REVIEW OF CHEMICAL SPILLS AT SEA

AND LESSONS LEARNT

a technical appendix to the

INTERSPILL 2009 Conference White Paper

"Are HNS spills more dangerous than oil Spills?"

compiled by Cedre ([1])

from Bonn Agreement and Helcom reports

and other miscellaneous sources

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FOREWORD

This appendix to the White Paper cited above was prepared with a view to providing additional background information on existing international experience on the response to HNS spills and the related response tools and techniques.

It successively delivers:

- In Chapter I, a summary of available global information on HNS incidents, with a table of the 47 recorded incidents and their primary causes.
- In Chapter 2, a review of all 47 incidents, including the risks incurred and the response measures undertaken, followed by a summary of the identified risks to human health and the environment.
- In Chapter 3, several short case studies of the 24 best-documented incidents, identified by type of pollutant, with the main lessons learned with regard to the type of pollutant concerned.
- In Chapter 4, the general lessons learnt with regard to the dangers, consequences and response tips.

Cover photo : The chemical tanker Ece sinking in the English Channel in 2000, with a cargo of styrene, methyl-ethyl-ketone and phosphoric acid

1. INFORMATION ON INCIDENTS

1.1. Background

During the last 30 years, there have been considerable developments in the maritime transport of chemical products, both in bulk and in packaged form. Incidents have followed. Some were well documented, while most remained poorly documented or basically ignored.

Past incidents are not only essential references of what happened some time ago. They are also, when properly reported upon, first hand sources of information on what may happen again and on what could better mitigate the consequences next time. Unfortunately, quality incident reports, giving a clear view of the lessons learnt, are far from being widely available or easily accessible. This paper is built on what could be accessed. Many gaps could not be filled and, in spite of the care and efforts made to verify information, errors may remain. Any corrective or additional information provided by the reader would be most welcome.

Chemical incidents at sea may involve products in bulk or packaged goods. Products in bulk are transported either by general cargo vessels (solid substances at ambient temperature), by chemical tankers (liquid substances at ambient or controlled temperature) or by gas carriers (liquefied gas). Gas carriers transport a single product. Their capacity can reach 100 000m³ (IMO, 1997). Chemical carriers may transport one or several products. Their capacity can reach 40 000m³, with tanks varying from 70m³ to 2 000m³. General cargo vessels may transport different products in different holds, with some in bulk and some in packaged form.

Concerned with the risks involved in chemical transport by sea, various international, regional and national authorities have published operational guides. Examples are the IMO manuals (IMO, 1987, 1992, 1998) the REMPEC Manuals for the Mediterranean (REMPEC, 1996, 1999), the Helsinki Baltic Sea Convention manuals (HELCOM, 1991), the North Sea Bonn Agreement manuals (BONN AGREEMENT, 1985) and other national documents, such as the Dutch developed ELSA (Emergency Level Scale-Procedure) software (OTSOPA, 1990) or the *Cedre* chemical pollution response guides, downloadable from our website. (www.cedre.fr)

1.2. Statistics

A statistical study conducted in the United States over five years (1992-1996) by the United States Coast Guard (USCG, 1999) lists 423 spills of hazardous substances from ships or port installations, giving an average of 85 spills each year. The total of these spills was 7 500 t, half of which involved sulphuric acid. The nine most frequently spilled products can be divided into three groups:

- Products which dissolve in water (sulphuric acid, phosphoric acid, caustic soda).
- Products which evaporate and dissolve in water (acrylonitrile, vinyl acetate).
- Petrochemical products which float and/or evaporate (benzene, toluene, xylene...).

Fifty-four percent of the spills were from ships/barges (mainly carrier barges) and 66 % from facilities (either a spill from the facility itself or from a ship/barge in dock). A complementary study carried out over a period of 13 years (1981 - 1994) on the ten largest and most important port zones reported 288 spills of hazardous substances, representing 22 incidents each year. There are no such statistics for other areas of the world.

1.3. Review of shipping incidents

In the absence of established statistics, for the purpose of the present report, available information on shipping incidents concerning chemical substances (definition) in European waters was collected and, as much as possible, for other areas as well. The framework used, insofar as the information was available, was as follows:

- Scene of the accident: location and causes.
- Chemical product(s) involved (nature, type of transport, properties and hazards).
- Response actions (mobilization, risk assessment, plan adopted, means developed).
- Impact: monitoring, economic impact, impact on the environment.

The results are summarized in table 1, with 47 incidents classified according to the type of transport and, for products transported in bulk, on their behaviour after being spilled at sea (dissolvers, floaters, sinkers, gases or evaporators). Most of the reported events occurred at sea, during sailing, mostly in adverse weather. Only ten occurred in port or in nearby zones, namely:

- The entrance to Mogadiscio Port (*Ariadne*).
- The Port of Texas city (*Grandcamp*).
- The Port of Brest (*Ocean liberty*).
- The entrance to the Port of Zhanjiang, China (*n° 1 Chung Mu*).
- Kearny Landing Stage, USA (*Cynthia M*).
- Tokyo Bay, Japan (*Yuyo Maru n° 10*).
- The Rio-Grande Port, Brazil (*Bahamas*).
- The Elba River, Germany (*Oostzee)*.
- Gijon Port waiting area *(Castillo de Salas).*
- Guadalquivir Estuary Channel *(Weisshorn)*.

Table 1: Summary of 49 chemical incidents at sea				
Name of ship	**Year**	**Chemical products**	**Country**	**Maritime zone**
PRODUCTS TRANSPORTED IN PACKAGES AND CONTAINERS				
VIGGO HINRICHSEN	1973	Chromium dioxyde, sodium dichromate…	Sweden	Baltic
SINBAD	1979	Chlorine	Netherlands	North Sea
ARIADNE	1985	Acetone, butyl acetate, toluene…	Somalia	Indian Ocean
CASON	1987	Sodium, aniline, creosol, …	Spain	Atlantic
PERINTIS	1989	Lindane	France	Channel
OOSTZEE	1989	Epichlorhydrin	Germany	North Sea
ARIEL	1992	White spirit	Netherlands	North Sea
SHERBRO	1993	Pesticides	France	Channel
MSC CARLA	1997	Flammable, combustible, radioactive ...	Portugal	Atlantic
MSC ROSA M	1997	Hazardous substances	France	Channel
APUS	1998	Flammable solids (lighters)	Netherlands	North Sea
BAN-ANN	1998	Sulfur-phosphine	Netherlands	North Sea
EVER DECENT	1999	Hazardous substances	UK	North Sea
MELBRIDGE BILBAO	2001	Marine pollutant	France	Atlantic
ROKIA DELMAS	2006	Cocoa beans	France	Atlantic
NAPOLI	2007	Explosives, flammables, pollutants…	UK	Channel
PRINCESS OF THE STARS	2008	Pesticides	Philippines	South China Sea
DISSOLVERS IN BULK				
GRANDCAMP	1947	Ammonium nitrate	USA	Texas city port
OCEAN LIBERTY	1947	Ammonium nitrate	France	Bay of Brest
BRIGITTA MONTANARI	1984	Monomer vinyl chloride	Yugoslavia	Adriatic Sea
ANNA BROERE	1988	Acrylonitrile, Dodecylbenzene	Netherlands	North Sea
ALESSANDRO PRIMO	1991	Acrylonitrile, Dichloroethane	Italy	Mediterranean
CYNTHIA M	1994	Caustic soda	USA	Atlantic
ALBION 2	1997	Calcium carbide, phenol, caustic…	France	Bay of Biscay
PANAM PERLA	1998	Sulphuric acid	-	Atlantic
BAHAMAS	1998	Sulphuric acid	Brazil	Atlantic
BALU	2001	Sulphuric acid	France	Bay of Biscay
BOW EAGLE	2002	Methyl-ethyl-ketone, ethyl acetate…	France	Channel
FU SHAN HAI	2003	Potash	Sweden	Baltic
BOW MARINER	2004	Ethanol	USA	Atlantic
SAMHO BROTHER	2005	Benzene	Taïwan	Western Pacific
FLOATERS IN BULK				
LINDENBANK	1975	Coconut oil	Hawaii	Pacific
KIMYA	1991	Sunflower oil	UK	North Sea
GRAPE ONE	1993	Xylene	UK	Channel
N°1 CHUNG MU	1995	Styrene	China	China Sea
ALLEGRA	1997	Palm nut oil	France	Channel
CHAMPION TRADER	1998	Palm oil	USA	Mississippi
IEVOLI SUN	2000	Styrene, methyl-ethyl-ketone...	France	Channel
SINKERS IN BULK				
CASTILLO DE SALAS	1986	Coal	Spain	Bay of Biscay
NORAFRAKT	1992	Lead sulphur	Netherlands	North Sea
WEISSHORN	1992	Rice	Spain	Atlantic
INFINITI	1995	Rice	Curacao	Atlantic
FENES	1996	Wheat	France	Mediterranean
EUROBULKER IV	2000	Coal	Sardinia	Mediterranean
CO-OP VENTURE	2002	Corn	Japan	Pacific
ADAMANDAS	2003	Deoxidized iron balls	La Reunion	Indian Ocean
GASES OR EVAPORATORS IN BULK				
YUYO MARU 10	1974	Butane, propane…	Japan	Tokyo Bay
ASCANIA	1999	Vinyl acetate	UK	North Sea

1.4. Causes of incidents

The primary causes of the incidents identified above have broadly been classed into two groups (table.2):

- One linked to navigation risks, usually following bad weather conditions, causing the loss of part of the cargo, a shipwreck or a collision.
- The second linked to an initial internal event on board, such as a fire, mechanical failure, an improper manoeuvre (in ship ballasting, cargo stowage, etc.), or deliberate dumping of cargo or sinking of the ship.

Table 2: Primary causes of the reviewed chemical incidents

	Packaged products	Bulk transport	Total
Bad weather conditions	**7**	**16**	**23**
Loss of cargo	2	0	2
Grounding	0	5	5
Shipwreck	4	6	10
Collision	1	5	6
Incident onboard ship	**9**	**15**	**24**
Fire	1	5	6
Mechanical failure	2	2	4
Improper manoeuvre	5	7	12
Deliberate dumping/sinking	1	1	2
Total	**16**	**31**	**47**

Twice as many incidents involved chemicals transported in bulk than in packaged form (66% for bulk, compared to 34% for packaged). Considering both categories together, the primary group of causes was bad weather (51%), with an incident onboard ship (49%) representing only slightly less. Among specific causes, improper manoeuvre came first (22%), shipwreck came second (20%) and collision came third (13%), closely followed by grounding and fire (11% each).

However, these results must be considered with caution as, in general, first hand information from the incident investigation could not be accessed. As a result, there is a high probability that the actual primary cause was missed in a number of cases.

2. Characterization of incidents, risks and response

2.1. Short description of incidents

All 47 incidents are briefly described below, including identification of the related risks and response actions taken. The 24 best-documented incidents are further detailed and discussed in the subsequent chapter.

2.1.1. Packaged form transport

Seventeen incidents involving chemicals in packaged form have been identified and documented (see table 3 hereunder)

Table 3 : packaged transport

SINBAD, 1979 - Netherlands
Incident: Loss of part of the cargo at sea during bad weather conditions: 51 cylinders of chlorine (1t each).
Risks: Related to the possible recovery of the cylinders in fishermen's trawler nets: toxic product, harmful to human health (inhalation) and reactive, producing a corrosive acid when mixed with water.
Response: Locating by sound and rapid recovery of 7 cylinders. Recovery of 5 other cylinders by fishermen (lack of safety measures). Search 5 years later for other cylinders: 27 found and destroyed. Thirteen cylinders still missing.

ARIADNE, 1985 - Somalia
Incident: While sailing out of the Port of Mogadishu (Somalia), the container ship Ariadne grounded on rocks about 100 metres from the shore.
Risks: The ship was transporting a cargo of 118 containers of hazardous chemicals, including acetone, butyl acetate, tetraethyl lead, toluene, trichloroethylene and xylene.
Response: Salvage attempts failed. As time passed, the ship listed more and more, part of the deck collapsed and a fire started above one of the decks. Toxic fumes and chemical emissions drifted towards the city. Authorities ordered the evacuation of a number of inhabitants and companies in the port area. The vessel broke in two and large quantities of oil and cargo, including drums of chemicals, began to come ashore. A few days later, the rear part of the ship broke off further and began to list at a 90° angle. Despite the lack of protective clothing, a vast operation was set up to recover the cargo washed up on the shore.

CASON, 1987 - Spain
Incident: The ship caught on fire, sought shelter and grounded on the Galician "Death Coast".
Risks: The ship cargo on fire included a number of hazardous substances, including diphenyl methane di-isocyanate (MDI) orthocresol, aniline, sodium, all toxic to the environment and harmful to human health, some explosively reactive with water.
Response: European assistance (emergency task-force) and IMO expertise were mobilised for identification of the cargo, initially unknown. Plans to unload hazardous substances from the ship were hampered by bad weather conditions and fire on board. The operation necessitated 3 months work, with monitoring of water and air contamination. Following an explosion, 15 000 people were evacuated from the surrounding area overnight with buses. Great difficulties were encountered in evaluating risks involved without proper information on the cargo. A delay occurred in transporting intervention equipment to the site. Information to the public was poor.

PERINTIS, 1989 - France
Incident: The ship was wrecked during a storm, with a cargo including containers of pesticides: lindane (5.8 t), permethrine (1 t), cypermethrine (0.6 t). Containers of lindane were lost during towing.
Risks: Contamination of the environment.
Response: Unsuccessful search for a lindane container. Immediate recovery, by the British Marine Pollution Control Unit (MPCU) of drums of permethrine and cypermethrine near the wreck. Surveillance of the contamination of the marine environment in the zone where the lindane container was presumed lost. Efficient French-British cooperation.

OOSTZEE, 1989 - Germany
Incident: Vessel was carrying 975 t in 3 900 drums of Epichlorhydrin. Badly stowed drums deteriorated and, in bad weather conditions on the Elba river, the Epichlorhydrin leaked out. All 14 crew were hospitalised for 10 days.
Risks: A flammable, toxic substance (fumes) of carcinogenic nature.
Response: Inspection of the ship, crew taken to hospital for medical checks. Towing and unloading of the ship in safe conditions. Cleaning operation on-board. Long term effects (toxic fumes) on the crew (several years).

ARIEL, 1992 - Netherlands
Incident: Loss of 45 drums of white spirit at sea, washed up on the coastline.
Risks: Contamination of the environment due to leakage from drums.
Response: Recovery of drums grounded on the coastline.

SHERBRO, 1993 - France
Incident: Loss of 88 containers in bad weather, including 10 with hazardous substances, mainly pesticides, including thiocarbamate (Apron Plus, 188 000 sachets).
Risks: 'Apron Plus' dangerous for the environment, reactive with water (forming phosphine, a toxic gas). Grounding of sachets reported along the French, Dutch and German coasts.
Response: Offloading of badly-stowed containers in the Port of Brest. Storage of containers of hazardous substances classified 3, 4, 5, 6 and 8, under tarpaulin, respecting the compatibility of the products. Drift predictions for 15 containers lost at sea. Recovery of pesticide sachets on beaches in France, Germany and Netherlands (91% of lost sachets recovered). Good cooperation between the countries concerned. Technical advice from the chemical industry.

MSC CARLA, 1997 - off the Azores, Portugal
Incident: The container carrier MSC Carla broke in two in a violent storm, while sailing off the coast of Azores. The 34 crew members were safely evacuated. 74 containers were lost.
Risks: Lost containers were loaded with wine, alcohol, flammable and combustive products, poisonous and corrosive substances. Fourteen carried "marine pollutant" classified products. Also, one container transported 3 biological irradiators with their radioactive sources (Cesium 137).
Response: The aft part of the ship was taken in tow while the fore part sank in waters 3 000 m deep, with the containers still on board. The documentation reviewed showed that the container transporting the biological irradiators was positioned in the fore part of the ship. The cesium protective cells, designed to resist a pressure of 20 atmospheres, would have imploded while the section of the ship was sinking. The French Institute of Protection and Nuclear Security (IPSN) carried out assessments of the possible impact on humans and the fauna in the area. Because of the great depth (3 000 m), a high

dilution capacity limited the exposure. The risk to consumers was minimal, as trawling in the zone was carried out at depths of less than 2 000 m.

MSC ROSA M, 1997 - France

Incident: The ship listed more than 20° after a ballasting error, with 70 t of hazardous substances on board (liquid gases, flammable solids, corrosive and oxidizing substances).

Risks: The wrecking of the ship could have potentially generated a multi-chemical hazard, similar to the Cason incident.

Response: Collection of information on the cargo onboard. Rapid towing and beaching of the ship in a sandy bay. Chemical risk assessments performed by specialized HNS emergency teams. Water pumped from ballast to rebalance the ship and return it to Le Havre port for unloading and repairs.

APUS , 1998 - Netherlands

Incident: Loss from a ferry of a trailer’s container with 2 100 boxes of fire lighters**.** Grounded on the coastline.

Risks: Product harmful to human health (urea-formaldehyde), an environmental contaminant (kerosene).

Response: Recovery of fire lighters buried in sand on beaches. Costs reimbursed by shipowner.

BAN-ANN , 1998 - Netherlands

Incident: Deliberate dumping at sea of sachets of anti-vermin product containing sulphur-phosphine (Detia-Ex-B).

Risks: Chemical reacting with humidity, generating a toxic gas.

Response: Recovery and destruction of sachets washed up the coastline.

EVER DECENT, 1999 -UK

Incident: Container ship collided with an ocean liner. Fire on board, involving containers of hazardous materials, notably cyanide, organic lead and pesticides.

Risks: Chemical risk from fire on board container ship.

Response: Towing of ship. Fire fighting. Control of air contamination (fear of cyanide).

MELBRIDGE BILBAO, 2001- Molène Island, France

Incident: The container ship Melbridge Bilbao missed the Ushant traffic separation scheme by 17 Miles and ran aground at full speed on a sandy beach of the island of Molène.

Risks: The ship carried 218 containers and 330 cases, including one container with 17t of IMDG class 9 catalysts. It also had on board 180 t of fuel oil and 60 t of diesel oil.

Response: The ship was able to be refloated at high tide and towed to a waiting area for inspection by divers before being towed to a dry dock in Brest harbour following verification of the actual hazards related to the catalyst. There, it was decontaminated and repaired.

ROKIA DELMAS, 2006 - Isle of Ré, France

Incident: On 24 October 2006, at around 4 a.m., the container ship the Rokia Delmas, suffering from total engine failure, was driven ashore by a storm on the south coast of the Ile de Ré, French Atlantic coast and hit a rocky outcrop, 1 nautical mile south of the coast.

Risks: The vessel was mainly transporting cocoa beans, wood and more than 500 t of IFO 380 and 50 t of marine diesel. The cocoa beans could rot if spilled and generate organic pollution in a major oyster farming area.

Response: As a precautionary measure, the Polmar Land Plan for Charente Maritime was activated. An oil spill response vessel was sent to the site. Oyster beds were protected by booms. During a 15-month operation, the ship cargo was removed, the wreck was cut into five pieces and the pieces were removed.

NAPOLI, 2007- Channel, France and United Kingdom

Incident: At the entry to the English Channel during a storm, the container ship Napoli, suffered a leak and a failure of her steering system.

Risks: The ship was transporting 2 394 containers, carrying nearly 42 000 t of merchandise, of which some 1 700 t was classed as hazardous substances. In her bunkers, she held over 3 000 t of heavy fuel oil.

Response: Crew members were evacuated by rescue helicopters. The risks for responders (explosive or flammable substances and toxic gases) and the risks for the marine environment (aquatic pollutants, toxic substances for the flora and fauna) were analyzed. After inspection, the Napoli was towed to the Dorset port of Portland. En route, due to the growing risk of the vessel breaking, the convoy was diverted to Lyme Bay, where the Napoli was beached. In total, 103 containers were lost overboard, with 57 of them being washed ashore, many in Lime bay. In France, packets of chocolate biscuits covered in fuel oil, landed on the coasts of northern Finistère and Côtes d'Armor. In Lyme Bay, the ship was unloaded and cut in two pieces, which were towed away.

PRINCESS OF THE STARS, 2008 - Philippines
Incident: On 21 June 2008, the Princess of the Stars ferry hit typhoon Fengshen and sank with 850 people onboard, off the coast of Sibuyan Island. Many passengers and crew died.
Risks: On 28 June, operations to recover the bodies were suspended due to the presence of containers of pesticides onboard. It was considered necessary to remove these substances before continuing to recover the corpses or attempting to refloat the wreck.
Response: A 5 km exclusion zone was set up around the wreck, where fishing and aquaculture activities were prohibited. On 9 July, a team of European experts arrived on site to assess the human and environmental risks. 5 highly toxic pesticides were being transported in 2 containers onboard the ferry: a 40-foot container held 10 t of Endosulfan and a 10-foot container stored 4 other pesticides in smaller quantities. Samples around the wreck showed no water pollution. The containers were ultimately removed, undamaged, from the hold.

2.1.2. Transport in bulk

Twenty-eight incidents involving chemicals transported in bulk have been identified and documented:

- 12 for dissolvers (table 4)
- 7 for floaters (table 5)
- 8 for sinkers (table 6)
- 2 for gases or evaporators (table 7)

Table 4 : transport in bulk, dissolvers

GRANDCAMP, 1947 - Texas City, USA
Incident: On 16 April 1947, the liberty ship *Grandcamp* was loading fertilizers, including ammonium nitrate, when fire broke out. It exploded while taken in tow away from the loading pier. Fire and explosions continued for 6 days, destroying most port equipment and facilities, as well as many houses and buildings. 600 people died, 3 000 were wounded.
Risks: Ammonium nitrate is an agricultural fertilizer compound, soluble in water, highly explosive when heated.
Response: Fire fighting and rescuing the wounded.

OCEAN LIBERTY, 1947- Bay of Brest, France
Incident: The liberty ship *Ocean Liberty,* loaded with 3158 t of ammonium nitrate safely entered Brest Harbour. However, after mooring, smoke was seen pouring from one of the closed holds, and a fire rapidly spread.
Risks: Ammonium nitrate is an agricultural fertilizer compound, soluble in water, highly explosive when heated.
Response: After a series of small explosions, the ship was towed away with the available means and salvors undertook to flood the holds. In spite of these measures, a huge explosion occurred that was felt within a 60 km radius, killing 26 people and causing hundreds of casualties, as well as destroying 4 000 to 5 000 houses and buildings downtown. The harbour cranes lay on the ground. The gas works and the oil depot were in flames. There was no report of any water pollution.

BRIGITTA MONTANARI, 1984 - Adriatic Sea, Yugoslavia

Incident: The *Brigitta Montanari* was transporting 1 300 t of vinyl chloride monomer, in short VCM (GE, MARPOL cat Y) when she sank in the Adriatic, to a depth of 82 m.

Risks: VCM is carcinogenic and when spilled evaporates into an extremely flammable gas, forming an explosive mixture with air.

Response: It was decided almost 3 years later to refloat the ship and to pump out the VCM. A leak was detected and a hole was bored in the bridge, through which VCM was first released (on an estimated basis of 3 t/day). Then divers connected PVC tubes to the hole through which VCM was released at the water surface, where it dispersed and was burnt. Finally, the ship was returned to a depth of 30 m and the 700 t of VCM still on board were pumped and transferred to another tanker.

ANNA BROERE, 1988 – Netherlands

Incident: In a collision with another ship, the chemical tanker Anna Broere spilled 547 t of Acrylonitrile [DE] and 500 t of Dodecylbenzene [F].

Risks: Acrylonitrile is toxic, flammable and explosive. When on fire, it gives off toxic fumes.

Response: Establishment of safety perimeter (10 miles for navigation, 300 m for air transport). Unsuccessful attempts were made to lift the ship. Ship was cut in two and cargo lightered. Environmental monitoring continued during the whole operation. Work undertaken in safe conditions (protective clothing, chemical monitoring). Two months of effective co-operation between various teams of intervention personnel.

ALESSANDRO PRIMO, 1991 – Italy

Incident: Ship wrecked in a storm, with 594 barrels of Acrylonitrile (DE) and 3 013 t of Dichloroethane (SD).

Risks: Acrylonitrile is toxic, flammable and explosive, giving off toxic fumes (HCN) in the event of fire. Dichloroethane is harmful to human health.

Response: Wreck found 108 m deep by a remote control underwater vehicle. Beginning of cargo recovery 2 months after the accident, with priority given to the acrylonitrile. Recovery of 900 t of acrylonitrile and 2 750 t of dichloroethane completed over three months. Advantage of experience of the *Anna Broere* shipwreck. Maximum safety precautions for recovery workers (fire alarms, emergency training, protective clothing, and medical services on site).

CYNTHIA M, 1994 - Kearny, New Jersey, USA

Incident: When the barge *Cynthia M,* loaded with 1 200 m³ of caustic soda was moored at a landing stage in the south of Kearny, New Jersey, USA, with a list of 70°, she spilled 490 t of her cargo into the Hackensack River and the Bay of Newark.

Risks: The pH alongside the barge reached 12 very quickly and lowered to 9 three hours later. Only the area in the immediate vicinity of the barge was affected by the pollution**.**

Response: No recovery was possible. The discharge of caustic soda caused a fish kill and the destruction of the neighbouring marshes.

ALBION II, 1997 - North Atlantic Sea, Bay of Biscay, Brittany, France

Incident: The cargo vessel *Albion II* broke in two and sank silently off the Bay of Biscay in waters 120 m deep, its 25 crew members sank with it.

Risks: The vessel was carrying 10 dangerous substances, according to the IMO code, plus 1 100 t of propulsion fuel (IFO 180). With regard to the chemicals, the main risk was related to the 12 bars (120 m of water) resistance of the barrels containing calcium carbide. Acetylene would form in case of water infiltration, inducing a possibility of ignition.

Response: No response known.

PANAM PERLA, 1998 – Atlantic
Incident: Seep in double hull of a cargo tank of sulphuric acid (100 t) [D], which was no longer watertight,.
Risks: Corrosive product, reactive with water: a risk of ignition and explosion (formation of hydrogen). Harmful to human health. Marine pollutant.
Response: Pumping of the acid out of the double hull was completed 1 week after the leak was reported. Neutralisation of acid lost (3.4 t) using bicarbonate. Note speed of operations

BAHAMAS, 1998 – Brazil
Incident: Error in the handling of the pumping system during unloading, generating an internal crisis, culminating in a spill of 1 700 t of sulphuric acid [D] and ship abandonment.
Risks: See Panam Perla above.
Response: Initial errors resulted from ship's dilapidated condition, incompetence of the crew, lack of means to stock very corrosive diluted acid, impossibility of neutralisation due to lack of basic neutralising agent, which led to the acid being pumped from the hold and dumped in the port as the tide was going out, with a chemical monitoring of pH. Court ordered to dump the cargo out at sea. A 12 000 t lightering operation was implemented, using another chemical carrier. The ship was then towed and scuttled in international waters. These various operations took 10 months. Monitoring showed some Impact on the environment, with direct and indirect reactivation of toxic metals absorbed in the port sediment.

BALU, 2001 - Bay of Biscay, limit of the French and Spanish territorial waters
Incident: The chemical tanker *Balu* transporting 8 000 t of sulphuric acid (D, MARPOL cat Y) sank without sending out a Mayday in the Bay of Biscay at a depth of 4 600 m.
Risks: Mixed with water, the concentrated acid releases great quantities of heat. In shallow waters, the water can be carried to boiling. In very deep waters, the pressure would probably prevent boiling. When spilled in large quantities, the acid would sink and is diluted in water.
Response: No response known.

BOW EAGLE, 2002 - Channel, France
Incident: The *Bow Eagle* collided with a trawler in the middle of the night, in the Channel.
Risks: The ship transported 510 t of lecithin of soya (Fp, MARPOL cat Y), 1652 t of sunflower oil (Fp, MARPOL cat Y), 1 050 t of methyl-ethyl-ketone (DE, MARPOL cat Z) 4 750 t of cyclohexane (E, MARPOL cat Y) 3 108 t of toluene (MARPOL cat Y), 500 t of vegetable oil FA201 (Fp, MARPOL cat Y) 2 100 t of ethyl acetate (DE, MARPOL cat Z), 4 725 t of benzene (E, MARPOL cat Y), 5 250 t of ethanol (D, MARPOL cat Z). 200 t of ethyl acetate leaked from the tanker before the chemical could be transferred to another tank. Luckily, there was no significant pollution.
Response: The breach was sealed.

FU SHAN HAI, 2003 Baltic, Sweden
Incident : on 31 May 2003, the Chinese bulk carrier *Fu Shan Hai* collided with the Polish freighter *Gdynia* about 40 km southwest of Sweden in the western Baltic Sea and sank at 68 meters water depth from where it began to leak oil.
Risks: The ship was carrying 66 000 tons of potassium carbonate (potash). It had bunkers of 1680 t of heavy fuel oil, 110 t of diesel oil and 35 t of lubricating oil. The response focused on oil seeping from the wreck.
Response: coastal cleaning of the spilled oil. No action with regards to the potash

BOW MARINER, 2004 - Off Virginia, USA
Incident: The *Bow Mariner* sank quickly 50 miles off the coast of Virginia (USA) to a depth of 80 m, following a fire on the bridge and several very severe explosions. Eighteen of the 27 crew members disappeared during the shipwreck.
Risks: The ship transported 11 000 t of ethanol (D, Marplot Z).
Response: Given that ethanol is completely soluble in water, no containment or recovery was attempted. No impact study was implemented. The only recognized pollution was that produced by the bunker fuel, 720 t of IFO 380 and 166 t of MDO transported by the vessel for its use.

SAMHO BROTHER, 2005 – Off Taïwan, China
Incident: On 10 October 2005, the chemical tanker *Samho Brother*, capsized after colliding with the Nigerian cargo ship TS *Hong Kong*, off the Northwestern coast of Taiwan, China, and sank 70 m deep, with a cargo of 3,100 t of benzene and bunkers of 85 t of fuel and 16 t of diesel.
Risks: Benzene is highly toxic for marine fauna and flora
Response: There was no evidence of a benzene and/or hydrocarbon leak at the surface. Auhorities demanded that the ship owner remove the benzene, fuel and other hydrocarbons. The ship owner did not comply. Two years later, bombers made two attempts to explode the shipwreck with containment and recovery vessels standing by. No benzene was detected later, neither in the air nor in water and at shore.

Table 5 : transport in bulk, floaters

LINDENBANK, 1975 - South of Hawaii
Incident: Grounding on Fanning Atoll, south of Hawaii, with 18 000 t of cane sugar and other foodstuffs on board, including 9 500 t of copra, seeds of cocoa beans, palm oil and coconut oil [F].
Risks: Oil impact on coral reef.
Response: Unsuccessful attempts to raise the ship from the coral reef. Unloading of 18 000 t of cargo in the water. Monitoring of possible impact of coconut oil on reef.

KIMYA, 1991 - UK
Incident: Stranded during a storm, spilling 1 500 t of sunflower oil [F].
Risks: Oil impact on the environment.
Response: Ship was refloated. Environmental monitoring confirmed some impact on intertidal populations.
GRAPE ONE, 1993- UK
Incident: Error while ballasting ship caused shipwreck with 3 041 t of Xylene [FE] on board.
Risks: Moderate pollutant, but very flammable.
Response: Crew evacuated and winched to safety. Ship stranded and shipwrecked with cargo in the Channel.

N° 1 CHUNG MU, 1995 - China
Incident: Collision with another ship at the entrance of the Port of Zhanjiang. Spill of 230 t of styrene [FE].
Risks: Reactive product (exothermic polymerisation), flammable and irritant, with impact on the environment (tainting fishing and mariculture products).
Response: Attempt to limit the leakage and to stop the spill by intervention of scuba divers. A construction site had to be temporarily evacuated. Risks concerning the sea environment were assessed as styrene changes the organoleptic characteristics of the flesh of fish and shellfish (tainting).

ALLEGRA, 1997 - France
Incident: Collision with another ship in the Channel (foggy weather), loss of 700 t of palm nut oil [F].
Risks: Oil impact on the environment.
Response: Slick drift monitoring and prediction (observation by air and by sea, positive use of remote sensing, French-British cooperation). Recovery of oil residues on the coast (12 t).

CHAMPION TRADER, 1998 - Mississippi River, USA
Incident: An explosion caused the release of 460 t of palm oil in the Mississippi river (OSIR, 1998).
Risks: Oil impact on the environment.
Response: The oil drifted 3 km downriver. Only 20 t were recovered.

IEVOLI SUN, 2000 - Channel, France

Incident: Faced with a water intake, the chemical tanker *Ievoli Sun* was evacuated by its crew and sank by 70 m depth in the north of Casquets, while on tow to a port of refuge, with 6 000 t of chemicals on board.

Risks: The ship had a cargo of 4000 t styrene (FE, MARPOL cat Y), 1 000 t methyl ethyl ketone (MEK, DE, MARPOL cat Z) and 1 000 t isopropanol (IPA, D, MARPOL cat Z) plus bunkers of 160 t of Fuel (IFO 180) and 40 t of diesel oil. The behaviour of those chemicals in the prevailing conditions around the wreck was totally unknown. Experiments were quickly implemented.

Response: It was agreed that the shipowner would pump the styrene and fuel, and release the MEK and IPA, under the control of the Authorities. Work was completed on May 31, after 51 days of intervention entirely carried out by ROVs, in challenging conditions.

Table 6: transport in bulk, sinkers

CASTILLO DE SALAS, 1986 - Bay of Gijon, Spain

Incident: While at anchor in the waiting area of the port of Gijon, with 100 000 t of coal onboard, the ship was washed by a storm on to a submerged reef and broke in two.

Risks: An impact study by the Spanish Oceanographic Institute concluded that this particular type of coal was not dangerous for humans or the environment.

Response: Fore part towed away and sunk in high seas. Aft part remained stranded on submerged rock. Gijon city beaches were repeatedly soiled by coal dust and pellets mixed with fuel. Landings of coal dust and fuel were recognized as a nuisance and authorities contracted the removal of the ship remains.

NORDFRAKT, 1992 - Germany

Incident: Shipwreck due to displacement of the cargo, 1 600 t of lead sulphur [S].

Risks: Potential impact on the environment.

Response: Refloating of the wreck and its cargo.

WEISSHORN, 1992 – Spain

Incident: On 27 February 1994, the cargo vessel *Weisshorn*, travelling from Thailand and bound for Sevilla with a full cargo of rice, became stranded on a sandbank in the Guadalquivir estuary channel.

Risks: Possibility of organic pollution by rotting rice.

Response: No response known.

INFINITI, 1995 – Curaçao

Incident: Stranded in marine park, 400 t of rice spilled.

Risks: See Weisshorn above.

Response: No response known.

FENES, 1996 – France

Incident: Grounding in a marine reserve, loss of 2 600 t of wheat.

Risks: Wheat fermentation, with production of gaseous fermentation products (H_2S) capable of intoxicating intervention personnel and generating local acidity, which is damaging to sessile benthos.

Response: Once the ship's fuel and oil had been removed, the rotting cargo was dumped over the sea bed (15-20 m), where it formed a coat of up to 2m. It was recognised as a pollutant, to be removed. It was pumped onto a barge and dumped in the high sea at a low density. The ship remains were collected and removed during an eight month operation.

EUROBULKER IV, 2000 - San Pietro Channel, Sardinia

Incident: Ship sank in the Channel with 14 000 t of coal on board.

Risks: The Channel is an ecologically rich area, with beds of *Posidonia oceanica*, which were affected by mechanical phenomena (smothering of the vegetation, covering of the sediment).

Response: Environmental impact study by ICRAM.
CO-OP VENTURE, 2002 – Japan
Incident: Stranded, unknown tonnage of corn spilled.
Risks: See Fenes above. Two firemen sent on board died from poisoning by hydrogen sulphide.
Response: No response known.

ADAMANDAS, 2003 - La Reunion, France
Incident: The *Adamandas* bulk carrier, transporting 21 000 t of deoxidized iron balls, noted an increase in temperature of its cargo. It sailed to La Réunion, as it was the only place in the Mozambique strait where it could seek assistance.
Risks: uncontrollable heating, fire and explosion
Response: There was no adequate structure in the port and, due to the risks for the population, the authorities moved the ship 10 nautical miles away and scuttled it in waters 1 700 m of deep.

Table 7: Transport in bulk, gases or evaporators

YUYO MARU N°10, 1974 - Japan
Incident: Collision in Tokyo Bay with cargo of propane, butane and naphtha [G]
Risks: Flammable gases.
Response: Ship on fire, towed and anchored out at sea.
MULTI-TANK ASCANIA, 1999 - UK
Incident: Fire on-board ship with cargo of 1 750 t of vinyl acetate [ED].
Risks: Flammable and polymerisable product, possibly carcinogenic.
Response: Evacuation of the crew because of a fire on-board. Ship stranded half a mile from the coast. Establishment of a temporary 5 km exclusion zone, necessitating the evacuation of 200 inhabitants. Reconnaissance by helicopter of the hot spots on-board ship (risk of explosion) using an infrared camera. Advantages of a chemical exercise two weeks earlier and of positive action taken by the crew before abandoning ship. Importance of an intervention team for chemical risks and of availability of emergency towing equipment.

2.2. Identified risks

2.2 1. Human health

Risks which affect human health come mainly from reactive substances (reactivity with air, water or between the products themselves). The maximum hazard was clearly shown in the grounding of the *Cason* (Spain, 1987), with a fire on-board a ship carrying a number of toxic and highly reactive flammable substances (reactivity of sodium with water), aggravated by the fact the products' identity and classification (IMDG code) were unknown during the first few hours following the accident. The evaluation of the chemical risks of ships in difficulty, when they are carrying diverse hazardous substances, is a priority of the response authority (see the *Rosa M,* France, 1997, the *Ever Decent,* UK, 1999, the *Napoli*, the English Channel, 2007.

Certain substances which are transported in large quantities can pose very serious risks to human health. One tonne cylinders of chlorine, a highly reactive and corrosive gas lost by the *Sinbad*

(Netherlands, 1979), is an example of the problems involved in the transportation of chemicals in packaged form. Fumes of epichlorhydrin, leaking from the damaged drums on the *Oostzee* (Germany, 1989), seriously affected the ship's crew. Years later, cancer, likely linked to the incident, was diagnosed in several crew members and some died soon after.

As far as the transport of chemicals in bulk is concerned, five types of products must be noted as being particularly reactive and hazardous:

- Ammonium nitrate (*Grandcamp* and *Ocean liberty*, 1947) is a highly explosive compound, holding the world record for human casualties in a single chemical shipping incident.
- Acrylonitrile (*Alessandro Primo*, Italy, 1991, *Anna Broere,* Netherlands, 1988) is a toxic product, both flammable and explosive and, in the event of fire, phosgene, a highly toxic gas, is produced.
- Styrene (*N° 1 Chung Mu*, China, 1995, *Ievoli Sun*, the Channel, 2000) can polymerise in the form of a violent exothermic reaction.
- Sulphuric acid leak on-board ship (*Panam Perla*, Atlantic, 1998, *Bahamas*, Brazil, 1998), cause risks to the ships themselves, diluted acid being much more corrosive than pure acid. A mixture of acid with water also gives off explosive hydrogen.
- Vinyl acetate is a flammable and polymerizable plasticizing product. In the case of the *Multi Tank Ascania* incident (United Kingdom, 1999), the explosion zone was evaluated as 2 km long and 1 km wide.

2.2.2. Environment

Hazards to the environment are varied and highly dependent on packaging, quantity and time of the year. Examples of particular interest are:

- The almost 200 000 sachets of pesticide (thiocarbamate) lost by the *Sherbro* (France, 1993) which drifted to the coasts of France, Belgium, Netherlands and Germany, were totally innocuous as long as the sachets remained sealed. However, they would become a dangerous pollutant were they to break open.
- The loss of a 5 t container of lindane (*Perintis*, France, 1989), similarly innocuous if it remained tightly sealed, could have been a dramatic source of pollution if it leaked.
- The spill of 1 600 t of lead sulphur (*Nordfrakt*, Germany, 1992) resulted in an input of lead equal to the overall amount of the metal over the whole of the North Sea in a full year.

Substances considered as non-pollutants such as vegetable oils (*Lindenbank*, Hawaii, 1975, *Kimya*, UK 1991, *Allegra*, France, 1997) can also lead to the mortality of certain species in the environment or to disturbances affecting the use of local amenities.

Even a substance as inoffensive as wheat, a food product (*Fenes*, France, 1997), can cause risks. Wheat fermentation in the marine environment, in an anoxic reaction, results in the release of hydrogen sulphur, a highly toxic gas which makes it necessary for intervening personnel to wear respiratory protection on site.

3. CASE STUDIES

3.1. Containers and packages

Five incidents involving container ships are analysed here:

- *MSC Carla,* 1997, wrecked in high seas off Azores, Portugal, loss of 74 containers, one with radioactive cells.
- *MSC Rosa M*, 1997, 20° list in the English Channel, with 70 t of HNS onboard.
- *Melbridge Bilbao,* 2001, Brittany, Molène Island, France, stranded with 218 containers and 330 cases.
- *Rokia Delmas,* 2006, stranded south of Ré Island with, among other cargo, containers of cocoa beans.
- *Napoli,* 2007, the English Channel, structural failure with 600 containers on board.

3.1.1. MSC Carla

In 1997, the container carrier MSC Carla, sailing off the coast of Azores in a violent storm, broke in two. The 34 crew members were safely evacuated. Seventy-four containers of wine, alcohol, flammable and combustive products, marine pollutants and corrosive substances were lost. The aft part of the ship was taken in tow while the fore part sank at a depth of 3 000 m. During towing, it appeared that the ship had one container onboard containing 3 biological irradiators, with their radioactive sources (Cesium 137).

Literature research carried out by Cedre indicated that the container transporting the biological irradiators was positioned in the sunken part of the ship. The protective cells of the radioactive sources were designed to resist a pressure of 20 atmospheres. Thus, they imploded while at a depth of some 200 m when the half ship was sinking. The French Institute of Protection and Nuclear Security (IPSN) carried out assessments of the possible impacts on the fauna in the vicinity of the wreck and on bottom fish consumers. The great depth (3 000 m), the high dilution and the absence of fisheries in the area limited the exposure risk.

3.1.2. MSC Rosa M

In 1997, inadequate tank ballasting in the container ship *MSC Rosa M* in the bay of Seine, led it to a 30° list off Cherbourg. The ship was beached by the salvors in a shallow bay. The loading plan indicated the presence in containers of approximately 70 t of dangerous substances, in particular flammable gases and liquids, as well as corrosive and oxidizing substances. The ship also contained 2 900 t of fuel oil. The 32 crew members were evacuated and taken to hospital. The risk of pollution of the marine environment required not only full cargo information, but also direct observation of the state of the ship and its cargo and dialogue with experts of the shipowner. Finally, the contents of the holds were pumped out; the ship recovered its normal waterline, and was towed at high tide to Cherbourg harbour.

3.1.3. Melbridge Bilbao

In 2001, the container ship *Melbridge Bilbao* missed the Ushant traffic separation scheme by 17 miles and ran aground at full speed on a sandy beach of the island of Molène. It carried 218 containers and 330 cases on board, loaded with 1 078 t of various goods (tobacco, alcohol, telephones, honey, glycerine, metals, furniture, cigars, catalyst, empty packaging). The catalyst, 17 t in one container, was classified IMDG class 9. The ship also had 180 t of fuel oil and 60 t of diesel oil on board. The ship was refloated at high tide and towed to a waiting area in the Bay of Berthaume, for inspection by French Navy divers before being towed to dry docks, following verification of the actual hazards associated with the catalyst. Enlargements of a poor quality photocopy allowed identification of the shipper of the product, a Mexican company in Ciudad Del Carmen. It indicated its phone number and qualified the product as “mezcla quimica” (chemical mix). After waiting for the office to open in Mexico, Cedre was able to speak to the company and learn that the shipment was the return of a rejected French product with nothing more dangerous in its composition than diesel oil as a solvent. Shortly thereafter, the convoy was allowed to enter the Bay of Brest and the dry dock.

On the following day, fuel began to leak from a breach to the ballast tanks under the ship, indicating that the internal partitions of the double bottom were damaged and that fuel had circulated between the fuel and ballast tanks. The pumping operations to completely clean the ship before repair and the cleaning of the dry dock extended over several days. The duration of these operations, carried out under optimal conditions, in confined a space, showed the damage that Molène Island had escaped. Had the ship not been refloated immediately, it would have been gradually dismantled by the winter storm, requiring cleaning operations extending over several months.

3.1.4. Rokia Delmas

On 24 October 2006, at 4 a.m., the container ship *Rokia Delmas*, faced with an engine failure in a storm, was stranded by winds, currents and waves on a submerged rocky bank, one nautical mile south of Ré Island. The ship had on board, amongst other cargo, containers of cocoa beans, wood and least 500 t of fuel oil (IFO 380) and 50 t of marine diesel. The crew was airlifted to safety, except the Master and 5 crew members that remained to assist the salvors with the response measures.

The ship had a breach in the hull and listed at a 20° angle. No pollution was observed, but the marine pollution response plan of Charente Maritime was activated nevertheless. Cedre was mobilized and sent two technical advisers on site. The high seas oil spill response vessel *Alcyon* sailed from Brest with containment and recovery equipment. The first investigations showed that it was impossible to refloat the vessel at high tide that evening. The following day, divers detected a 20 m long breach, confirming that it would be impossible to tow the vessel in her current state. The *Préfecture de département* decided to protect the oyster beds in the area using booms. Two barges equipped with skimmers and with storage capacity were deployed. On 30 October, 430 m^3 of fuel was pumped out of the tanks and stored on the *Alcyon*. The main concern then turned to the 300 containers of cocoa beans onboard the vessel. Upon request from the *Préfecture Maritime*, Cedre set up a series of experiments to determine the behaviour of cocoa beans, in the event the containers fell into the water. By the third day of immersion, a great abundance of suspended matter and turbidity was observed in the water. Over time, an increasing proportion of beans sank and a white oily film on the surface indicated the release of lipids. Monitoring of the gaseous release showed the generation of hydrogen sulphide by the fermentation of cocoa beans in seawater.

The *"préfet maritime"* of the Atlantic issued an order to the shipowner to remove the wreck and its cargo. Removal of the containers and the cargo of timber began on 10 November 2006. The speed of operations was dictated by the sea state. Several openings were made in the vessel to access the various decks and to remove the cargo trapped within. Together with the salvage plan, a pollution contingency plan was established, which consisted of deploying a boom around the entire site and pre-positioning oil recovery equipment (skimmers, sorbents, booms, etc.). On 9 March 2007, the salvage company began to remove the wreck's superstructures.

The cutting up and removal of the superstructures continued until September 2007. The hull could not be refloated. It was cut into five vertical sections, which were removed by a crane barge, prior final disposal at a demolition site. The last section of hull was hoisted out of the Port of La Pallice on 28 November 2007. Residual debris was removed and the works were finalized on 19 December.

3.1.5. MSC Napoli

On 18 January 2007, the British container ship the *Napoli*, en route from Antwerp to Lisbon, was caught in a storm at the entry to the Channel. She suffered a leak and a failure of her steering system. She was transporting 2 394 containers, carrying nearly 42 000 t of merchandise, of which some 1 700 t were classed as hazardous substances (explosives, flammable gases, liquids and solids, oxidants, toxic substances, corrosive materials...). In her bunkers, she held over 3 000 t of heavy fuel oil. The 26 crew members were evacuated from the vessel by rescue helicopters. The French *Préfecture Maritime* of the Atlantic conducted a risk assessment before carrying out a towing attempt on the abandoned ship. Cedre participated by carrying out drift predictions in the case of a spill and analysing the pollution risks posed by products in the cargo classed as hazardous, selected from a 106-page list containing up to 7 entries per page.

Two types of dangers were examined, and discussed: the risks for responders (explosive or flammable substances and toxic gases) and the risks for the marine environment (aquatic pollutants, toxic substances for the flora and fauna). The difficulty in this type of situation was not so much the dangers caused by a single product in isolation, for which information could be found in specialised technical literature, but rather the possibility of interference and reactivity between the products. Despite these uncertainties, the risk analysis was carried out in six hours and by midnight a committee of experts had finalized the hazard assessment, having provided a detailed opinion to the operational services of the "maritime prefect".

The risk of the vessel breaking during towing could not be excluded. Following inspection, the assessment team gave clearance for the *Napoli* to be towed and the decision was made to head for Portland, on the Dorset coast. Over the following hours, the convoy moved out of the French zone of responsibility and rescue management was taken over by the UK Maritime and Coastguard Agency. Whilst en route, due to the growing risk of the vessel breaking, the convoy was diverted to Lyme Bay, where the *Napoli* was beached.

In total, 103 containers were lost overboard, with 57 of the containers being washed ashore, many on Branscombe beach. The cargo of motorcycles, wine casks, nappies, perfume, car parts etc. attracted hundreds of scavengers, despite police warnings that any wreck material recovered must be reported.

In France, packets of chocolate biscuits, made in Turkey and covered in fuel oil, landed on the northern Finistère and Côtes d'Armor coasts over the weekend of the 27-28 January 2008. Questions were raised as to whether the packets of biscuits and the fuel oil came from the *Napoli*. Backtrack drift modelling showed that this was possible. Samples of the *Napoli* fuel oil were compared with samples collected on the shoreline. While analysis was underway, the Turkish manufacturer of the chocolate biscuits was identified on the Internet and contacted. The company provided the references of two containers loaded with 14 t of the biscuits (200 000 packets). These were the two containers lost overboard at the beginning of the incident. There was no doubt left. Over the following week, local communities from Finistère and Côtes d'Armor, helped by a Civil Protection Response Unit, cleaned up sandy beaches and rocky areas polluted by accumulations of oiled biscuit packets and patches of fuel oil.

In Lyme Bay, the shipowner unloaded the containers and the fuel from the ship. By the end of March, all the containers on the deck and the fuel oil had been unloaded. An assessment made at this stage indicated that it would not be possible to refloat the vessel with its cargo onboard and a decision was made to remove all the remaining containers. The first phase of the removal of the *MSC Napoli* could then begin. In August 2008, the bow section was towed to a yard in Northern Ireland. The stern section was expected to follow by mid-2009.

Biomonitoring, carried out by the University of Plymouth, was implemented in the bay to assess the general impact of the incident and the particular impact of ship's bunker oil.

3.1.6. Experience gained

Considered together, these incidents show that:

i) We are here faced with a world of extreme diversity, with the initial concerns of the responders were to identify the exact location of the containers in/on the ship and the specific product contained in each container, but also to gather information on product packaging. This information was sought in order to determine whether the container/package would either float or sink if were to fall overboard and to what extent the packaging included a waterproof layer.

ii) As a consequence of the high diversity of the chemicals present on the vessel, responders had to identify and quantify both the individual fate of each chemical, as well as the possible reactions resulting from the mixing of two or more substances.

iii) The great majority of chemicals involved in the incident had only a temporary and localized impact on marine life. No impact studies were implemented following the cleaning operations.

3.2. Packages / containers on fire

Two incidents involving packages and/or containers of diverse HNS catching fire are analysed hereunder:

- *Ariadne,* 1985, Somalia, stranded and on fire with 118 containers of hazardous chemicals (acetone, butyl-acetate, tetraethyl lead, toluene, trichlorethylene, xylene).
- *Cason,* 1987, cape Finisterre, Spain, 22 chemical products and fuel oil representing 1 000 t of chemicals, almost 5 000 barrels, cans, containers or bags of flammable products (xylene, butanol, butyl acrylate, cyclohexanone, sodium),toxic products (aniline, diphenylmethane, O-cresol, dibutyl phthalate) and corrosive products (phosphoric acid, phtalic anhydride).

3.2.1. Ariadne

While sailing out of the Port of Mogadishu (Somalia), the container ship *Ariadne* grounded on rocks approximately 100 m from the shore. She was transporting a cargo of 118 containers of hazardous chemicals, including acetone, butyl acetate, tetraethyl lead, toluene, trichloroethylene and xylene. Attempts to salvage her failed. As time passed, she continued to list. Part of the deck collapsed and a fire started above one of the decks. Toxic fumes and chemical emissions drifted towards the city. Authorities ordered the evacuation of a number of inhabitants and companies in the port area.

The vessel broke in two and large quantities of oil and cargo, including drums of chemicals, began coming ashore. A few days later, the rear part of the ship broke off and the vessel began to list at a

90 degree angle. Despite the lack of protective clothing, an operation was initiated to recover the cargo washed up on the shore.

3.2.2. Casón

While sailing off the coast of Spanish Finisterre, in December 1987, the general cargo vessel *Casón* announced a fire on board and requested assistance. The fire spread and the ship lost control. In spite of fast deployment of the rescuers, 23 of the 31 crew members died. Towing attempts failed, the fire propagated, the ship drifted and ran aground on rocks only 100 m from the coast, near the town of Corcubion.

The hull was damaged and water penetrated the holds. It was only after grounding that the full diversity of the cargo became known. Part of the cargo on deck was being unloaded (orthocresol and formaldehyde), when a series of explosions occurred. Operations were suspended. The complete declaration of the loading list disclosed the presence of close to 1 000 t of chemicals onboard, including 1 400 barrels of sodium and 10 containers of flammable, toxic and/or corrosive chemicals loaded on deck. There were 300 barrels of butanol (D, MARPOL CAT , cat Z), o-cresol (MARPOL CAT , cat Y), cyclohexane (E, MARPOL CAT , cat Y), aniline (MARPOL cat), butacrylate (FED, MARPOL CAT ,
cat Y) and phtalic anhydride (MARPOL CAT , cat Y) bags in the five cargo holds.

Fifteen thousand people within a 5 km radius were evacuated overnight. This required the mobilization of 300 buses. Once the danger of explosion was ruled out, quality control of air, water and marine organisms was carried out, in order to evaluate the possible threat to the public and the environment in the affected area. The results showed moderate levels of air and water contamination. Continuing bad weather conditions facilitated the dispersion and neutralisation of the chemicals spilled. Analyses of marine organisms (mussels, barnacles, octopuses) showed no bio-accumulation of aniline nor orthocresol.

3.2.3. Experience gained

These incidents show:

i) The difficulty of responding to a fire on a vessel that is transporting a variety of toxic products.

ii) The importance of having quick access to public or private means and personnel for responding in a toxic environment.

iii) The difficulty of rapidly obtaining a fully detailed list of the products transported and the loading plan, in order to properly assess the dangers for response personnel and the public.

iv) That crew members, unaware of the full nature of the products being transported and not trained in first response in the event of an incident, can easily become victims.

v) That the evaluation of the environmental damage and the related economic activities (especially fishing and aquaculture), following a chemical spill, is a real challenge.

3.3. Mineral chemicals transported in bulk

Five incidents, involving chemicals obtained from non-oil, mineral sources are described hereunder:

- *Ocean liberty,* 1947, Brest, France, 3 158 t of ammonium nitrate.
- *Cynthia M,* 1994, Kearny, New Jersey, USA, 490 t of caustic Soda.
- *Albion II,* 1997, off Brest, France, 114 t of calcium carbide.
- *Balu*, 2001, Bay of Biscay, Spain, 8 000 t of sulphuric acid.
- *Adamandas,* 2003, La Reunion, 23 000 t deoxidized iron balls.

3.3.1. Ocean liberty

When the *Ocean's Liberty* cargo of 3158 t of ammonium nitrate started burning after mooring in Brest Harbour and having suffered a series of small explosions, the master of the bulk carrier *Ocean Liberty* wanted it towed away immediately. However, a huge explosion occurred half way to safety, killing 26 people and causing hundreds of casualties, as well as blasting 4 000 to 5 000 houses and downtown buildings. There was no report of any water pollution.

3.3.2. Cynthia M

When the barge *Cynthia M,* loaded with 1 200 m^3 of caustic soda, was moored at a landing stage in the south of Kearny, New Jersey, USA, with a list of 70°, she spilled 490 t of her cargo in the Hackensack River and Bay of Newark. The pH alongside the barge reached 12 very quickly and came down to 9 three hours later. The pollution only affected the area in the immediate vicinity of the barge. No recovery was possible. The discharge of caustic soda caused a fish kill and the destruction of neighbouring marshes.

3.3.3. Albion II

When the cargo vessel *Albion II* broke in two and sank silently off the Bay of Biscay at depth of 120 m, its 25 crew sank with it. The vessel was carrying 10 dangerous substances, according to the IMDG Code, plus 1 100 t of propulsion fuel (IFO 180). With regard to the chemicals, the main risk was related to the low resistance of the barrels containing calcium carbide at a depth of 120 m (12 bars: acetylene formation in case of water infiltration could possibly induce ignition). For the phenol, lead oxides, naphthalene, caustic soda, camphor, iodine, resins, solids and paints onboard, the potential risk was likely quite limited in terms of space and time.

3.3.4. Balu

The chemical tanker *Balu,* transporting 8 000 t of sulphuric acid (D, MARPOL CAT , cat Y), sank in the Bay of Biscay at a depth of 4 600 m. When mixed with water, the concentrated acid releases significant quantities of heat. In shallow waters, the water can be brought to boiling. In very deep waters, the pressure would likely prevent this from occurring. Spilled in large quantities, the acid would sink and be diluted in the water. The product is miscible in water in any proportion and would be completely diluted in the long term. No response was possible.

3.3.5 Adamandas

In 2003, the *Adamandas* bulk carrier, transporting 21 000 t of deoxidized iron balls, noted an increase in the temperature of its cargo. It sailed to La Reunion, as this was the only place in the area where it could seek assistance. It did not have the authorization to berth and remained in Possession Bay to air its holds and to evacuate hydrogen by natural ventilation. This proved insufficient to cool the cargo. Deoxidized iron balls tend to reoxidize, releasing heat and hydrogen in contact with air or humidity. This is why this loading of this type must be carried out with significant caution, i.e. dry loading into clean and watertight nitrogen-saturated holds. The principal risk is the that of explosion, if hydrogen is produced and not properly ventilated, and weakening of the ship's structures if exposed to heat. In this case, the authority in charge, moved the ship 10 nautical miles away from Pointe des Galets and, after having evacuated the crew, scuttled the ship, sinking it at a depth of 1 700m.

3.3.6. Main lessons

Considered together, these incidents show that:

i) Responders may be faced with families of chemicals presenting very different characteristics and dangers.

ii) The most aggressive acid or soda may cause dramatic damage at high concentrations and generate a toxic cloud. These chemicals, however, are fully soluble in seawater and longer present a hazard from tens of meters to some hundred metres from the spill source.

iii) Some chemicals, like ammonium nitrate, generate far different hazards in air and water. In air, ammonium nitrate is a potent explosive. In water, it is a fertilizer, hypothetically capable of generating, depending of the area and season, either a small, localized phytoplankton bloom, or a major bloom, the consequences of which may be of considerable importance.

iv) Metals, such as deoxidized iron balls, can produce an exothermic chemical reaction in air that would be immediately stopped in water.

3.4. Edible oil transported in bulk

Vegetable oils are classified as Fp (Floating persistent) as their viscosity is > 10 cSt. According to the SEBC Code, they are included in the category Y of appendix II of MARPOL CAT (IMO, 2007). They were not considered as dangerous (MARPOL CAT , cat D, i.e. presenting a discernible risk for marine resources, human health and/or the other uses of the sea) in the marine environment, until January 2007, the date of entry into force of the new IBC code.

Since January 2007, they have been recognized as being in category Y, i.e. "*liquid substances which are deemed to present a hazard to either marine resources or human health or cause harm to amenities or other legitimate uses of the sea and therefore justify a limitation on the quality and quantity of the discharge into the marine environment*".

Some information of interest was collected on two incidents involving food products, namely:

- *Kimya*, 1991, Irish Sea, 1 500 t of sunflower oil.
- *Allegra,* 1997, the Channel, France, 900 t of palm kernel oil.

3.4.1. Kimya

The Kimya incident is an interesting example of a chemical polymerizing in seawater; the sunflower oil molecules polymerized under the action of the waves and, once on the beaches, polymerized oil and sand formed a waterproof aggregate imprisoning wildlife.

Near the wreck, mussels died by suffocation. Also, Mudge et al (1993) showed that certain molecules of the sunflower oil's fatty-acids (linoleic, oleic, palmitic) accumulated in the flesh of mussels in a 3 km radius around the wreck.

3.4.2. Allegra

On 1 October 1997, off the coast of Guernsey in the English Channel, the Liberian tanker the *Allegra* was involved in a collision and subsequently spilled 900 t of palm kernel oil. The oil solidified quickly forming an 800 m by 400 m slick. The slick continued to spread and broke up into a series of slicks extending over an area of 20 km long by 4 km wide. Part of the solidified oil came ashore on the Channel Islands and on the Coast of the French Cotentin, where it beached at the high water mark. It was made up of 5 to 50 cm margarine-like rubbery balls with a spongy yellow core and a whitish crust.

The slicks were tracked over the 2 days following the spill by French Customs and British Coastguard remote sensing aircraft, using airborne sideways looking airborne radars, housed in pods under the fuselage. Recovery tests were undertaken with surface trawl nets. This spill would have been of paramount importance had it occurred in summer, as one can easily imagine the social impact of wide scale landing of "margarine" balls on beaches at the height of the summer season.

The main difference from a crude oil spill was that palm oil is solid at room temperature. Three factors were investigated: slick drift, and physical and chemical changes to the oil and its dispersion pattern in the marine environment. The locations of the slicks, as indicated by the remote sensing aircraft, were compared to computer-generated predictions designed for oil spills. However, computer modelling did not appear to be suited to dealing with this kind of oil, due to its solid state.

Oil samples were collected both from the sea and from the beaches, in order to investigate the effect of water on the product. Upon investigation, no change in its physical properties was observed. Small scale testing was conducted at the Cedre in a bid to simulate the spill.

The oil solidified almost instantaneously into very small particles only a few millimetres in diameter, which later aggregated into "margarine" balls, 5 to 10 cm in diameter. Testing showed that the oil dispersed naturally in the water column which may well explain why a large quantity of the spilled oil seemed to have disappeared. A post-spill research programme subsequently elucidated the fact that the physical state of the oil is of crucial importance when a spill occurs. The drift of the slick, surface behaviour patterns and response equipment and methods are radically different for solid and liquid pollutants.

The example of the Allegra incident is a good illustration of the fate of vegetable oil at sea. There was no significant impact on wildlife. Twenty-six tonnes of solid pellets were collected from beaches by hand, a fast and at low cost option. On the whole, some 870 t of oil disappeared, constituting, to some extent, both a source of consumable lipids for the marine flora and fauna and a potential threat as the degradation. Palm kernel oil is likely to produce compounds such as alkanes, esters, aldehydes or alcohols (Hui, 1992), some of which are harmful for marine fauna, like pentane and hexanal (CDCP, 2002).

The very large quantity of oil not recovered remains unexplained. Degradation by bacteria is a possible assumption. Studies carried out in the laboratory on soybean oil and samples of palm kernel oil from the *Allegra* highlighted this bacteriological degradation. Marine bacteria preferentially break down polyunsaturated fatty-acids ($C_{18:2}$, linoleic acid, in both cases). The kinetics of degradation of the oleic acid ($C_{18:1}$) is slower. The bacteria first break down palmitic acid ($C_{16:0}$) with a shorter chain than the stearic acid ($C_{18:0}$), whose degradation starts later (Le Goff, 2002).

The same results were obtained in sea water by Hui (1992) in experiments on the degradation of vegetable oils in the atmosphere.

3.4.3. Main lessons

Considered together, these incidents show that:

i) Accidental release of edible oil in the open sea generates highly visible drifting slicks.

ii) Slicks drifting in high energy water bodies are quickly dispersed and have no measurable effect on the ecosystem.

iii) However, the same release in a shallow bay may result in the destruction of coastal habitats and hamper beach usage.

As a whole, none of the incidents studied involving edible oil were a source of a major environmental, human health or economic problem.

3.5. Edible solid sinkers in bulk: wheat, rice, etc.

Within the framework of the international marine pollution conventions, food products, such as wheat, corn and rice, are not regarded as marine pollutants. When an incident occurs involving a ship carrying such products, the pollution concern is initially centred on the fuel and oils of the vessel. Preventing fuel and oil from being released or, if released, from drifting on the sea surface and impacting fishing, fish farming and the coastline is the priority of the first response measures.

A food product is not seen as a pollutant. There is a general belief that it will be good food for marine life. It is only in the second phase that concern extends to the food product spilled, when it remains uneaten and begins rotting.

Some information of interest was collected on two incidents involving solid food products, namely the following:

- *Weisshorn*, 1992, stranded with a cargo of rice near the mouth of the Guadalquivir.
- Cargo vessel *Fenes*, 1996, stranded on Lavezzi islands, Corsica, France, with 2 700 t of wheat on board.

3.5.1. Weisshorn

On 27 February 1994, the cargo vessel *Weisshorn,* coming from Thailand with a full cargo of rice and bound for Sevilla, became stranded on a sandbank in the access channel to the Guadalquivir estuary. The ship could not be moved from its position. It was left spilling its cargo and was dismantled over time by winter storms. No monitoring of the possibility of organic pollution by rotting rice was undertaken.

3.5.2. Fenes

The *Fenes* incident shows that a massive discharge of cereals in a marine area will mostly remain in place, smothering the sessile fauna and marine flora of the zone, and will rot on site. The case did not prove to be as simple and inoffensive as first appeared, forcing response authorities to face far more complex challenges than they had originally imagined. Two months later, decomposition of organic matter appeared, resulting in an exothermic reaction, creating exceptionally favourable conditions for the development of sulphate-reducing micro flora. This micro flora contributed to the degradation of the organic matter on the site, with significant production of hydrogen sulphide (H_2S), a toxic gas, which forced the response personnel to don respiratory protection equipment.

The majority opinion is that cereals, such as rice, wheat, corn, are not sources of pollution for the population or the environment. But a massive discharge of cereals in a marine area remain will mostly in place, smothering the sessile fauna and marine flora of the zone, and rot on site, presenting particular challenges to responders. However, the particular case of the wheat carrier *Fenes*, stranded in a late 1996 storm on one of the Lavezzi islands (Bonifacio Strait, Corsica) is an example where pollution was generated not by the product spilled, but by its transformation through the rotting process.

3.5.3. Main lessons

These incidents show that:

i) While an accidental release of edible grain in the open sea and/or in high energy areas has no measurable effect, the same release in a shallow bay may result in the destruction of bottom flora and sessile fauna, buried under a thick coat of organic product.

ii) With time, an organic product in a thick layer on the sea bottom may rot and release H_2S, creating the need for an exclusion or protection area around the wreckage.

3.6. Non-edible solid ore in bulk: coal

Some information of interest was collected on two incidents involving coal transported in bulk:

- *Castillo de Salas,* 1986, Bay of Gijon, Spain, 100 000 t of coal.
- *Eurobulker IV,* 2000, San Pietro Channel, Italy, 14 000 t of coal.

3.6.1. Castillo de Salas

When the *Castillo de Salas* sank in a storm in 1986, while in the waiting area of Gijón Harbour, the fore part was towed away to be sunk in high seas, but the fore part remained stranded on a submerged rock half a mile off the San Lorenzo beach, the largest Gijon city beach. During the following months, San Lorenzo beach was regularly soiled by coal dust and pellets mixed with fuel. Although an impact study conducted by the Spanish Oceanographic Institute concluded that this particular type of coal was not dangerous to humans nor the environment, this repeated nuisance led the authorities in charge to contract the removal of the ship remains, except for the compartmented double bottom, which was left in place to become an artificial reef, after all accessible fuel was pumped out. This solved the coal pollution problem, but not that of fuel pollution. Sixteen years later, the double bottom began, once again, to release fuel. In the end, it had to be thoroughly cleaned, cut into pieces and removed. In this incident, the pollution due to coal was mostly visual, affecting an amenity beach, with no assessed consequences on local flora and fauna.

3.6.2. Eurobulker IV

The coal carrier *Eurobulker IV* sank in the San Pietro Channel (southern Sardinia), in 2000. The Channel is recognized as an ecologically rich area, with beds of *Posidonia oceanica.* These were not affected by chemical contamination of the water column, but mainly by mechanical phenomena (smothering of the vegetation, abrasion of the leaves, covering of the sediment) related to the coal. Chemical analyses of the heavy metal of the content of the coal were carried out. However, the wreck lay in a zone of chronic heavy metal contamination by industrial wastes and it proved impossible to determine the exact origin of the detected chemical compounds.

3.6.3 Main lessons

Considered together, these 2 incidents show that:

i) Spilled coal has no demonstrated toxic or coating effect on waterfowl and marine life, except when in a thick layer.

ii) Coal dust stranded on an amenity beach is unacceptable to the public, but pollution risks/response after a coal spill remain far less important than the risks and response related to the ship's bunkers.

3.7. HNS in bulk from oil distillation

Seven incidents involving HNS obtained through the cracking (=distillation) of crude oil and transported in bulk have, to some extent, been documented:

- *Brigitta Montanari,* 1984, Adriatic Sea, Yugoslavia, 1 300 t of vinyl chloride monomer.
- *Anna Broere*, 1988, North Sea, Netherlands, acrylonitrile.
- *Alessandro Primo*, 1991, Adriatic Sea, Italy, 3 013 t of 1,2-Dichloroethane and 549 t of acrylonitrile.
- *N°1 Chung Mu*, 1995, access to the port of Zhanjiang, South of China, Styrene monomer.
- *Ievoli Sun*, 2000, North of Batz Island, France, styrene, methyl-ethyl-ketone, isopropylic alcohol.
- *Bow Eagle*, 2002, off Sein Island, France, ethyl acetate and cyclohexane.
- *Bow Mariner,* 2004, Virginia, USA, ethanol.

3.7.1. Brigitta Montanari

The *Brigitta Montanari* was a chemical tanker transporting vinyl chloride monomer, or VCM (GE, MARPOL CAT , cat Y), when she sank in the Adriatic Sea in 1984, in 82 m of water. VCM is an extremely flammable gas, forming an explosive mixture with air. It is a carcinogenic substance. The assumption that the cargo tanks were not damaged made it possible, some three years later (in August 1987), to refloat the ship and to pump out the VCM. A leak of VCM was, however, detected at the beginning of the operations. Were there to have been a massive release of VCM, the refloating would have become very dangerous.

In order to prevent that risk, a hole was bored in the bridge, through which VCM was released on an estimated 3 t/day basis. A concentration of more than 5µg/l was measured in the water column up to 300 m from the wreck. Most of the chemicals solubilised quickly in the sea water. Following several days of release, the divers connected PVC tubes to the previously made holes and released VCM at the water surface, where it either dispersed in the atmosphere or burned. The ship was resunk to a depth of 30 m and the 700 t of product still on board was pumped out and transferred to another chemical tanker.

The biological monitoring of the benthic communities of the contaminated area started later (1987), including examination of histopathologies and biochemical tests. The results showed no acute toxicity on the organisms taken near the wreck.

3.7.2. Anna Broere

The *Anna Broere,* carrying acrylonitrile, sank in the North Sea at a depth of 30 m, 50 miles east of Yjmuiden (near Amsterdam) following a collision with a container ship. When released in the environment, acrylonitrile evaporates, producing a flammable and explosive cloud. In the event of fire, it produces phosgene, a highly toxic gas. The ship could not be left on site. It was refloated over the next 73 days, with only 25 of those suitable to carry out the work due to poor weather conditions.

The response operation was done properly and correctly. The costs were much greater than expected, but this was mostly due to the bad weather conditions. The 200 tonnes of acrylonitrile that leaked out did cause damage to marine biota, but with significantly less impact than anticipated. As the concentrations of the pollutant were continuously measured, no unnecessary risks were taken by rescue personnel.

3.7.3. Alessandro Primo

The *Alessandro Primo* sank to a depth of 108 m in the Adriatic Sea, 30 km of Molfetta (Italy) with 3 013 t of 1.2 dichloroethane (SD, MARPOL CAT cat Y) and 549 t of acrylonitrile (MARPOL CAT , cat Y) onboard. The position of the wreck made it non-refloatable. Five days the sinking, acrylonitrile concentration rose to 2.7 ppm, at a depth of 500m directly above the wreck. A rapid intervention was needed to stop, or at least reduce, the diffusion of the substance.

This operation was carried out by an underwater team of divers and the residual product remaining in the tank was recovered. The acrylonitrile leak was stopped by fitting special joints on the valves of the affected tank and by coating the supports with a special epoxy resin. Once the urgent matter had been dealt with, a cargo recovery project was set up and implemented by expert salvors. Some 900 m^3 of acrylonitrile and sea water were recovered, along with 2 750 t of dichloroethane.

At the time, the operation constituted the first of its kind worldwide.

3.7.4. N°1 Chung Mu

On 9 March 1995, the *Chung Mu N°1*, a chemical tanker built in 1994 and loaded with styrene monomer, suffered a collision with the cargo boat *Chon Stone N°1*, in the access channel to Zhanjiang's Harbour (Southern China). When the ships collided, 230 t of styrene monomer were spilled at sea. The breach was immediately sealed by divers using wooden plugs; however it is likely that some styrene continued to gradually leak out. When immediate human health risks had been eliminated (styrene vapours are neurotoxic), the risks to the sea environment could be characterized by a change in the organoleptic characteristics of the flesh of fish and shellfish. Short styrene monomers are moderately toxic for aquatic life and bio-accumulate only to a small extent in the environment.

The *Chung Mu* was immobilized by the authorities and was ordered to provide a significant bank guarantee because of the potential damage to aquatic species. The P&I Club insurers contracted Cedre to carry out two missions in China, in order to assess the damage the living resources. This estimation allowed the P&I Club to come to an agreement with the authorities on the payment of a reasonable bank guarantee and the eventual release of the ship.

3.7.5. Ievoli Sun

In 2000, the chemical tanker *Ievoli Sun* sank to the depth of 70 m in the north of Casquets, France, while in tow to a port of refuge, with 6 000 t of chemicals on board. The crew was evacuated in time. The cargo consisted of styrene (4 000 t, FE, MARPOL CAT cat Y), methyl ethyl ketone (MEK, 1 000 t, DE, MARPOL CAT cat Z) and the isopropanol (IPA, 1 000 t, D, MARPOL CAT cat Z). There were also 160 t of fuel (IFO 180) and 40 t of diesel oil on board. The behaviour of these chemicals in the prevailing conditions around the wreck was unknown. Experiments were quickly implemented at Cedre to determine the behaviour of the products and their effect on marine species. These studies made it possible to identify the risk of styrene polymerisation, to evaluate the feasibility of a controlled release of the methyl ethyl ketone (MEK) and isopropyl alcohol (IPA), and to study the exposure of marine organisms to styrene.

This illustrated the need for to have a good knowledge of the characteristics and behaviour in sea water of the chemicals transported in order to intervene effectively and safely in the event of an accident. In this case, it was agreed between the French and British authorities and the shipowner that the shipowner would pump the styrene and fuel, and release the MEK and IPA, under the control of the Authorities. The operations began on 12 April 2001. They allowed the recovery of 3 012 m³ of styrene and heavy fuel remaining in the ship. Work was completed on 31 May, after a 51-day response carried out entirely by ROVs, in challenging sea conditions and in strong currents.

3.7.6. Bow Eagle

In 2002, the Norwegian chemical tanker *Bow Eagle*, transporting 510 t of soya lecithin (Fp, MARPOL CAT cat Y), 1 652 t of sunflower oil (Fp, MARPOL CAT cat Y), 1 050 t of MEK (DE, MARPOL CAT cat Z) 4 750 t of cyclohexane (E, MARPOL CAT cat Y) 3108 t of toluene (MARPOL CAT cat Y), 500 t of vegetable oil FA201 (Fp, MARPOL CAT cat Y) 2 100 t of ethyl acetate (DE, MARPOL CAT cat Z), 4 725 t of benzene (E, MARPOL CAT cat Y), 5 250 t of ethanol (D, MARPOL CAT cat Z), en route to Rotterdam, reported a breach on its port side to the Maritime Rescue Coordination Centre (MRCC) of Jobourg, France, following a collision with a trawler in the middle of the night. The trawler sank quickly and 4 of the 9 crew members died. Two hundred tonnes of ethyl acetate leaked from the tanker before the chemical could be transferred to another tank and the breach could be sealed.

One can only imagine the effect on the coast or in a harbour entry from a wreck involving this cocktail of 9 different food products and chemicals such as that contained on this vessel, two of which are considered to be severe pollutants (benzene, toluene). Luckily, there no notable pollution was identified.

3.7.7. Bow Mariner

The *Bow Mariner* sank quickly 50 miles off Virginia (USA) to a depth of 80 m, after a fire on the bridge and several severe explosions. It was transporting 11 000 t of ethanol (D, MARPOL CAT cat Z). Eighteen of the 27 crew members disappeared during the shipwreck and only 3 bodies were recovered. Given that ethanol is completely soluble in water, no containment or recovery was attempted nor was any impact study implemented. The only recognized pollution was that produced by the 720 t of IFO 380 and 166 t of MDO transported by the vessel for its use.

3.7.8. Samho Brother

On 10 October 2005, the chemical tannker *Samho Brother*, registered in South Korea, capsized after colliding with the Nigerian cargo ship the TS *Hong Kong*, off the Northwestern coast of Taiwan, China, sinking in 70 m of water, with a cargo of 3,100 t of benzene and bunkers of 85 t of fuel and 16 t of diesel. The 14 crew members were successfully rescued by the Taiwanese Coast Guard. There was no evidence of a benzene and/or hydrocarbon leak at the surface of the sea.

Water and air samples were collected and analysed daily. Authorities demanded that the ship owner remove the benzene, fuel and hydrocarbons. The shipowner did not comply and, two years later, it was decided that the ship should be detonated. After looking at various explosives options, to either placed by divers or delivered via torpedos, shot from a short distance, bombing was identified as the preferred method.

On 27 October 2007, an Air Force F16 carrying 4 bombs, made two attempts to explode the shipwreck. Twelve boats and 10 oil recovery vessels were standing by in the surrounding 10 nautical mile area to deal with emergencies. Two more explosion attempts were made by army helicopters. In spite of these efforts, the *Samho Brother* suffered only damaged to the hull of the bow. No benzene was detected in the air or water, nor at the shore.

3.7.9. Main lessons

Considered together, these incidents show that:

i) A number of spilled oil distillate chemicals are not only recognized as carcinogenic nor as marine pollutants, but can evaporate to form a moderately toxic gas, often capable of producing an flammable and/or explosive mix in air.

ii) Most of these chemicals have no demonstrated toxic or coating effect on waterfowl and marine life, except when in a thick layer.

iii) With some, the risks of fire and explosion onboard, or of a toxic cloud upwind of the ship, along with crude oil in particular conditions, are major risks.

iv) Little is known about the actual marine pollution effect of most of these substances, in practice. The general rule is, to the extent possible, to recover them and to voluntarily release the smallest possible quantity.

v) For ships carrying different products in different tanks, those products in the above category and that are soluble in seawater are customarily released at sea in controlled conditions, with some minor and temporary pollution deemed acceptable, while responders focus on the more dangerous chemicals and products.

vi) Fuel and lubrication oils onboard always receive the same attention as the most dangerous chemical in the cargo. Whenever possible, they are recovered.

4 RETURN OF EXPERIENCE

4.1 Danger in air

4.1.1. Explosion

The *Grandcamp* and *Ocean Liberty* incidents, with respective tolls of 600 and 26 human lives plus 3 000 and several hundred injured, are the two most obvious demonstrations that fire in a chemical cargo can generate a massive explosion with dramatic consequences, at a distance of 1 km or more from the source.

The *Adamandas* is an example of a drastic response to a risk of explosion in a harbour, i.e. the towing of the ship and voluntary sinking together with its cargo in high seas. However, such extreme situations represent only three out of 45 incidents.

Human casualties and evacuations have also taken place in a few oil spill incidents. The human casualties' record is held by the collision, on 10 April 1991, of the *Moby Prince* ferry with the *Agip Abruzzo* oil tanker*,* at anchor outside of Livorno Harbour. Hitting the tanker by the bow, the ferry caused a breach in the wall of a cargo tank which was engulfed in a ball of fire. One hundred and forty of the 141 passengers and crew on board the ferry died. Not all the deaths were caused by the fire. A large number of the victims died as result of inhalation of toxic fumes and smoke, while gathered in the main internal room of the ship. There were no casualties onboard the tanker.

Second, in terms of casualties, comes the explosion of the oil tanker *Bételgeuse* at Bantry Bay Terminal (Ireland) on 8 January 1979, resulting in 50 lives lost, mostly crew members and family, and 8 terminal workers.

The largest evacuation operation involving a tanker on fire, with a risk of explosion, took place in La Coruna, Spain, in December 1992, when several hundred inhabitants of the neighbouring homes were affected by the fire and smoke from the oil tanker *Aegean Sea*'s burning cargo. The vessel had missed the port entrance and broke up on the rocks of the Roman tower point.

On the whole, Ammonium nitrate involved in a fire has demonstrated a higher killing and injury capacity than oil. It can therefore be said that there are HNS that are more dangerous than oil, in terms of danger of fire and explosion.

4.1.2. Toxic cloud

The *Multitank Ascania*, *Ariadne* and *Cason* incidents are demonstrations of evacuations of coastal populations implemented due to the threat of a toxic cloud, ranging from 200 people for the *Multitank Ascania,* to 15 000 evacuated overnight in the case of the *Cason*. The *Ievoli Sun* is an example of air pollution monitoring undertaken to protect the public and with a view to being prepared for an emergency evacuation.

There are many mentions of local citizens complaining of dizziness and headache after smelling crude oil vapors in spill response reports, at a significant distances from the spill site (and up to 30 km in the case of the *Amoco Cadiz*). There are also frequent interrogations, in reports of spill response investigation commissions, on the potential long-term effects of human exposure to oil vapours. But, for the time being, oil spills are not considered as sources of dangerous vapour clouds and oil pollution contingency plans do not include evacuation plans.

However, the 14 August 2003, spill of the *Tasman Spirit* oil tanker, stranded at the entrance channel to Karachi Harbour (Pakistan), has generated many claims of throat, respiratory and digestive problems, including vomiting and diarrhoea, related to breathing of oil vapours. Children were reportedly particularly affected. This may be the first oil pollution incident ever to generate investigation into the actual danger of breathing oil vapours.

However, for the time being, the danger of a toxic cloud is only of concern for chemical spills responders.

4.3. Danger in water

4.3.1. Coastal waters

The *Lindenbank*, the *Kimya*, the *Allegra*, the *Champion Trader,* the *Castillo de Salas* and the *Eurobulker IV* spills are examples of coastline pollution from a floating chemical or from coal dust.

The *Sherbro* and the *Napoli* incidents are examples of the coastline being affected by the stranding of thousands of sealed plastic bags containing a pollutant (pesticides) or manufactured food products (chocolate biscuits).

None of these incidents generated damages nor response needs comparable to those of a major oil spill. As a consequence, it can be said that the danger of coastline pollution is a far greater concern for oil spills than in HNS spills.

4.3.2. Open seas

The *Brigitta Montanari*, the *Alessandro Primo*, the *Anna Broere*, the *Cynthia M,* the *Bow Eagle* and the *Fenes* all generated some marine pollution. However, the pollution remained localized and it was not considered of such importance as to justify an impact study comparable to those implemented following an oil spill. As a consequence, it can be concluded that the danger of marine pollution is a far greater concern for oil spills than in HNS spills.

4.4. Response tips

Response measures undertaken obviously differ according to the conditions of the incident, the spilled chemical and the risks involved. It is, however, possible to show a certain number of significant and/or specific elements in chemical incidents at sea.

4.4.1. Information on the ship's cargo

Information on the cargo used for the evaluation of chemical risks is of primary importance before any operational decision is taken, especially when the ship is carrying a wide variety of chemical products in packaged form. Information concerning the cargo is not always immediately available, as shown in the case of the *Cason* and, to a lesser extent, in the *Ever Decent* and the *Napoli* incidents. The method of loading containers is also to be taken into account, although the rules are not always respected (*Rosa M*).

The evaluation of the chemical risk involved is an essential element which can rely on national chemical emergency centres (British for the *Multitank Ascania*, French and British for the *Ievoli Sun* and *Napoli*), on co-operation with the chemical industry (*Sherbro*, *Sindbad*) as well as on international cooperation (*Princess of the Stars*). The value of a specialised intervention team to deal with chemical risks was underlined in the UK by the *Multitank Ascania* incident and was recommended by the French inquiry commission after the *Rosa M* incident.

4.4.2. Ship crew response

Initial response actions can be carried out by the ship's crew, whose effectiveness depends on the professional competence of the sailors and officers. It may be excellent, as seen during the *Multitank Ascania* incident before the ship was abandoned, present, as seen in the *Ievoli Sun* incident, or disastrous, as seen in the unloading of the sulphuric acid from the *Bahamas*.

External response assistance is, nevertheless, needed. Several incidents (*Multitank Ascania*; *Rosa M*) show the importance of the actions undertaken during emergency towing. Delays in the transportation of response resources and bad weather conditions can have extremely serious effects on the efficiency of planned operations (*Cason*). In a port, the facilities available to lighter a chemical tanker in difficulty, whether onshore or on-board, are not always anticipated, as shown in the transfer of a cargo of sulphuric acid from the *Bahamas*.

4.4.3. Response tools

Specific or non-specific tools used in chemical incidents are also mentioned. Different ways of dispersing a chemical pollutant in water and in air are used to evaluate risks to human health and impacts on the marine environment (*Anna Broere*; *Alessandro Primo*), as well as the different ways in which floating objects or products drift (*Sherbro*; *Allegra*).

Remote sensors, normally used for the detection of oil slicks, are also effective when monitoring drifts of vegetable oil (*Allegra)*. An evaluation of the state of the shipwreck (*Alessandro Primo*) or a search for spilled products, such as cylinders of chlorine (*Sinbad*), can be conducted by underwater remote control vehicles or by sonar.

Fires on board chemical tankers require specific safety measures, taking into account the risk of explosion. A remote evaluation of hot points by infrared camera was used during the incident of the *Multitank Ascania*.

4.4.4. Response personnel

The toxic effects of a chemical can be extremely harmful to response personnel during the response phase (wheat fermentation and the production of hydrogen sulphide during the recovery operation of the cargo of the *Fenes*) or in the long term and may involve medical monitoring over several years (exposure of the crew of the *Ootzee* to toxic fumes of epichlorhydrin).

Response on-board a ship in difficulty involves a large quantity of often very specialised equipment. The environment is highly unsafe, necessitating protective clothing, monitoring of any contamination, emergency procedures and a means of evacuation (*Anna Broere*, *Alessandro Primo, Ievoli Sun*).

The efficiency of the response action depends on the competence of each member of the personnel involved and on the co-ordination of operators. Experience gained from the response on the wrecked *Anna Broere* to recover acrylonitrile proved useful some three years later for a similar operation on the wrecked *Alessandro Primo*. Response to the *Multitank Ascania* incident was made much easier by a pollution response exercise on chemical risks that had been conducted two weeks earlier.

4.4.5. Communication

Communication is extremely important during chemical incidents. This applies firstly on an operational level, between responders (the lack of dialogue between the captain of the *Bahamas* and the Brazilian port authorities had a disastrous effect).

It also applies to communication with the public, always very anxious about chemical risks, as shown by the incidents of the *Cason* and to a lesser extent of the *Rosa M*.

This particularly applies to environmental impact, necessitating the monitoring of the quality of the environment and a study on the effects of the pollutant on flora and fauna. Such monitoring is equally necessary for substances considered as non-pollutants such as vegetable oils (*Kimya*). Indirect effects on the environment must also be considered as in the remobilization of toxic metals absorbed in sediments, due to a decrease in pH caused by an acid spill (*Bahamas*), or the production of hydrogen sulphide as a consequence of wheat fermentation by sulphate-reducing bacteria (*Fenes*).

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