Annex A

IMSBC Code - schedule entry for aluminium smelting/remelting by-products

ALUMINIUM SMELTING BY-PRODUCTS or
ALUMINIUM REMELTING BY-PRODUCTS UN 3170

DESCRIPTION
Aluminium smelting by-products are wastes from the aluminium manufacturing process. Grey or black powder or lumps with some metallic inclusions. The term encompasses various different waste materials, which include but are not limited to:

ALUMINIUM DROSS
ALUMINIUM SALT SLAGS
ALUMINIUM SKIMMINGS
SPENT CATHODES
SPENT POTLINER

CHARACTERISTICS

ANGLE OF REPOSE	BULK DENSITY (kg/m^3)	STOWAGE FACTOR (m^3/t)
Not applicable	1220	0.82
SIZE	**CLASS**	**GROUP**
Not applicable	4.3	B

HAZARD
Contact with water may cause heating with possible evolution of flammable and toxic gases such as hydrogen, ammonia and acetylene.
This cargo is non-combustible or has a low fire-risk.
Fire is unlikely but may follow an explosion of flammable gas and will be difficult to extinguish.
In port, flooding maybe considered, but due consideration should be given to stability.

STOWAGE & SEGREGATION
"Separated from" foodstuffs and all class 8 liquids.

HOLD CLEANLINESS
Clean and dry as relevant to the hazards of the cargo.

WEATHER PRECAUTIONS
This cargo shall be kept as dry as practicable. This cargo shall not be handled during precipitation. During handling of this cargo all non-working hatches of the cargo spaces into which this cargo is loaded or to be loaded shall be closed.

LOADING
Trim in accordance with the relevant provisions required under sections 4 and 5 of the Code.

PRECAUTIONS

Prior to loading this cargo, a certificate shall be provided by the manufacturer or shipper stating that, after manufacture, the material was stored under cover, but exposed to the weather in the particle size to be shipped, for not less than 3 days prior to shipment. Whilst the ship is alongside and the hatches of the cargo spaces containing this cargo are closed, the mechanical ventilation shall be operated continuously as weather permits. During handling of this cargo, "NO SMOKING" signs shall be posted on decks and in areas adjacent to cargo spaces and no naked lights shall be permitted in these areas. At least two self-contained breathing apparatus, in addition to those required by SOLAS regulation II-2/10.10, shall be provided on board. Bulkheads between the cargo spaces and the engine-room shall be gastight. Inadvertent pumping through machinery spaces shall be avoided.

VENTILATION

Continuous mechanical ventilation shall be conducted during the voyage for the cargo spaces carrying this cargo. If maintaining ventilation endangers the ship or the cargo, it may be interrupted unless there is a risk of explosion or other danger due to interruption of the ventilation. In any case mechanical ventilation shall be maintained for a reasonable period prior to discharge. Ventilation shall be arranged such that any escaping gases are minimized from reaching living quarters on or under the deck.

CARRIAGE

For quantitative measurements of hydrogen, ammonia and acetylene, suitable detectors for each gas or combination of gases shall be on board while this cargo is carried. The detectors shall be of certified safe type for use in explosive atmosphere. The concentrations of these gases in the cargo spaces carrying this cargo shall be measured regularly, during voyage, and the results of the measurements shall be recorded and kept on board.

DISCHARGE

No special requirements.

CLEAN-UP

Water shall not be used for cleaning of the cargo space which has contained this cargo, because of danger of gas.

EMERGENCY PROCEDURES

SPECIAL EMERGENCY EQUIPMENT TO BE CARRIED Nil
EMERGENCY PROCEDURES Nil **EMERGENCY ACTION IN THE EVENT OF FIRE** Batten down and use CO_2 if available. **Do not use water**. If this proves ineffective, endeavour to stop fire from spreading and head for the nearest suitable port. **MEDICAL FIRST AID** Refer to the Medical First Aid Guide (MFAG), as amended.

IMSBC Code - 16 point cargo information list and cargo declaration form

Section 4

Assessment of acceptability of consignments for safe shipment

4.1 Identification and classification

4.1.1 Each solid bulk cargo in this Code has been assigned a Bulk Cargo Shipping Name (BCSN). When a solid bulk cargo is carried by sea it shall be identified in the transport documentation by the BCSN. The BCSN shall be supplemented with the United Nations (UN) number when the cargo is dangerous goods.

4.1.2 If waste cargoes are being transported for disposal, or for processing for disposal, the name of the cargoes shall be preceded by the word “WASTE”.

4.1.3 Correct identification of a solid bulk cargo facilitates identification of the conditions necessary to safely carry the cargo and the emergency procedures, if applicable.

4.1.4 Solid bulk cargoes shall be classified, where appropriate, in accordance with the UN Manual of Tests and Criteria, part III. The various properties of a solid bulk cargo required by this Code shall be determined, as appropriate to that cargo, in accordance with the test procedures approved by a competent authority in the country of origin, when such test procedures exist. In the absence of such test procedures, those properties of a solid bulk cargo shall be determined, as appropriate to that cargo, in accordance with the test procedures prescribed in appendix 2 to this Code.

4.2 Provision of information

4.2.1 The shipper shall provide the master or his representative with appropriate information on the cargo sufficiently in advance of loading to enable the precautions which may be necessary for proper stowage and safe carriage of the cargo to be put into effect.

4.2.2 Cargo information shall be confirmed in writing and by appropriate shipping documents prior to loading. The cargo information shall include:

.1 the BCSN when the cargo is listed in this Code. Secondary names may be used in addition to the BCSN;

.2 the cargo group (A and B, A, B or C);

.3 the IMO Class of the cargo, if applicable;

.4 the UN number preceded by letters UN for the cargo, if applicable;

.5 the total quantity of the cargo offered;

.6 the stowage factor;

.7 the need for trimming and the trimming procedures, as necessary;

.8 the likelihood of shifting, including angle of repose, if applicable;

.9 additional information in the form of a certificate on the moisture content of the cargo and its transportable moisture limit in the case of a concentrate or other cargo which may liquefy;

.10 likelihood of formation of a wet base (see subsection 7.2.3 of this Code);

.11 toxic or flammable gases which may be generated by cargo, if applicable;

.12 flammability, toxicity, corrosiveness and propensity to oxygen depletion of the cargo, if applicable;

.13 self-heating properties of the cargo, and the need for trimming, if applicable;

.14 properties on emission of flammable gases in contact with water, if applicable;

.15 radioactive properties, if applicable; and

.16 any other information required by national authorities.

4.2.3 Information provided by the shipper shall be accompanied by a declaration. An example of a cargo declaration form is set out in the next page. Another form may be used for cargo declaration. As an aid to paper documentation, Electronic Data Processing (EDP) or Electronic Data Interchange (EDI) techniques may be used.

FORM FOR CARGO INFORMATION
for Solid Bulk Cargoes

BCSN	
Shipper	Transport document number
Consignee	Carrier
Name/means of transport Port/place of departure	Instructions or other matters
Port/place of destination	
General description of the cargo (Type of material/particle size)	Gross mass (kg/tonnes)
Specifications of bulk cargo, if applicable: Stowage factor: Angle of repose, if applicable: Trimming procedures: Chemical properties if potential hazard*: * e.g., Class & UN No. or “MHB”	
Group of the cargo ☐ Group A and B* ☐ Group A* ☐ Group B ☐ Group C * For cargoes which may liquefy (Group A and Group A and B cargoes)	Transportable Moisture Limit Moisture content at shipment
Relevant special properties of the cargo (e.g., highly soluble in water)	Additional certificate(s)* ☐ Certificate of moisture content and transportable moisture limit ☐ Weathering certificate ☐ Exemption certificate ☐ Other (specify) * If required
DECLARATION I hereby declare that the consignment is fully and accurately described and that the given test results and other specifications are correct to the best of my knowledge and belief and can be considered as representative for the cargo to be loaded.	Name/status, company/organization of signatory Place and date Signature on behalf of shipper

Carrying solid bulk cargoes safely - booklet

Carrying solid bulk cargoes safely

Guidance for crews on the International Maritime Solid Bulk Cargoes Code

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Contents

Introduction

Carrying solid bulk cargoes involves serious risks, which must be managed carefully to safeguard the crew and the ship. These risks include reduced ship stability (and even capsizing) due to cargo liquefaction; fire or explosion due to chemical hazards; and damage to ship structures due to poor loading procedures.

The main legislation governing safe carriage of solid bulk cargoes is the International Maritime Solid Bulk Cargoes (IMSBC) Code, which became mandatory on January 1, 2011, under the SOLAS Convention[1].

This pocket guide will help you understand the IMSBC Code's key requirements and give you greater confidence in managing the risks associated with the carriage of solid bulk cargoes. It outlines the precautions you should take before accepting cargoes for shipment and the procedures you should follow for safe loading and carriage, and details the primary hazards associated with the different types of solid bulk cargo.

It also contains a quick reference checklist and flowchart summarising the steps you need to follow.

Note: This guide is only an introduction to the IMSBC Code; you should always consult the full Code to check the requirements for each cargo you are carrying. It does not cover carriage of grain in bulk; this is covered by the International Grain Code.

Look for "Consult the Code" headings within this publication, which refer you to specific sections of the Code for more information.

[1]For a list of other IMO legislation and guidance relating to bulk cargoes, see Appendix 1.

1. General requirements for carrying solid bulk cargoes

No matter what solid bulk cargo you are carrying, the same general requirements apply for accepting them for shipment and loading them. Section 2 of this pocket guide covers the typical requirements for different types of cargo.

Accepting cargoes for shipment

Information required from the shipper

Before you can accept a cargo for shipment, the shipper must provide the Master with valid, up-to-date information about the cargo's physical and chemical properties. The exact information and documentation they must provide is listed in the Code under 'Assessment of acceptability of consignments for safe shipment; Provision of Information', and includes the correct Bulk Cargo Shipping Name[2] and a declaration that the cargo information is correct.

Consult the Code – see Section 4

Checking the cargo schedule

Individual cargoes are listed in 'schedules' which are contained in Appendix 1 of the Code. These describe each cargo's properties and detail the requirements for handling, stowing and carrying it safely. You must always consult the relevant schedule in the Code to find out what hazards the cargo presents.

Consult the Code – see Appendix 1

Cargo being worked

[2]This is the cargo's official name used in the Code.

Accepting cargoes not listed in the IMSBC Code

The list of individual cargoes contained in the Code is not exhaustive. If a cargo not listed in the Code is presented for shipment, the shipper and the appropriate competent authorities[3] must follow this process:

1. Before loading, the shipper must provide details of the characteristics and properties of the cargo to the competent authority of the port of loading.
2. Based on this information the competent authority of the port of loading will assess the acceptability of the cargo for shipment.
   – If the assessment defines the cargo as Group A or B[4], the competent authorities[3] will set the preliminary suitable conditions for carriage.
   – If the cargo is Group C[4] then carriage can be authorised by the port of loading and the competent authorities of the unloading port and flag state will be informed of the authorisation.
3. In both cases, the competent authority of the port of loading will give the Master a certificate stating the characteristics of the cargo and the required conditions for carriage and handling. The competent authority of the port of loading will also provide the same information to the IMO.

Consult the Code – see Section 1.3

Exemptions

Under section 1.5 of the Code, a competent authority (or authorities) can grant an exemption which allows ships to carry a cargo outside the requirements specified in its schedule, provided that equivalent provisions have been put in place.

Agreement of all three competent authorities is required to ship a cargo under an exemption. Acceptance of an exemption by authorities not party to it is discretionary: i.e., if the loading port authority issues an exemption, the unloading port and flag state authorities can choose to accept it or reject it.

An exemption can be valid for up to five years and does not necessarily lead to the creation of a new or revised schedule.

Consult the Code – see Section 1.5

[3]The competent authorities of the port of loading, the port of unloading and the flag state.
[4]The Code categorises cargo into three Groups – A, B and C. See page 7 for their definitions.

Loading

Inspecting and preparing cargo spaces

In general, before loading a cargo you must inspect and prepare the cargo spaces, checking that:

- bilge wells and strainer plates are prepared to facilitate drainage and prevent cargo entering the bilge system
- bilge lines, sounding pipes and other service lines are in good order
- cargo space fittings are protected from damage, and
- measures are in place to minimise dust entering living quarters or other interior spaces, or coming into contact with moving parts of deck machinery and external navigational aids.

Distribution and stability

You must also make sure that cargoes are properly distributed throughout the ship's holds to provide adequate stability and ensure that the ship's structure is never overstressed. Information can be found in the ship's stability information booklet or you can use loading calculators if they are available. The Master will need to calculate the stability for the anticipated worst conditions during the voyage as well as for departure and demonstrate that the stability is adequate.

Loading Plan

Before loading or unloading, the Master and the terminal representative must agree a Loading Plan to ensure that the permissible forces and moments on the ship are not exceeded. What this Plan should include is detailed in the Code of Practice for the Safe Loading and Unloading of Bulk Carriers (the BLU Code) and in the checklist on page 16.

2. The Code's three cargo groups

The IMSBC Code categorises cargoes into three groups:

Group A – cargoes which may liquefy if shipped at a moisture content exceeding their Transportable Moisture Limit (TML)[5].

Group B – cargoes which possess a chemical hazard which could give rise to a dangerous situation on a ship.

Group C – cargoes which are neither liable to liquefy (Group A) nor possess chemical hazards (Group B). Cargoes in this group can still be hazardous.

You can find the Group for a particular cargo in its schedule.

Liquefied nickel ore (Image courtesy of MTD)

[5]The TML is the maximum moisture content considered safe for carriage. See page 9.

Group A cargoes (cargoes which may liquefy)

What is liquefaction and how does it affect cargo?

Liquefaction means that a cargo becomes fluid (liquefies). On ships, this happens when the cargo is compacted by the ship's motion. Cargoes which are prone to liquefaction contain a certain quantity of moisture and small particles, although they may look relatively dry and granular when loaded. Liquefaction can lead to cargo shift[6] and even to the capsize and total loss of the ship, and can occur even when cargoes are cohesive and trimmed level.

Consult the Code – see Section 7

Examples of Group A cargoes

Mineral concentrates

Mineral concentrates are refined ores in which valuable components have been enriched by eliminating most waste materials. They include copper concentrate, iron concentrate, lead concentrate, nickel concentrate and zinc concentrate.

Nickel ore[7]

There are several types of nickel ore which vary in colour, particle size and moisture content. Some may contain clay-like ores.

Coal

Coal (bituminous and anthracite) is a natural, solid, combustible material consisting of amorphous carbon and hydrocarbons. It is best known as a Group B cargo due to its flammable and self-heating properties, but it can also be classed as Group A because it can liquefy if predominantly fine (i.e., if 75% is made up of particles less than 5mm in size). In these cases, it is classed as both Group A and B.

Coal being loaded. Coal is most commonly a Group B cargo, but can also be classed as both A and B.

[6]Cargo shift can be divided into two types: sliding failure or liquefaction consequence. Trimming the cargo can prevent sliding failure.

[7]Nickel ore is not to be confused with nickel concentrate.

Typical requirements for accepting and loading Group A cargoes

Information required from the shipper

To control the risks of liquefaction, Group A cargoes are tested to determine their Transportable Moisture Limit (TML) and their actual moisture content before they can be shipped. The TML is the maximum moisture content considered safe for carriage. The actual moisture content of the cargo must be below the TML.

The information supplied by the shipper to the master must include a signed certificate stating the TML, and a signed certificate or declaration of the cargo's actual moisture content.

Hui Long, a bulk carrier which sank in 2005. The cause was believed to be liquefaction, possibly due to the TML being exceeded.

What you need to do

Follow these steps when carrying Group A cargoes to reduce the risk of liquefaction:

– Make sure the shipper has supplied the required information, including the TML and the actual moisture content.

– Only accept the cargo if the actual moisture content is less than its TML.

– Carry out visual monitoring during loading. If there are any indications of high moisture content, stop loading and seek further advice.

– Consider trimming the cargo to reduce the likelihood of cargo shift.

– Take measures to prevent water or other liquids entering the cargo space during loading and throughout the voyage.

Practical guidance on managing the risks of liquefaction is also available from the UK P&I Club at **www.ukpandi.com/loss-prevention**

Consult the Code – see Sections 7 and 8

Group B cargoes (cargoes with chemical hazards)

Group B cargoes are classified in two ways within the Code: 'Dangerous goods in solid form in bulk' (under the International Maritime Dangerous Goods (IMDG) Code; and 'Materials hazardous only in bulk' (MHB).

You will find this information in the "characteristics" section of the cargo's schedule. Cargoes classified as dangerous goods in solid form in bulk will also have a 'UN' number in the Bulk Cargoes Shipping Name.

Consult the Code – see Section 9

Dangerous goods in solid form in bulk

In the Code these cargoes are classed as follows:

Class 4.1: Flammable solids
Class 4.2: Substances liable to spontaneous combustion
Class 4.3: Substances which, in contact with water, emit flammable gases
Class 5.1: Oxidizing substances
Class 6.1: Toxic substances
Class 7: Radioactive materials
Class 8: Corrosive substances
Class 9: Miscellaneous dangerous substances and articles.

Materials hazardous only in bulk (MHB)

MHB cargoes are materials which possess chemical hazards when transported in bulk that do not meet the criteria for inclusion in the IMDG classes above. They present significant risks when carried in bulk and require special precautions. They are described as follows:

Combustible solids: materials which are readily combustible or easily ignitable

Self-heating solids: materials that self-heat

Solids that evolve into flammable gas when wet: materials that emit flammable gases when in contact with water

Solids that evolve toxic gas when wet: materials that emit toxic gases when in contact with water

Toxic solids: materials that are acutely toxic to humans if inhaled or brought into contact with skin

Corrosive solids: materials that are corrosive to skin, eyes, metals or respiratory sensitisers.

Examples of Group B cargoes and the risks they present

The major risks associated with Group B cargoes are fire and explosion, release of toxic gas and corrosion.

Coal

Coal may create flammable atmospheres, heat spontaneously, deplete oxygen concentration and corrode metal structures. Some types of coal can produce carbon monoxide or methane.

Direct reduced iron (DRI)

DRI may react with water and air to produce hydrogen and heat. The heat produced may cause ignition. Oxygen in enclosed spaces may also be depleted.

The damage caused by a DRI explosion (Image courtesy of Burgoynes)

Metal sulphide concentrates

Some sulphide concentrates are prone to oxidation and may have a tendency to self-heat, leading to oxygen depletion and emission of toxic fumes. Some metal sulphide concentrates may present corrosion problems.

Organic materials

Ammonium nitrate-based fertilisers

Ammonium nitrate-based fertilisers support combustion. If heated, contaminated or closely confined, they can explode or decompose to release toxic fumes and gases.

Wood products transported in bulk[8]

Wood products transported in bulk are listed in a new schedule to the Code: Wood Products – General. They include logs, pulpwood, roundwood, saw logs and timber. These cargoes may cause oxygen depletion and increase carbon dioxide in the cargo space and adjacent spaces.

[8]These are wood products loaded and discharged by methods such as elevators and grabs. They are distinct from wood products listed in other schedules.

Typical requirements for accepting and loading Group B cargoes

Information required on board ship for dangerous goods in solid form in bulk

To carry dangerous goods in solid form in bulk, your ship must have a Document of Compliance for the Carriage of Dangerous Goods, supplied by the ship's flag or classification society. The Master must have a special list, manifest or stowage plan identifying the cargo's location, and there must be instructions on board for emergency response.

Segregation

Because of their potential hazards, many Group B cargoes are incompatible and must be segregated. When segregating cargoes, you should take into account any secondary risks they present.

Consult the Code – see Section 9.3

Coal on fire in a cargo hold

Specific risk mitigation measures

The cargo's schedule and the information provided by the shipper will detail the precautions you must take when carrying Group B cargoes. The following are some of the common risk mitigation measures you will employ.

Fire and explosion

Depending on the cargo, precautions against fire and explosion may include ventilating or inerting the cargo holds and the enclosed spaces adjacent to the holds: in some cases the ventilators will need to be explosion proof. The atmosphere in the cargo holds and the enclosed spaces adjacent to the holds may also need to be monitored with an appropriate gas detector.

Toxic gas

Toxic gas risks will be mitigated using natural or forced mechanical ventilation. The choice of ventilation will depend on the type of cargo and the properties of the gas (i.e., whether it creates an explosive atmosphere). You may need to monitor the cargo hold atmosphere.

Corrosion

Corrosion can be caused by some Group B cargoes and their residues. A coating or barrier may need to be applied to the cargo space structures before loading. Before loading and unloading corrosive cargoes, make sure the cargo space is clean and dry.

DRI which has self heated (Image courtesy of Burgoynes)

Group C cargoes (cargoes which are neither liable to liquefy nor possess chemical hazards)

Although Group C cargoes do not present the dangers associated with Group A and B cargoes, they can still carry risks.

Examples of Group C cargoes, their risks and mitigation measures

Iron ore and high density cargoes

These cargoes can be extremely dense and can overstress the tanktop. Make sure that their weight is evenly distributed during loading and during the voyage so that the tanktop is not overstressed, and also consider trimming the cargo. Loading rates of iron ore are normally very high and you should also consider the ship's ballasting operations and loading sequences.

Sand and fine particle materials

Fine particle materials can be abrasive. Silica dust is easily inhaled and can result in respiratory disease.

You should take appropriate precautions to protect machinery and accommodation spaces from the dust of sand and fine particle cargoes, and to prevent the cargo from getting into the bilge wells. People who may be exposed to cargo dust should wear goggles or other equivalent dust eye-protection, dust filter masks and protective clothing.

Cement

Cement may shift when aerated during loading. Dust can also be produced from this cargo. Follow the precautions for sand and fine particle materials (above).

3. Other hazards associated with carrying solid bulk cargoes

Entering enclosed spaces

Always follow the appropriate procedures before entering an enclosed space, taking into account IMO Resolution A.1050(27) – Revised Recommendations for Entering Enclosed Spaces Aboard Ships. Note: after a cargo space or tank has been tested and generally found to be safe for entry, small areas may exist where oxygen is deficient or toxic fumes are still present.

Pesticides

The risks of using pesticides include the accumulation of gas in spaces adjacent to the cargo holds being treated or, if it is essential to ventilate the cargo holds, accumulation of fumigant in accommodation and working areas.

Fumigants such as Phosphine and Methyl Bromide are poisonous to humans and if they are not handled correctly, they can also represent a fire risk. They should only be used by specialists and not by the ship's crew.

Carry out any fumigation in line with the IMO Circular, MSC.1/Circ.1264 – Recommendations on the Safe Use of Pesticides in Ships Applicable to the Fumigation of Cargo Holds. This is contained in the supplement to the Code.

The ship should carry gas-detection equipment, adequate respiratory protective equipment, a copy of the latest version of the Medical First Aid Guide for Use in Accidents Involving Dangerous Goods (MFAG), and appropriate medicines and medical equipment.

4. Checklist and flowchart for accepting and loading solid bulk cargoes

The checklist on the next two pages and the loading flowchart on page 18 bring together all the key procedures you must follow when accepting and loading any solid bulk cargo for shipment. Always consult the Code itself to ensure that all mandatory measures and specific advice have been implemented.

Download a large version of the flowchart at **www.lr.org/imsbc**

Checklist

Before accepting and loading a cargo, ask yourself the following questions:

1. Has the shipper delivered the cargo information and documentation listed in the Code under 'Assessment of acceptability of consignments for safe shipment; Provision of Information', including the correct Bulk Cargo Shipping Name (BCSN), and provided a declaration that the cargo information is correct? ☐

2. Have you consulted the relevant IMSBC Code schedule to find out the cargo's general and specific hazards? ☐

3. If the cargo is listed as Group A, have you followed all procedures relating to the safe carriage of cargoes which may liquefy? ☐

4. If the schedule indicates the cargo is Group B has the shipper provided a statement that the chemical characteristics of the cargo are, to the best of his knowledge, those present at the time of loading? ☐

   a) If the cargo is classified as 'dangerous goods in solid form in bulk' does the Master have a special list, manifest or stowage plan identifying its location, are there instructions on board for emergency response, and does the ship have a Document of Compliance for the Carriage of Dangerous Goods? ☐

(Continued on the next page)

Checklist (continued)

5. Whatever the cargo Group, have you taken the recommended precautions to remove or minimise the cargo's hazard, including:
   a) preparing recommended safety equipment and procedures? ☐
   b) activating any cargo monitoring equipment ready for loading? ☐

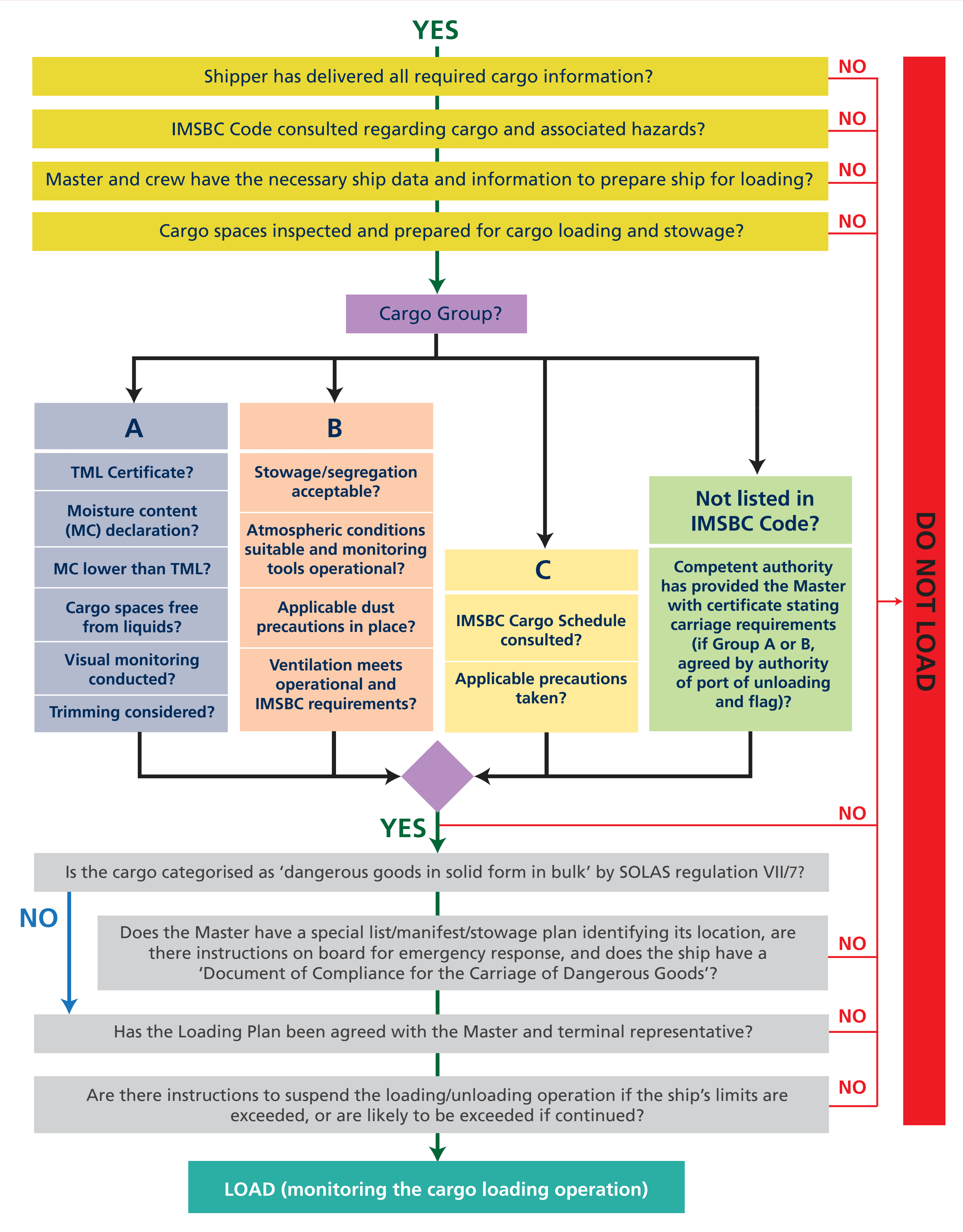
6. Have the Master and Terminal Representative agreed a Loading Plan to ensure that the permissible forces and moments on the ship are not exceeded during loading or unloading? This should include the sequence, quantity and rate of loading or unloading, the number of pours and the de-ballasting or ballasting capability of the ship. ☐

7. Are there instructions to suspend the loading or unloading operation if the ship's limits are exceeded, or are likely to be exceeded if the operation continues? ☐

8. Are you monitoring the cargo loading or unloading procedure, is the ship's draught being monitored and recorded in the logbook, and have any significant deviations been corrected? ☐

9. Before sailing on the loaded passage, have you considered other factors, such as the ingress of water, which could affect the cargo during the passage? ☐

Loading flowchart – follow the steps to see if it is safe to load your cargo



Appendix 1 – IMO regulations and guidance relating to the transport of solid bulk cargoes

Mandatory regulations

International Convention for the Safety of Life at Sea (SOLAS)
– Chapter VI: Carriage of cargoes
– Chapter VII: Carriage of dangerous goods
– Chapter XII: Additional safety measures for bulk carriers

International Maritime Solid Bulk Cargoes (IMSBC) Code – facilitates the safe stowage and shipment of solid bulk cargoes by providing information on the risks associated with their shipment, and the procedures to be adopted for carriage.

International Code for the Safe Carriage of Grain in Bulk (International Grain Code) – contains regulations and guidance for ships engaged in the carriage of grain in bulk.

Code of Safe Practice for Ships Carrying Timber Deck Cargoes – provides stowage, securing and other operational safety measures designed to ensure the safe transport of timber cargoes, primarily stowed on deck.

MARPOL Annex V – Regulations for the Prevention of Pollution by Garbage from Ships – includes requirements for discharge of dry bulk cargo residues and cargo hold wash-water containing cargo residues.

Guidance

Code of Practice for the Safe Loading and Unloading of Bulk Carriers (BLU Code) – assists those responsible for the safe loading or unloading of bulk carriers to carry out their functions and to promote the safety of bulk carriers.

Circulars and Resolutions

- MSC.1/Circ.1160 – Manual on Loading and Unloading of Solid Bulk Cargoes for Terminal Representatives.
- MSC. 1/Circ.1357 – Additional Considerations for the Safe Loading of Bulk Carriers

Circulars and Resolutions (continued)

- MSC. 1/Circ.908 – Uniform Method of Measurement of the Density of Bulk Cargoes
- MSC. 1/Circ.1395 – Lists of Solid Bulk Cargoes for which a Fixed Gas Fire-extinguishing System may be Exempted or for which a Fixed Gas Fire-extinguishing System is Ineffective
- Resolution A.1050(27) – Revised Recommendations for Entering Enclosed Spaces Aboard Ships
- MSC. 1/Circ.1264 – Recommendations on the Safe Use of Pesticides in Ships Applicable to the Fumigation of Cargo Holds
- BC. 1/Circ.69 – Contact Names and Addresses of the Offices of Designated National Competent Authorities Responsible for the Safe Carriage of Grain and Solid Bulk Cargoes.

Appendix 2 – the Code section by section

Section 1 – General provisions – including application, definitions, related SOLAS regulations

Section 2 – General loading, carriage and unloading precautions – cargo distribution and loading/unloading procedures

Section 3 – Safety of personnel and ship - poisoning, corrosive and asphyxiation hazards, dust hazards, flammability and ventilation

Section 4 – Assessment of acceptability of consignments for safe shipment – identification of cargoes, and the tests and documentation required for their safe carriage

Section 5 – Trimming procedures

Section 6 – Methods of determining angle of repose

Section 7 – Cargoes that may liquefy – the dangers of liquefaction, conditions under which liquefaction may take place and precautions to prevent it

Section 8 – Test procedures for cargoes that may liquefy

Section 9 – Materials possessing chemical hazards – classification of hazards, stowage and segregation requirements

Section 10 – Carriage of solid bulk wastes – their classification, segregation and stowage

Section 11 – Security provisions

Section 12 – Stowage factor conversion tables

Section 13 – References to related information and recommendations

Appendices

Appendix 1 – Individual schedules of solid bulk cargoes

Appendix 2 – Laboratory test procedures, associated apparatus and standards

Appendix 3 – Properties of solid bulk cargoes

Appendix 4 – Index of solid bulk cargoes

Supplement – this contains supporting documents including the BLU Code and IMO circulars (see Appendix 1)

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LIFE MATTERS

Material Safety Data Sheet for U-IBA

MATERIAL SAFETY DATA SHEET According to EU Directive nr. 1907/2006 and nr 1272/2008 en 453/2010		
Untreated Incinerator bottom ash		
Produced by: IndusTox Consult (fj)	**Version:** 1.0 **Edition**: 23-02-2012	

1. IDENTIFICATION OF THE MATERIAL

1.1. Identification of the compound	
Product name:	Untreated incinerator bottom ash
Chemical name:	A mixture of particles consisting of minerals like calcium carbonate, calcium sulphate, iron oxide en aluminium silicates together with scrab and metal particles like aluminium, lead, zinc and copper
Commercial name:	Raw IBA
CAS nr:	Not applicable

1.2. Usage of the material
Raw IBA is the untreated IBA which is produced as a residue by incineration of household and commercial waste. Raw bottom ash contains big pieces of bottom ash together with scrap and non ferrous metals mainly aluminium. Also there is a minor piece of unburned material in it. The product is heterogeneous. De raw bottom ash is upgraded by treatment to produce IBA which is a building material which is used in the road construction industry. The treatment consists of separating the scrap, non-ferrous particles and unburned pieces form the mineral pieces which are minimized to a maximum grain size of 40 mm.

1.3. Identification of the producer	
Producer: Address: Place: Telephone: Fax: E-mail: Web site:	

1.4. Telephone numer in case of Emergency	
Producer: Telephone (24 hours a day): National contact: Telephone:	

2. IDENTIFICATION OF THE RISKS

2.1. Classification of the material	
Classification according to EU 1272/2008	No risk classification. This product contains respirable crystalline silica as an impurity. The concentration of respirable quartz is less than 1%. Therefore it is non-hazardous. The Industrial Mineral Producers (IMA) pose that silicoses is the critical effect of inhalation of respirable crystalline silica and that lung cancer is a secondary effect. This product is classified according to the criteria of the Industrial Mineral Producers (IMA). The product contains Pb as an impurity. Lead compounds are harmful to the reproduction. The concentration is less than 0,3 % and therefore the product is not classified as harmful to the reproduction.

EG-classification/EWC	Non-hazardous waste with code 19.01.12 according to the European Waste catalogue: bottom ash and slag which are not in the category of bottom ash containing hazardous compounds”.

2.2. Labelling	
	No risk labelling

2.3. Other risks	
	None

3. SAMENSTELLING / INFORMATIE OVER DE BESTANDDELEN

Name	**Percentage (v/v)**	**Risks of the constituents**
Raw AEC-bodemas	100%	-
Pb-compound	1 - 2 g/kg	H360, H332, H302, H373, H410
Zn-compound	3 - 4 g/kg	H302, H314, H410
Sum of 6 PCB’s	< 175 μg/kg	H373, H410
Dioxins (as TEQ)	0,02- 0,05 μg/kg	H373, H350
Total-PAH	< 30 mg/kg	H350, H340, H360, H317, H410
Respirable crystalline silica, under which quartz	Max 0,01 % (v/v)	H350, H373

4. First Aid Arrangements

Rae IBA is rich of chalk and has a pH of 9 - 12 and therefore it is an alkaline product. The following points are addressed to this property

4.1. Ogen	
Effect: First aid:	Possible irritating for the eyes. Red eyes and tears. Flush with water and when necessary consult a doctor.

4.2. Inhalation	
Effect: First aid:	Possible light irritation of the air way, but not to expect. Fresh air; when necessary consult a doctor.

4.3. Swallowing	
Effect: First aid:	Inflamed feeling in the stomach. Flush mouth, drink water, consult the Urgent Help of the nearest hospital when the complaint last longer than one hour.

4.4. Skin	
Effect:	Possibly light irritating, red skin.
First aid:	Wash skin and hands with soap before eating, drinking, toileting and smoking, take of polluted clothes and wash regularly. When skin eruption occurs ask a doctor

5. FIRE PREVENTION

Fire prevention by:	The material is inflammable. No dangerous situation can be expected in case of fire.
Suitable quenching aids	All quenching aids are permitted

6. MEASUREMENTS WHEN DUST IS RELEASED ACCIDENATALY

6.1. Personal precaution	
	Direct contact with the skin is not advisable. Wear complete covering working clothes, use working gloves and wear safety goggles and breath protection FFP3.

6.2. Environment precaution	
	Keep windows and doors of building and vehicles closed when possible. Avoid contact of raw bottom ash with the sewer, surface water or direct contact with the soil.

6.3. Cleaning methods	
	Avoid flying away of dust and spray after enduring dryness. Spoiled product can be discharged according to the European Waste catalogue (code 19.01.12). Don’t flush the spoiled material into the sewer or into the surface water.

7. HANDLING AND STORAGE

7.1. Safe handling	
	Dust category S5: Hardly sensitive to dust when > 15% of moisture. Can be categorized to higher class when the moisture content is < 15% Prevent forming of dust when handled. Use protection of airways when ventilation is not possible. Don’t eat, drink and smoke on the working place. Wash hands after using. Take of personal protection and working clothes when an eating place is entered.

7.2. Conditions for save storage	
	Raw bottom ash has puzzolanic properties whereby the granulate will form a bound mass. When stored in a closed facility ventilate.

8. PRECAUTIONS TO CONTROL EXPOSURE / PERSONAL PROTECTION

8.1. Limits for exposure	
Technical arrangements:	When handling IBA take measurement to prevent dust.
Exposure limits	Target limit for inhaling: 3,0 mg/m^3 als TGG-8 uur.
Personal protection means	**Inhalation** Working when dust: dusk mask with FFP3-filter. **Hands** Working with contact: Working gloves. **Eye** Working when dust: Safety goggles. **Skin and body** In dirt surroundings: Complete covering working clothes

9. FYSICALK AND CHEMICAL PROPERTIES

9.1. General information	
Fysical form:	Solid compound both lumps and dust. Can contain big pieces of metals
Smell:	Typical light cement smell
Colour:	Dark grey till black

9.2. Important health, environmental and safety information	
pH:	Between 9 en 12
Density:	When deposited ca. 1550 kg/m^3 , Densed ca. 1800 kg/m^3
Damp density:	Not applicable
Melting point:	Not applicable
Flame pint:	Inflammable
Boiling point:	Not applicable
Explosive:	Non-explosive
Solubility in water:	Insoluble. A part of the metal compounds and salts can leach.

10. STABILITY AND REACTIVITY

10.1. Stability product	
	Avoid contact with groundwater because compounds which are harmful to the environment can be leached. When stored for a long time the temperature can rise very little because of cementious reactions..

10.2. Materials to avoid	
	Not known and not to expect

10.3. Hazardous decomposing compounds	
	When contacted with water (H_2O) possible formation of hydrogen gas (H_2-gas). Under reducing circumstanced ammonia can be formed (NH_3). Accidentally fosfine (PH_3) can escape.

10.4 Reactivity	
	Not known and not to expect

11. TOXICOLOGAL INFORMATION

11.1. Acute toxicity	
Lethal dose (LD)50 oral, rat:	Not known
Direct consequences:	When dust enters the eyes it can irritate. When swallow it can irritate the stomach and intestinal tube

11.2. Chronically toxicity	
Long term consequences:	Not known.

12. ECOLOGICAL INFORMATION

Ecotoxicity: Ecotoxicologal information is not known. It is to be expected that because of pH adjustment there can be effect in aquatic systems

13. INSTRUCTIONS FOR REMOVING

13.1. Waste/Unused products	
	Take spoiled material back to the pile or bring it to a certified handler according to the EWC.

13.2. Packing	
	No special demands

14. INFORMATION ABOUT TRANSPORT

UN-number and class:	None
ADR/ADNR/RID:	Not applicable
General:	No special precautions needed according to the transport demands for non hazardous goods. Avoid dust formation and spoiling during loading.

	Cover when transported.

15. OBLIGATORY LEGAL INFORMATION

EG classification waste materials:	Non-hazardous waste with code 19.01.12 according to the European Waste catalogue: bottom ash and slag which are <u>not</u> in the category of bottom ash containing hazardous compounds".
EG-hazardous classification	EG-hazardous classification is not applicable because bottom ash is a waste. According to the classification of the Industrial Mineral Producers Association (IMA) this material is to be classified as non-hazardous (see also section 16)

16. OTHER INFORMATION

16.1. Other information	
IMA classification rules quartz	The Industrial Minerals Producers (IMA) have determined that respirable crystalline silica (=RCS) is best to classified as STOT RE Category 1 because of the danger of silicoses. STOT means 'Specific Target Organ Systemic Toxicant'. RE means "Repeated Exposure". Based on scientific evidence it is determined that is general necessary to inhale over a longer period repeated significant amounts of RCS on the working spot before possible health effect can occur. Because of the classification all products that contain RCS, despite the fact this is an impurity, additive or constituent has to be classified as: - STOT RE 1, when de RCS concentration ≥10%; - STOT RE 2, when de RCS concentration is between 1 and 10%.

UN Test N.5, extract from the Manual of Tests and Criteria

33.4.1.4 *Test N.5: Test method for substances which in contact with water emit flammable* gases

33.4.1.4.1 Introduction

The ability of a substance to emit flammable gases on contact with water is tested by bringing it into contact with water under a variety of conditions.

33.4.1.4.2 Apparatus and materials

No special laboratory apparatus is required.

33.4.1.4.3 Procedure

33.4.1.4.3.1 The substance should be tested according to the procedures described below; if spontaneous ignition occurs at any stage then no further testing is necessary. If it is known that the substance does not react violently with water then proceed to 33.4.1.4.3.5.

33.4.1.4.3.2 A small quantity (approximately 2 mm diameter) of the test substance should be placed in a trough of distilled water at 20 °C. It is noted:

(a) Whether any gas is evolved; and

(b) If spontaneous ignition of the gas occurs.

33.4.1.4.3.3 A small quantity of the test substance (approximately 2 mm diameter) should be placed on the centre of a filter paper which is floated flat on the surface of distilled water at 20 °C in a suitable vessel, e.g. a 100 mm diameter evaporating dish. The filter paper is to keep the substance in one place, under which condition the likelihood of spontaneous ignition of any gas is greatest. It is noted:

(a) Whether any gas is evolved; and

(b) If spontaneous ignition of the gas occurs.

33.4.1.4.3.4 The test substance should be made into a pile approximately 20 mm high and 30 mm diameter with a hollow in the top. A few drops of water are added to the hollow. It is noted whether:

(a) Any gas is evolved; and

(b) If spontaneous ignition of the gas occurs.

33.4.1.4.3.5 For solids, the package should be inspected for any particles of less than 500 μm diameter. If that powder constitutes more than 1% (mass) of the total, or if the substance is friable, then the whole of the sample should be ground to a powder before testing to allow for a reduction in particle size during handling and transport. Otherwise, as for liquids, the substance should be tested in its commercial state. This test should be performed three times at ambient temperature (20 °C) and atmospheric pressure. Water is put into the dropping funnel and enough of the substance (up to a maximum mass of 25 g) to produce between 100 ml and 250 ml of gas is weighed and placed in a conical flask. The tap of the dropping funnel is opened to let the water into the conical flask and a stop watch is started. The volume of gas evolved is measured by any suitable means. The time taken for all the gas to be evolved is noted and where possible, intermediate readings are taken. The rate of evolution of gas is calculated over 7 hours at 1 hour intervals. If the rate of evolution is erratic or is increasing after 7 hours, the measuring time should be extended to a maximum time of 5 days. The five day test may be stopped if the rate of evolution becomes steady or continually decreases and sufficient data has been established to assign a packing group to the substance or to determine that the substance should not be classified in Division 4.3. If the chemical identity of the gas is unknown, the gas should be tested for flammability.

33.4.1.4.4 Test criteria and method of assessing results

33.4.1.4.4.1 A substance should be classified in Division 4.3 if:

(a) Spontaneous ignition takes place in any step of the test procedure; or

(b) There is an evolution of a flammable gas at a rate greater than 1 litre per kilogram of the substance per hour.

33.4.1.4.4.2 Packing group I should be assigned to any substance which reacts vigorously with water at ambient temperatures and generally demonstrates a tendency for the gas produced to ignite spontaneously, or which reacts readily with water at ambient temperatures such that the rate of evolution of flammable gas is equal to or greater than 10 litres per kilogram of substance over any one minute period.

33.4.1.4.4.3 Packing group II should be assigned to any substance which reacts readily with water at ambient temperatures such that the maximum rate of evolution of flammable gas is equal to or greater than 20 litres per kilogram of substance per hour, and which does not meet the criteria for packing group I.

33.4.1.4.4.4 Packing group III should be assigned to any substance which reacts slowly with water at ambient temperatures such that the maximum rate of evolution of flammable gas is greater than 1 litre per kilogram of substance per hour, and which does not meet the criteria for packing groups I or II.

33.4.1.4.5 Examples of results

Substance	**Rate of gas emission (litre/kg.h)**	**Spontaneous ignition of gas (yes/no)**	**Result**
Manganese ethylene bis (dithiocarbamate) complex with zinc salt 88% (Mancozeb)	0	Not applicable	Not 4.3

Marchwood Scientific Services flammable gas release test reports

HAZARD ASSESSMENT-GAS EVOLUTION FOR INCINERATOR BOTTOM ASH MVV DEVONPORT

Client	[redacted] MVV Devonport Ltd Creek Road Plymouth PL2 2BG
Report prepared by:	[redacted]
Report reviewed by:	[redacted]
Report number:	MSSL 117/563
Date:	3rd February 2017

INTRODUCTION

Marchwood Scientific Services Ltd (MSSL) has been commissioned to perform an assessment of gas evolution for a provided sample of Incinerator Bottom ash (IBA).

Background-
MSSL received a representative sample of IBA from MVV Devonport referenced MVV_IBA_250117_52_AWr for analysis. The analysis requirement was to assess the material for flammability/gas evolution in accordance with the latest United Nations Recommendations on the Transport of Dangerous Goods (ADR Regulations)
In accordance with the ADR Regulations a substance would be listed as Class 4.3 Hazardous when a substance, which, when in contact with water emits a flammable gas.
The regulations also state that Packing Group 111 shall be assigned to any substance which reacts slowly with water at ambient temperature such that the measured rate of evolution of flammable gas is greater than 1 litre per kilogram of substance per hour and which does not meet the criteria of Packing Groups 1 and 11.
The regulations include the Manual of Tests and Criteria Part 111 Section 33.4 and specify a test that must be undertaken to assess a substance as above.
The provided sample of IBA was tested by MSSL using methods in accordance with those specified,

TEST RESULTS-

The results of the laboratory analysis of the provided samples are provided below. Note that for all of the tests undertaken the material was ground to <500 µm particle size. This was not only required in order to obtain a sample of the correct specification for testing but also the regulations require this if initial inspection of a material indicates the presence of finer particles. This would indicate that the material may breakdown in transit.

Test specified in Section 33.4.1.4.3.2-

In accordance with this test a small quantity of substance (<2mm diameter) was placed in a trough of demineralised water at 20° C

RESULT- NO GAS OBSERVED

Test specified in Section 33.4.1.4.3.3-

In accordance with this test a small portion of the ground (<2mm diameter) material was placed on a filter paper (as support) and floated on the surface of an evaporating dish containing distilled water at 20° C.

RESULT- NO GAS OBSERVED

Test specified in Section 33.4.1.4.3.4-

In accordance with this test a portion of the ground (<2mm diameter) material was placed in a pile measuring 20mm high and 30mm diameter and a hollow made in the top of the pile. A few drops of water were then added to the hollow.

RESULT- NO GAS OBSERVED

Test specified in Section 33.4.1.4.3.5-

This method specifies that a portion of the ground (<500 µm diameter) material is placed in a conical flask and then water applied to the solid using a separating funnel. The rate/quantity of gas evolved, if any, is then measured over a prolonged period and the evolution rate calculated and compared with the limit value of 1 litre of gas evolved per kilogram of substance per hour.

Results-
The method does not specify the quantity of water that should be applied to the solid material therefore some experimentation was undertaken.
In order to accurately measure the rate of gas evolved a Buchner conical flask was used with side-arm. The side arm of the conical was then connected to a Tipping Bucket gas flow meter designed to measure very low gas flows. The Tipping Bucket gas flow meter is employed as part of the approved apparatus used as part of the Biomethane Potential (BMP) and Dynamic Respiration (DR4) tests.
The separating funnel was placed onto the Buchner flask and the water added. The separating funnel was then removed and the Buchner flask sealed. The gas evolved was then measured.
Applying a few drops of water resulted in no measurable gas flow. The gas was monitored over a period of 5 hours to check there was no delayed reaction. The test was then repeated using increasingly large quantities of water and the gas evolution measured. The results are provided in the table below-

Quantity of Solid used (grams)	**Quantity of water added (mls)**	**Quantity of Solid used (kilograms)**	**Gas evolved (litres/kilogram per hour) #**	**Limit value (litres/kilogram per hour)**	**Test Pass/Fail**
19.2	3.0	0.019	<0.01	1	Pass
18.6	10.0	0.019	<0.01	1	Pass
18.4	20.0	0.018	<0.01	1	Pass

this value is the maximum gas evolution rate per hour. Visibly some very small short-lived emissions of gas were observed within the first minute of each of the tests but these were below the measuring capabilities of the test apparatus.

CONCLUSION

The measured gas evolution rate for this material was below the 1 litre/Kg/Hour limit value.

Report by The Hydrogen Hazards Unit, London Southbank University

London South Bank University

<u>Report to the Marine Accident Investigation Branch</u>

<u>Assessment of the likely hydrogen concentration involved in the Nortrader explosion (13th January, Plymouth anchorage)</u>

11th April 2017

[redacted]

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Assessment of the likely hydrogen concentration involved in the Nortrader explosion (13th January, Plymouth anchorage)

From details of the accident investigation supplied it is clear that the explosion was initiated in the fo'c's'le and propagated back into the main cargo hold causing further ignition of a second much larger volume of hydrogen.

In this case we can safely assume that the flammable gas mixture has not detonated (see Note A) and the explosion can be classed as a vented deflagration. In simple terms the explosion is likely to have proceeded as follows.

Prior to the explosion the cargo hold was nominally sealed. Following the propagation of the explosion back into the cargo hold the pressure in the hold will have begun to rise as hydrogen/air is combusted. The flame will accelerate (depending on the hydrogen concentration and turbulence generated by flow over obstacles) as it propagates down the length of the hold. After a period of time (in this case estimated to be of the order of 0.15s) the pressure generated has caused the cleats to fail and hatches to lift. Depending on the rate of combustion and hence rate of pressure rise the lifting of the hatches will limit the ultimate pressure experience by the hold/hull to some degree i.e. they act as explosion relief vents. In the case of hydrogen, vents that are both very large and that can open rapidly (low inertia) are usually required to prevent an enclosure experiencing a significant overpressure above that required to open the vent.

The primary aim of this report is the estimation of the likely concentration of hydrogen present in the hold at the time of ignition.

1. Minimum possible quantity of hydrogen

The absolute minimum quantity of hydrogen involved in the explosion i.e. that needed to lift the weight of the hatches and break the cleats can be readily estimated by equating the hatch weight combined with the breaking force of the cleats to a force exerted on the hatches by an internal pressure in the cargo hold.

From the data supplied, the mass of all hatches (8x14 Tonne + 4 Tonne) equates to 116 Tonne and multiplying by gravity (9.8 m/s^2) a weight of 1138 kN. For the cleats the total break force works out to be ((56 x 8.75 Tonne + 10 x 9 Tonne) x 9.8 = 5690 kN. This then gives a combined force required to lift the hatches and break the cleats (F) of 6828 kN.

The internal pressure in the hold required to produce this amount of lift can then be estimated as F divided by the total surface area of the hatches (S) of 556 m^2. This then gives a pressure (Pv) of 12kPa (1.78 psi, 0.123 bar, 0.121 atm).

For explosions inside closed volumes the pressure generated can normally be equated to that determined theoretically by assuming constant volume adiabatic combustion. This pressure is most accurately determined using a thermochemical equilibrium solver such as STANJAN[1] or GASEQ[2]. The results of such calculations for hydrogen/air at an initial pressure of 1 atm and 298K are given in Figure 1.

It can be seen from figure 1, that the concentration required to produce 0.121 atm is theoretically very small and works out to be only 0.3%(v/v). Estimating the ullage volume of the hold (Note B) as 1900 m^3 this gives a volume of hydrogen of 6m^3 .

However, as can also be seen from figure 1, this value is well below the Lower Flammable Limit of 4% (v/v). For an explosion to generate close to 0.121 atm at 0.3% hydrogen (v/v) the 0.3%(v/v) would need to be confined to a localised region (e.g. all in a thin layer at the top of the hold or in a localised plume close to the fo'c's'le) at over 4% (v/v). For the situation described in this incident it seems highly unlikely that there would be significant stratification of hydrogen in the hold for the following reasons:

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[1] STANJAN is a computer program which calculates chemical equilibrium using the method of element potentials. It was developed by Professor W. C. Reynolds, Department of Mechanical Engineering, Stanford University, Stanford, CA 94305

[2] GASEQ is a thermochemical equilibrium solver for combustion problems developed by Chris Morley. http://www.gaseq.co.uk/

- From information provided by the MAIB it seems likely that the aluminium in the ash and hence the hydrogen production was distributed fairly evenly across the surface of the ash
- The generation and hence release of hydrogen to the cargo ullage was likely slow and chronic it would therefore be unlikely to have a large plume that would extend to ceiling level before mixing.
- The relatively high temperature of the waste bed would induce convection currents in the cargo hold and aid mixing.

On the assumption that the hydrogen is well mixed above the cargo the concentration in the cargo ullage would have to have been at least at the lower flammable limit of 4% for ignition to occur.

However, if well mixed, the ullage concentration would almost certainly have been significantly above 4%(v/v) (concentration as volume per volume percentage). Whereas with most fuels there is negligible difference between the concentration at which a mixture becomes flammable and when it becomes explosive, this is not true for hydrogen. For most fuels the upwards flammability limit corresponds to an adiabatic flame temperature of around 1000°C and the concentration is typically around 50% of the stoichiometric[3] concentration. In the case of hydrogen, however, the theoretical adiabatic flame temperature of a 4% (v/v) mixture is only 350°C and the concentration is 14% of stoichiometric. The reason for this is related to the high diffusivity of hydrogen in comparison to oxygen. Preferential diffusion occurs and the flame becomes unstable and breaks into cells. The hydrogen concentration at the convex flame cells increases and hence the localised flame temperatures, in excess of the calculated adiabatic flame temperature, are generated at the flame fronts. Near LFL (i.e.4%(v/v)) mixtures of hydrogen/air are therefore less "explosive" than near LFL mixtures of most other fuels (smaller temperature/pressure rises, slower flame velocities and incomplete combustion).
Between 4 & 9 % the overpressure experienced is some fraction of that predicted by thermodynamic calculation, as shown by the green shaded region on figure 1, (probably almost zero for most quiescent vessels) and depends on the geometry of

[3] The minimum concentration required to react with all the oxygen present. In the case of hydrogen/air 29.5%(v/v) .

the vessel, the point of ignition, initial turbulence of the mixture, and obstructions in the vessel which could cause turbulence. Flammability limits are often determined observing flame propagation in a tube. The 4%(v/v) limit is for upwards flame propagation i.e. ignition source at the bottom of a vertical tube . If ignition is at the top downwards propagation the length of the tube is not observed until 9%(v/v). If the tube is mounted horizontally sideways propagation is achieved around 6%(v/v). Additionally, mixtures at the upwards LFL of 4% require a flame or a high energy spark for ignition (15kV & 10J is typical for test apparatus).

Returning to the Nortrader incident, it was reported that there was an ignition of a volume of hydrogen/air mixture, starting inside a switch box in the fo'c's'le, which then propagated back into the cargo hold (probably via an insecure cargo light access plate). For this to have occurred it seems likely that the hydrogen concentration in the cargo hold (and the fo'c's'le) would have been at least 6%(v/v). At less than 6%(v/v) it's unlikely the ignition in the foc's'le would have propagated back into the cargo hold. For the foc's'le to contain 6%(v) hydrogen the mixture vented into there from the hold would have had to have been at least that concentration. Additionally given the shape of the cargo hold, mixtures at much less than 6%(v/v), would quite likely not have generated sufficient overpressure to lift the hatches.

In summary it is concluded that the hold was most likely at a concentration of at least 6%(v/v) 114 m^3 of hydrogen assuming an ullage volume of 1900 m^3.

2. Maximum possible quantity of hydrogen.

In order to try to place an upper bound on the hydrogen concentration in the hold, calculations have been carried out to gauge the likely effectiveness of the lifting of the hatches in reducing the overpressure experience by the vessel structure. It is clear that there was relatively little damage to the vessel. Regarding explosions occurring in industry in general from a comparison of damage to vulnerable refinery parts, by Stephens as cited in [1], significant damage might be expected at 0.3 bar and serious damage at 0.5 to 1 bar. It is also likely from the photos following the explosion that the hatchcovers were not lifted significantly since they are not significantly displaced from their original positions (some returned to their original positions but were clearly lifted to an extent as their cleats had broken) and so the vent area that was realised during the explosion would have been a relatively small fraction of the total hatch area.

One of the most important parameters that is required for explosion relief vent sizing is the rate of pressure rise within the vessel. It is found that the maximum rate of pressure rise in a vessel of volume (V) is characterised by the “cubic law” given below:

$$(dP/dt)_{\max} \cdot V^{1/3} = \text{constant} = \mathrm{K}_{\mathrm{G}}$$

K_G is known as the explosion index (deflagration index) and normally quoted for hydrogen as 550 bar.m.s^{-1}. K_G is a measure of the violence of an explosion. A value of 550 bar.m.s^{-1} is a worst case value applicable to hydrogen/air mixtures at around 30%(v/v). Hydrogen has one of the highest K_G values and is therefore difficult to vent. However, at lower hydrogen concentrations, flame speeds and rate of pressure rise reduce considerably. The K_G value at lower concentrations K_{Gc} can be estimated from the eqn.

$$K_{G_c} = K_G \cdot \frac{S_c}{S_{\max}}$$

Where S_{max} is the maximum fundamental burning velocity (S_{max}= 3 m/s for hydrogen/ air), S_c is the fundamental burning velocity at a specific concentration. At 10% hydrogen in air (burning velocity 0.1 m/s) this suggests a K_G of only 18 bar m s^{-1}. Measured K_G for low concentrations of hydrogen are sparse but data is presented for H_2/O_2 mixtures at an initial pressure of 5 bar absolute and 20°C in Reference 2. At 10%(v/v) the K_G value was observed to be only 10 bar m s^{-1}, reducing to only 0.8 bar m s^{-1} at 6%(v/v). This would suggest that the above equation is possibly slightly pessimistic.

NFPA68 [3] provides a number of venting correlations intended for the design of relief vents on process plant. The equation, from NFPA68, below applies to enclosure capable of withstanding more than 0.1 bar.

$$A = \left[\left(0.1265 \cdot \log_{10} \cdot K_G - 0.0567\right) \cdot P_{red}^{-0.5817} + 0.1754 \cdot P_{red}^{-0.5722} \cdot \left(P_{stat} - 0.1\right)\right] \cdot V^{2/3}$$

Where

A	=	geometrical vent area (m^2)
K_G	=	Explosion index bar m s^{-1}
P_{stat}	=	Static activation pressure (bar)
P_{red}	=	Reduced explosion pressure (bar)
V	=	enclosure volume (m^3)

For long enclosures an expression to calculate additional vent area to be added to that calculated from the above equation is given by.

$$\Delta A = \frac{A_v K_G \left(\frac{L}{D} - 2\right)^2}{750}$$

Unfortunately this only applies up to a length to diameter ratio of 5. Taking the length to diameter as 5 in the case of the cargo hold will potentially underestimate the required area.

The above equations can be applied to the Nortrader explosion to gauge what scale of vent opening would have been needed to be realised in order to keep the overpressure experience by the vessel hull etc (i.e. P_{red}) to a level commensurate with the observed damage, for varying initial hydrogen concentrations (by varying K_G). Assuming that P_{red} = 0.3 bar and taking P_{stat} as 0.123 bar the vent area can be determined for different K_G values and hence hydrogen concentrations. The free volume (ullage) in the cargo hold was estimated as 1900 m^3 (Note B). These are summarised in the table below.

H_2%(v/v)	K_G (bar m s^{-1})	Pred (bar)	Vent Area, m^2
6	1	0.3	*
10	18	0.3	40

15	70	0.3	103
30	550	0.3	694
6	1	0.5	*
10	18	0.5	30
15	70	0.5	77
30	550	0.5	515
6	1	1	*
10	18	1	20
15	70	1	51
30	550	1	344

* Correlation goes negative for K_G values less than 3 suggesting little vent area would be required.

It can be seen from the above table that above 10% Hydrogen the required vent area increases substantially. Additionally the vent inertia of the hatch panels is considerably in excess of that recommended for explosion relief vents (i.e. 200 kg/m^2 as opposed to 20 kg/m^2). Bjerketvedt [1] et al state that, in their experience vent panels of 30 to 50 kg/m^2 are too heavy to have a significant effect on peak pressure. The higher the hydrogen concentration and rate of pressure rise the greater the influence of the vent intertia.

It is clear that during the incident the hatch panels did move and vent the explosion to some degree, but it seems unlikely that they could have been opened sufficiently within the timescales required to effectively vent anything other than a weak explosion. Had the panels been lifted sufficiently to realise a vent area of 15m^2 that would equate to lifting all the panels vertically to a height of around 0.1m.

Overall, while it is difficult to be certain, the maximum hydrogen concentration in the cargo hold was unlikely to have been much in excess of around 9%(v/v) hydrogen where combustion would become fast and complete. This would correlate with a flame temperature of around 1000°C.

3. Conclusions

In summary, considering the evidence available, the likely hydrogen concentration in the cargo hold at the time of the explosion was in the range of 6 to 9 %(v/v). This equates to a volume of between 114 and 171 m^3. The damage could have been caused by a smaller total amount of hydrogen confined to a localised volume at higher concentration, but this seems less likely given the distributed and slow/steady nature of the hydrogen release. The upper bound on the concentration is based on the limited damage observed and the displacement of the hatches and their likely poor effectiveness at venting an explosion (limiting overpressure) at higher concentrations.

References

1. D. Bjerketvedt et al. "Gas Explosion Handbook", Journal of Hazardous Materials 52 (1997) 1-150
2. Schroeder V., Holtappels K., Explosion characteristics of hydrogen-air and hydrogen-oxygen mixtures at elevated pressures, International Conference on Hydrogen Safety, September 8-10 2005, Congress Place, Pisa, Italy
3. NFPA 68, "Guide for venting of deflagrations", National Fire Protection Association, Quincy, MA, 2002

Note A The distinction is important in assessing the likely consequences of an explosion. During a deflagration the flame propagation is subsonic and the pressure produced by an explosion inside an enclosure can be approximated to a static pressure, whereas a detonation exerts localised shock loadings. In the case here, detonation can be excluded on the basis that primarily a) likely hydrogen concentration was too low to sustain a detonation and also b) likely insufficient run – up distance for a DDT (Deflagration to Detonation Transition) considering that the ullage is relatively uncongested and c) the nature of damage is inconsistent with a detonation.

Note B The volume was calculated by taking the hold dimensions as 61.5 x 9 x 6.16 = 3409 m^3 and then subtracting the volume of the cargo (1505 m^3) giving an ullage volume in the hold of 1900 m^3. The cargo volume was estimated assuming a load of 2333 tonne and a density of 1550 kg/m^3. .

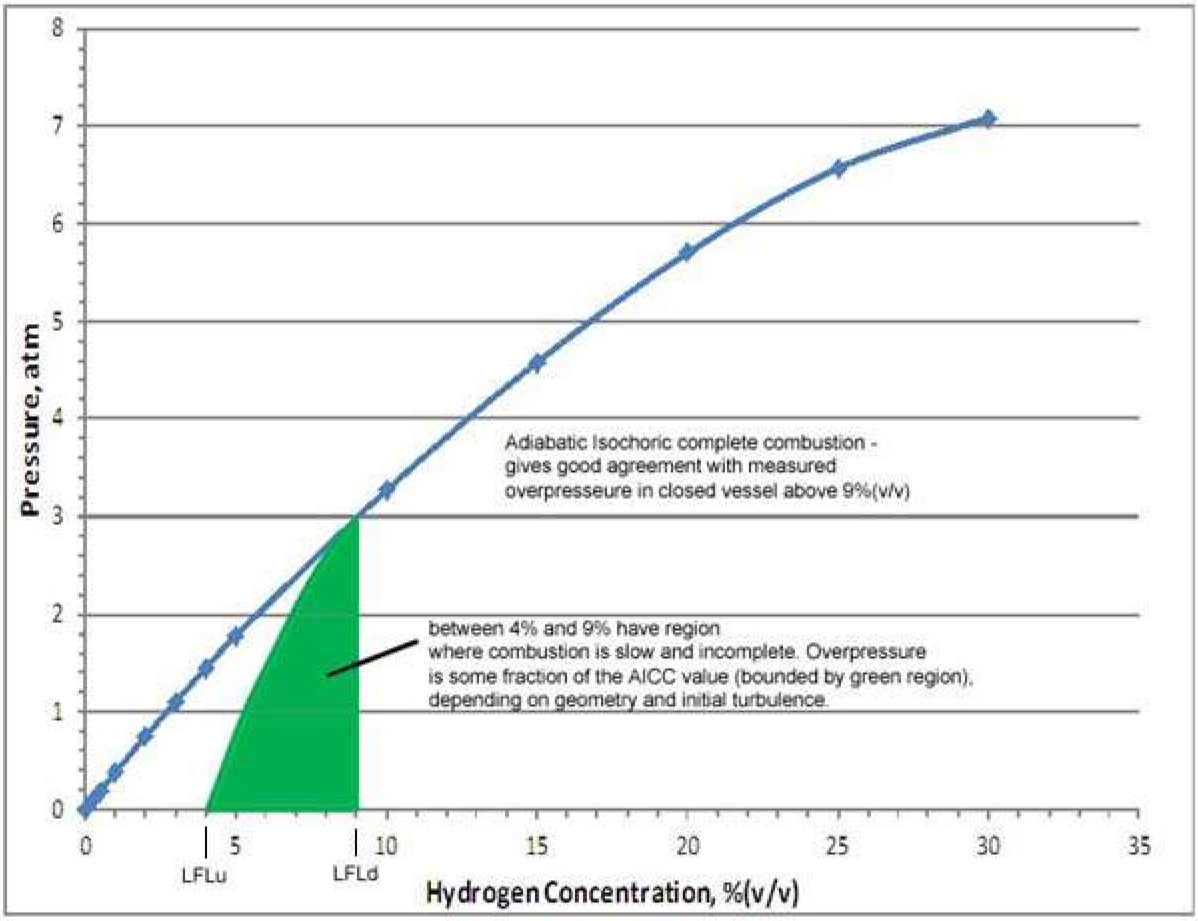

Figure 1 The AICC overpressure produced for a given hydrogen/air mixture

MAIB safety flyer

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

SAFETY FLYER TO THE SHIPPING INDUSTRY

Explosion of gas released from cargo of unprocessed incinerator bottom ash on *Nortrader*, 13 January 2017

Nortrader at Victoria Wharf, Plymouth

Narrative

At 1447 on 13 January 2017, the dry cargo vessel *Nortrader* suffered two explosions in quick succession. The vessel was anchored in Plymouth Sound and had loaded unprocessed incinerator bottom ash (U-IBA) the day before at Plymouth. The first explosion was in the forecastle store and the second in the cargo hold. The force of the explosion in the cargo hold dislodged all the heavy steel hatch covers and all but one of the holding down cleats were broken. Many of the hatch covers and sections of the hold coaming were distorted.

The chief engineer was in the forecastle store at the time, testing the emergency fire pump. He suffered second degree burns and had to be airlifted to a nearby hospital. His recovery was prolonged and he was only declared fit for work again 4 months later. The vessel was out of service until 20 April.

The MAIB investigation established the following:

- *Nortrader*'s master had received an email from the vessel's charterer that the intended cargo of U-IBA was a 'non dangerous' cargo.
- Hydrogen gas released from the cargo seeped into the forecastle store through a slack cargo light access cover. The hold was unventilated at the time.
- All the natural ventilation outlets in the forward compartment, including the forecastle store, were closed in preparation for imminent heavy weather. This allowed hydrogen to accumulate in the forecastle store.
- The starter panel for the emergency fire pump had a broken fixing lug at its door and was therefore not sealed.
- The first explosion was likely to have been triggered by the arcing between the contact terminals of the emergency fire pump starter panel when it was switched off.
- There had been 34 similar shipments of U-IBA from Plymouth to the Netherlands. Despite U-IBA not being listed in the International Maritime Solid Bulk Cargoes (IMSBC) Code, no steps had been taken to seek approval from the competent authorities for its carriage by sea.

Safety lessons

- The only approved means of ensuring safe carriage of solid bulk cargoes is through the application of the IMSBC Code. The schedules included in Appendix 1 of the Code clearly classify cargoes and identify the necessary requirements for safe carriage. Where no schedule is listed for a specific cargo, the required classification procedure is stated at Section 4 of the Code, with further guidance provided by MSC Circ.1453, Marine Guidance Note (MGN) 512 and the guidance document *Carrying solid bulk cargoes safely* published by Lloyd's Register, UK P&I Club and INTERCARGO.
- The application of the IMSBC Code has been mandatory since 2011. It replaced the Code of Safe Practice for Solid Bulk Cargoes (BC Code), which was for guidance only.
- The IMSBC Code requires the shipper to provide the vessel's master with a comprehensive list of information about the intended cargo.

This flyer and the MAIB's investigation report are posted on our website: www.gov.uk/maib

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