

Report on the investigation of the
explosion of gas released from a cargo
of unprocessed incinerator bottom ash on

Nortrader

at anchorage in Plymouth Sound

on 13 January 2017



Extract from
The United Kingdom Merchant Shipping
(Accident Reporting and Investigation)
Regulations 2012 – Regulation 5:

“The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame.”

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

BC Code	-	Code of Safe Practice for Solid Bulk Cargoes
BCSN	-	Bulk Cargo Shipping Name
DOC	-	Document of compliance
EA	-	Environment Agency
ESA	-	Environment Services Association
EU	-	European Union
EWC	-	European Waste Catalogue
H&V	-	Hudig & Veder BV
H ₂	-	Chemical formula of hydrogen gas
H ₂ O	-	Chemical formula of water
HHU	-	Hydrogen Hazards Unit
HP	-	Hazard property
IBA	-	Incinerator bottom ash
IMDG Code	-	International Maritime Dangerous Goods Code
IMO	-	International Maritime Organization
IMSBC Code	-	International Maritime Solid Bulk Cargoes Code
INTERCARGO	-	International Association of Dry Cargo Ship Owners
l/kg/hour	-	litres per kilogramme per hour
LoW	-	List of Wastes
MARPOL	-	[MARPOL 73/78] International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978
MBL	-	Minimum breaking load
MCA	-	Maritime and Coastguard Agency
MGN	-	Marine Guidance Note
MIN	-	Marine Information Note
MSDS	-	Material Safety Data Sheet
MVVD	-	MVV Environment Devonport Limited
NH ₃	-	Chemical formula of ammonia

NLS	-	The Environment Agency's National Laboratory Services
PH ₃	-	Chemical formula of phosphene
SMS	-	Safety Management System
SOLAS	-	International Convention for the Safety of Life at Sea 1974, as amended
SR	-	Standard Rules
STCW	-	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended (STCW Convention)
t	-	tonnes
TC	-	Time charter
U-IBA	-	Unprocessed incinerator bottom ash
UN	-	United Nations
UN Test N.5	-	United Nations Test method for substances which in contact with water emit flammable gases
VHF	-	Very high frequency
WM3	-	Guidance on the classification and assessment of waste, Technical Guidance WM3

TIMES: all times used in this report are UTC unless otherwise stated.

SYNOPSIS

At 1447 on 13 January 2017, the Antigua & Barbuda registered dry cargo vessel *Nortrader* suffered two explosions in quick succession while anchored in Plymouth Sound, England. The vessel was loaded with a cargo of 2333 tonnes of unprocessed incinerator bottom ash. The first explosion was in the forecastle store and the second in the cargo hold. The chief engineer, who was inside the forecastle store at the time, suffered second degree burns and was airlifted to a nearby hospital. He was repatriated to Ukraine after 12 days and was declared fit for duty 4 months later. The vessel suffered extensive damage and was out of service until 20 April.

The MAIB investigation established that the explosions were caused by the ignition of hydrogen gas released from the cargo. Prior to this accident there had been 34 similar shipments of incinerator bottom ash from Plymouth to the Netherlands and, despite it not being listed in the International Maritime Solid Bulk Cargoes Code, no steps had been taken to seek approval from the competent authorities for its carriage. The investigation also found that the testing protocols in place for assessing if the waste was capable of producing flammable gases were inappropriate and inadequate.

The MAIB has published a safety flyer to disseminate the lessons from this accident and improve awareness of the International Maritime Solid Bulk Cargoes Code. The MAIB has also provided the Maritime and Coastguard Agency with the results of laboratory tests and technical research conducted during the investigation.

The Maritime and Coastguard Agency has set up tripartite agreements between the UK, the Netherlands and several other administrations for the safe carriage of incinerator bottom ash and proposed its inclusion in the International Maritime Solid Bulk Cargoes Code.

The Maritime and Coastguard Agency has been recommended to update the Merchant Shipping (Carriage of Cargoes) Regulations to refer to the International Maritime Solid Bulk Cargoes Code and to work with the Environment Agency to ensure that test protocols for the classification of cargoes are fit for purpose.

Recommendations have also been made to *Nortrader's* owners to review their safety management system to reflect the requirements of the International Maritime Solid Bulk Cargoes Code.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *NORTRADER* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	<i>Nortrader</i>
Flag	Antigua & Barbuda
Classification society	Bureau Veritas
IMO number	9557393
Type	Dry cargo
Registered owner	NTO Shipping GmbH & Co.KG
Manager(s)	NTO Shipping GmbH & Co.KG
Construction	Steel
Year of build	2012
Length overall	87.91m
Gross tonnage	1934 tonnes
Minimum safe manning	6
Authorised cargo	General cargo
VOYAGE PARTICULARS	
Port of departure	Plymouth, England
Port of arrival	Beverwijk, the Netherlands (intended)
Type of voyage	Short international
Cargo information	2333t of unprocessed incinerator bottom ash
Manning	7
MARINE CASUALTY INFORMATION	
Date and time	13 January, 1447
Type of marine casualty or incident	Serious Marine Casualty
Location of incident	Plymouth Sound, England
Place on board	Cargo hold
Injuries	1
Damage/environmental impact	Material damage to ship, no environmental impact
Ship operation	Normal service
Voyage segment	Anchored
External environment	Calm seas, light breeze, good visibility, occasional rain
Persons on board	7



Nortrader

1.2 NARRATIVE

1.2.1 Instructions to load

On 10 January 2017, the master of *Nortrader* received instructions by email to load a full cargo of unprocessed incinerator bottom ash (U-IBA) at Plymouth, England for Beverwijk in the Netherlands. The email was sent from Hudig & Veder Chartering BV (H&V), a company based in the Netherlands. It specified that the cargo was *non dangerous* and stated:

...cargo also include some foreign materials which is no problem. Cargo can be loaded/discharged in rain. [sic]

On receipt of these instructions, the master and chief officer referred to the International Maritime Solid Bulk Cargoes Code (IMSBC Code), but did not find an entry for U-IBA. The master decided to load as instructed, and did not receive any further information about the cargo.

1.2.2 Cargo loading and anchorage

Nortrader berthed at Victoria Wharf, Plymouth, at 0655 on 12 January. Loading commenced at 0815, and by 1600 that day 2333t of U-IBA had been loaded in heavy and persistent rain (**Figure 1**). After completion of the final draught survey, the master checked the weather forecast and decided to anchor off Plymouth and wait for the imminent bad weather to pass. At 1900, the vessel left the berth and anchored 30 minutes later in Plymouth Sound (**Figure 2**).



Figure 1: *Nortrader* at Victoria Wharf, Plymouth

1.2.3 Explosions in the cargo hold

The following morning, on the bridge, the chief officer instructed the bosun to wash the deck and superstructure. The chief engineer, also present on the bridge at the time, requested that the bosun use the electric emergency fire pump for the task in order to test it. The bosun started the emergency fire pump from the bridge, but a short while later he reported to the chief engineer that it was not delivering any water. He then changed over to the main fire pump and the crew completed washing by 1200.

At approximately 1440, the chief engineer went to the forecandle store (**Figure 3**) where the emergency fire pump main starter panel was located. He opened the door to enter the store and used the hook on its outside to secure the door in the open position. He then went down the ladder into the store and started the emergency fire pump. From the sound of its operation he suspected that the pump was running dry and so he returned to the forecandle and opened a fire hydrant, to confirm that no water was being pumped. He then returned to the store and stopped the emergency fire pump using the stop button on the starter panel (**Figure 4**).

As soon as he stopped the pump, there were two loud explosions in quick succession. The fire detection system registered this event at 1447. The first explosion threw the chief engineer onto the emergency fire pump starter panel. The second explosion pushed him violently backwards and he fell on the deck under the starter panel.



Figure 3: Forecandle deck and entrance to forecandle store

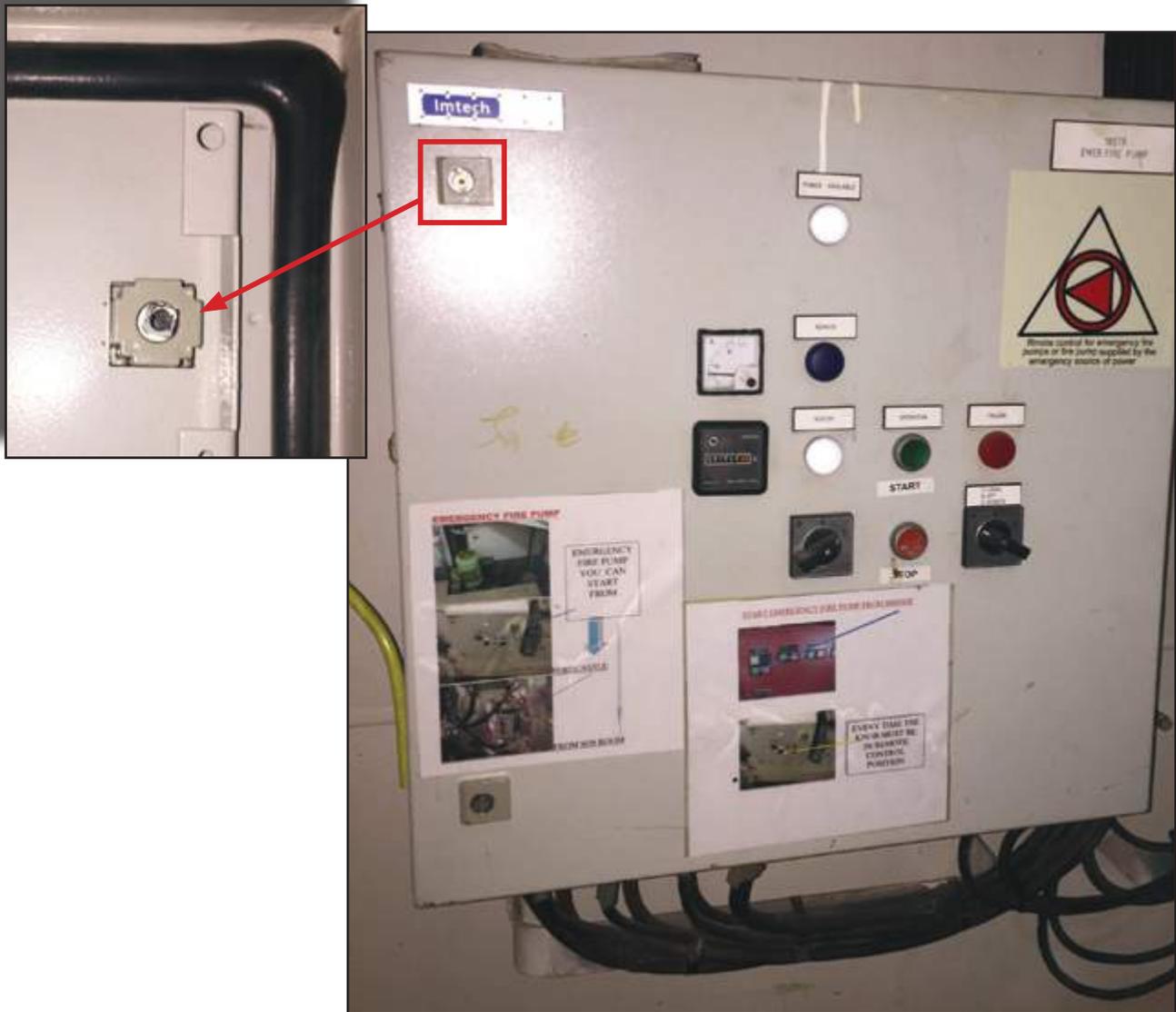


Figure 4: Emergency fire pump starter panel (**inset:** reverse of door, showing broken door lug)

1.2.4 Post-accident response

At the time of the accident, the third officer was on watch. On hearing the explosions, the master and the rest of the crew immediately came to the bridge. They saw the chief engineer staggering along the starboard side of the main deck between the cargo holds and shipside protective railing. The bosun met him halfway between the forecabin and the accommodation, and escorted him to the mess room. The synthetic fibre-filled parka¹ coat that the chief engineer had been wearing had melted onto his body and head. He was conscious and complained of being in extreme pain. Once in the mess room, the chief officer cut the chief engineer's coat off him (**Figure 5**) and attempted to make him comfortable.

The master called the coastguard using very high frequency (VHF) radio to inform them about the explosions and asked for immediate medical assistance for the chief engineer. By 1531, rescue helicopter R924 was in position above the vessel.

A paramedic was landed on board *Nortrader* and, following a quick assessment, the chief engineer was lifted into the helicopter and evacuated to Derriford Hospital in Plymouth from where he was subsequently transferred to the Acute Burns Clinic

¹ Parka coat: a coat used in cold weather usually stuffed with a synthetic fibre or down.



Figure 5: The chief engineer's burnt parka coat

at Southmead Hospital, Bristol. He had suffered first degree burns to his face and second degree burns to his body, both hands and lower extremities. On 25 January, he was discharged and repatriated to Ukraine, where his treatment was continued for 3 weeks. He was declared fit for duty in May 2017.

1.2.5 Damage

The explosions dislodged and distorted all nine of the vessel's steel hatch covers, breaking all but one of the 66 hatch cleats in the process (**Figure 6**). Some of the hatch covers dropped into the cargo hold and were found resting on top of the cargo. The cargo hold coaming bar was also damaged in several locations and the cargo ventilation trunking tower flaps were deformed.

There was no fire damage, although there was evidence of intense heat within the forecastle store. A parka coat, like that worn by the chief engineer, which had been hung at the entrance to the forecastle store, had been severely melted and several laminated sheets and plastic document wallets were heat damaged (**Figure 7**).

1.2.6 Post-accident actions

A Maritime and Coastguard Agency (MCA) surveyor inspected *Nortrader* while still at anchor and gave the master permission to return to Plymouth. On 14 January, *Nortrader* berthed at Victoria Wharf, and over the next 3 days discharged the entire cargo. The cargo was returned to the storage shed at Victoria Wharf.

The MCA prohibited further sea transportation of U-IBA from the UK until the procedures described in the IMSBC Code for cargoes not listed in it had been completed.



Dislodged hatch covers



Distorted hatch covers



Broken cleat

Figure 6: Damage caused by the explosion



Figure 7: Evidence of short-lived heat damage

Nortrader's Classification Society, Bureau Veritas, carried out a damage assessment survey, which concluded that the vessel had not sustained any structural damage, and it was granted a dispensation to sail to Rotterdam for repair. Five of the nine hatch covers were replaced along with all of the hatch cleats and the cargo hold coaming bar. The cargo ventilation trunking tower flaps were repaired. The vessel returned to service on 20 April.

1.3 VESSEL

1.3.1 Cargo hold

Nortrader had a single cargo hold of 3409m³ capacity. It was possible to sub-divide the hold with two movable bulkheads. At the time of the accident, the bulkheads were not in use and were stored at the aft end of the hold. There were two forced draught fans for ventilation. These were not in use and their inlets had been closed and dogged down after loading, in preparation for poor weather.

There were two cargo lamps at the forward end of the hold. The access to the starboard lamp was from within the forecandle store. The access plate for this was found loosely fitted using two of ten bolts, and the sealing gasket was missing (**Figure 8**).

The previous cargo carried by the vessel had been cattle feed. After this cargo was discharged, the holds had been washed clean and ventilated.

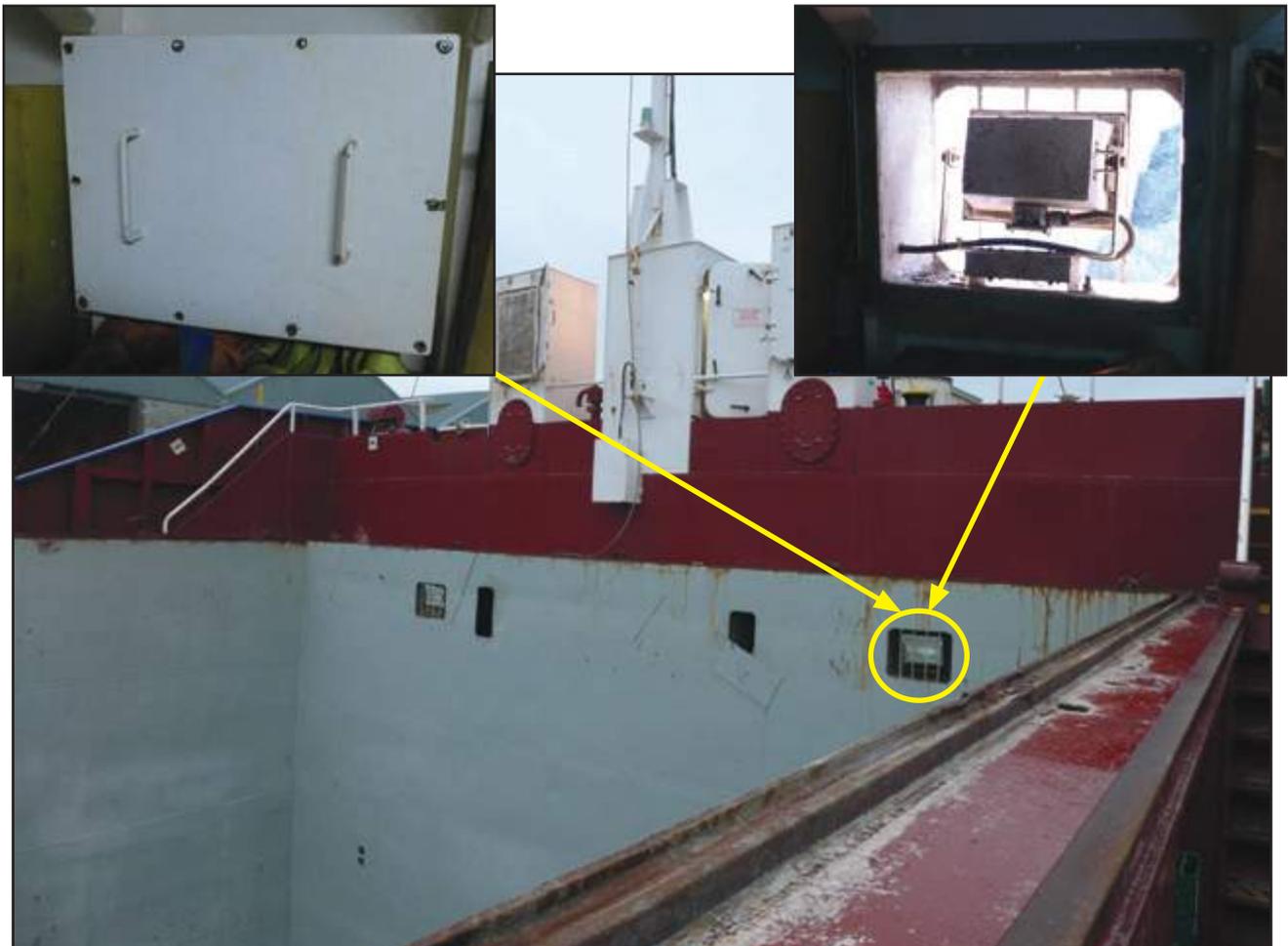


Figure 8: Cargo hold lamp access
(insets: views from forecandle store with maintenance hatch closed and removed)

1.3.2 Hatch covers

The hold had eight large hatch covers each weighing 14t, and a smaller central one weighing 5t. These hatch covers were made tight against the coaming bars with 66 hatch cleats that had minimum breaking loads (MBL) of 8.75t (athwartships cleats) and 9.0t (longitudinal cleats). There were also 40 steel wedges (3.5t MBL) used to interlock the tops of adjacent hatch covers (**Figure 9a and b**).

1.3.3 Forecastle store

The forecastle store was located in a compartment forward of the hold. It was accessed via a door on the forecastle deck and down a short stairway. The starter panels for various equipment, including the emergency fire pump and cargo hold ventilation fans, were located in the forecastle store. The emergency fire pump and bow thruster were located at the bottom of the compartment and were accessed by a vertical ladder from the store. At the time of the accident, the emergency fire pump starter panel door was not properly closed as one of its two fastening lugs was broken.

The forecastle store was used to store consumables for deck maintenance. The rope and paint stores were located forward of the forecastle store and both stores were open to each other. The store was naturally ventilated by gooseneck vent pipes to the forecastle above. On the day of the accident, all these vents had been closed in preparation for heavy weather.

1.4 CREW

Nortrader's crew comprised the master, chief officer, third officer, chief engineer and three ratings from the Russian Federation and Ukraine. Their contracts were 4 months long, and none of them had any previous experience on ships carrying U-IBA.

The master held an STCW² II/2 (unlimited) certificate of competency gained in 1991 and had completed six contracts as master on *Nortrader*. He was 59 years old.

The chief engineer was 31 years old and held an STCW III/2 (unlimited) chief engineer's certificate of competency. He had completed four contracts on *Nortrader* and had last joined the vessel in September 2016.

1.5 UNPROCESSED INCINERATOR BOTTOM ASH

1.5.1 Production and storage

U-IBA is the ash accumulated at the bottom of the furnace when waste material is incinerated. The cargo of U-IBA loaded onto *Nortrader* was generated at the incinerator plant owned and operated by MVV Environment Devonport Limited (MVVD) located in Devonport, Plymouth.

MVVD started operating in June 2015 and handled approximately 250,000t of non-recyclable waste in a year, which included 80,000t of commercial waste. Waste from the Plymouth and Torbay areas and Devon County Council was incinerated at the plant and the heat energy produced was recovered in a combined heat and power plant. The waste was not sorted prior to incineration.

² International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended (STCW Convention).

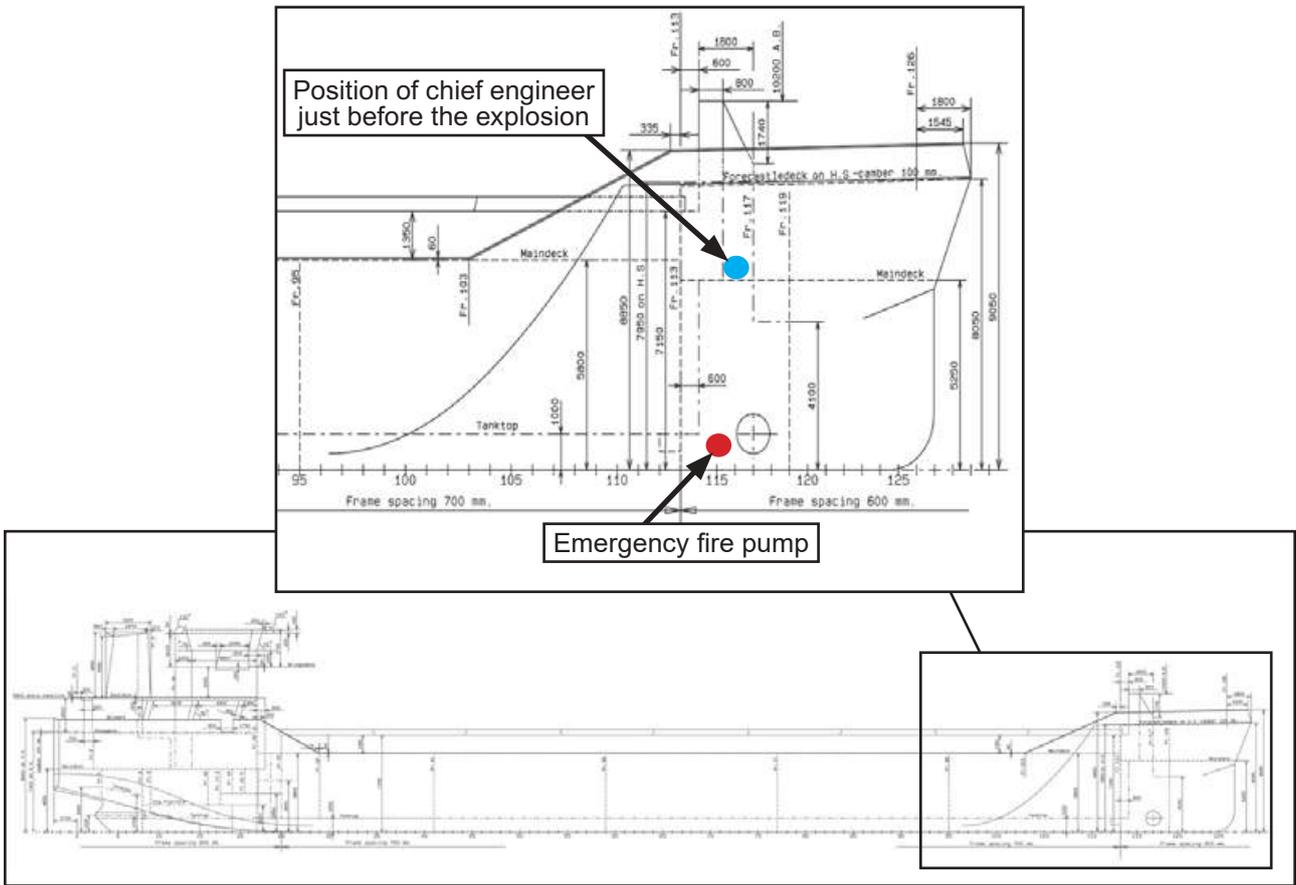


Figure 9a: General arrangement of the vessel



Figure 9b: Hatch covers undergoing temporary repairs

At the time of the accident, there were 32 operational municipal waste incineration plants in the UK. All of these except for MVVD processed their incinerator bottom ash (IBA) either on site, or off-site within the UK. Transportation to off-site processing plants was carried out using open top or tarpaulin covered freight lorries.

Other than during initial start-up, the combustion in the furnace was sustained entirely by the waste, and the furnace temperature ranged from 800°C to 1100°C. On leaving the furnace the IBA was quenched in water before being stored in an open bunker adjacent to the incinerator. The cargo discharged from *Nortrader* was typical of the U-IBA from the MVVD facility and included items such as unburnt paper, domestic gas cylinders and wheels from motor vehicles (**Figure 10**).

Approximately 200t of U-IBA per day was transferred by freight lorries to the storage shed at Victoria Wharf in Plymouth. The shed had a maximum capacity of 4000t and was naturally ventilated by its open front. The U-IBA was stored in a large pile in the shed where old and new batches were not segregated.

1.5.2 Sea transportation

Since MVVD started operating in June 2015, there had been 34 shipments of U-IBA from Plymouth to Beverwijk on 26 vessels similar in tonnage to *Nortrader*. The description of the cargo for all shipments had been identical to that provided during the engagement of *Nortrader*. More than a third of these vessels had the document of compliance (DOC) required to carry dangerous goods, although this was not a requirement of the charter party³ agreement for shipment.

The first shipment of U-IBA employed the vessel *Kine*, which had a DOC for dangerous cargoes. On that occasion, H&V acted as a broker between the ship owner and the shipper of the cargo, Rock Solid BV. The material safety data sheet (MSDS) for U-IBA was provided to *Kine*. After the first shipment, except when masters of vessels specifically requested for it, the MSDS was not sent to the vessels.

1.6 ORGANISATIONS INVOLVED IN TRANSPORTATION OF U-IBA

1.6.1 Vessel owners

Nortrader's registered owner was NTO Shipping GmbH based in Germany. NTO Shipping GmbH owned and operated 18 vessels, and was part of the EMS-Fehn Group, which offered services including logistics, forwarding, port operation and crewing.

1.6.2 Disponent owner of the vessel

From 15 December 2016 *Nortrader* was on time charter to Hudig & Veder (H&V), a shipping company based in Rotterdam, making it the disponent⁴ owner of the vessel. H&V offered a variety of services including chartering, cargo inspection, stevedoring and port agency. It also owned nine ships similar in construction and size to *Nortrader*.

³ A charter party is the contract between the owner of a vessel and the charterer for the use of a vessel.

⁴ The disponent owner is a person or company that assumes the legal responsibilities of the registered owner of the vessel during the term of a time charter or bareboat charter.



Figure 10: U-IBA from *Nortrader* after the explosion

On 10 January 2017, H&V chartered *Nortrader* to the shipper, Rock Solid BV, for a single voyage to load U-IBA at Plymouth on 12 January for discharge at Beverwijk. The charter party agreement described the cargo as follows:

a full and complete cargo avi-slakken (bodem as) stw dw in bulk, untreated incinerator bottom ash in bulk, cargo non dangerous, non-imo classed. [sic]

H&V acted as brokers for the first shipment of U-IBA from Plymouth. For the following 33 shipments they either used their own vessels or engaged vessels on short-term charters.

1.6.3 Shipper of the cargo

The shipper was Rock Solid BV, a company based in the Netherlands that specialised in processing U-IBA to recover mineral residues. The remainder of the ash was prepared for use in the road building and construction industries, landfill and the production of fertilisers.

MVVD and Rock Solid BV had agreed a contract that committed MVVD to supply Rock Solid BV with 68000t of U-IBA annually. Rock Solid BV took ownership of the U-IBA at the point of production and was responsible for transporting it from MMVD to its processing facility at Alkmaar in the Netherlands. The Bill of Lading⁵ for the cargo loaded on *Nortrader* showed MVVD as the shipper, but for all practical purposes Rock Solid BV was the shipper of the cargo.

1.7 REGULATIONS AND GUIDANCE FOR THE CARRIAGE OF BULK CARGOES

1.7.1 SOLAS Convention

The International Convention for the Safety of Life at Sea 1974, as amended (SOLAS) Chapter VI 'Carriage of Cargoes', parts A and B contains the mandatory provisions concerning the carriage of bulk cargoes. It requires the governments involved in the transportation chain to provide information regarding the cargo, including the precautions required for its safe carriage. SOLAS refers to the IMSBC Code for further information about the cargo and requirements for its safe carriage.

1.7.2 International Maritime Solid Bulk Cargoes Code

The IMSBC Code entered into force on 1 January 2011 under the provisions of the SOLAS Convention. Appendix 1 of the Code, *Individual schedules of solid bulk cargoes*, listed all solid cargoes permitted to be shipped in bulk and provided a schedule of requirements for the safe handling and carriage for each. The Code also grouped cargoes according to the hazards associated with their carriage⁶. Those in groups A or B were also entered into the International Maritime Dangerous Goods (IMDG) Code. An example of a schedule for a cargo that can develop small quantities of hydrogen and ammonia, *aluminium smelting/remelting by-products, processed*, is at **Annex A**.

⁵ A bill of lading is a legal document between the shipper and the carrier providing details of the quantity, type and destination of the cargo, and also serves as a receipt of shipment.

⁶ Group A consisted of cargoes that may liquefy if shipped at a moisture content in excess of their transportable moisture limit. Group B consisted of cargoes that posed a chemical hazard which could give rise to a dangerous situation on a ship. Group C consisted of cargoes that did not belong to Groups A or B.

Section 4.2.2 of the IMSBC Code contained a list of information about the intended solid bulk cargo that the shipper was to provide to the master prior to loading. Of the 16 items on this list, item 1 was the bulk cargo shipping name (BCSN) if listed in the IMSBC Code, item 2 was the cargo group (A, B, A and B, or C) and item 14 was *properties on emission of flammable gases in contact with water, if applicable*. The MSDS was not part of the required information. In addition to this list of information, the shipper was required to provide the master with a completed and signed cargo declaration form (**Annex B**).

Solid bulk cargoes not listed in Appendix 1 of the IMSBC Code were not permitted to be loaded until the competent authority at the loading port had authorised the intended cargo. In the UK, the competent authority was the MCA and the procedure to be followed was stated in Marine Guidance Note (MGN) 512, *Solid Bulk Cargoes - Guidelines for the submission of information and completion of the format for the properties of cargoes not listed in the International Maritime Solid Bulk Cargoes (IMSBC) Code and their conditions of carriage*, issued in June 2014. This note was specifically aimed at *all ship owners, ship operators, terminal operators, port authorities, classification societies, agents, charterers, shippers, consignors, masters and all other parties involved in the transport of solid bulk cargoes by sea*. At section 1.1 it stated:

Shippers of solid bulk cargoes intended for carriage and which are not listed in appendix 1 of the International Maritime Solid Bulk Cargoes (IMSBC) Code, are required, prior to loading, to provide the Competent Authority of the port of loading with the characteristics and properties of the cargo in accordance with Section 4 of the Code.

The International Maritime Organization's (IMO) Marine Safety Committee (MSC) Circular 1453, *Guidelines for the submission of information and completion of the format for the properties of cargoes not listed in the International Maritime Solid Bulk Cargoes (IMSBC) Code and their conditions of carriage* provided a questionnaire to aid the gathering of information about an intended cargo. The application of these guidelines became mandatory on 1 January 2015. Under *Hazardous properties*, the questionnaire contained the following question:

Does the cargo react with water causing toxic or flammable gases to be released? Which gases? How toxic or flammable are the gases? What is the rate of evolution?

If the proposed cargo was assessed to belong to group A or B of the IMSBC Code, the competent authorities at the ports of loading and discharge, along with the Flag State of the intended vessel were required to agree conditions for the carriage of that cargo; this was known as a tripartite agreement. If the proposed cargo was assessed to belong to Group C in the IMSBC Code, the competent authority was able to permit the carriage without involving other parties.

Between the introduction of the IMSBC Code in 2011 and this accident, the MCA had not received any request or enquiry concerning the carriage of cargoes not included in the IMSBC Code.

1.7.3 Further guidance on the application of the International Maritime Solid Bulk Cargoes Code

In addition to the guidance provided by MGN 512 and IMO MSC Circ.1453, Lloyd's Register, UK P&I Club and the International Association of Dry Cargo Ship Owners (INTERCARGO) published *Carrying solid bulk cargoes safely*, included at **Annex C**. This straightforward guide on the application of the IMSBC Code stated in its introduction:

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 and a declaration that the cargo information is correct.

A loading flowchart contained in this guide provided clear guidance to the seafarer on the steps required to be taken before agreeing to load solid bulk cargoes (**Figure 11**).

1.7.4 National regulations

The UK's Merchant Shipping (Carriage of Cargoes) Regulations 1999 (Statutory Instrument 336) stated:

The owner and master of every ship to which these Regulations apply, other than a ship engaged in the carriage of grain, shall ensure that appropriate documentation, relevant to the cargo and its stowage and securing, which should specify in particular the precautions necessary for the safe carriage of that cargo by sea, is carried on board...

The regulation referred to the *Code of Safe Practice for Solid Bulk Cargoes (BC Code)*. The BC Code was superseded by the IMSBC Code in January 2011 but the regulation had not been updated to reflect this. In contrast with the IMSBC Code, the BC Code provided non-mandatory guidance and did not require masters to take action before loading a non-listed cargo.

The MCA published Marine Information Note (MIN) 349, *Solid Bulk Cargoes – Adoption of the International Maritime Solid Bulk Cargoes (IMSBC) Code* in 2009 advising the industry, including ship owners, managers, masters and officers that the application of the IMSBC Code would become mandatory through SOLAS Convention (as amended) from 1 January 2011. This MIN expired on 31 May 2010.

1.8 COMPETENCY EXAMINATION SYLLABUS FOR SENIOR DECK OFFICERS

The STCW syllabus for chief officers and masters required, under the heading *Cargo handling and stowage at the management level*, that candidates demonstrate the: *Ability to establish procedures for safe cargo handling in accordance with the provisions of the relevant instruments such as IMDG Code, IMSBC Code, MARPOL⁷ 73/78 Annexes III and V and other relevant information.*

⁷ MARPOL: International Convention for the Prevention of Pollution from Ships

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

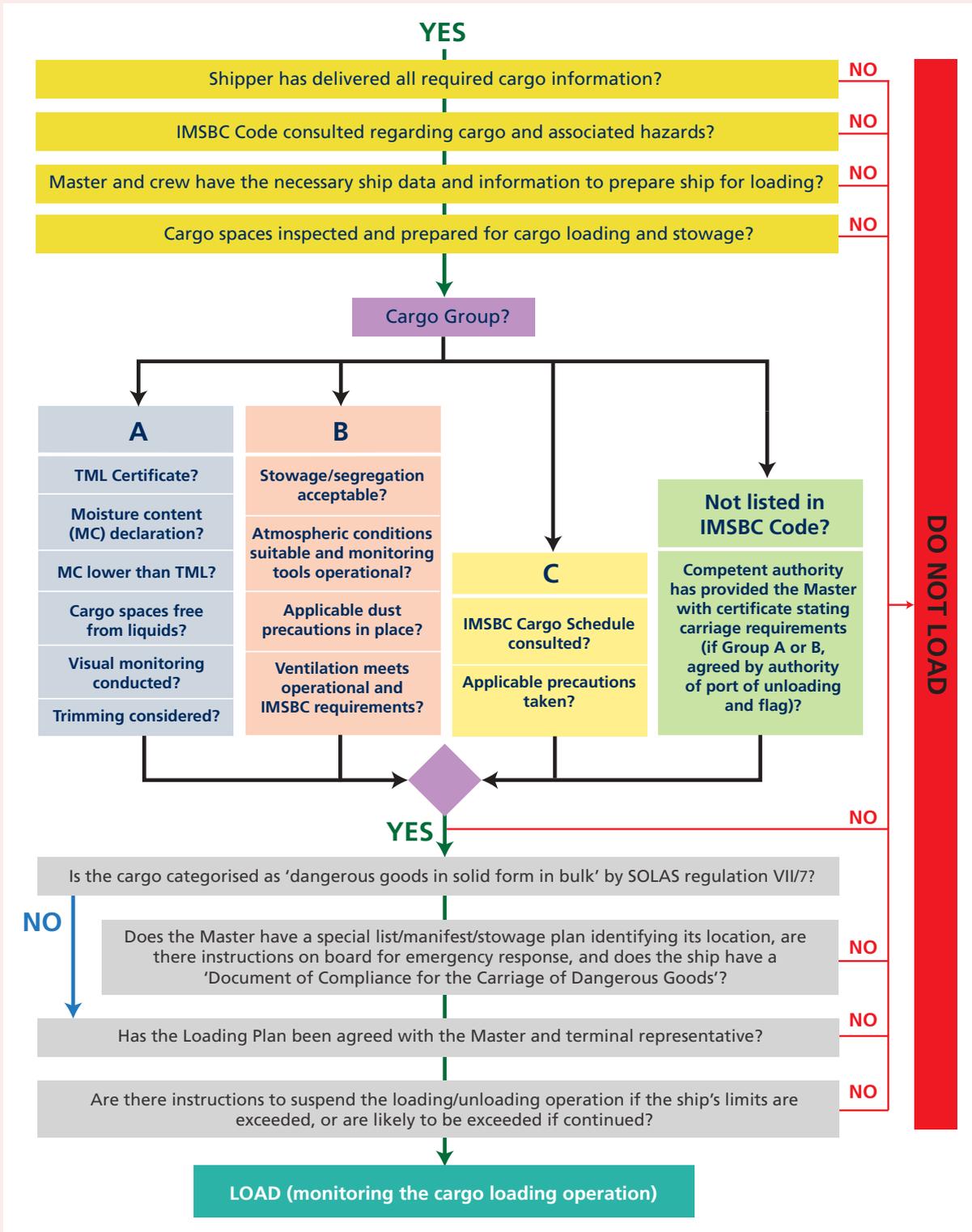


Figure 11: Quick guide to IMSBC Code

1.9 VESSEL SAFETY MANAGEMENT SYSTEM

The vessel's safety management system (SMS) contained specific and detailed procedures concerning cargo operations under a section titled *Procedure Cargo Operations*. It stated that the master, with the assistance of the chief officer, was responsible for assisting the owner in meeting his obligation to receive, stow, carry safely and deliver the cargo. It further stated:

In doing so, the reputation of the Owners and the Master will assure that the vessel is regarded as a reliable carrier ... Such a good reputation has a positive financial effect both in the freight business and with insurance companies.

Under the sub-section titled *Cargo Acceptance*, further instructions to the master were available to ensure the cargo was as specified, undamaged and the quantity as agreed. In the final section *Dangerous Goods* the SMS stated:

The IMDG-Code and / or the IMSBC-Code (newest editions) are mandatory for the carriage of dangerous goods.

There was no guidance in the SMS concerning the carriage of a cargo not included in the IMSBC Code.

The SMS stated that the working language on board was English.

1.10 VESSELS CERTIFIED TO CARRY DANGEROUS CARGO

SOLAS Chapter II-2 Regulation 19.4 listed the special requirements for vessels carrying dangerous goods. These included specific requirements for fire-fighting and detection systems, safety of electrical equipment (where permitted by the Administration to be fitted inside enclosed cargo spaces), personnel protection, bilge pumping and ventilation systems. Additionally, cable penetrations of decks and bulkheads were required to be sealed to prevent the passage of gas or vapour.

The requirements for ventilation stated:

Adequate power ventilation shall be provided in enclosed cargo spaces. The arrangements shall be such as to provide for at least six air changes... , and for removal of vapours from the upper or lower parts of the cargo spaces, as appropriate.

1.11 REGULATIONS AND GUIDANCE FOR WASTE MANAGEMENT

1.11.1 Waste classification

European Union (EU) Directive 2008/98/EC on waste, generally known as the 'Waste Framework Directive', lays down the principles of waste management to prevent health risks to human beings and harm to the environment. The European Waste Catalogue (EWC) is a hierarchical list of waste descriptions. It is divided into 20 main chapters, each of which has a two-digit code between 01 and 20. IBA was coded as 19.01.12 and was not appended with an asterisk mark, indicating that it was not considered hazardous⁸.

⁸ Pursuant to Article 1(4) first indent of Directive 91/689/EEC.

The UK incorporated the guidance provided by the Waste Framework Directive into *Guidance on the classification and assessment of waste, Technical Guidance WM3* (WM3). This document was jointly published by the Environment Agency (EA) in England and its equivalents in Scotland, Wales and Northern Ireland. WM3 provided step by step instructions for classifying waste as required by the List of Wastes (LoW) Regulations 2005, which itself was a transposition of the EWC into UK law. (The LoW Regulations 2005 were revoked in July 2015 and domestic legislation has since referred to the Waste Framework Directive.)

In the LoW, U-IBA was classified as ‘mirror hazardous’, which implied that it could be either hazardous or non-hazardous depending on the results of regular testing. In the UK, incinerator operators who were members of the Environmental Services Association⁹ (ESA) undertook to test the U-IBA they produced on a monthly basis.

1.11.2 Testing protocol for waste classification

To determine the classification of waste material, WM3 categorised 15 hazard properties (HP) numbered HP1 to HP15. Of these, HP3 defined the flammability of the waste product together with its ability to emit flammable gases in dangerous quantities when in contact with water. The threshold for categorising a product as dangerous was its ability to generate more than 1 litre of gas per hour per kg (l/kg/hour).

In 2012, the ESA developed a test protocol for identifying the hazards associated with U-IBA¹⁰, which was endorsed by the EA. Following the guidance provided in WM3, this protocol discounted six hazard properties including HP3. One of the sub categories of the discounted HP3 was HP3A: *substances and preparations which in contact with water or damp air, evolve highly flammable gases in dangerous quantities*. The ESA protocol justified the discounting of HP3 by stating the following:

IBA has been through an incineration process and therefore compounds present in the ash are not flammable.

The ESA protocol also recommended that full characterisation and assessment of the 15 hazard properties be undertaken annually; MVVD had not carried out such annual tests.

MVVD was not a member of the ESA and contracted out all its U-IBA testing to Marchwood Scientific Services, also not a member of the ESA. However, as the ESA protocol was the only available guidance for U-IBA testing, it was universally followed by members and non-members of ESA, including Marchwood Scientific Services. Before this accident, none of the waste incineration facilities in the UK tested U-IBA for HP3.

1.11.3 Environment Agency regulations

The EA’s Standard Rules SR2012 No13 on the treatment of IBA stated:

hydrogen gas is released from the IBA during the ageing process as aluminium reacts with calcium hydroxide and water to form aluminium hydroxide.

⁹ The Environmental Services Association is a trade association for the UK’s waste management industry.

¹⁰ Assessment of hazard classification of UK IBA – Report for the January-June 2011 IBA dataset.

SR2012 No13 also stated that if the ash was stored in a building or under cover, adequate ventilation should be provided to safely disperse any gas generated. Furthermore, it stated that where there was the likelihood of a flammable or explosive atmosphere being formed, such areas should be assessed in accordance with the Dangerous Substances and Explosive Atmosphere Regulations (2002).

1.11.4 Material safety data sheet for U-IBA

The purpose of an MSDS is to provide information regarding the safe handling and use of a material. They provided useful information to ships' crews regarding the risks associated with contact with a cargo and, as such, should be carried on board. However, MSDS are not required by the IMSBC Code as they had no place in assessing the suitability of a cargo for safe carriage.

The MSDS for U-IBA (**Annex D**) was supplied by Rock Solid BV to H&V in October 2013. Another MSDS for processed incinerator bottom ash aggregate was also supplied in 2016 to H&V by Rock Solid BV, and this was erroneously included in the voyage charter party for the carriage of U-IBA by *Nortrader*. On the fifth page of both of these 6-page documents, the MSDS stated under the heading 'Hazardous decomposing compounds':

When in contact with water (H₂O) possible formation of hydrogen gas (H₂-gas).

The MSDS for U-IBA further stated:

Under reducing circumstances ammonia can be formed (NH₃). Accidentally phosphine (PH₃) can escape [sic]

The MSDS also stated that the EWC waste catalogue classified U-IBA as non-hazardous. The spaces in the MSDS labelled 'Identification of the producer' and 'Telephone number in case of Emergency' were left blank.

1.12 TESTS

1.12.1 United Nations Manual of Tests and Criteria

The United Nations publication *Recommendations on the transport of dangerous goods, Manual of tests and criteria*, commonly known as the UN Manual of Tests and Criteria, contained guidance for competent authorities to identify and classify goods as dangerous for transportation. This publication did not apply directly to bulk transport of dangerous goods in bulk carriers but the IMSBC Code refers to the UN Manual of Tests and Criteria, part III, for the classification of such cargoes. The competent authority had the discretion to vary the tests or require additional tests if they judged deviation from the prescribed tests to be necessary.

UN Test N.5, *Test method for substances which in contact with water emit flammable gases*, described in section 33.4.1.4 (**Annex E**) of the UN Manual of Tests and Criteria, was designed to determine if a substance should be categorised as dangerous with respect to its ability to generate flammable gases when in contact with water. The test involved grinding the substance to a homogeneous mixture and measuring the gases released when small quantities (heaps of diameter 2mm and 20 mm) were mixed with distilled water. These results were then extrapolated to provide an estimate of gas released in litres per kg per hour (l/kg/hr). If this exceeded 1 l/kg/hour, the substance was classified as dangerous.

Due to the heterogeneous nature of U-IBA and the presence of large metallic objects, it was very difficult to ensure that samples created for testing were similar in composition to the bulk U-IBA from which they were taken. Despite following a detailed sampling protocol¹¹ developed by the ESA, this investigation has identified significant variability across samples.

1.12.2 Gas generation potential and homogeneity of U-IBA

Following the accident, on 17 January, MAIB inspectors collected 4 samples, 20kg to 25kg each, from the discharged cargo. These samples were placed in sealed containers and stored at MVVD.

The MAIB commissioned WRc (an environmental consultancy, recognised as experts in waste characterisation and classification) to organise the testing of these samples and interpret the results. WRc was tasked with answering two questions:

1. Was the U-IBA loaded on *Nortrader* similar in physical and chemical characteristics to that produced by other incinerator plants in the UK and the MVVD plant from the time of its commissioning?
2. What gases are released from the U-IBA samples of *Nortrader* and how much of each gas was the sample capable of releasing?

On 8 February WRc collected the sealed samples taken by the MAIB from MVVD along with a fresh sample from the MVVD incineration plant. Two methods were used to test these samples for the release of flammable gases:

1. UN Manual of Tests and Criteria, Test N.5;
2. An in-house test developed by the EA's National Laboratory Services (NLS).

The main difference between these two test methods was the quantity of water added to the samples. For the UN Test N.5, the liquid-to-solid ratio was 1.5:1 and for the NLS test it was 6:1.

The sample preparation method employed by WRc was to separate the ferrous and non-ferrous metal items, grind the remaining sample to less than 4mm particle size, subsample and grind again to less than 250 microns. For flammability tests, the separated metal was then ground to less than 1mm particle size and returned to the sub-samples proportionately.

The reported results can be summarised as follows:

- UN Test N.5: No gas was produced by the three sub-samples taken from the MAIB sample. One of the three sub-samples from the WRc sample produced hydrogen at the rate of 0.43 l/kg/hour, stopping after 6 hours.
- NLS in-house flammability test: All three sub-samples of the MAIB sample produced hydrogen at an average rate of 0.41 l/kg/hour and all three sub-samples of the WRc sample produced hydrogen at an average rate of 0.77 l/kg/hour.

¹¹ Four crane grab samples are taken from the ash pit. Five samples of 10kg each are taken from each grab producing a sub-sample of 200kg of ash. This sample is then mixed, coned and quartered (a method to reduce systemic bias). Two opposite quarters are then selected for tests.

The MAIB samples were also tested to quantify metals, and several other parameters including alkalinity and moisture content. The report stated that, assuming all the non-ferrous metal in the U-IBA sample provided by MAIB was metallic aluminium, the total theoretical hydrogen production potential was 31 l/kg.

The WRc report concluded as follows:

- *In general the U-IBA collected from the ship on the 17th of January 2017 exhibited similar chemical characteristics to UK wide U-IBA samples analysed by WRc.*
- *The concentration of major elements and metals with the potential to form flammable gases were within the expected range for UK U-IBA from municipal waste facilities based on WRc's in-house data set.*
- *Neither the MVVD U-IBA sample collected from the ship post the explosion, or the sample of fresh U-IBA collected directly from the Devonport facility were hazardous by HP3-A (Highly flammable – water reactive waste).*
- *Although neither U-IBA samples tested were hazardous by HP3; when exposed to water a low rate of H₂ generation was observed during both the UN test N.5 and the in-house NLS test method (0.43 and 0.77 l kg⁻¹ h⁻¹ respectively). Considering the rate of H₂ production, scenario specific risk assessments should be conducted regarding U-IBA transport and storage where confined conditions are used. There could be a potential risk of explosive atmosphere formation in certain conditions when the quantity of U-IBA is large relative to the effective air space.*

1.12.3 MVV Environment Devonport tests

Every month, in accordance with EA requirements, MVVD had two samples of U-IBA tested using the ESA protocol. **Figure 12** shows a comparison between the results of these tests and WRc's in-house data made up of the test results from over 21 similar incinerator facilities in the UK. A comparison between the test results of the routine test carried out by MVVD and the sample collected by the MAIB after the accident is shown in **Table 1**. The total metal content in the MAIB sample was estimated as 10.6%, of which the non-ferrous content was 2.6%.

Parameter	Routine test carried out by MVV after production	Test carried out post-accident by a different lab
Aluminium ¹² [mg/kg]	19,248	26,246
Moisture [% weight]	14.5	12.4
pH value or measure of alkalinity	12.6	11.8

Table 1: Comparison of test results of U-IBA loaded on *Nortrader*

¹² The aluminium content reported in these tests is that found in the clinker and does not contribute towards the production of hydrogen.

Appendix B Analytical Data

B1 Compositional Data

Table B.1 MVV Devonport U-IBA - summary of composition data

Determinand	Units	MVVD-IBA-MAIB-ANN-170117	WRc MW U-IBA data ranges 2014-date	
			Average	95 th Percentile
Moisture content	% wt.	12.4	18.0	25.0
pH	pH units	11.8	12.4	12.8
Alkali Reserve	g NaOH 100g ⁻¹	0.11	0.71	1.50
ANC @ pH4	mol kg ⁻¹	0.98	3.31	5.49
ANC @ pH7	mol kg ⁻¹	0.37	2.50	5.00
TC	%	1.02	1.52	1.89
TOC as C	%	0.61	0.97	2.45
LOI @ 550°C	%	3.61	2.29	4.33
Aluminium	mg kg ⁻¹	26 246	21 785	30 263
Antimony	mg kg ⁻¹	55.9	60.4	105
Arsenic	mg kg ⁻¹	11.3	7.03	12.9
Barium	mg kg ⁻¹	637	421	708
Beryllium	mg kg ⁻¹	0.88	0.59	0.90
Boron	mg kg ⁻¹	143	79.1	125
Cadmium	mg kg ⁻¹	6.40	11.1	23.5
Calcium	mg kg ⁻¹	95 694	90 869	128 103
Chromium (total)	mg kg ⁻¹	116	104	163
Chromium (VI)	mg kg ⁻¹	0.09	0.14	0.48
Cobalt	mg kg ⁻¹	30.5	36.2	63.7
Copper	mg kg ⁻¹	2 102	2 175	3 299
Iron	mg kg ⁻¹	42 431	38 533	63 063
Lead	mg kg ⁻¹	684	737	1 470
Lithium	mg kg ⁻¹	23.4	16.5	23.2
Magnesium	mg kg ⁻¹	7 758	6 856	9 208
Manganese	mg kg ⁻¹	1 174	891	1 634
Mercury	mg kg ⁻¹	0.44	0.55	0.85
Molybdenum	mg kg ⁻¹	10.6	10.3	22.9
Nickel	mg kg ⁻¹	94.5	103	205
Phosphorus	mg kg ⁻¹	4 827	5 132	7 123
Potassium	mg kg ⁻¹	2 867	3 678	5 403
Selenium	mg kg ⁻¹	0.44	0.64	0.86
Silver	mg kg ⁻¹	1.87	5.96	15.2
Sodium	mg kg ⁻¹	8 331	8 447	10 913
Strontium	mg kg ⁻¹	214	214	322
Thallium	mg kg ⁻¹	0.09	0.46	0.86
Tin	mg kg ⁻¹	159	145	245
Titanium	mg kg ⁻¹	1 903	1 702	2 291
Vanadium	mg kg ⁻¹	43.2	40.1	114
Zinc	mg kg ⁻¹	3 463	2 308	3 369
Cyanide (Free)	mg kg ⁻¹	0.88	0.83	0.87
Cyanide (Total)	mg kg ⁻¹	0.88	0.87	0.95
Fluoride	mg kg ⁻¹	1.84	77.0	313
Ammoniacal Nitrogen	mg kg ⁻¹	8.76	6.59	8.64

Elemental composition results are the mean of three replicate *aqua regia* digestions and determinations. Results for Cu, Ni, Pb and Zn are the mean of eleven replicates

Results are presented on an 'as-received' (wet-weight) basis

Key	
ANC:	Acid neutralising capacity
TC:	Total carbon
TOC:	Total organic carbon
LOI:	Loss on ignition

Figure 12: Comparison of U-IBA sample from *Nortrader* with national averages (extracted from the WRc report)

Following the accident, at the request of Rock Solid BV, MVVD sent 10 samples of U-IBA to be tested for the release of flammable gases. These tests, carried out in accordance with UN test N.5, showed negligible gas release for all 10 samples. Marchwood Scientific Services' report is included at **Annex F**.

1.13 BURGOYNES & PARTNERS INVESTIGATION

Burgoynes & Partners were appointed by *Nortrader's* hull and machinery insurers to complete an independent investigation of the explosion. Their report stated that the explosion was most likely to have been the result of hydrogen released from the cargo.

Burgoynes tested for gas within small holes dug into a heap of U-IBA after it had been discharged ashore from *Nortrader* and measured 1.4% hydrogen and 0.2% carbon monoxide. The test was repeated the next day, but neither gas was registered on the gas meter.

1.14 ESTIMATION OF POTENTIAL HYDROGEN PRODUCTION

1.14.1 Production of hydrogen

Hydrogen is a colourless, odourless gas that is 14 times lighter than air. It is highly volatile and burns easily in air at concentrations between 4% and 75%. Compared to other flammable gases, hydrogen has the lowest minimum ignition energy, which is a measure of the electrical energy contained in a spark across two conductors sufficient to cause ignition of the flammable mixture¹³.

The predominant source of hydrogen generation in U-IBA is the reaction of elemental aluminium with water in alkaline conditions. Other metals such as iron, nickel and copper can also produce hydrogen, but their contribution is negligible when compared to aluminium.

1.14.2 Study to estimate hydrogen volume

The MAIB commissioned the Hydrogen Hazards Unit (HHU) of London South Bank University to carry out a study to determine the approximate concentration of hydrogen gas required to generate the explosive forces experienced on board *Nortrader*. The MAIB provided HHU with relevant information, including the drawings and dimensions of the cargo hold and forecastle store, weights and material of hatch covers, breaking strengths of cleats and wedges used to secure the hatch covers, and photographs of the damage. The results of the tests carried out by WRc, and other U-IBA test results made available to the MAIB, were not supplied to HHU.

The HHU report (**Annex G**) stated that the flame generated during the first explosion would have propagated into the cargo hold and that the pressure in the hold would have risen as the hydrogen air mixture within it combusted. It was estimated that after approximately 0.15 second, the hatch covers would have lifted, allowing the pressure built up in the hold to vent to atmosphere. The temperature of the hydrogen flame front was estimated to have been approximately 1000°C.

¹³ LECTURE. Sources of hydrogen ignition and prevention measures (Compiled by S.Tretyakova-McNally; reviewed by D.Makarov).

The report concluded:

In summary, considering the evidence available, the likely 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 m³ [of hydrogen gas].

1.15 PREVIOUS/SIMILAR ACCIDENTS

1.15.1 Accidents at sea

In January 2008, two crew members died of asphyxiation in the forward store room of the dry cargo vessel *Sava Lake* (MAIB report 15/2008). The oxygen level had been depleted by the cargo of steel turnings, a cargo the vessel was not authorised to carry. The atmosphere in the cargo hold was inadvertently equalised with that of the forward store due to modifications carried out on the ventilation trunking.

1.15.2 Accidents ashore

In 2006, following an explosion in a disused oil well that was used to store U-IBA, the Swedish Thermal Engineer Research Institute carried out a study to estimate the hydrogen generation potential of U-IBA.¹⁴

In 2009, the Health and Safety Executive in the UK reported severe injuries to a worker who was using an angle grinder to cut steel reinforcement in a concrete structure which utilised U-IBA.

Several other incidents of cracks developing in concrete and overlay asphalt on roads, due to the production of hydrogen by the U-IBA used, have also been reported by organisations, including the UK's Health and Safety Executive.

¹⁴ Maria Arm and Johanna Lindeberg, 2006: Gas generation in incinerator ash.

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 THE EXPLOSION

2.2.1 Conditions for the explosion

Laboratory tests have established that hydrogen gas was the only flammable gas released by the U-IBA carried on board *Nortrader* and that a sufficient quantity of hydrogen could have been released from the cargo to form an explosive atmosphere. Several underlying conditions combined to cause the explosion:

- The presence of 2.6% non-ferrous metals including aluminium, the alkalinity of the cargo, and an increased moisture content due to heavy rain during loading led to the generation of hydrogen.
- The 19 hours spent at anchor allowed the generated hydrogen to accumulate in the unventilated cargo hold.
- The unsecured and unsealed cargo hold lamp access cover in the forecastle store allowed hydrogen gas to enter the forecastle store.
- The closed vents and access door of the forecastle store allowed the hydrogen to accumulate in the forecastle store.
- The broken lug of the emergency fire pump starter panel door allowed the accumulated hydrogen to enter the space in the circuit breaker.

2.2.2 Connection between cargo hold and forecastle store

The access plate for the starboard cargo hold lamp fitting had been left loosely secured by two bolts with no gasket. It is likely that the bulb in this fitting was prone to regular failure, due to the vibration generated in the area during the bow thruster operation, resulting in a need for frequent access. However, leaving the access plate slack and unsealed effectively connected the cargo hold with the forecastle store, allowing the atmosphere of both spaces to equalise. Had *Nortrader* been certified to carry dangerous goods, the access to the cargo lamps might have been better designed and more strictly controlled.

As on *Sava Lake* (see 1.15.1), the gas tight integrity of the cargo hold of *Nortrader* was breached. On *Nortrader*, this allowed the lighter than air hydrogen generated by the cargo to rise and enter the forecastle store. Hydrogen being an odourless, colourless gas, the chief engineer would not have been alerted to its presence when he entered the space.

2.2.3 Ignition leading to explosions

The propensity of hydrogen to form an explosive mixture with air across a broad range of concentrations, and the ability of a weak ignition source to ignite this mixture, resulted in the first explosion. The ignition source for the hydrogen air mixture was most likely to have been electrical arcing between the contactors in the switch gear in the emergency fire pump starter panel when the chief engineer stopped the pump.

The initial explosion in the forecastle store would have led to a rapid increase in pressure in the store. This pressure was responsible for throwing the chief engineer against the starter panels before it was released through the open weathertight door. The flame front from the initial explosion propagated through the unsealed cargo lamp access cover and ignited the hydrogen air mixture in the hold. The pressure created in the hold by the resulting explosion was sufficient to break all the hatch cleats and dislodge the hatch covers. There were no subsequent explosions since the hold was then open to atmosphere, stopping any further accumulation of hydrogen.

HHU estimated the flame front temperature to have been 1000°C. However, the passage of the flame front would have been very quick as the accumulated hydrogen burned. The chief engineer appeared to have suffered the full brunt of the first explosion, causing the synthetic fibre-filled coat he was wearing to melt onto his body.

2.3 DECISION TO LOAD

2.3.1 Precedent

There had been 34 shipments of U-IBA from Plymouth to Beverwijk since the incinerator plant started operating in 2015. However, U-IBA was not listed in the IMSBC Code and no steps had been taken to seek approval from the competent authorities for its carriage, as required by the Code.

Had the explosion on *Nortrader* not taken place, these unauthorised and dangerous shipments would probably have continued without change.

2.3.2 Master

The master had the ultimate responsibility for accepting the cargo and could have challenged the instructions he received from H&V on the basis that the cargo was not listed in the IMSBC Code. However, *Nortrader's* SMS incorrectly stated that the IMSBC Code was only to be used when carrying dangerous cargoes. This was the way that the IMSCB Code's predecessor, the BC Code, had been used. The charter party stated that U-IBA was *non dangerous* and *non-IMO classed* (implying that it was not a recognised dangerous cargo under the IMDG Code). Therefore, it is not surprising that the master, along with the masters of the vessels carrying the previous 34 shipments, followed the loading instructions from H&V.

2.3.3 Shipper

All cargoes of U-IBA from MVVD had been arranged by Rock Solid BV through H&V. Since U-IBA was not listed in the IMSBC Code, Rock Solid BV (the shipper of the cargo) should have provided the MCA (the competent authority at the port of loading) with the required information regarding the intended cargo, prior to the first carriage of this cargo in June 2015. However, Rock Solid BV was unaware of this requirement as it had no shipping expertise, and expected H&V to provide marine advice as required, despite there being no written agreement between them to this effect.

H&V restricted its action to identifying and chartering 'suitable' vessels, without referring to the IMSBC Code. Its selection was based on the limited information contained in the MSDS for U-IBA provided by Rock Solid BV in October 2013 (**Annex D**). While this was inappropriate use of the MSDS, it did state that U-IBA could release hydrogen and other dangerous gases when in contact with water. In contrast, the charter party for *Nortrader* inaccurately stated that U-IBA was *non dangerous*.

The charter party also stated that U-IBA was *non-IMO classed* although it would have been more accurate to state that U-IBA had not been given a BCSN since it had never been assessed, as required by the IMSBC Code.

2.3.4 UK regulations

The UK Carriage of Cargoes Regulations had not been updated, and referred to the guidance provided by the superseded BC Code and not the mandatory IMSBC Code. However, this factor did not influence the skipper's decision to load U-IBA or contribute in any way to the accident on *Nortrader*. Furthermore, it is considered unlikely that past shipments were carried out with the intent of exploiting any potential loophole in the UK regulations.

2.4 UNIQUENESS OF CARGO OR VESSEL

2.4.1 Cargo

There had been 34 shipments of U-IBA from MVVD since June 2015, without any untoward incidents. Yet the cargo loaded on *Nortrader* caused a major explosion. The human consequences of this accident could have been severe, and it is extremely fortunate that the chief engineer survived the explosion.

The cargo loaded on *Nortrader* comprised U-IBA produced at MVVD over a period of 15 consecutive days. The tests carried out by WRc on samples collected after the explosion established that the chemical and physical characteristics of the cargo were consistent with those of the U-IBA from other facilities in the UK.

2.4.2 Vessel

More than a third of the vessels employed to carry the previous shipments were certified to carry dangerous cargoes. Breaches between cargo hold and adjoining spaces were therefore less likely to have existed and electrical equipment, where fitted in the cargo space, would have been intrinsically safe, thus reducing the potential for ignition sources. It is also possible that some vessels operated natural

or forced exhaust ventilation systems for the cargo holds while carrying U-IBA, thus protecting themselves by avoiding the potential for the accumulation of hydrogen. However, *Nortrader's* design and construction, including that of its cargo hold and ventilation systems, were similar to many of the other vessels that had been engaged to carry U-IBA from MVVD.

2.4.3 Conclusion

Neither the U-IBA cargo loaded onto *Nortrader* nor the vessel itself were unique in any way that might have contributed to this accident.

2.5 CLASSIFICATION OF U-IBA

2.5.1 Carriage of U-IBA by sea

U-IBA had not been assessed or classified for carriage in bulk by sea. 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, MGN 512 and the guidance document *Carrying solid bulk cargoes safely (Annex C)*.

It is likely that this accident would not have happened had the IMSBC Code requirements been followed, as the dangers would have been identified and procedures for safe carriage developed and implemented prior to loading.

2.5.2 Classification of U-IBA ashore

The UK's LoW regulation, revoked in July 2015, categorised U-IBA as mirror hazardous. Monthly testing was voluntarily undertaken by the majority of incinerator facilities in the UK, based on a protocol developed by the ESA and endorsed by the EA. This protocol represented a significant step forward in the understanding of the classification and properties of IBA and was a good example of an industry led protocol. However, the protocol discounted the potential for the generation of flammable gases on the erroneous assumption that the incineration process would have rendered the U-IBA non-flammable, without considering the possibility of the ash releasing flammable gases when wet.

Ashore, the release of hydrogen gas from moist U-IBA was a recognised phenomenon. The EA's SR2012 No13 identified that wet U-IBA would release hydrogen and stated that ventilation was required to disperse the hydrogen where U-IBA was stored under cover. In view of this, the EA's endorsement of the ESA test protocol that did not include HP3 was inappropriate.

2.6 ADEQUACY OF UNITED NATIONS TEST N.5

2.6.1 Non-replicability of test results

Flammable gas release tests conducted by Marchwood Scientific Services on 10 fresh samples, and on samples collected by the MAIB after the accident, did not produce any hydrogen when subject to UN Test N.5. However, the fresh sample

collected by WRc from MVVD tested positive for hydrogen release. The NLS in-house method test of the MAIB sample proved positive, although a smaller quantity of hydrogen was released compared to the fresh WRc sample during this test.

Sample preparation, inter-lab variability, the variability in the two test methodologies, and the aging of the sample may account for some of the difference in results. The UN Test N.5, like the NLS in-house method test, assumed that the sub samples used for testing were representative of the cargo. However, visual observation of U-IBA and its test results demonstrate that it was highly heterogeneous in nature and, despite the best efforts to reconstitute the test samples as per their original composition, it is difficult if not impossible to achieve reliable and repeatable results.

2.6.2 Rate of release of flammable gas

It is evident that the release of hydrogen was localised and perhaps limited to pockets. If the results of the UN Test N.5 on the WRc sample are extrapolated, the total hydrogen produced in 6 hours (the duration after which the gas production was observed to have ceased) would amount to 6019m³. The strength of explosion of such a quantity of hydrogen would have resulted in far worse damage to the vessel. The estimation by HHU of London South Bank University, that the quantity of hydrogen present in the hold was unlikely to have exceeded 171m³, was considered to be more realistic.

At the time of the explosion, the hold had been sealed for approximately 19 hours. It cannot be known whether the cargo was still producing hydrogen, but subsequent testing showed that some was still being produced in one sample. The production of 171m³ of hydrogen from 2333t of cargo equates to a minimum theoretical rate of release of approximately 0.004l/kg/h. While this is a rough approximation, it is clear that the 1l/kg/h threshold for categorising a cargo as hazardous (UN Test N.5) is inappropriate for bulk cargoes, and that the competent authorities' discretion to require additional tests should be exercised. For purposes of transportation in bulk by sea, the release of any quantity of flammable gas should be considered dangerous. The MCA has recognised this and has categorised U-IBA as a cargo posing a chemical hazard that could give rise to a dangerous situation on a ship.

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. Hydrogen gas was the only flammable gas released by the U-IBA carried on board *Nortrader*, and a sufficient quantity of hydrogen could have been released from the cargo to form an explosive atmosphere. [2.2.1]
2. The gas tight integrity of the cargo hold was breached, allowing the hydrogen generated by the cargo to enter the forecastle store. [2.2.2]
3. The ignition source for the hydrogen air mixture was most likely to have been electrical arcing between the contactors in the switch gear in the emergency fire pump starter panel. [2.2.3]
4. There had been 34 shipments of U-IBA from Plymouth to Beverwijk despite U-IBA not being listed in the IMSBC Code, during which no steps had been taken to seek approval from the competent authorities for its carriage. [2.3.1]
5. *Nortrader's* SMS incorrectly stated that the IMSBC Code was only to be used when carrying dangerous cargoes. [2.3.2]
6. The shipper, Rock Solid BV, was unaware of the requirements of the IMSBC Code. [2.3.3]
7. Hudig & Veder restricted its action to identifying and chartering 'suitable' vessels, without referring to the IMSBC Code. [2.3.3]
8. Had the IMSBC Code requirements been followed it is likely this accident would not have happened as the dangers would have been identified and procedures for safe carriage developed and implemented prior to loading. [2.5.1]
9. For purposes of transportation in bulk by sea, the release of any quantity of flammable gas should be considered dangerous. [2.6.2]

3.2 SAFETY ISSUES NOT DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. The UK Carriage of Cargoes Regulations had not been updated and referred to the guidance provided by the superseded BC Code and not the mandatory IMSBC Code. [2.3.4]
2. The test protocol adopted by the ESA and endorsed by the EA erroneously discounted the potential for the generation of flammable gases. [2.5.2]
3. The Environment Agency's endorsement of the ESA test protocol that did not include HP3 was inappropriate. [2.5.2]
4. Due to its heterogeneous nature, it is difficult if not impossible to achieve reliable and repeatable results using UN Test N.5 on U-IBA. [2.6.1]
5. The 1l/kg/h limit suggested by (UN Test N.5) is inappropriate for bulk cargoes. [2.6.2]

SECTION 4 - ACTION TAKEN

4.1 MAIB ACTIONS

The **Marine Accident Investigation Branch** has:

- Published a safety flyer intended to promulgate the lessons learned from this accident with particular emphasis on the application of the IMSBC Code.
- Worked with several trade bodies including the International Group of Protection & Indemnity Clubs, International Chamber of Shipping, International Association of Dry Cargo Ship Owners, and Institute of Chartered Shipbrokers to help disseminate the safety flyer.
- Provided the MCA with the results of laboratory tests and technical research conducted during this investigation to support its submissions to the IMO.

4.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

The **Maritime and Coastguard Agency** has:

- Set up a tripartite agreement between the UK, the Netherlands and several other Administrations for the safe carriage of U-IBA.
- Proposed two papers to the International Maritime Organization: to include U-IBA in the schedule of authorised cargoes in the IMSBC Code; and to raise the issue of the inadequacy of UN test N.5 for non-homogeneous bulk cargoes.

MVV Environment Devonport Limited has:

- Installed hydrogen gas monitors and a hydrogen warning system in the U-IBA storage bunker.
- Revised the risk assessment and procedures for U-IBA storage and movement from the site.

The **Environment Services Association** has:

- Published a notice on its website about incinerator bottom ash, which includes the hazard of hydrogen release.
- Commissioned further tests on un-ground U-IBA samples for the generation of hydrogen gas.

SECTION 5 - RECOMMENDATIONS

The **Maritime and Coastguard Agency** and the **Environment Agency** are recommended to:

2017/153 Work collaboratively to identify reliable methods and protocols for testing non-homogeneous solid bulk cargoes for the property of evolving flammable gases when wet.

The **Maritime and Coastguard Agency** is recommended to:

2017/154 Update The Merchant Shipping (Carriage of Cargoes) Regulations 1999 with appropriate references to the IMSBC Code.

Hudig & Veder BV is recommended to:

2017/155 Review its operating procedures to ensure that the requirement to apply the provisions of the IMSBC Code to all bulk cargoes is clear.

NTO Shipping GmbH & Co.KG is recommended to:

2017/156 Review its safety management system to ensure that the requirement to apply the provisions of the IMSBC Code to all bulk cargoes is clear.

Safety recommendations shall in no case create a presumption of blame or liability

