Report on the technical inquiry into the

ADAMANDAS

Bureau d'enquêtes sur les évènements de mer

Report on the investigation of the

TOTAL LOSS

OF THE BULK CARRIER

ADAMANDAS

ON 22nd SEPTEMBER 2003
OFF THE ISLAND OF LA REUNION
FOLLOWING THE RE-OXIDATION
OF A CARGO OF DIRECT REDUCED IRON

Warning

This report has been drawn up according to the provisions of Clause III of Act No.20023-3 passed by the French government on 3rd January 2002 relating notably to technical and administrative investigations after accidents at sea and the decree of enforcement No. 2004-85 of 26th January 2004 relating to technical investigations after marine casualties and terrestrial accidents or incidents, and in compliance with the "Code for the Investigation of Marine Casualties and Accidents" laid out in Resolutions A.849(20) and A.884(21) adopted by the International Maritime Organization (IMO) on 27/11/97 and 25/11/99.

It sets out the conclusions reached by the investigators of the BEAmer on the circumstances and causes of the accident under investigation.

In compliance with the above mentioned provisions, the analysis of this incident has not been carried out in order to determine or apportion criminal responsibility nor to assess individual or collective liability. Its sole purpose is to identify relevant safety issues and thereby prevent similar accidents in the future. The use of this report for other purposes could therefore lead to erroneous interpretations.

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List of abbreviations

ABS	:	American Bureau of Shipping
ATEX	:	Explosive atmosphere (from the French : Atmosphère Explosive)
BC Code	:	Code of Safe Practice for Solid Bulk Cargoes
***BEA*mer**	:	Bureau d'enquêtes sur les évènements de mer (Marine Accident Investigation Office)
BV	:	Bureau Veritas
CEDRE	:	Centre de Documentation de Recherche et d'Expérimentations sur les pollutions accidentelles des eaux (Centre of Documentation, Research and Experimentation on Accidental Water Pollution)
CODIS	:	Centre Opérationnel Départemental d'Incendie et de Secours (Departmental centre of operations for fire and rescue services)
COMAR	:	Commandement de la Marine (Naval command centre)
COSRU	:	Centre Opérationnel de Sauvetage de la Réunion (Centre for rescue operations in La Réunion)
DRI	:	Direct Reduced Iron
GL	:	Germanischer Lloyd
HBI	:	Hot Briquettes Iron
IACS	:	International Association of Classification Societies
IMO	:	International Maritime Organization
INERIS	:	Institut National de l'Environnement industriel et des Risques (National Institute for the Environment and Risks)
LEL	:	Lower Explosive Limit

LRS	:	Lloyd's Register of Shipping
P & I	:	Protection and Indemnity
PPM	:	Parts par million
PVC	:	Polyvinyl chloride
SAMSA	:	South African Maritime Safety Authority
SECMAR	:	Plan de SECours MARitimes (maritime assistance plan)
SOLAS	:	International Convention for the Safety of Life at Sea
SRSR	:	Société Réunionnaise de Sauvetage et Remorquage (tug and salvage company in La Réunion)

1 CIRCUMSTANCES

On 11th September 2003, while 65 miles south of Réunion Island, the Cyprus registered bulk carrier *ADAMANDAS*, carrying 21000 tonnes of direct reduced iron (DRI) requested permission to call at Réunion Island.

She wished to obtain nitrogen to inert one of her holds in which an abnorrnal rise in temperature, accompanied by emanations of hydrogen, had been observed.

She was given permission to proceed to the anchorage area off the village of La Possession.

A multidisciplinary assessment team went on board on 12th September to gather more information and decide whether it was possible to inert the hold.

At the same time, the Greek owners and the underwriters dispatched representatives to the scene, including a specialist in fire fighting, to find a solution to the problem of the rise in temperature of the cargo.

On 15th September, with the vessel still at anchor, the assessment team carried out further checks on board. The temperature and hydrogen content were lower in Hold No.2, but slightly higher in Hold No.3.

It was not conceivable for the vessel to enter port in these conditions and as the owners gave no sign of taking any meaningful action to make the vessel safe, the Prefet de la Réunion, acting in his capacity as representative of the government for the Action of the State at Sea, sent an injunction to the owners, reminding them of their responsibilities and setting a date – Wednesday 17th September – beyond which the French authorities would intervene if the situation had not been brought back to normal. He also asked the INERIS to set up a crisis management team making it possible for the authorities to examine thoroughly the owner's proposals for handling the problem before giving their approval.

On 18th September the situation was unchanged but as no effective measures had been taken by the owners, the Préfet addressed them a further injunction.

On 19th September no tangible progress had been made with the owners : two teams of specialists were sent on board, one to assess how dangerous the cargo was and discuss the situation with the crew, the other to get the vessel ready for a possible tow. A new increase in temperature was observed at one point in Hold No.2 reaching 619°C.

On 20th September the situation on board the *ADAMANDAS* had worsened. The cargo in Hold No.1 which, up until then, had given no problems, began to give off hydrogen. The master sent a formal request to the French authorities at the beginning of the afternoon asking them to ensure the safety of his crew and to evacuate 6 crew members who no longer wished to remain on board.

The Préfet de la Réunion then ordered rescue resources to be deployed and ordered the master to move his vessel away from the coast but to remain in territorial waters. He also offered the use of state-requisitioned resources in the event of his not being able to proceed by himself after a possible partial or total evacuation of the crew.

On 21st September at about 0030, as the master had not obeyed the Préfet's order, the *ADAMANDAS* was taken in tow by the l'Abeille *CILAOS* of the SRSR and towed to a position off the Pointe des Galets, in territorial waters. At the master's request most of the crew were transferred ashore before towing commenced.

In the afternoon at the end of a last-ditch meeting with all the interested parties present (owners, charterer, master, underwriters and specialists), the owners were unable to put forward any rapid, safe, effective technical solution corresponding to the State's deadline and safety requirements.

Later that evening, on the basis of decree 86-38 relating to Police measures and taking into account the worsening situation on board the Préfet de la Réunion ordered the vessel to be destroyed and sunk (Prefectorial Order No.2216/SG/AEM of Sunday 21st September 2003 – 2345).

On 22nd September at 0900 the hull of the vessel was pierced by explosives and finally sank at 1400 local time in 1750 metres of water 20 miles north-west of la Réunion in position 20°56.7' S – 054°59.9' E. The operation was carried out by French navy bomb-disposal divers in favourable weather conditions.

The slight pollution observed at the surface was treated by French navy patrol vessels with the help of a specialist from the CEDRE.

On 26th September the risk of any further pollution was totally under control.

2 DIRECT REDUCED IRON (DRI)

2.1 Definitions

Iron obtained by direct reduction (DRI) is made from iron ore. It is a metallic product which is the result of a manufacturing process which consists in reducing iron oxide, that is removing oxygen from the ore at temperatures below the melting point of iron. After the ore has been ground to liberate the silica grains which are the main constituant of the gangue and the hematite and gangue have been separated using the magnetic or flotation separation techniques, the Fe_2O_3 hematite fines are pelletized using bentonite (clay) as a cold binder.

The composition of the hematite by dry weight is approximately the following : 67% Fe; 1.5% lime, 1.5% silica and various other elements including about 1% aluminium oxide. The pellets of hematite are then heated until they harden giving them the physical and chemical properties, such as resistance to crushing, required to make them easier to handle.

When the lime and silica are heated to 1400℃ a vit reous phase is obtained which serves as a binder for the pellets. After jigging (3 to 5% of the weight) the pellets are placed in a reactor through which methane gas flows (Midrex process) obtaining reduction of the hematite to metallic iron by stripping away the oxygen which binds to the methane to form carbon dioxide and water vapour.

There are various direct reduction processes which use either coal or natural gas as their sources of energy in different types of reactor.

Classification of reduction processes

Energy source	Reactor (ore)	Process
Natural gas	Fluidisation (Fines)	Fior/Finmet Iron Carbide
Natural gas	Shaft furnace (Pellets / calibrated lump ore)	Midrex Hyl III
Coal	Rotating kiln (Pellets / calibrated lump ore)	SLRN
Coal	Fluidisation (Fines)	Circofer
Coal	Rotary hearth furnace (Fines)	Fastmet

The most widely used process is the Midrex process representing about 70% of the total world production of DRI.

Once their oxygen has been removed the metallic iron pellets are very porous. Their structure is similar to that of a sponge which makes them prone to rapid re-oxidation.

DRI is a relatively recent product in the steel manufacturing industry. The first Midrex plants came on line in the seventies. The main producing countries are Venezuela, Trinidad, Egypt, Saudi Arabia, Iran, the USA, Inidia and Russia.

About 10 million tonnes of DRI are exported annually.

The main DRI exporting countries are Venezuela, Libyan Trinidad and Russia.

The world manufacturing capacity for DRI is about 50 million tonnes per year.

2.2 Different types of DRI

DRI comes in the following forms :

2.2.1 Pellets

Average size 6 to 25 mm diameter. Up to 5% fines (particles less than 4 mm).

They are very porous and thus have a very strong tendency to re-oxidize, which makes them difficult to transport.

This form involves the greatest risk of spontaneous heating. Thus various methods of treating DRI have been tried in order to reduce this risk.

2.2.2 Cold moulded briquettes

Cold moulded briquettes are those which have been moulded and compressed by roller presses at a temperature of less than 650℃. They have a density of under 5.0 g/cm^3.

They look like a piece of soap about 35 to 40 mm in size.

The aim of the operation is to reduce the porosity, and by so doing, the surface area in contact with the surrounding environment likely to react to humidity. They can also be passivated.

This type of briquette is relatively fragile as they are compressed at a low temperature. They crumble easily and may break during loading operations which increases the surface area in contact with the atmosphere, stimulating a reaction with the ambient humidity, making them as difficult to transport as pellets.

2.2.3 Hot moulded briquettes

They are obtained by compressing freshly produced pellets into briquettes at high temperature. This is a variation on the previously described process, in which the basic material is moulded at a temperature over 650℃ and attains a density of more than 5.0 g/cm^3.

They have the following characteristics :

- length 90 to 130 mm ;
- width 80 to 100 mm ;
- thickness 20 to 50 mm ;
- weight 0,5 to 2,0 kg ;
- up to 5% fines (less than 4mm).

These briquettes are less fragile then the cold moulded type and show less propensity to break while being handled. They can also be passivated.

When pellets are compressed at very high pressures the product obtained is known as HBI (Hot Briquettes Iron). HBI oxidizes very slowly and can be stored for three years on industrial sites. It is used in electric arc furnaces.

It is probably one of the safest types of DRI and one of the easiest to transport, which explains why its use has become more and more widespread. However, it too has a tendency to heat up and evolve hydrogen under certain conditions. Furthermore it presents the disadvantage of requiring more energy for its processing than pellets.

Typical characteristics of HBI :

- Total iron 91,014
- Metallic iron 84,050
- Metallization 92,190
- Al_2O_3 0,54
- MgO 0,43
- CaO 0,64
- SiO_2 1,75

Carbon content fluctuates between 1.0 and 1.2; maximum phosphorus content is 0,06, maximum suphur content 0,01.

Its bulk density is between 2.4 and 2.8 tonnes per m^3 and its apparent density 4.9 to 5.5.

A high total iron content is the mark of highly reduced iron.

HBI is used as an accelerator in blast furnaces and as a substitute for scrap iron in electric arc furnaces. It can be used in converters as a cooling agent instead of scrap iron.

Hot moulded briquettes are sometimes referred to as iron ore briquettes, briquetted iron ore or DRI briquettes.

2.2.4 Other types

One manufacturer in South America also offers crushed DRI particles for carriage by sea. This is a raw product obtained from the reduction process before jigging for pelletization.

This cargo is probably more dangerous to carry than DRI pellets.

DRI and its by-products can also be referred to under other names. In a recently reported accident, the cargo was described as crushed iron ore pellets. The shipper had confirmed that the cargo was not dangerous and the vessel had accepted it as such.

This description, however, was incorrect and it turned out that the cargo in question was a mixture of jigged DRI particles and jigged iron ore pellets; the bill of lading described the cargo as particles of iron oxide.

The cargo oxidized during the voyage and there was an explosion caused by the hydrogen which had evolved, causing the death of two crew members. Another sustained serious injuries and the ship was badly damaged.

The vessel involved, the *KARTERIA,* was a bulk carrier of 34900 tonnes deadweight flying the Maltese flag; she had loaded at Mississipi River on 16th August 1999 and was scheduled to unload in Antwerp on behalf of Cockerill. The explosion occurred on 25th August 1999 in holds 4 and 5 when the ship was in position 37°28' N – 45°30' W.

More recently, on 28th February 2004, another accident happened on board the *YTHAN,* a conbulker of 35310 tonnes deadweight registered in the Marshall Islands, carrying 35000 tonnes of iron from Venezuela to China.

A series of explosions occurred in the holds when the ship was about 20 miles off Punta Aguja north of Santa Marta (Colombia), as a result of which the ship sank. The master was killed and five crew members were reported missing. The first explosion was in hold No.1 followed shortly after by three successive explosions in hold Nos. 5, 4 and 3 which opened up a large gash in the hold. The cargo consisted of hot moulded briquettes and iron particles obtained by direct reduction.

2.3 Properties

After they have been obtained by reduction, the iron pellets can re-oxidize very rapidly. This re-oxidation occurs if they are heated by air above a certain temperature or if they come into contact with water, including the ambient humidity. The porous structure of the product helps to boost the oxidation.

In contact with water, the DRI changes into Fe2O3 by absorbing the oxygen from the water and liberating the hydrogen. The water is the oxidizing agent.

The reaction is exothermic and the hydrogen evolved represents a risk of explosion. The ignition temperature is about 125℃.

When the temperature in the hold is sufficiently high and the hydrogen content is above its lower explosive limit of about 4% an explosion may occur in the hold of the vessel.

The heat given off by the reaction itself can, in turn, stimulate the re-oxidation of the dry pellets and thus set up a chain reaction throughout the cargo which can lead to temperatures, in the open air, of more than 1000℃, high enough to affect the strength of steel.

(*) Laboratory tests have shown that there is a marked acceleration of the exothermic reaction above 260℃ for DRI fines and 300℃ for pe llets.

It is similar to a coke fire; if water is sprayed on to it, the fire is fuelled. The only thing to do then is to completely and swiftly flood the product to stop the reaction.

The propensity of this product to re-oxidize on contact with water, with the accompanying problems of the production of heat and hydrogen this causes, represents the major difficulty for its carriage by sea.

Indeed, it has been shown that it re-oxidizes more slowly with fresh water than with seawater.

The carriage of this type of product presents risks which it is necessary to be aware of, particularly in the presence of humidity from seawater and due to the humidity of the ambient air in the marine environment.

Contamination by seawater can lead to spontaneous ignition. For this reason DRI pellets are generally passivated. Passivation consists in treating the pellets to protect them from humidity.

Manufacturers in different countries use different processes some of which are more efficient and long-lasting than others

However, no treatment makes DRI completely safe.

Some manufacturers apply a supplementary heat treatment to the pellets to passivate them (high temperature treatment during the final stage of production).

Thus the pellets obtain some measure of protection against fresh water and air. If they are contaminated by rain or snow the pellets will be likely to self-heat, but the temperatures will not reach dangerous levels with the attendent risk of spontaneous ignition.

During handling, the pellets may crumble due to crushing forming fines or dust which are dangerous because they are prone to autoignition. An accumulation of a few centimetres of dust can heat up and ignite.

2.4 Conditions of carriage

DRI is one of those substances having dangerous chemical properties which are subject to the relevant regulations of Chapters VI and VII of the SOLAS convention on the one hand, and to the Code of Safe Practice for Solid Bulk Cargoes (BC Code) on the other hand.

2.4.1 SOLAS

Chapter VI : Carriage of cargoes

Part A : General provisions.

Regulation 2 : Cargo information.

It is the responsibility of the shipper, before loading begins, to determine the physical and chemical properties of his cargo and to impart this information to the master or his representative.

Thus, 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. Such information shall be confirmed in writing and by appropriate shipping documents prior to loading the cargo on the ship.

Regulation 3 : Oxygen analysis and gas detection equipment.

When transporting a bulk cargo which is liable to emit a toxic or flammable gas, or cause oxygen depletion in the cargo space, an appropriate instrument for measuring the concentration of gas or oxygen in the air shall be provided together with detailed instructions for its use.

Crews must be trained in the use of such instruments.

Part B : Special provisions for bulk cargoes other than grain.

Regulation 6 : Acceptability for shipment.

Chapter VII : Carriage of dangerous goods in packaged form or in solid form in bulk.

Part A-1 : Carriage of dangerous goods in solid form in bulk.

2.4.2 BC Code

The safety measures applicable to the carriage of direct reduced iron pellets are stipulated in Annex B of the code and are recalled below.

Pellets and cold moulded briquettes

Special requirements :

Certification :

A competent person recognized by the National Administration of the country of shipment should certify to the ship's master that the DRI, at the time of loading, is suitable for shipment.

Shippers should certify that the material conforms to the requirement of the BC Code.

Shipper's requirements :

Prior to shipment, DRI should be aged for at least 72 hours, or treated with an air passivation technique, or some other equivalent method that reduces the reactivity of the material to at least the same level as the aged product.

Shipper should provide necessary specific instructions for carriage :

- either maintenance throughout the voyage of cargo spaces under an inert atmosphere containing less than 5% oxygen. The hydrogen content of the atmosphere should be maintained at less than 1% by volume;

- or that the DRI has been manufactured or treated with an oxidation and corrosion-inhibiting process which has been proved, to the satisfaction of the competent authority, to provide effective protection against dangerous reaction with seawater or air under shipping conditions.

The provision of the above paragraph may be waived or varied if agreed to by the competent authorities of the countries concerned, taking into account the sheltered nature, length, duration, or any other applicable conditions of any specific voyage.

Precautions :

- The ship selected should be suitable in all respects for carriage of DRI :

Prior to loading :

All cargo spaces should be clean and dry. Bilges should be kept dry during the voyage.

Wooden fixtures such as battens, etc., should be removed.

Where possible, adjacent ballast tanks, other than double-bottom tanks, should be kept empty. Weather deck closures should be inspected and tested to ensure integrity.

- DRI should not be loaded if material temperature is in excess of 65℃ or 150℉.

- Unless the DRI has been treated with an oxidation and corrosion-inhibiting process, any material, which is wet or is known to have been wetted should not be accepted for carriage. Materials should be loaded, stowed and transported under dry conditions

- Monitoring for the presence of oxygen and hydrogen should be carried out at regular intervals throughout the voyage, recorded, and the information kept on board and made available on request.

- Cargo spaces containing DRI materials may become oxygen-depleted and all due caution should be exercised upon entering such compartments.

- No smoking, burning, cutting, chipping or other source of ignition should be allowed in the vicinity of cargo spaces containing DRI.

Hot moulded briquettes

Properties :

Material may slowly evolve hydrogen after contact with water. Temporary self-heating of about 30℃ may be expected after material handling in bul k.

Observations :

Open storage is acceptable prior to loading.

Loading, including transfer from one ship to another, during rain is unacceptable. Unloading under all weather conditions is acceptable. During discharge a fine spray of fresh water is permitted for dust control.

Segregation and stowage requirements

Boundaries of compartments where DRI is carried should be resistant to fire and passage of water.

Separated from goods of classes 2, 3, 4 and 5 and class 8 acids.

Special requirements :

Certification :

A competent person recognized by the National Administration of the country of shipment should certify to the ship's master that the DRI, at the time of loading, is suitable for shipment.

Shippers should certify that the material conforms to the requirement of the BC Code.

Shipper's requirements :

The shipper may provide advice in amplification of the Code but not contrary thereto in respect of safety during carriage.

Precautions :

Prior to loading :

The same precautions as those stipulated above for the loading of pellets and cold moulded briquettes are to be applied.

Hot-molded briquettes should not be loaded if product temperature is in excess of 65℃ (150℉).

Cargo spaces containing DRI materials may become oxygen-depleted and all due caution should be exercised upon entering such compartments.

Adequate surface ventilation should be provided.

2.5 Emergency measures in the event of fire

In this case the BC Code makes the following recommendations :

- the hatches should kept closed. Water should not be used. Specialists should be consulted for advice.
- inert gas should be used as soon as possible as this can be an effective measure against slow combustion.

Furthermore, DRI professionals (manufacturers, users and carriers) have defined different means of combatting the exothermic reaction of DRI in the hold of a ship.

These means consist in preventing the DRI from coming into contact with air :

- by totally covering the surface of the DRI stack with sand,
- by flooding the DRI with water as quickly as possible in order to limit the emission of hydrogen,
- by blanketting the DRI with nitrogen.

CO_2 should not be used as there is a risk of CO being formed.

They also recommend unloading the cargo as quickly as possible.

3 THE VESSEL

The *ADAMANDAS* was a bulk carrier built in 1986 by the Guaymas shipyards in Mexico. She had been flying the Cyprus flag since 23rd September 1992.

She was registered in LIMASSOL.

Successive names :

- *ADAMANDAS* (15/12/95) ;
- *LAPIS LAZULIS* (01/12/94 - 14/12/95) ;
- *PATRIOTICOS* (29/04/92 - 01/12/94) ;

- *ATLAHUA* (04/03/86 - 18/03/92).

Successive flag states :

- Mexico (04/03/86 - 25/02/91) ;
- Marshall Islands (25/02/91 - 18/03/92) ;
- Cyprus (since 29/04/92).

Owners :

From 02/10/94, Sulzer Shipping - 45, avenue Vasilissis Sofias, Athens.

Managers :

Pacific & Atlantic 45, Avenue Vassilis Sofias, Athens (for 10 years).

Classification Societies :

- American Bureau of Shipping from 01/01/86 to 28/05/98;
- Lloyd's Register of Shipping since 28/05/98.

Class :

100A1 – SS12/00 - bulk carrier strengthened for heavy cargoes , Nos. 2&4 holds may be empty – ESP – LI – ESN-Hold 1 Ice Class 1C – LMC.

3-1 Particulars

The vessel's main characteristics were as follows :

- **Length overall : 165 m ;**
- **Breadth : 23.65 m ;**
- **Length between perpendiculars : 155.38 m ;**
- **Moulded depth amidships : 13 m ;**
- **Gross tonnage : 14487 ;**
- **Deadweight : 22580 tonnes ;**
- **Propulsion : IHI 5 cylinder 10592 kW diesel engine;**

- **Service speed** : **16.5 knots;**
- **IMO number** : **8115681.**

The vessel had 6 holds.

She had been insured since 03/09/03 by the Assuranceforeningen Gard Norway.

She carried solid bulk cargo.

Her Document of Compliance was issued in Piraeus by Lloyd's Register on 30/01/02 and was valid until 30/12/05.

The vessel could carry hot moulded briquetted iron (HBI/DRI) in her 6 holds.

She could also carry type A and type B ammonium nitrate-based fertilisers in holds 1, 2, 3, 4 and 5 (6 empty).

Her safety management certificate was issued by Lloyd's Register on 11th June 2003 and was valid until 16th February 2008.

An intermediate survey certificate was issued by Lloyd's on 3rd August 2003. Inspection of manholes giving access to holds 1, 2, 3, 5 and 6.

Hull special survey : carried out on 31/12/00 ;
due on 30/12/05.

Drydocking : carried out on 30/04/00 ;
due on 29/04/03 ;
postponed until 10/03.

Annual survey : due on 31/12/03.

Intermediate survey : due on 31/12/03.

The following observations were made :

Survey of 08/06/03 :

The tank top was dented. The bottom transverse and bottom stringer in the No.3 starboard double bottom ballast tank which were damaged in way of frame 135 needed to be closely inspected and dealt with, if necessary.

A leak in the upper part of No.6 starboard ballast tank (provisionally repaired) needed to be closely inspected and dealt with, if necessary.

The vessel also had to comply with Regulations 12 and 13 of Chapter XII of the SOLAS Convention : "Additional safety measures for bulk carriers".

Regulation 12 : Installation of water level detectors for hold, ballast and dry spaces ; no later than the date of the annual, intermediate or class renewal survey after 1st July 2004, whichever was the earliest.

Regulation 13 : Availability of pumping systems ; no later than the date of the first intermediate or class renewal survey to be carried out after 1st July 2004 but, in any case, no later than 1st July 2007.

The vessel was fitted with thermocouples for measuring temperatures in the holds.

3.2 Port State Control Inspections

PSC Organization	Authority	Port of inspection	Date	Detained	Number of deficiencies
Paris MoU	Greece	Pireus	31/01/02	No	17
Paris MoU	Greece	Pylos	17/03/01	No	3
Tokyo MoU	Russia	Vladivostok	28/08/00	No	0
Paris MoU	Russia	Novorossiysk	25/02/98	No	5

The deficiencies observed during the inspection of 31/01/2002 concerned :

- Crew and accommodation : 1
- Life saving appliances : 1
- Fire safety : 2
- Safety in general : 5
- Alarm signals : 1

- Load lines : 5
- Safety of navigation : 1
- ISM : 1

Inspection of 29/08/04

During the call at Durban between 29th August and 4th September, the South African maritime authorities conducted an inspection in an attempt to discover the cause of the overheating of the cargo of DRI.

The special inspection of 15th September at la Réunion, while the vessel was at anchor in Saint Paul's bay.

The inspection report mentioned the poor condition of the holds with extensive corrosion.

The ship management company PACIFIC & ATLANTIC manages a fleet of 22 vessels comprising :

- 5 15- to 20-year-old bulk carriers,
- 16 15- to 23-year-old general cargo ships,
- 1 15 year-old container ship.

Most of the ships are registered in Cyprus, with 4 ships being registered in Malta (general cargo ships).

All the vessels are classed by Classification Societies belonging to IACS such as American Bureau of Shipping (ABS), Bureau Veritas (BV), Germanischer Lloyd (GL), Lloyd's Register of Shipping (LRS).

During the last three years, 132 inspections have led to the detention of 6 vessels. While deficiencies were recorded in 65.22% of the inspections only 4.35% resulted in detentions.

4 MANNING

The crew comprised 22 persons. The master and the other crew members were

Filipino. The supercargo on board was from Trinidad.

The master held the qualification of master mariner.

5 CONDITIONS FOR THE CARRIAGE OF DRI ON BOARD THE *ADAMANDAS*

5.1 The vessel's cargo

The charter party was dated 10th July 2003.

According to the bill of lading drawn up on 5th August 2003 the cargo comprised 20894.98 tonnes of direct reduced iron pellets (DRI).

The chemical specification of the product delivered by CARRIBEAN ISPAT LTD is generally as follows :

- Total iron	: 91 - 93%
- Metallic iron	: 84 - 89%
- CaO	: 0,6 - 1,5%
- MgO	: 0,2 - 0,6%
- SiO_2	: 1,0 - 2,0%
- Al_2O_3	: 0,5 - 1,0%
- MnO	: 0,2% maximum
- TiO_2	: 0,15% maximum
- Carbon	: 1,5 - 2,5%
- Sulphur	: 0,0035% maximum
- L or H	: 0,06% maximum

5.2 Examination before loading of the suitability of the vessel for carrying the cargo

The vessel was inspected by the competent authorities of Trinidad & Tobago on 31st July 2003. The holds were tested for watertightness and their suitability for the carriage of DRI.

Two representatives of the competent authorities were present during the inspection.

It began at 1240 and ended at 1430.

- All the hatch covers on holds 1, 2, 3, 5 and 6 were shown to be watertight.
- All the bilge wells, port and starboard, were dry and clean.
- All the holds inspected were clean and dry and demonstrated to be watertight.
- All the bilge wells had been made watertight.
- The vessel was deemed suitable for the carriage of DRI in the holds inspected.

Thermocouples were fitted and arranged as follows :

At the bottom of the cargo (just above the tank top)

- TC1 (in the forward part of the hold on the port side) – TC2 (in the forward part of the hold on the starboard side) – TC3 (in the middle) – TC4 (in the after part of the hold on the port side) -TC5 (in the after part of the hold on the starboard side).

In the middle of the cargo (4 m above the bottom of the hold)

- TC6 (in the middle) – TC7 (in the after part on the port side) – TC8 (in the after part on the starboard side).

5.3 The shipper's instructions to the master

On 31st July the master of the *ADAMANDAS* received instructions and recommendations from the shipper CARIBBEAN ISPAT LTD to be followed during the carriage of the DRI from Point Lisas (Trinidad) to Surabaya (Indonesia) and during unloading.

They were as follows :

1. The temperature and hydrogen content of the holds were to be measured during the voyage at regular intervals of no more than 8 hours. The measurements were to be taken by the supercargo in presence of a representative of the master.
   If the cargo was stable, and with the master's approval, the number of checks could be reduced to two a day, at 0800 and 1600.

2. The daily readings of all the data were to be transmitted regularly to the shipper and the charterer.

3. Any abnormal values observed by the supercargo were to be reported immediately to the shipper and the charterer.

4. Hatches – the hatch covers and hold ventilators were to be kept tightly closed during the voyage except in the following circumstances : if the rise in the level of hydrogen in any hold exceeded 1%, the hold was to be ventilated until the level dropped back below 1%.

5. If the temperature of any thermocouple rose to 150° C or even 100° C, the ventilation should remain off. If the temperature continued to rise to 200° C for more than one thermocouple, then the vessel should proceed to the nearest port. If it were not possible to reach the nearest port sufficiently quickly, flooding of the hold should be considered as quickly as possible while proceeding to the nearest port.
   But flooding the hold with water should only be considered as a last resort.

6. The supercargo was instructed to cooperate and give advice if necessary.

7. If the temperature of any thermocouple on the tank top above empty bunker tanks was above 85°C, the double bottom tanks were to be completely filled with water.

8. The electricity supply, if any, in the duct keel was to remain switched off.

9. Smoke detectors, if installed, were not to be used.

10. The bilge well suctions were to remain disconnected except in the event of an emergency.

11. A spare waterproof adhesive tape was to be available for use, if needed.

12. All ballast tanks were to remain empty until unloading was completed. In the event of ballasting becoming necessary during unloading, it was to be limited to those ballast tanks close to empty holds and they should not be pressed right up.

13. During unloading the same precautions as during loading were to be taken to prevent the cargo from becoming wet.

14. Any action regarding the cargo was to be taken after consulation with the shipper's representative on board.

15. After a period of rain during loading, the channels of the hatch cover were to be blown dry to prevent drippings during reopening. If this was not possible, a tarpaulin was to be placed over the hatch cover whilst loading was not in progress.

6 THE SEQUENCE OF EVENTS

6.1 Arrival and loading in Trinidad

30th July 2003 :

Arrival of the vessel at Point Lisas Trinidad.

31st July 2003 :

Inspection of the holds. The certificate attesting the fitness of the holds of the vessel for the carriage of direct reduced iron (DRI) was issued by the Trinidadian authorities.

3rd August 2003 :

The vessel berthed alongside the loading berth. A representative of Lloyd's Register came on board and issued an interim certificate of fitness for the carriage of DRI.

6th August 2003 :

The *ADAMANDAS* left Trinidad for Indonesia with a cargo of 21000 tonnes of deoxydised iron pellets. The cargo was inerted (nitrogen).

The temperature of the cargo throughout the holds varied between 31° and 50° C (TC6 hold No.2); there was no emission of hydrogen.

The vessel was scheduled to call at Durban on 26th August and her ETA at Surabaya was 12th September.

6.2 The call at Durban

29th August 2003 :

0900 : the vessel arrived at Durban to take on supplies and bunkers.

She berthed at berth 104 for bunkering.

Around 1500 : with the vessel still alongside, while the supercargo was recording the temperatures, he noticed a considerable rise in temperature in hold No.2. It was above 250° C with an O_2 content of 19.9% and an H_2 content of 33 ppm. He informed the master who notified the P&I and they, in turn, advised the South African Maritime Safety Agency (SAMSA) at 1800.

A SAMSA inspector went on board at 1830. He informed the master that he would not be able to set sail as long as the temperatures and oxygen content remained above acceptable limits.

It was decided to inert hold No.2 with nitrogen.

At 2200 an initial operation to inject about 3.5 tonnes of liquid nitrogen in gaseous form was undertaken. It was completed on 30th August at 0600.

30th August 2003 :

At 1000, a further 20 tonnes of nitrogen were supplied and injected between 1500 and 2130. Readings taken at 2200 showed a sharp drop in temperature but thermocouples TC3 and TC5 displayed temperatures of 102° C and 124° C respectively, well above the acceptable limit of 65° C.

In addition the shipper had indicated the the temperatures would not be stabilized until 48 hours after the injection of nitrogen and had asked for another 20 tonnes of nitrogen to be made available.

The temperatures would continue to fall for the following 24 hours.

1st September 2003 :

At 1200, readings indicated that thermocouple TC8 had shown an increase in temperature and was now in excess of 100° C.

Temperatures remained stable for the next 24 hours, with 3 thermocouples recording values equal to or in excess of 60° C.

The owners decided once again to inject an extra 20 tonnes of nitrogen. To this end the vessel was moved to Island View where nitrogen could be injected at a higher rate.

Once this supplementary inerting had been carried out, H_2 and O_2 levels were lower than those previously recorded.

3rd September 2003

Towards 0800 all the temperatures had stabilized below the maximum limit of 65°C.

4th September 2003

The vessel was at anchor in Durban. The temperatures as well as the H_2 and O_2 levels were stable.

5th September 2003

Towards 1500 the vessel set sail from Durban.

The South African maritime authorities had suggested that the vessel wait a few more days to make absolutely sure that the temperatures in hold No.2 had become stable but their advice was not heeded.

The vessel sailed 24 hours after the temperatures had fallen below the recommended maximum.

6.3 The voyage from Durban to Surabaya

On 6th, 7th and 8th September the weather conditions worsened.

9th September 2003

The vessel was on passage; the temperature in hold No.2 rose to 380° C. The competent authority advised the master to spray fresh water over the cargo.

10th September 2003

The master and the owners both received a message from the competent authority recommending that they curb the temperature increase in hold No.2 in the event of a rapid rise in temperature above 450°C.

It was only a recommendation, the final decision being the responsibility of the owners and the master.

Following the instructions they had received the crew sprayed the cargo in hold No.2 with fresh water (2 tonnes of water in all). The temperature decreased but there was an increase in the amount of H_2 given off.

The temperature rose to 820℃ and the hydrogen content reached 100 %. At 2230, the master was considering the possibility of proceeding to Mauritius, but taking into account the improvement in the weather conditions and the high temperatures observed in hold No.2, he finally decided to head for La Réunion.

11th September 2003 :

1431 (local time)

Pacific Altlantic Corp sent an email message to the forwarding agents Indoceanic Services in La Réunion informing them that the *ADAMANDAS* had to be rerouted to Port Réunion because of a substantial increase in temperature in hold No.2. The owners wished to know if the port installations could accommodate the vessel and if fresh water and nitrogen were available. Having received an affirmative answer, they asked the forwarding agent to designate a surveyor and to ask him to be in attendance when the vessel arrived.

The following times are in UTC.

1245

The COSRU received a call from the forwarding agent with a request for a vessel on which there had been a considerable rise in the temperature of the cargo in hold No2. to call at La Réunion in order to take on supplies of fresh water and nitrogen.

The harbourmaster's office was informed, asked for more information about DRI and indicated that there were no berths available before 15th September.

1255

The vessel clarified her situation : she was carrying 21000 tonnes of DRI and there had been a considerable rise in temperature in hold No.2, with some thermocouples giving readings of around 250℃.

1332

The COSRU sent a telex to the master of the vessel acknowledging his request to make a stopover at La Réunion. For this to be examined, it was necessary to know why the temperature had risen in hold No.2, what DRI was, as well as the vessel's position course and speed and the number of persons on board.

1411

The master answered the COSRU : the rise in temperature in hold No.2 was due to the nature of the cargo, DRI meant direct reduced iron , his position was 23°10' S – 056° 01' E, course 012° and speed 11.5 knots, 22 crew on board.

The DIRCOS and the COMAR were informed.

1450

The forwarding agent asked if the vessel had been granted permission to anchor in Saint Paul's Bay.

1455

The CODIS was informed.

1624

The COSRU sent a telex to the ship asking if there was a risk of fire or explosion, how much DRI there was in hold No.2 and whether fresh water was required.

1656

The vessel answered the COSRU : hold No.2 contained 4200 tonnes of DRI, there was no risk of fire or explosion, heat would probably be generated, the fresh water had been requested by the competent authority.

1711

A meeting of a work group comprising the DIRCOS, COMAR, Préfet et CODIS was convened to decide whether to give the go ahead to the vessel's request to make a stopover.

The COSRU asked the master to supply further information about the *ADAMANDAS* concerning :

- The nature of the previous cargo,
- the cause of the combustion reaction,
- how the rise in temperature had been detected,
- the longitudinal position of hold No.2 compared to the engine room and the bunkers,
- the volume of the hold involved,
- how the nitrogen which had been requested was to be used on board.

The master was also informed that, if he called at La Réunion, his vessel would be submitted to a Port State control inspection to assess the risk and her seaworthiness before she was allowed to leave again.

1729

The forwarding agent passed the contact details of the owner Pacific & Atlantic to the COSRU.

The owners' answer to the COSRU's request for information was received :

- previous cargo : soya
- detection of the rise in temperature : there was a supercargo on board to check the temperature of all the thermocouples as well as the H_2 and O_2 content of the cargo throughout the whole voyage.
- The longitudinal position of the hold compared to the engine room and the bunkers : hold No.2 was 77 metres from the engine room and 20 metres from the nearest fuel bunker.
- Volume of hold No.2 : 5082 m^3
- The operation on board for which nitrogen had been requested was to cool down the cargo.
- Nationalities : the master and crew were Filipino, the supercargo was from Trinidad et Tobago.

The owners had no objection to Port State control inspections on arrival and departure. They reminded the COSRU that the vessel had been "successfully" inspected in Durban on 5th September.

1742

The forwarding agent was informed that the Préfet had deferred the decision as to whether the vessel would be allowed to stop over until the next day.

2004

The COSRU sent the vessel a telex asking her to report how the temperatures in hold No.2 had evolved over the last 6 hours and to report her position, course and speed every four hours.

2146

The vessel transmitted the temperatures observed in hold No.2 at 1730 to the COSRU.

TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9
63	110	44	288	70	231	203	205	36

6.4 The call at La Réunion

12th September 2003 :

0200

The vessel was in position 21°41.6' S – 055°23.7' E, outside the 12 mile limit, waiting for permission to anchor in Saint Paul's Bay.

0335

The DIRCOS informed the CODIS that the vessel had been given permission to proceed to the anchorage.

0346

The forwarding agent informed the COSRU that a representative of the owner and a surveyor working on behalf of the insurance comany were arriving that morning to find and implement solutions to the problem.

0700

The multidisciplinary assessment team went on board. The team comprised :

- a ship safety inspector
- a pilot
- three officers from the SDIS one of whom was a chemist
- a representative of the COMAR (Action of the State at Sea)

1103

The assessment team was back in port.

1528

After a debriefing session with the COMAR, the vessel received permission to anchor in position 20°54.5' S – 055°20.5' E (0.7 miles from the Pointe de la Ravine à Malheur) while the specialists designated by the owners and the charterer analysed the situation.

1818

The vessel was at the anchorage and had received the following safety instructions :

- the whole crew were to remain on board;
- the vessel was to be ready to get under way at all times;
- life-saving appliances were to be ready for use;
- the hatch covers of hold No.2 were to be unfastened;
- the situation in hold No.2 – temperature, H_2 and O_2 content, water level in bilge wells – was to be communicated by fax or telex every 4 hours.

The patrol vessel La Jonquille was placed on SECMAR alert at one hour's notice.

1950

The COSRU sent an email to the Trinidad and Tobago port authorities informing them of the situation of the vessel and asking how the cargo inerting operation should be carried out.

2045

The latest readings for hold No.2 were transmitted to the CODIS.

Ten 10 m^3 cylinders of nitrogen were ordered.

13th September 2003 :

0354

Operations to transfer supplies from the shore to the vessel got underway, using the harbour tug Abeille Mahavel : six cylinders of nitrogen and a number of pressure reducing valves were transferred to the vessel. The representative of the owner went on board.

0615

The weather forecast for the next 72 hours was transmitted to the master : swell of 2.5 metres or more was expected from the south-west.

0730

The insurance company's firefighting and safety specialist went on board. A representative for the charterers was also present.

1200

The specialists made their report and recommended :

- that the holds should be ventilated using natural ventilation without opening the hatch covers,
- that the inerting operation should be carried out on Sunday using 6 cylinders,
- that 40 tonnes of liquid nitrogen should be loaded for the inerting operation alongside,
- that a 6 tonne tank of nitrogen should be loaded to maintain the inert condition during transit.

1700

Following a meeting with the services concerned and after listening to the partial conclusions reached by the representatives of the underwriters, of the owners and by the firefighting specialist, the Prefet, acting in his capacity as representative of the government for the Action of the State at Sea, decided that permission to enter the port would only be granted if

- the hydrogen content was below 20% of the lower explosive limit,
- hold temperatures were under control,
- technical solutions had been found for the inerting operation.

15th September 2003 :

A further inspection was conducted by the assessment team to verify that the measures concerning ventilation recommended by the specialist representing the underwriters had been put into effect. They observed that temperatures and hydrogen content were lower in hold No.2 but had risen slightly in hold No.3. In these conditions it was not possible for the ship to enter the port and as those responsible for the ship showed no signs of taking any meaningful, effective action to make her safe, the Prefet decided on the following measures :

- the owners were ordered to bring the situation back to normal by 1200 (local time) on Wednesday 17th September;
- the master of the *ADAMANDAS* was to make a statement to the maritime gendarmerie to clarify the situation and remind him of his responsibilities regarding safety;
- the forwarding agent was summoned so that he could inform the authorities of any concrete measures the specialist team representing the private interests were considering taking in the near future;
- the matter was referred to the Classification Society Lloyd's Register) and the flag State (Cyprus) so that they could compel the vessel to navigate in compliance with the provisions of their particular rules;
- the INERIS was brought in and set up a crisis committee to monitor the situation so that the authorities could approve any solutions the owners might propose.

16th September 2003 :

The situation had stabilized as far as hold No.3 was concerned but remained uncertain for hold No.2 because, although ventilating the hold brought down the hydrogen content, it also revived the slow combustion and resulted in temperature increases in some parts of the cargo.

17th September 2003 :

The temperature reached 544℃ at one point in the c argo.

The owners sent a letter to the Prefet, in which they drew his attention to the fact that, during the meeting of 13th September, the specialists had suggested directly injecting liquid nitrogen over the cargo by means of suitable stainless steel pipes.

The parties considered that, in view of the circumstances, this was the best option unless an evaporator was available straightaway.

They believed the French authorities had ruled out the solution of directly injecting liquid nitrogen.

However, they were afraid that this refusal and the absence of an evaporator could result in a fire.

In the event of a fire, the vessel would be at great risk and the only option would be to flood the hold as fast as possible with water pumped from the shore as the vessel did not have sufficient pumping capacity on board.

If the hold were flooded, the vessel would not be able to put to sea and the cargo would have to be unloaded at La Réunion.

To guard against this contingency, they would appreciate the authority's preparing an emergency plan.

18th September 2003 :

The situation remained stable. The operators brought in by the owners favoured the solution of nitrogen inerting alongside. But access to the quayside was conditional on bringing the temperatures and hydrogen levels back down to safe levels, because the dependence of La Réunion on its one and only port imposed stringent safety precautions.

In view of the failure of the owners to take effective action, the Prefet repeated his previous injunction.

19th September 2003 :

The owners had still not made any official proposals. At 0430 an increase in temperature to 580℃ was observed in another part of hold No.2. The temperature rose even more and reached 619℃; it did not fall below 590℃ until the last of the next day's readings.

20th September 2003 :

The situation took an unfavourable turn, the cargo in hold No.1, which, until then, had not given cause for concern, began to evolve hydrogen. The Prefet ordered rescue resources to be deployed and asked the master to move his ship away from the coast but to remain within territorial waters.

The P&I club asked SMIT TAK to intervene.

21st September 2003 :

Towards 0300 the *ADAMANDAS* was taken in tow by the tug Abeille CILAOS. During the afternoon, at the end of a long meeting (which lasted from 1400 to 1800) with all the parties interested in the *ADAMANDAS* and her cargo (owners, charterer, master of the vessel, underwriters and specialists) the owners were unable to offer an immediate, safe and effective technical solution corresponding to the requirements of the State regarding safety and deadlines. Moreover, differences of opinion and differing assessments of the situation had appeared among the various public sector parties involved. At 2345, having received a fax that evening from the Secrétariat Général de la mer stating that they had no objection to his proposed course of action, the Prefet issued an official order for the destruction of the vessel, within a time frame guaranteeing the safety of the participants, in order to remove the danger.

The interested parties were informed of the decision, including the flag State.

22nd September 2003 :

The vessel was sunk by the armed forces in position 20°56.7' S – 54°59.9' E in 1750 metres of water, bearing 295° from Saint Gilles les Bains at a distance of 13.5 miles.

SMIT TAK arrived.

7 DETERMINING AND COMMENTING ON THE CAUSES OF THE ACCIDENT

The method used for determining the causes of the accident was that used by the *BEA*mer in all of its enquiries in compliance with Resolution A.849-20 of the IMO as amended by Resolution A.884-21.

The contributory factors were placed in the following categories :

- **natural causes;**
- **equipment failure;**
- **the human element.**

The *BEA*mer investigators listed the possible factors of each category and attempted to define their nature ; were they :

- **certain, probable or hypothetical,**
- **decisive or contributory,**
- **incidental or structural?**

Their goal, after careful examination of the factors, was to rule out those which had no bearing on the events and retain only those which, with some degree of probability, could be considered as having participated in the course of events. They are aware that this means they may have left aside some of the questions raised by the accident. As their aim is to prevent this type of accident from happening again, they have favoured an impartial inductive analysis of those factors which, by their fundamental nature, could lead to the same thing happening again.

7.1 External factors

7.1.1 Conditions of loading

According to the owners, there was a period of rainfall while the vessel was loading at Point Lisas.

Indeed, the cargo log book indicates that it rained on 4th and 5th August, but that the holds were closed during this time.

The cargo was transferred to the ship by means of a conveyor over a distance of about 2 to 3 kilometres. Hold No.2 was the first one to be loaded and it is possible that it was loaded with the top part of the pile which may have been wet.

Another possibility was the fermentation of residues from the previous cargo : the hold had previously been loaded with soybean meal pellets which can cause fermentation if the hold is not correctly cleaned. DRI is not compatible with organic matter.

However, during the pre-loading inspection the state of the holds was found to be satisfactory for the carriage of DRI by the competent authority.

As far as the product itself was concerned, according to the owners, it had been passivated by heating. When it was loaded its temperature was between 33℃ and 50℃. The loading instructions stipulated that it was not to be loaded if its temperature was above 65℃.

7.1.2 Weather conditions during the voyage

From the 10th August on, the supercargo noted in his cargo log book that the vessel was continuously taking spray on deck, that there were rough seas (waves 4 metres high) and strong winds. Conditions remained the same during the following days.

They worsened after 14th August.

The master mentioned the adverse weather conditions affecting the ship on 15th, 16th, 23rd, 24th, 25th, 26th, and 27th August in his sea protest. He noted that the vessel was rolling and pitching heavily in rough seas with winds of force 5, 6, 7 and 8 on the Beaufort scale. The vessel was shipping seas on her main deck which broke against the hatch coamings sending spray up over the hatch covers.

The hatch covers on holds 1, 2 and 3 were the most exposed to the seas being shipped.

No readings were made between 24th and 26th August because the supercargo could not carry out his tasks on deck in complete safety due to the state of the sea.

From 28th August the weather conditions improved.

On 5th September the weather conditions again deteriorated.

On 6th September, after calling at Durban, on passage towards Indonesia, the vessel again encountered adverse weather conditions with seas running over the deck from port to starboard, heavy spray and strong winds.

The bad weather continued until 10th September, to such an extent that the vessel had to alter course so that readings could be made.

It also meant that the ventilation of hold No.2 could not be carried out correctly.

The state of the sea only decreased on 11th September.

7.1.3 Weather conditions at the anchorage in La Réunion

On 21st September the weather conditions deteriorated : wind easterly force 5, sea state 4.

7.2 Evolution of the cargo temperatures and hydrogen emissions

From 8th August onwards temperatures in the middle of the cargo were seen to increase steadily by 1℃ per day. This process cont inued until 16th August, after which date they remained stable.

Generally speaking, the temperatures were seen to fluctuate. The variations in temperature could have been due partly to the thermocouples themselves, some of which did not seem to be 100% reliable, partly to the heating of fuel in bunker tanks adjacent to the holds and partly to changes in the temperature of the sea, the effect of which was more noticeable in the lower part of the cargo.

After examination of the evolution of the temperatures in hold No.2 between 6th August 2003 and 28th August 2003 most of the thermocouples were observed to have remained stable, but TC6 showed a tendency to rise by about 1° or 2℃ every day while TC7, after a tendency to rise at the beginning of the voyage, later showed a decrease in temperature.

TC6 was the only thermocouple to exceed 60℃ and stabilized after 29th August.

For a period of 23 days temperatures in hold No.2 remained at acceptable levels, below 65℃, similar to those in the other holds.

The highest temperatures were recorded at TC6 and TC7.

On 27th August hydrogen was detected for the first time with an H_2 content of 24 ppm in hold No.2. This indicated that a re-oxidation reaction had begun in the cargo and thus that there was water present.

The O_2 content of hold No.2 was 12.5% which meant that to all intents and purposes the hold was no longer inerted.

There was no emission of hydrogen before 27th August 2003.

On 28th August, in order to reduce the H_2 content, hold No.2 was naturally ventilated by opening the forward and after manhole covers.

After the hold had been ventilated, the H_2 content dropped to 15 ppm but the O_2 content rose to 17.3%

On 29th August, during the call at Durban, the temperature in hold No.2 was observed to have risen above 200℃ with an H_2 content of 21 ppm, in spite of the ventilation.

By 30th August the H_2 content had risen to 33 ppm. Injection of nitrogen began (15 tonnes), the O_2 content fell to 5.2%.

On 31st August inerting was completed, the H_2 content was now only 4 to 7 ppm, the O_2 content 0.6%.

As soon as nitrogen was injected on 30th August and 31st August, the temperatures in hold No.2 dropped. However TC8 remained at around 100°C but it did fluctuate.

On 1st September the H_2 content increased to 13 ppm while the O_2 content did not change (0.6%).

After further inerting hold No.2 by injecting another 20 tonnes of nitrogen on 2nd September, the H_2 content was 0 ppm, the O_2 content 0.1% and the temperature of the cargo had decreased.

On 3rd and 4th September all the temperatures had fallen back to normal levels, the H_2 content was between 5 and 8 ppm and seemed to have stabilized. The O_2 content was stable at 0.1 – 0.2%.

On 5th September, the day on which the vessel left Durban, there was an increase in the H_2 and O_2 levels from 14 to 17 ppm and by 1% respectively; the levels continued to rise on 7th September (46 ppm and 1.9%) and 8th September (68 ppm and 1.8%), on which date the temperature given by TC4 reached 124°-160°C.

On 7th September the supercargo ventilated the hold for about 20 minutes to eliminate the H_2.

On 8th September, TC4 oscillated between 124°C and 160°C.

On 9th September TC2 and TC6 rose to 90°C and 390°C respe ctively, the H_2 content reached 100 ppm and O_2 3%.

On 10th September the situation worsened.

Although the level of H_2 did not go above 100 ppm, the temperatures progressed to 120°C for TC4 and 820°C for TC4.

It is to be noted that, from the beginning, the part of the cargo above TC4 was not the seat of the re-oxidation reaction, the temperatures there remained stable.

On 11th September at 1500 the H_2 level had dropped to 40 ppm but a general increase in the temperatures in hold No.2 was observed.

TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9

Morning	58	108	150	661	61	256	233	225	30
Afternoon	66	135	59	285	70	246	244	162	34

On 12th September at 2300 the O_2 content was 11.1% and the H_2 level was 100 ppm. As regards the temperatures, the following values were recorded :

Hold No. 2	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9
	64	83	74	265	148	165	113	109	35
Hold No. 3	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9
	24	169	24	22	23	64	31	35	25

The different readings show that the H_2 content of hold No.2 remained stable between 9th and 14th September at 100 ppm. During the same period the O_2 content of hold No.2 rose from 3% to a maximum of 11.6% due to the hold's being ventilated to reduce its H_2 content.

The temperatures in hold No.2 for the period between 9th and 14th September varied between 854℃ for TC4 (highest value, recorded on 1 0th September) and 44℃ for TC3 (lowest value, recorded at 1730 on 11th September)

The H_2 content decreased from 1500 on 14th September to 0830 on 17th September, varying between 31 and 41 ppm. On the other hand temperatures remained high; the highest, recorded at 0830 on 17th September, were TC6 (458℃), TC3 (445℃) and TC8 (445℃). As for the O_2 content, it varied between 14.8% and 17%.

Even if loading of a cargo which had become wet after being stocked in the open air cannot be excluded, the increases in temperature before Durban and then before La Réunion were detected after periods of bad weather.

As DRI reacts readily with seawater, the correlation can be made between the adverse weather conditions and the first indications of hydrogen emission and rising temperatures.

This can be considered to be the **root cause** of the reaction of the DRI.

7.3 Equipment failure

7.3.1 Deficiencies in the watertightness of the deck and the hatch covers

On 28th August the supergo took advantage of the improved weather conditions to check the watertight sealing tapes on the hatch covers of holds 1, 2, 3 and 5.

Some of them had been damaged and had to be replaced.

On 29th August 2003 the supercargo noted that there was sea water between the sealing tapes and the hold and in the bilge well of hold No.2.

The inspection conducted by the South African maritime authorities in Durban brought the following facts to light :

- the adhesive sealing tape used on the hatch covers to enhance watertightness was in poor condition and had come unstuck in several places on most of the hatch covers. The supercargo stressed the fact that tape should have been heated before it was applied to enhance its adhesive qualités.

- at 1600 on 30th August, during sounding of the holds' bilge wells at the request of the competent authority, 5 cm of water were found in the starboard bilge well of hold No.2.

The origin of the water is not known but a connection could be made with the heavy weather which the vessel encountered on 15th, 16th, 23rd, 24th, 25th, 26th and 27th August 2003 and the fact that several sounding pipes on the main deck were closed with wooden plugs instead of the regulation screw-on caps.

Upon examination it was seen that the screw thread on the caps and sounding pipes had been damaged and was unusable.

As the nature of the cargo and the hydrogen emissions made it impossible to carry out any hot work on deck, a solution was found to the problem by screwing PVC caps on the sounding pipes and then glueing them.

These provisional repairs were considered to be adequate because the vessel was due for a refit in dry dock after the voyage.

As a result, the sudden rise in temperature observed could have been due to water leaking into the hold during the period of heavy weather : through the non-watertight hatch covers as well as through the scuppers and sounding pipes.

The increases in temperature began at the bottom of the cargo and then spread upwards.

The presence of water in the bilge wells confirmed that water had accumulated at the bottom of the hold.

At 1700 on 2nd September the supercargo again recorded water - 6 cm - in the starboard bilge well of hold No.2.

When the vessel was inspected at Point Lisas the bige wells had been dry.

Water leaking into the hold due to deficiencies in the watertightness of the hatch covers and the deck can be considered to be the **decisive factor** in triggering the re-oxidation of the DRI

7.3.2 Inerting

The holds were inerted with nitrogen at the end of loading before the vessel left the port.

Although the holds had been declared to be watertight when inspected before loading, they were, nevertheless, not gas-tight.

Consequently the nitrogen charge injected at the end of loading gradually dissipated due to the leaks.

This process was confirmed by the daily readings of the oxygen content of the holds and was underlined by the supercargo in the readings he took on 7th August.

On 6th August when the vessel left Point Lisas, the O_2 content varied between 1% and 3.8% (2.3% for hold No.2).

On 7th August the readings were :

Hold No.1 : 8,4% ; hold No.2 : 2,9% ; hold No.6 : 9%.

On 8th August :

Hold No.1 : 11,6% ; hold No.2 : 3,5% ; hold No.6 : 12,4%.

The inerting level had thus greatly decreased in hold Nos.1 and 6.

On 13th August the following values were recorded :

Hold No.1 : 18,5% ; hold No.2 : 7,5% ; Cale 5 : 6,5% ; hold No.6: 18,8% .

It can thus be considered that the inerting of holds No.1 and 6 had disappeared in one week and that the O_2 content of holds No.2 and No.5 was above the value of 5% recommended by the BC Code.

On 16th August the O_2 levels reached :

Hold No.1 : 19,2% ; hold No.2 : 9,8% ; hold No.5 : 8,7% ; hold No.6 : 19,2%.

The inerting level had therefore greatly decreased in holds No.2 and 5 and was non-existant in holds No.1 and 6, in which conditions were practically the same as the atmosphere.

The O_2 levels in holds No.2, 3 and 5 continued to rise until 27th August, on which date a reading of 24 ppm of H_2 was observed in hold No.2. The O_2 content in hold No.2 was then 12.5%, signifying that the hold was no longer inerted.

On 28th August hold No.2 was naturally ventilated to reduce the the H_2 content by opening the forward and after manhole covers.

After the hold had been ventilated the H_2 level dropped to 15 ppm while the oxygen content rose to 17.3%.

On the 2nd September, after the hold had once more been inerted, H_2 = 0 ppm, O_2 = 0.1%.

On 10th September H_2 = 100 ppm ; O_2 = 9,5%.

The hold was no longer inerted because it had been ventilated after the re-oxidation reaction had started again.

The vessel did not have a supply nitrogen gas nor was she able to produce her own nitrogen. She needed a large quantity of nitrogen which would therefore have to be stored in liquid form in special containers.

Injecting nitrogen into the holds must be effected by means of an evaporator in order to first transform the liquid nitrogen into gas. Injecting liquid nitrogen directly into the hold can be dangerous if it impinges on the structure of the vessel.

However, the carriage of liquid nitrogen cylinders by sea is not an easy task, so it was not possible to top up the hold with nitrogen during the voyage.

Hold No.2 was re-inerted in Durban. The nitrogen was injected as gaseous nitrogen into the upper part of the hold through a manhole using an evaporator.

According to the supercargo the whole 45 tonnes of liquid nitrogen requested were not delivered which could explain why the measure was not totally effective and the re-occurrence of the phenomenon less than two days after the vessel's departure from Durban on 5th September.

The fact that the holds were not gas tight and that they had to be ventilated led to the dissipation of the nitrogen.

The fact that the holds were no longer inerted can be considered to be a **contributory factor.**

8 RISKS INCURRED

8.1 To the vessel and her crew

a) Weakening of the hull structure.

The stucture of the vessel could be weakened by the thermal stresses caused by the hot spots at the bottom of the hold resulting from the heat given off by the reaction.

Thus the temperature recorded by thermocouple No.4 in hold No.2 between 10th and

12th September attained 820℃ .

b) Risk of the formation of an explosive atmosphere (ATEX).

The lower and upper flammable limits of H_2 in air are 4% and 75% respectively.

Between these two limits the concentrations of the H_2/air mixture are liable to propagate a flame.

If there is a source of ignition, a flame will travel through the H_2/air mixture.

The mixtures most likely to explode are those lying within the limits of the explosive range (18% to 59% H_2).

The hydrogen was partly consumed by heat at the bottom of the hold. It was more dangerous in the upper part of the hold.

The lack of oxygen in the hold was only a partial protection against explosion which remained a distinct possibility due to the movements of the vessel and shifting of the cargo which was liable to produce sparks.

It was therefore necessary to make sure that there was no source of ignition, including from electrostatic discharges, since the minimum ignition energy was extremely low (a few tens of microjoules). It is to be noted that the minimum auto-ignition temperature of an air/H_2 ATEX is 640℃.

The blast effect of an explosion would only have been felt over a fairly short distance, but the detonation could have broken the vessel's back if her hull had had been weakened by thermal stresses.

8.2 To the environment

The main risk was the risk of the hydrogen exploding. As a worst case scenario the specialists of the INERIS estimated that such an explosion would have been dangerous in an area within 400 metres around the ship.

9 ACTION OF THE FLAG STATE

The enquiry was conducted in collaboration with the administration of the flag State (Cyprus). The latter audited the company following the accident.

All the recommendations made by the French authorities during their management of the crisis were sent to the flag State and met with its approval.

10 ACTIONS OF THE SERVICES OF THE COASTAL STATE

The authorities of the coastal State took the measures it deemed necessary to ensure the safety of the crew of the vessel and the local population on the one hand, and to protect the environment on the other hand.

10.1 Affaires Maritimes - Préfecture - COMAR

The coastal State acted through the Préfet, the State services and competent organizations.

It called in the various specialists and firefighting and rescue services.

It acted in cooperation with the owners and the various private parties concerned.

It had to keep the port open and protect the population and the environment.

On Friday 12th September 2003 a multidisciplinary assessment team was sent on board the vessel. They found a hot spot with a temperature of around 400℃ in hold No.2 and observed that the temperature was rising steadily. The team went on board again in the morning of Monday 15th September and found that the state of the vessel, the organization of the crew and the involvement of the master were not satisfactory.

The Préfet insisted that all the solutions put forward should be approved by the INERIS, especially the inerting.

On 15th September he sent a preliminary order by injunction to the Pacific & Atlantic

Corp.

The order stipulated that Pacific & Atlantic would make every effort to :

- *"take any measures necessary to render safety equipment operational (firefighting and lifesaving appliances whether for personnel or equipment),*
- *bring the H_2 content in all the holds, but particularly in holds 1, 2 and 3 down to a level of less than 0.8% H_2 corresponding to an explosimeter reading below 20% of the explosive limit, by any means possible while ensuring the safety of the vessel and the persons on board*."

The authorities of the coastal State followed the evolution of the vessel's situation very closely. They made available those means of assistance which they had at their disposal. Their main concern was to ward off the danger to the local population and they took the necessary steps to evacuate the crew.

The evacuation of the crew was carried out on 20th September at the request of the master. The operation took place in two stages. At the end of the afternoon a first group of six seamen was evacuated, making it impossible henceforward for the *ADAMANDAS* to manoeuvre by herself; then during the night, towards 0100, the whole crew (the 16 remaining seamen including the master) was evacuated before the towing operation got under way.

10.2 INERIS

At 1200 on 13th September the INERIS was contacted for the first time by the CEDRE and placed on standby. At the end of the day the standby alert was lifted and the services of the INERIS were stood down.

On 15th September the Chief of Staff for the area of La Réunion contacted the INERIS to find out exactly how they could intervene.

On 16th September the INERIS was again contacted by the headquarters staff of the area of La Réunion to supply technical support and quantify the risk.

In their analysis, the INERIS examined the worst possible scenario by considering the composition of the air/H_2 mixture to be stochiometric. They sent a written reponse the same day to the area headquarters staff.

After looking at the situation, the INERIS considered that it was necessary to halt the heating of the DRI and to at least limit the hydrogen emissions. According to the INERIS, if the situation remained unchanged, hydrogen could be expected to evolve at a rate which it was not possible to assess with great accuracy and which might even increase as the heating process of the DRI spread throughout the cargo (the readings of the temperatures in hold No.3 bore witness to this).

The INERIS recommended that the hold of the vessel should continue to be ventilated by air so that the hydrogen would be sufficiently diluted to prevent the formation of an explosive atmosphere.

On 17th September the INERIS was consulted by the CODIS for advice as to whether to spread sand over the cargo or inject liquid nitrogen. The INERIS sent a written answer the same day detailing the various techniques which could be used :

a) Spreading sand over the cargo

To prevent air from reaching the DRI, the surface of the entire stack would have to be covered otherwise the DRI would continue to burn. If air could no longer reach the stack, oxidation of the DRI would cease, as would the emission of heat, and it would begin to cool down. It would be necessary, however, for the DRI to cool to a temperature low enough so that, if it came into contact with air again, the oxidation reaction would not be reactivated.

As DRI is a poor conductor of heat, it could take a fairly long time (several days) for such a cooling process to take place.

Using this technique implies being able to make sure that air cannot reach the stack other than by its upper surface.

b) Flooding the hold

To limit the amount of hydrogen evolving from the DRI when it is re-oxidizing after coming into contact with water, the DRI must be flooded as quickly as possible.

Due to the cooling effect of the water on the DRI, the rate at which hydrogen evolved would be reduced.

It would not be possible to prevent the air and the hydrogen from mixing together thereby forming an explosive atmosphere (ATEX) but, by not confining this ATEX in the hold (by opening the hatch covers, for example) the risk of explosion would be decreased.

Once the DRI was completely flooded, the oxidation reaction would cease, as would the emission of hydrogen.

A priori, it would take less time to bring the situation under control by flooding the hold with water than by spreading sand over the DRI.

c) Injecting nitrogen

Using this solution presupposes that it would be possible to maintain a permanent nitrogen blanket all around the DRI. This would only be possible by providing a flow of nitrogen difficult to quantify but which, in any case, would be substantial.

Even if this condition were fulfilled, it would not be certain that the nitrogen would provide a complete, permanent blanket for the DRI.

The nitrogen used has a much lower specific heat than the DRI which meant, according to the INERIS, that it would not have had a particularly significant impact on the cooling process, bearing in mind that the reaction was well under way. It would take a long time to sufficiently cool the DRI.

As far as unloading the vessel and allowing the crew to remain on board were concerned :

- difficulties in unloading might be encountered because of the risk of the DRI solidifying into large lumps in some parts of the cargo;

- assuming that hydrogen was evolving in large quantities and that there was no wind, the resulting ATEX might stagnate near the holds or even the bridgehouse near the stern where crewmembers might be present. There could be several different reasons why it might ignite, including electrostatic charges perhaps generated by members of the crew themselves;

- the ATEX could also be ignited during operations to recover the DRI which had not yet begun to heat up or by sources of ignition ashore if the vessel was berthed alongside.

In the event of the cargo being unloaded at sea, oxidation of the DRI would, in theory, produce iron oxide and its reaction with water would produce a hydroxide and hydrogen neither of which would be very harmful to the environment.

10.3 Marins Pompiers de Marseille (Marseilles Marine Fire Brigade)

The Marseilles Marine Fire Brigade was consulted on 13th September for advice on technical matters.

Their recommendations corresponded closely to those of the Departmental Fire and Rescue Service of La Réunion (SDIS), and emphasized the following points :

- water should not be used,
- the hold concerned should be inerted as soon as possible,
- the hold shoud be ventilated to limit the risk of explosion,
- at a later stage, part of the cargo (in the adjacent holds) should be transferred elsewhere to prevent the reaction from spreading.

11 ACTIONS OF THE PRIVATE PARTIES

11.1 The Supercargo

The supercargo was responsible for monitoring the condition of the cargo throughout the voyage by taking daily readings of the temperatures and the H_2 and O_2 content. He regularly informed the competent authority of these.

He was painstaking in his duties and monitored the cargo closely as can be seen from the scrupulous entries in his record book. The enabled the re-oxidation reaction to be discovered as soon as it started and to take counter measures to try and halt it or at least limit its consequences.

Thus, detecting the reaction in Durban enabled appropriate counter measures to be taken straightaway.

As soon as H_2 was detected on 27th August, the supercargo began ventilating the hold by removing the forward and after manhole covers to prevent hydrogen from accumulating and decrease the risk of explosion.

On 29th August 2003 the supercargo ventilated hold No.2 during the morning. The temperatures observed that morning were normal and identical to those recorded the day before.

6 hours later, during the afternoon, he took the temperatures again and noted that the temperatures in hold No.2 had risen sharply and exceeded 200℃ at most of the lower thermocouples as well as at TC8 in the middle of the cargo in the after part of the hold on the starboard side.

The supercargo also checked the watertightness of the hatch covers and replaced the watertight tape where it had been damaged by seas breaking on deck.

On 29th August 2003 he made arrangements to have hold No.2 inerted with nitrogen. This operation apparently brought satisfactory results and reduced the temperatures of the lower thermocouples.

On 30th August 2003, while taking soundings, the supercargo observed 5 cms of water in the starboard bilge well. He also noted that there was a little water in No.2 port and starboard double bottom ballast tanks

The port bilge well was dry. Soundings were taken daily and it was only on the dates mentioned above that any water was detected in the bilge wells.

On 6th September, weather conditions were extremely bad, with seas sweeping across the deck from port to starboard, very strong winds and heavy spray. It was not possible to take readings. The supercargo asked the master to alter course long enough for him to take temperature readings at least once a day around midday.

On 7th September the supercargo ventilated hold No.2 again for 20 minutes to dissipate the H_2.

He was only able to take H_2 readings in holds 1 and 2; the sampling tubes in the other holds were wet.

On 9th September, as the sea was very rough with spray on deck, only one fan was used to ventilate the holds to avoid sucking in spray.

11.2 The master

On 8th September, the master and the supercargo consulted the competent authority for instructions as to what measures should be taken to halt the oxidation reaction of the DRI.

On 11th September, the master sent a message to the competent authority informing them that fresh water had been sprayed over the cargo in hold No.2 in compliance with the instructions he had received and relaying the temperatures recorded at 0800.

When making his statement to the French authorities, the master was very evasive about how the vessel had been loaded and how the reaction had developed.

After their inspection of the vessel on 15th September, the assessment team noted that the organization of the crew and the involvement of the master were not satisfactory.
They expressed serious doubts about whether the crew were aware of the risks they were running and had the rust chipping work being carried out on the deck stopped.

On 20th September after the time limit set by the second injunction had expired, the master revealed just how dangerous the situation was for the cargo and the vessel.

He asked the French authorities to evacuate his crew.

11.3 Charter party instructions

In the event of an emergency, the instructions in Article 5 of the charter party stipulated : "Should the temperature increase to 150℃ at any one thermocouple or 100℃, ventilation is to be closed. If temperature continues to increase to 200℃ at more than one thermocouple, head for the nearest port. However, if the nearest port cannot be reached, flooding of the hold is to be considered at the fastest rate possible on way to nearest port. Flooding of hold with water should always be the very last resort."

11.4 The shipper – the competent authority

According to the shipper, DRI has been shipped worldwide from Trinidad since 1981. This was the first time an incident of this type had occurred at sea as every precaution is taken during loading and there are regular checks of the cargo throughout the voyage to detect any occurrence of a reaction.

When hydrogen was detected there was an exchange of messages with the vessel. The information was transmitted from the competent authority to the shipper (Caribbean ISPAT Limited) then relayed to ISPAT Shipping in London, then to the owners and the master of the vessel.

The first signs that anything abnormal was happening when the supercargo detected H_2 appeared on 27th and 28th August and the temperature in the hold increased from 29th August onwards.

During this time ISPAT exchanged messages with the owners and the master and sent instructions to inert the cargo with nitrogen.

All the information was given on an advisory basis and the onus of the decision as to whether or not to take the advice lay with the owners and the master.

The owners were kept informed of any changes in the development of the situation concerning the cargo.

On 10th September 2003, in order to block the increase in temperature in hold No.2 at TC4 and TC4, the competent authority suggested, in the event of a rapid rise in temperature exceeding 450℃, that the following measures should be applied :

- open all the cargo ventilators and hatch covers of hold No.2 for an hour to dissipate all the accumulated H_2;

- open the hatches slowly to avoid making sparks;

- spray fresh water over the cargo from port to starboard using a fire hose. The idea would be to saturate the pellets with water without filling the hold or flooding the cargo;

- the area on the port side where the cargo had first begun to heat up would be wetted last, that is to say, the area around TC2 and TC4;

- smoke would be generated in the cargo but that would be normal;

- The hatch covers should be left open until all the visible smoke had dissipated, the covers could then be closed but the cargo ventilators should remain open for the rest of the voyage.

Again, these measures were advisory, the final decision was the responsibility of the owners and the master.

It would be preferable to apply these measures rather than return to Durban which could take up to 4 or 5 days, and if the temperature rose rapidly.

If there was a shortage of fresh water on board, the vessel could head for the nearest port to replenish supplies.

If cargo spraying with fresh water was carried out in the nearest port, it would be necessary to make sure that fresh water was available in sufficient quantities.

The crew sprayed fresh water over the cargo in hold No.2 according to the instructions (about 2 tonnes of water in all), an "operation prohibited by the BC Code". The temperature decreased but a larger quantity of hydrogen evolved; the H_2 explosive limit : 4% of the total volume of air in the hold.

The temperature then rose to 820℃ and the hydrogen concentration reached 100 %.

Although this action first enabled the cargo to be cooled down it nevertheless restarted a hydrogen production cycle and constituted a **contributory factor** to the accident.

The explosive limit were exceeded.

Nota : The water vapour produced could have had an inhibiting effect on the explosive limits of the H_2/air mixture by raising the LEL.

Humidity acts to produce 2 contrasting phenomena :

- it can produce H_2 by reacting with the DRI;

- at the same time it raises the LEL of the H_2/air mixtures.

11.5 Air Liquide

On 12th September Air Liquide Réunion received an order by telephone to supply 6 cylinders of nitrogen (B50 – 9 Nm^3/cylinder) fitted with pressure reducing valves and 4 metres of flexible tubing.

On 13th September 6 cylinders of nitrogen were delivered by Air Liquide Réunion.

On 15th September the owners again contacted Air Liquide Réunion for an inerting operation on the vessel but did not clearly define the terms and conditions. Air Liquide Réunion possessed a nitrogen production unit, particularly for supplying hospitals, but did not have the vaporizing equipment needed for carrying out an inerting operation. This equipment was thought to be available from BJPPS in Dubai.

To this end, Air Liquide contacted SSI, a subsidiary of both Air Liquide and BJPPS specialized in the use of industrial gases, and in particular, nitrogen for inerting operations.

On 16th September 2003, SSI asked BJPPS to carry out a feasability study for arranging an inerting operation (equipment, personnel, transporting equipment, technical procedures, safety procedures, etc.) and supplying nitrogen.

On 18th Spetember 2003 BJPPS confirmed that the operation was possible and that the equipment and personnel were available and ready for transport by air.

The operation would be set in motion in the 24 hours following the receipt of an order in writing and payment by bank transfer.

An initial offer detailing the costs of supplying nitrogen inerting equipment was sent to the owners who accepted it.

On 19th September 2003 a telephone conversation took place between the SSI and the master of the vessel during which he confirmed his acceptance of the offer. The final offer was transmitted but did not contain SSI's general conditions of sale which the owners asked for later on that evening. At the same time, Air Liquide Réunion presented the owners with a quotation for supplying 50 tonnes of nitrogen.

No further contacts were made after this.

11.6 The owners – the underwriters

The first solution considered on 18th September by the private operators brought in by the owners was :

- inerting with nitrogen to stop the chemical reaction and cool down the holds.

- ventilating the holds to reduce the H_2 content (with the risk of increasing the temperature because the air would provide fuel for the combustion).

As far as the inerting was concerned, the owners first considered having an evaporator delivered to the island of Mauritius from where it could be shipped to La Réunion and used to inject nitrogen into the ship as gas.

On 17th September, the parties sent a letter to the Préfet in which they informed him that they had not yet received confirmation that a generator to produce gaseous nitrogen was available . As the situation in hold No.2 was worsening and there was a risk of fire, they suggested pumping the nitrogen directly from the tanker on to the cargo through a stainless steel pipe. This solution was refused by the French authorities. In the event of a fire, the only option would be to flood the hold with water as fast as possible but, on the one hand, the vessel did not have sufficient pumping capacity on board and, on the other hand, if the hold were flooded, the vessel would not be able to put to sea and the cargo would have to be unloaded.

On 19th September 2003, the Réunion Ships Agency announced that a surveyor from Lloyd's Register would be arriving during the evening of 21st September. The Lloyd's surveyor expressed reservations about the way liquid nitrogen was used underlining that it had to be used with the greatest care to prevent it from coming into contact with the structure of the vessel.

The possibility of using a heavier gas was also looked out.

12 CONCLUSIONS

12.1 On the conditions of loading and carriage

The vessel had already carried DRI on two previous occasions, without incident.

In compliance with the provisions of the BC Code the vessel had been declared fit for the carriage of DRI after inspection by the competent authority. She had the necessary equipment for monitoring the cargo during the voyage : measuring devices for determining oxygen and hydrogen content in the holds and thermocouples for taking readings of the cargo temperatures.

The holds had been inerted with nitrogen upon completion of loading. However, due to the fact that the holds were not gastight, the charge of nitrogen rapidly became depleted and could not be renewed because the vessel could neither produce it nor stock it on board.

The master was given detailed instructions by the shipper stipulating, in particular, the precautions to be taken if the product started to react.

Be that as it may, the BEAmer did not receive confirmation that the master had been given a certificate attesting that the product was in compliance with the provisions of the BC Code, on the one hand, nor that the product had undergone passivation treatment to reduce its reactivity, on the other hand.

A supercargo was especially designated to monitor the cargo throughout the voyage.

His meticulous monitoring enabled the oxidation reaction (increasing temperatures and hydrogen content) to be detected as soon as it started, and the appropriate measures to try and stop it to be taken.

Concerning the loading conditions, bearing in mind the weather during the call at Point Lisas, it cannot be excluded that some of the cargo may have been wet when it was loaded.

12.2 On the causes of the accident

For the reaction to occur, the DRI must come into contact with water. The cargo might have been wet when it was loaded, but according to the information collected during this inquiry, DRI is particularly reactive to seawater.

Hydrogen evolves when the cargo comes into contact with water. The rapid absorption of the oxygen in the water results in a rise in temperature and the emission of hydrogen.

After the vessel had weathered very rough seas at the end of August, the supercargo noticed that the temperature and the hydrogen content of hold No.2 had both substantially increased.

Insufficient watertightness of the weather deck led to the ingress of seawater into hold No.2 and the loss of the inert condition of the hold. The fact that water was detected in the bilge wells would seem to confirm this hypothesis.

Although the possibility that wet cargo was loaded cannot be ruled out, it is nevertheless far more likely that the reaction was caused by the ingress of water into the cargo, with the ensuing sudden rise in temperature and emission of hydrogen.

12.3 On the management of the accident

As soon as the reaction started the supercargo took the appropriate measures, working in close collaboration with the shipper and the competent authority.

Because of this, when the nitrogen deficiency was made up in Durban, the reaction seemed, at first, to have stabilized.

However, according to the supercargo, the full quantity of liquid nitrogen ordered was not delivered, which could explain why the measure was not totally effective and why the reaction started again less than two days after the vessel had left Durban.

Indeed, 4 inerting runs by volume are necessary for complete inerting (1 kg of liquid nitrogen = $0.84m^3$ of gaseous nitrogen).

The measures taken at Durban were thus insufficient to stifle the reaction (which had only just started). During the call at Durban the possibility of unloading the affected part of the cargo and flooding it should have been considered. The vessel had protective inert gas at her disposal as well as shore-based equipment which could have been used to unload the affected part of the cargo and put an end to the problem. This procedure is recommended by DRI professionals. In this way, it would have been possible to prevent the reaction from starting again and spreading, which eventually led to the total loss of the vessel.

As for spraying fresh water over the cargo after the reaction had started again, on the advice of the competent authority, this action is disputed and could be considered to be a **contributory factor** to the accident.

Four solutions were then considered for halting the chemical reaction of the DRI during the call at La Réunion.

Inerting the hold by saturation with nitrogen gas

This solution could not be implemented because it was not sufficiently well formulated and the necessary technical resources were not readily available in La Réunion. Thus the vessel never fulfilled the safety conditions required for her to be allowed to enter the port. In this case, the inerting operation would have to be carried out at sea.

This was a difficult task, bearing in mind how far the reaction had already progressed, requiring stringent safety measures for the personnel while the equipment was being installed and during the actual inerting.

It also implied being able to permanently top up with nitrogen for the rest of the voyage to prevent any resumption of the reaction (this should also have been done after the call at Durban) and this meant having nitrogen available on board.

Inerting the hold by injecting liquid nitrogen directly on to the cargo

This solution was ruled out as being too dangerous notably due to the risk of setting up thermal stresses which might weaken the structure of the vessel.

Spreading sand over the cargo

This solution was rejected, on the one hand because it meant that the vessel had to come into the harbour, and on the other hand because it meant running the risk of fire or explosion in the harbour.

Flooding the cargo with water

The pumping capacity of the vessel was insufficient to carry out rapid flooding.

Such a method could have caused irreparable damage to the vessel and even sunk her.

All the solutions considered required the deployment of the appropriate equipment and operational resources, involving logistical support, technical expertise and a rapidity of intervention which were not available.

The main risk was the hydrogen exploding causing harm to people and the environment. The more time went by, the greater the risk became.

The vessel could not resume her voyage as that would put her crew in grave danger.

It was dangerous to keep the vessel in French territorial waters close to the shore. Because of this danger the Préfet decided to move the ship away from the coast. As the crew had asked to be taken off the ship, she became a derelict and continued to represent a danger.

Thus, the main preoccupation of the authorities of the coastal State was to ensure the safety of human life and to protect the environment.

Following the two injunctions they had received, the owners were unable to put forward any rapid, safe, effective technical solution corresponding to the State's deadline and safety requirements and the Préfet de la Réunion ordered the vessel to be destroyed and sunk, justifying his decision by the imminent danger represented by the vessel.

12.4 On this accident as an example

This accident is not an isolated case, other ships carrying similar cargoes have been victims of explosions with loss of life and total loss of the vessels.

In the case of the *ADAMANDAS* the cargo reaction occurred while the vessel was in port or in circumstances permitting her to proceed rapidly to a port for assistance.

Thanks to the presence of a supercargo on board a serious accident at sea was avoided.

The serious accidents which have been brought to the notice of the *BEA*mer took place at sea with crews which had not been fully informed of the dangers, or which had received incomplete instructions, or when cargoes different from those noted on the bill of lading, or again, mixed products, were being carried.

This event brought the issue of the port of refuge into the spotlight. It also highlighted the right of the coastal State to protect its environment and population.

Various scenarios were imagined to assess the possible consequences on port activities and trade in the event of the vessel's being permitted to enter port

Calling on the expertise of the INERIS and the multidisciplinary make-up of the assessment team proved to be both useful and necessary given the complexity of the situation.

Setting up a crisis centre, as the Préfet did, seems to be an excellent way of managing this sort of crisis. It assumes that there will be close and active collaboration, not only on the part of the owners, as was the case here, but also on the part of the other interested parties : underwriters, classification societies and outside organizations called in to help.

13 RECOMMENDATIONS

13.1 Manufacture

The risks inherent in the carriage of DRI depend to a large extent on the manufacturing process..

Hot briquetted iron (HBI) is less prone to an oxidation reaction but more energy is required to process them than for DRI pellets.

Consultations should be carried out among DRI professionals with an aim to improving the passivation treatment of the product to decrease its reactivity and make it safer for carriage by sea.

13.2 Storage

Pellets should not be stored for more than a fortnight, if they are in the open air. The condition of the product should be continuously checked.

Regular samples should be taken from the stack to determine the humidity content and check the temperature before beginning to load.

Special precautions to be taken during handling and storage :

- dust recuperators should be fitted below overhead conveyor belts and regularly cleaned
- keep permanently dry.

If the product is stored in the open air, it should be protected from the rain. Avoid the build up of dust at transfer points. Cleaning should be carried out during loading and unloading in order to limit the amount of fines to a minimum

13.3 Carriage by sea

These recommendations should be considered to be a strict minimum and should be followed to the letter.

Taking into account the particular risk that seawater represents for this type of cargo, the watertightness of the holds should be carefully checked before loading and regularly thoughout the voyage.

DRI should be loaded perfectly dry into clean, watertight holds. The watertightness of the holds should be maintained whatever the weather conditions likely to be encountered during the crossing.

An inert atmosphere should be created by saturating the hold with nitrogen injected from the bottom of the hold to completely flush out all the air.

To make up for the leaks and maintain the inert atmosphere, it is recommended to top up the holds with nitrogen at regular intervals during the crossing; the nitrogen would be produced on board by a generator.

All vessels transporting DRI should be provided with a complete installation for measuring temperature at various points in the hold, for determining oxygen and hydrogen content, as well as a nitrogen production plant. As soon as the temperature reaches 60℃, increased vigilance is necessary. Deck equipment for the holds should be fitted with adequate systems giving protection against explosion.

The presence of a supercargo on board throughout the voyage is essential to ensure that the cargo is monitored at all times.

Unloading that portion of the cargo in which the reaction started should be one of the first solutions to be considered. The Port State authorities or the Flag State authorities should not allow the vessel to sail until the affected portion of the cargo has been unloaded.

13.4 The BC Code

The BC Code should define more clearly :

- the different types of DRI, why they are potentially dangerous and what precautions should be taken when handling and transporting them,

- conditions to be avoided and which products trigger dangerous reactions,

- the suitability criteria for vessels carrying this type of cargo,

- what action to take in the event of a reaction and what is prohibited.

Including DRI dust or fines in homogenous cargoes of briquettes or pellets should be prohibited. Residues at the bottom of stacks comprising mainly fines should not be loaded on board.

13.5 Crew information on the ships carrying the product

The master and crew should be informed in an appropriate manner how this product should be handled as well as what safety measures are called for if there is a reaction and emission of hydrogen.

A DRI contingency plan should be set up with DRI professionals outlining any special measures which need to be taken.

13.6 Means of intervention

13.6.1 This accident highlighted the necessity of reinforcing the means of intervention and the towage capacity available in La Réunion. The tugs could not remain at sea for more than 24 hours.

13.6.2 In this type of situation, calling in specialist companies for assistance should be considered by all parties concerned from the very outset of the crisis. The active participation of all interested parties is essential.

13.7 At the international level

As the accident involving the *ADAMANDAS* is not an isolated incident, the IMO Sub-committee on dangerous goods, solid cargoes and containers should collect and collate information on the various accidents which have occurred in order to determine what measures need to be taken.

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