, not to assessing risks associated with different water replacement technologies.
- 7 Technical queries that need to be addressed include the environmental significance of freshwater discharges, including water treated to drinking water standards, whether in port, or within or beyond the shelf. In the context of flow-through technologies, it will be necessary to evaluate potential for fouling on the interior surfaces of trunks, tanks and other compartments, as well as the efficacy, durability and maintenance (including safety) aspects of surface coatings used for anti-fouling purposes.
- 8 A performance testing programme for an alternative BWM system, leading to an application for type approval, will require a combination of theoretical computations, modelling, land-based and/or sea-

based trials using prototype ships or installations, as well as biological sampling and screening. The exact details of each programme will depend on the particular BWM system under investigation and may also be influenced by decisions regarding the regulatory and technical issues outlined above.

- 9 In order to advance the development of new and cost-effective BWM systems, it will be important for ship owners, ship designers, national administrations, the MEPC and biologists specializing in invasive species to collaborate in reviewing the BWM regulations and guidelines and, where necessary, to propose amendments and/or additions that will facilitate the testing, assessment and approval of innovative systems that meet the aims of the Convention.

6

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ANNEX 1

EABWS Workshop at the World Maritime University

Pre-conference Workshop on proving equivalency between G8/G9 approved treatment systems and alternative management options 26 January 2010

4.6 BACKGROUND

Background

In the years following the 2004 adoption of the International BWM Convention, various alternatives to the use of ‘conventional’ ballast water management systems – and consequent need for treatment to ensure tank discharges meet the D2 criteria – have been proposed and studied.

These emerging alternatives to ‘conventional’ BW management include concepts and designs for ‘ballast-less’ ships, ‘ballast-free’ ships, ‘ballast-thru’/‘flow-thru’ ships, and ‘solid-ballast’ ships. Indeed, Regulation B-3, paragraph 7 of the Convention predicts and allows for the development and future use of such alternatives. The workshop highlighted the inherent abilities of these alternatives to exceed or at least meet the Convention’s requirements, with particular focus on designs that rely on the continuous flushing or flow-through of seawater to achieve trim and stability.

The expected outcome of the workshop was to identify key issues of concern that can be brought to the attention of the two main IMO fora, the Sub-committee on Bulk Liquids and Gases (BLG) and the Marine Environment Protection Committee (MEPC), in order to facilitate the implementation, ratification and bringing into force of the BWM Convention.

4.7 OBJECTIVES AND STRUCTURE

The key aspects addressed during the workshop were:

- evaluating the emerging alternatives with respect to the present performance testing, type approval and monitoring requirements of the Convention and its G1-G14 Guidelines;
- determining equivalence with the Convention’s D-2 performance standard for BW discharges and its sediment management requirements;
- assessing how ship operators and Port States can check that vessels releasing non-compartmentalized ballast are meeting the D2-equivalent performance standard/s during routine operations, cargo loading and in extraordinary circumstances.

The Pre-conference Workshop on proving equivalency between G8/G9 approved treatment systems and alternative management options was attended by approximately 65 participants from administrations, academia, technology developers and the maritime industry. The main focus of the workshop were the key critical questions related to establishing a scientific basis for proving equivalency with systems approved under Guidelines G8 and G9, in terms of providing protection to the environment, human health, property or resources (Regulation B-3, paragraph 7).

The participants were welcomed to the meeting by Jose Matheickal, GloBallast Partnerships, IMO, who explained the rationale behind the meeting and why the Global Industry Alliance (GIA) saw the need to fund such an event. Dr. Matheickal’s welcome address was followed by a series of technical presentations.

Dandu Pughiuc, Biosafety Section, IMO, provided an overview of the BWM Convention and the provision for alternative management systems as per Regulation B-3, Paragraph 7.

Peilin Zhou, Dept. of Naval Architecture and Marine Engineering, University of Strathclyde, presented an overview of the available and emerging alternative systems, including no-ballast systems, flow through systems, partial ballast (increased buoyancy) systems and potable water systems.

Jan Linders, RIVM (National Institute for Public Health and the Environment), Netherlands, summarized the proposed draught procedure for approving other methods of ballast water management in accordance with regulation B-3.7 of the BWM Convention, as submitted to BLG 14 (document BLG 14/5/1).

Rob Hilliard, InterMarine Consulting, reported on the findings of an independent GIA/GloBallast study on options for establishing a scientific basis for equivalency.

The workshop was facilitated by **Brian Elliott**, European Maritime and Safety Agency (EMSA).

4.8 SUMMARY OF DISCUSSION

A thorough and in-depth discussion followed the presentations given at the start of the workshop. These ranged from specific issues on the design and equivalence of the specific technologies that were being discussed to the process being proposed in BLG 14/5/1, to generic issues on type approval, proving equivalence and the application of risk assessment.

One major issue in this discussion centered on the definition of the ‘same level of protection’ and how this can be achieved. As the BWM Convention was negotiated a while ago, there was an apparent lack of understanding over how the D-2 Standard was achieved, how the new proposal arose and whether or not the same level of protection can be linked to the D-2 Standard. During the discussion the background to, and the issues raised during the development of these guidelines was outlined. In addition, the following issues were raised, most of which may need clarification in the new guidelines:

- Proving the same level of protection will be difficult because of the variation in technologies being developed.
- In any new guidelines, there will be a need to outline the background to the D-2 Standard and explain how the absolute standard adopted in Regulation D-2 could be compared to a relative measure of risk reduction to prove the same level of protection to the environment, etc.
- Why is there a focus on numbers, i.e. 99.99% as an equivalent to the reduction caused by the D-2 Standard? Can other criteria be used?
- The absolute values for standards provided in Regulation D-2 may be convenient for administrations to relate to, in particular in terms of testing, verification and compliance monitoring. However, does this pose a constraint in bringing new concepts and ideas to address ballast water issues?
- If risk assessments are to be used in the approval of BWM systems, how can risk assessments be undertaken with no data? Theoretical versus practical proof – need for a prototype?
- Can the approval of alternative systems be done using a two-step process – basic, in-principle approval by MEPC based on theoretical/risk assessment models and final type approval by administrations after prototype trials?
- Should the guidelines provide specific risk assessment guidance for each type of system? The overall consensus of the meeting was that this would introduce a never-ending process where a new risk assessment procedure has to be developed for each new system. Discussions also focussed on whether or not this is IMO’s role or whether it should stay with the manufacturer.
- Can invasive species be used as a standard? The meeting agreed that this would undermine the BWM Convention. It would not be possible since there is a lack of information on the distribution of species on most parts of the world, as thereby also on what is an invasive species. A species may be invasive in one place but not another.
- There is a link to the CO₂ debate that needs to be addressed. Alternative systems – as well as conventional systems – will need to be energy efficient in order not to substitute one environmental impact for another.

- How can consistency be achieved between Type Approvals issued by different administrations?
- Should the developers of each alternative system provide benchmarking for Port State Control and Type Approval/Certification?

Some specific issues that need to be taken into consideration when discussing specific alternative management methods were also identified by the workshop.

For **flow-through systems**, the following issues were highlighted:

- Are these systems the D-1 standard under a different name?
- Can these be used in coastal waters?
- Would it provide same level of protection as D-2, if the ballast water inside tank is similar to the water outside (ambient)? How can this be verified?
- Would exchange with oceanic ‘blue water’ reach D-2 standards? Does exchanging oceanic ‘blue water’ pose no risks when discharged in coastal waters? Is there a need for data from actual trials to prove this?
- What happens to sedimentation and biofouling? How will the system be maintained?
- What happens to the water in the system when the vessel stops – will it leak and what risks does this pose?
- Is this ballast water, and does the definition of ballast water need to be adapted?

For **potable water systems** the discussion centered on the definition of ballast water and how it applies to potable water systems. Do these systems actually create ballast water? Can potable water tanks be classified as ballast water as they actually provide a ballast function? (It should be noted that it only falls under the Convention if the ballast water is discharged to the marine environment.)

There are also other issues with ballast water created on board that may need further investigation, for example the use of active substances (e.g. chlorine and other disinfection by-products) and issues related to maintaining potable water quality on board.

In summary, the pre-conference workshop served as a useful forum to initiate discussions regarding the applicability of the Convention to those systems that do not fall within the ‘traditional’ framework of BWM systems. The workshop was never intended to solve these issues, but provide a first stepping stone where the regulatory and technical issues and how they are linked together could be openly debated. This is a discussion that will by necessity need to continue in various other fora, but the issues identified in the pre-conference workshop will need attention as a matter of priority to ensure that BWM solutions that are environmentally sound, technically feasible and financially viable are available to the industry.

Note: This summary was compiled by the pre-conference workshop facilitator Mr. Brian Elliott, EMSA, and the GloBallast Partnerships PCU.

ANNEX 2

Excerpts from Guidelines for Drinking-Water Quality²²

6.8 SHIPS

6.8.1 Health risks

The importance of water as a vehicle for infectious disease transmission on ships has been clearly documented. In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human and animal excreta. Waterborne transmission of the enterotoxigenic *E. coli*, Noroviruses, *Vibrio* spp., *Salmonella typhi*, *Salmonella* spp. (non-typhi), *Shigella* spp., *Cryptosporidium* spp., *Giardia lamblia* and *Legionella* spp. on ships has been confirmed (see Rooney et al., in press).

Chemical water poisoning can also occur on ships. For example, one outbreak of acute chemical poisoning implicated hydroquinone, an ingredient of photo developer, as the disease-causing agent in the ship's potable water supply. Chronic chemical poisoning on a ship could also occur if crew or passengers were exposed to small doses of harmful chemicals over long periods of time. The supporting document Guide to Ship Sanitation (section 1.3) describes the factors that can be encountered during water treatment, transfer, production, storage or distribution in ships. This revised Guide includes description of specific features of the organization of the supply and the regulatory framework.

The organization of water supply systems covering shore facilities and ships differs considerably from conventional water transfer on land. Even though a port authority may receive potable water from a municipal or private supply, it usually has special arrangements for managing the water after it has entered the port. Water is delivered to ships by hoses or transferred to the ship via water boats or barges. Transfer of water from shore to ships can provide possibilities for microbial or chemical contamination.

In contrast to a shore facility, plumbing aboard ships consists of numerous piping systems, carrying potable water, seawater, sewage and fuel, fitted into a relatively confined space. Piping systems are normally extensive and complex, making them difficult to inspect, repair and maintain. A number of waterborne outbreaks on ships have been caused by contamination of potable water after it had been loaded onto the ship – for example, by sewage or bilge when the water storage systems were not adequately designed and constructed. During distribution, it may be difficult to prevent water quality deterioration due to stagnant water and dead ends.

Water distribution on ships may also provide greater opportunities for contamination to occur than onshore, because ship movement increases the possibility of surge and backflow.

6.8.2 System risk assessment

In undertaking an assessment of the ship's drinking-water system, a range of specific issues must be taken into consideration, including:

- quality of source water;
- water-loading equipment;
- water-loading techniques;
- design and construction of storage tanks and pipes;
- filtration systems and other treatment systems on board the ship;

²² Guidelines for Drinking-Water Quality, 3rd edition, Vol. 1, World Health Organization, 2008.

- backflow prevention;
- pressure of water within the system;
- system design to minimize dead ends and areas of stagnation; and
- residual disinfection.

6.8.3 Operational monitoring

The ship's master is responsible for operational monitoring. The primary emphasis of monitoring is as a verification of management processes. Monitoring of control measures includes:

- quality of source water;
- hydrants and hoses for cleanliness and repair;
- disinfectant residuals and pH (e.g. daily);
- backflow prevention devices (e.g. monthly to yearly);
- filters (before and during each use); and
- microbial quality of treated water, particularly after maintenance or repairs.

The frequency of monitoring should reflect the probable rate of change in water quality. For example, monitoring of drinking water on ships may be more frequent when the ship is new or recently commissioned, with frequencies decreasing in the light of review of results. Similarly, if the ship's water system has been out of control, monitoring following restoration of the system would be more frequent until it is verified that the system is clearly under control.

6.8.4 Management

The port authority has responsibility for providing safe potable water for loading onto vessels. The ship's master will not normally have direct control of pollution of water supplied at port. If water is suspected to have come from an unsafe source, the ship's master may have to decide if any additional treatment (e.g. hyper-chlorination and/or filtration) is necessary. When treatment on board or prior to boarding is necessary, the treatment selected should be that which is best suited to the water and which is most easily operated and maintained by the ship's officers and crew.

During transfer from shore to ship and on board, water must be provided with sanitary safeguards through the shore distribution system, including connections to the ship system and throughout the ship system, to prevent contamination of the water.

Potable water should be stored in one or more tanks that are constructed, located and protected, so as to be safe against contamination. Potable water lines should be protected and located so that they will not be submerged in bilge water or pass through tanks storing non-potable liquids.

The ship's master should ensure that crew and passengers receive a sufficient and uninterrupted drinking water supply and that contamination is not introduced in the distribution system. The distribution systems on ships are especially vulnerable to contamination when the pressure falls. Backflow prevention devices should be installed to prevent contamination of water where loss of pressure could result in backflow.

The potable water distribution lines should not be cross-connected with the piping or storage tanks of any non-potable water system.

Water safety is secured through repair and maintenance protocols, including the ability to contain potential contamination by valving and the cleanliness of personnel, their working practices and the materials employed. Current practice on many ships is to use disinfectant residuals to control the growth of microorganisms in the distribution system. Residual disinfection alone should not be relied on to 'treat' contaminated water, since the disinfection can be readily overwhelmed by contamination. Supporting programmes that should be documented as part of the WSP for ships include:

- suitable training for crew dealing with water transfer and treatment; and
- effective certification of materials used on ships for storage tanks and pipes.

6.8.5 Surveillance

Independent surveillance is a desirable element in ensuring drinking water safety on ships. This implies:

- periodic audit and direct assessment;
- review and approval of WSPs;
- specific attention to the shipping industry's codes of practice, the supporting document Guide to Ship Sanitation (Section 1.3) and port health or shipping regulations; and
- responding, investigating and providing advice on receipt of report on significant incidents.

ANNEX 3

Excerpts from the Guidelines for risk assessment under Regulation A-4 of the BWM Convention (G7)

6 RISK ASSESSMENT METHODS

6.1 General

6.1.1 There are three risk assessment methods outlined in these Guidelines for assessing the risks in relation to granting an exemption in accordance with regulation A-4 of the Convention:

- environmental matching risk assessment;
- species' biogeographical risk assessment;
- species-specific risk assessment.

6.1.2 Environmental matching risk assessment relies on comparing environmental conditions between locations, species' biogeographical risk assessment compares the overlap of native and non-indigenous species to evaluate environmental similarity and to identify high-risk invaders, while species-specific risk assessment evaluates the distribution and characteristics of identified target species. Dependent on the scope of the assessment being performed, the three approaches could be used either individually or in any combination, recognizing that each approach has its limitations.

6.1.3 Environment matching and species' biogeographical risk assessment may be best suited to assessments between biogeographic regions. Species-specific risk assessment may be best suited to situations where the assessment can be conducted on a limited number of harmful species within a biogeographic region.

6.2 Environmental matching risk assessment

6.2.1 Environmental matching risk assessments compare environmental conditions including temperature and salinity between donor and recipient regions. The degree of similarity between the locations provides an indication of the likelihood of survival and the establishment of any species transferred between those locations.

6.2.2 Since species are widely distributed in a region, and are rarely restricted to a single port, the environmental conditions of the source region should be considered.

6.2.3 These regions are typically defined as biogeographic regions. Noting that all of the existing biogeographical schemes were derived for different purposes than proposed here, it is suggested that the Large Marine Ecosystems (LME) scheme (<http://www.edc.uri.edu/lme>) be used based on best available information at this time, with local and regional adaptation as necessary. It is recognized that the suggested biogeographical scheme may not be appropriate in certain circumstances and in this case other recognized biogeographical schemes may need to be considered.

6.2.4 Environmental matching should therefore compare environmental conditions between the donor biogeographic region and the recipient port to determine the likelihood that any species found in the donor biogeographic region are able to survive in the recipient port in another biogeographic region. The environmental conditions that may be considered for environmental matching include salinity, temperature or other environmental conditions, such as nutrients or oxygen.

6.2.5 The difficulty in using environmental matching risk assessments is identifying the environmental conditions that are predictive of the ability of the harmful species to successfully establish and cause harm in the new location, and in determining whether the risk of ballast water discharge is sufficiently low to be acceptable. Environmental matching risk assessments have limited value where the differences between a donor biogeographic region and a recipient port are small, as high similarity is likely to indicate high likelihood of successful establishment.

6.2.6 Environmental conditions should also be compared between the donor and recipient ports. Similarity in key environmental conditions between the two ports is a stronger indication that species entrained in ballast water in the donor port could survive when released into the waters of the recipient port. The environmental conditions that may be considered for environmental matching include salinity, temperature or other environmental conditions, such as nutrients or oxygen.

6.2.7 The data necessary to enable a risk assessment using environmental matching includes but is not limited to:

- .1 origin of the ballast water to be discharged in recipient port;
- .2 biogeographic region of donor and recipient port(s);
- .3 the average and range of environmental conditions, in particular salinity and temperature.

This information is used to determine the degree of environmental similarity between the donor and recipient environments. In many cases, it should be possible to use existing data for part or all of these environmental profiles.

6.2.8 The following should be considered in gathering data on the environmental conditions:

- .1 The seasonal variations in surface and bottom salinities and temperatures at the recipient port and the larger water body the port is contained within (e.g. estuary or bay). Surface and bottom values are needed to determine the full range of environmental conditions available for a potential invader (e.g. low salinity surface waters allowing the invasion of a freshwater species). Salinity and temperature depth profiles are not required if available data indicates the waters are well mixed over the entire year.
- .2 In recipient ports with strong tides or currents, the temporal variations in salinity should be determined over a tidal cycle.
- .3 In areas with seasonal or depth variations, the salinity should be determined on a seasonal and/or depth basis.
- .4 Any anthropogenic influences on freshwater flow that could temporarily or permanently alter the salinity regime of the recipient port and surrounding waters.
- .5 The seasonal temperature variation of coastal waters for the biogeographic region of the recipient port. Consideration should be given to both surface waters and to how temperature varies with depth.

6.2.9 It is recommended that the analysis of environmental conditions be followed by a consideration of the species known to be in the donor region that can tolerate extreme environmental differences. If present, a species-specific approach should be used to evaluate the risks associated with these species. Such species include:

- species that utilize both fresh and marine environments to complete their life-cycle (including anadromous (e.g. Sea Lamprey) and catadromous (e.g. Chinese Mitten crab) species);
- species with a tolerance to a wide range of temperatures (eurythermal species) or salinities (euryhaline species).

6.3 Species' biogeographical risk assessment

6.3.1 Species' biogeographical risk assessment compares the biogeographical distributions of non-indigenous, cryptogenic, and harmful native species that presently exist in the donor and recipient ports, and biogeographic regions. Overlapping species in the donor and recipient ports and regions are a direct indication that environmental conditions are sufficiently similar to allow a shared fauna and flora. The biogeographical analysis could also be used to identify high-risk invaders. For example, native species in

the donor biogeographic region that have successfully invaded other similar biogeographic regions but that are not found in the recipient biogeographic region could be considered high-risk invaders for the recipient port or location. The larger the number of biogeographic regions that such species have invaded, the greater the potential that those species would be able to become established in the recipient port or biogeographic region if introduced by ballast water not meeting regulation B-3 or C-1. Another general indicator of risk would be if the donor biogeographic region is a major source of invaders to other areas.

6.3.2 The data necessary to enable a risk assessment using a species biogeographical approach includes but may not be limited to:

- .1 records of invasion in the donor and recipient biogeographic regions and ports;
- .2 records of native or non-indigenous species that could be transferred through ballast water in the donor biogeographic region that have invaded other biogeographic regions and the number and nature of biogeographic regions invaded;
- .3 records of native species in the donor region that have the potential to affect human health or result in substantial ecological or economic impacts after introduction in the recipient region through ballast water transfer.

6.3.3 The species' biogeographical risk assessment could also be used to identify potential target species in the donor regions as indicated by native species with wide biogeographical or habitat distributions or which are known invaders in other biogeographic regions similar to that of the recipient port.

6.4 Species-specific risk assessment

6.4.1 Species-specific risk assessments use information on life history and physiological tolerances to define a species' physiological limits and thereby estimate its potential to survive or complete its life cycle in the recipient environment. That is, they compare individual species' characteristics with the environmental conditions in the recipient port, to determine the likelihood of transfer and survival.

6.4.2 In order to undertake a species-specific risk assessment, species of concern that may impair or damage the environment, human health, property or resources need to be identified and selected. These are known as the target species. Target species should be selected for a specific port, State, or geographical region, and should be identified and agreed on in consultation with affected States.

6.4.3 To determine the species that are potentially harmful and invasive, parties should initially identify all species (including cryptogenic species) that are present in the donor port but not in the recipient port. Target species should then be selected based on criteria that identify the species that have the ability to invade and become harmful. The factors to consider when identifying target species include but should not be limited to:

- evidence of prior introduction;
- demonstrated impacts on environment, economy, human health, property or resources;
- strength and type of ecological interactions, e.g. ecological engineers;
- current distribution within biogeographic region and in other biogeographic regions; and
- relationship with ballast water as a vector.

6.4.4 Species-specific risk assessments should then be conducted on a list of target species, including actual or potentially harmful non-indigenous species (including cryptogenic species). As the number of species included in the assessment increases the number of low-risk scenarios decreases. This is justified if the species assessments are accurate. The difficulty arises when the assessments are conservative due to lack of data. It should be recognized, however, that the fewer the number of species analysed, the greater the uncertainty in predicting the overall risk. The uncertainty associated with limiting the analysis to a small number of species should therefore be considered in assessing the overall risk of invasion.

6.4.5 It should be noted that there are limitations involved with using a target species approach. Although some data and information can be obtained to support decision making, identifying species that may impair or damage the environment, human health, property or resources is subjective and there will be a degree of uncertainty associated with the approach. For example, it is possible that species identified as harmful in some environments may not be harmful in others and vice versa.

6.4.6 If species-specific risk assessments are undertaken when the donor and recipient ports are within different biogeographic regions, parties should identify and consider any uncertainties resulting from lack of data on the presence of potentially harmful species in the donor location.

6.4.7 The data necessary to enable a risk assessment using the species-specific approach includes but is not limited to:

- .1 biogeographic region of donor and recipient port(s);
- .2 the presence of all non-indigenous species (including cryptogenic species) and native species in the donor port(s), port region and biogeographic region, that are not present in the recipient port, to allow identification of target species;
- .3 the presence of all target species in the recipient port(s), port region, and biogeographic region;
- .4 the difference between target species in the donor and recipient ports, port region, and biogeographic region;
- .5 life history information on the target species and physiological tolerances, in particular salinity and temperature, of each life stage; and
- .6 habitat type required by the target species and availability of habitat type in the recipient port.

6.4.8 If a target species is already present in the recipient port, it may be reasonable to exclude that species from the overall risk assessment for that port unless that species is under active control. It is important to recognize, however, that even when a non-indigenous species or cryptogenic species has been reported from the donor and recipient ports, its continual introduction into the recipient ports could increase the probability that it will become established and/or achieve invasive population densities.

6.4.9 A risk assessment can take different forms. A simple assessment can be undertaken as outlined in paragraph 6.4.7 of whether a target species is present in the donor port but not in a recipient port and can be transported through ballast water. However, if considered appropriate, the likelihood of target species surviving each of the following stages may be assessed, including:

- .1 uptake probability of viable stages entering the vessel's ballast water tanks during ballast water uptake operations;
- .2 transfer probability of survival during the voyage;
- .3 discharge probability of viable stages entering the recipient port through ballast water discharge on arrival; and
- .4 population establishment probability of the species establishing a self-maintaining population in the recipient port.

6.4.10 To determine the likelihood of transfer and survival of a harmful species, the probability of each species surviving each of the stages contained in paragraph 6.4.9 may be assessed. To the extent possible, the different life stages of the target species may also be assessed considering seasonal variations of life stage occurrence in donor port with seasonal conditions in the recipient port. The overall risk assessment for the discharge of unmanaged ballast water is therefore determined based on the assessment of all target species surviving all these stages.

6.4.11 In assessing whether a species will survive in the recipient port, physiological tolerances of all life stages need to be considered.

- .1 The ability of the adults to survive would be indicated by the physiological limits for both temperature and salinity that fall within the environmental ranges observed in the recipient port and larger water body. As a check, a comparison could be made with the native and/or introduced ranges of the species to determine if the predicted tolerances (based on lab or field studies) reflect actual distributions.
- .2 For other life stages, the physiological requirements of each stage in the life cycle should be compared against the environmental conditions during the season(s) of reproduction, noting that these stage(s) may live in different habitats to complete their life cycle (e.g. coastal pelagic larvae of estuarine benthic invertebrates). Data should be collected as appropriate.

- .3 Comparisons of known physiological tolerances for other conditions should be conducted if the data are available and relevant.

6.4.12 To evaluate whether the species-specific risk assessment approach is sufficiently robust to predict invaders, the approach could be used to estimate the probabilities of invasion for a suite of existing invaders within the recipient port. Failure to accurately predict existing invaders may indicate that the model under predicts the risk.

6.5 Evaluation and decision-making

6.5.1 The port State granting exemptions shall, in both the evaluation and consultation processes, give special attention to regulation A-4.3, which states that any exemptions granted under this regulation shall not impair or damage the environment, human health, property or resources of adjacent or other States. Regulation A-4.3 also states that States that may be adversely affected shall be consulted, and Parties should refer to Section 8 regarding consultation.

6.5.2 It is important for the transparency and consistency of the risk assessments to define a priori criteria to distinguish between unacceptable high-risk scenarios and acceptable low-risk scenarios, where the risk of ballast water not meeting regulations B-3 and C-1 is unlikely to impair or damage the environment, human health, property or resources of the granting Party and of adjacent or other States. The specific criteria depend upon the risk assessment approach, as well as the uncertainty in the analysis.

6.5.3 For an environmental matching risk assessment:

- .1 a high-risk scenario could be indicated if the environmental conditions of the donor ports overlap the environmental conditions of the recipient region;
- .2 a low-risk scenario could be indicated if the environmental conditions of the donor port do not overlap the environmental conditions of the recipient region.

6.5.4 For the species' biogeographical risk assessment:

- .1 a high-risk could be indicated if the recipient port presently contains non-indigenous species whose native range includes the donor biogeographic region;
- .2 a high-risk could be indicated if the donor and recipient ports share non-indigenous species whose source is from other biogeographic regions;
- .3 a moderate to high risk could be indicated if the recipient biogeographic region presently contains non-indigenous species whose native range includes the donor biogeographic region;
- .4 a moderate to high risk could be indicated if the donor biogeographic region is a major source for invaders for other biogeographic regions.

6.5.5 For a species-specific risk assessment, an assessment could be deemed high risk if it identifies at least one target species that satisfies all of the following:

- likely to cause harm;
- present in the donor port or biogeographic region;
- likely to be transferred to the recipient port through ballast water; and
- likely to survive in the recipient port.

6.5.6 The overall probability of a successful invasion also depends in part on the number of organisms and the frequency with which they are introduced over the entire period of the exemption. Therefore, it is recommended that a risk assessment should consider estimates of at least the following four factors:

- .1 the total volume of water discharged;
- .2 the volume of water discharged in any event (voyage);
- .3 the total number of discharge events;
- .4 the temporal distribution of discharge events.

6.5.7 In all cases, the level of uncertainty needs to be considered in evaluating the extent of risk. High levels of uncertainty in the biogeographical distributions and/or physiological tolerances of a target

species may be sufficient in themselves to classify the risk as high. Additionally, the potential ecological impact of the target species should be considered in deciding the level of acceptable risk. The absence of, or uncertainty in, any information should not be considered a reason to grant an exemption to regulation B-3 or C-1.

6.5.8 Once the level of risk and the extent of uncertainty have been assessed, the result can be compared to the levels a Party(s) is willing to accept in order to determine whether an exemption can be granted.

6.5.9 Ships on a voyage(s) or route(s) that satisfy the requirements of regulation A-4.1 and that pass(es) the terms of acceptance in the risk assessment may be granted an exemption.

6.5.10 It is recommended that an independent peer review of the risk assessment method, data and assumptions be undertaken in order to ensure that a scientifically rigorous analysis has been conducted. The peer review should be undertaken by an independent third party with biological and risk assessment expertise.

7 PROCEDURES FOR GRANTING EXEMPTIONS

7.1 The purpose of this section is to provide guidance for Parties, Administrations and ships, engaged in the process of applying for, evaluating and/or granting exemptions in accordance with the provisions of regulation A-4. The appendix also identifies minimum information required for an exemption application.

7.2 Parties may undertake the risk assessment themselves in order to grant exemptions or require the shipowner or operator to undertake the risk assessment. In any event, the Party granting an exemption is responsible for evaluating the risk assessment, verifying the data and information used, and ensuring the risk assessment is conducted in a thorough and objective manner in accordance with the Guidelines. The recipient port State(s) should reject any application for exemption found not to be in accordance with these Guidelines, and should provide reasons as to why the application was not accepted.

7.3 Shipowners or operators wanting to seek an exemption should contact the relevant Parties to ascertain the risk assessment procedures to be undertaken and the information requirements of these procedures.

7.4 Where a Party has determined that the shipowner or operator should undertake the risk assessment, the Party should provide relevant information, including any application requirements, the risk assessment model to be used, any target species to be considered, data standards and any other required information. The shipowner or operator should follow these Guidelines and submit relevant information to the Party.

7.5 The port State shall ensure that, as required by regulation A-4.1.3, exemptions are only granted to ships that do not mix ballast water or sediments other than between the locations specified in the exemption. The port State should require evidence of the specific measures undertaken to ensure compliance with this regulation at the time the exemption is granted and over the duration of the exemption. Non-compliance during the period of exemption should result in prompt suspension or revocation of the exemption.

7.6 An exemption shall not be effective for more than five years from the date granted. The approval may contain seasonal and time-specific or other restrictions within the time of validity.

7.7 The result of the risk assessment should be stated as:

- .1 The voyage(s) or route(s) represent(s) an acceptable risk. The application for an exemption is granted.
- .2 The voyage(s) or route(s) may represent an unacceptable risk. Further consideration is required.
- .3 The voyage(s) or route(s) represent(s) an unacceptable risk. The exemption from the ballast water management requirements of regulation B-3 or C-1 of the Convention is not granted.

More Information?

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