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The *Herald of Free Enterprise* Accident: the Environmental Perspective*

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ABSTRACT

Five lorries shipped on board the ferry Herald of Free Enterprise *that sank off the Belgian coast in 1987 contained together over 100 different chemicals. During the intricate salvage operation that followed the tragedy, the environmental protection activities met with technical, scientific, legal and organizational difficulties. An assessment of the exact nature, harmfulness, and situation of the cargo had to be done while access to the casualty was limited, and information insufficient. The risks for the personnel and for the marine environment were evaluated using both simplified scenarios and sophisticated computer simulations. Environmental contamination was monitored and protective counterpollution measures were implemented under supervision of the authorities. Although more than half the dangerous cargo was lost, environmental damage was kept to a minimum.*

1 INTRODUCTION

On March 6, 1987, the British car ferry *Herald of Free Enterprise* (HFE) of Townsend Thoresen sank off the Belgian harbour of Zeebrugge causing

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the loss of about 200 lives. The ship had heeled over just a few minutes after leaving port and was lying on its side in a depth of 10 m. After the initial rescue operation, which was one of the most dramatic in history, the recovery of vessel and cargo was made both urgent and delicate by the presence on board of five lorries carrying various dangerous substances. While the owner of the ferry retained his rights and remained responsible for salvaging the ship, the Belgian State assumed overall control of the operations. Refloating the ferry took 52 days and represented a major technical achievement. All work was interrupted six times by bad weather, sometimes for several days. The salvage vessels succeeded in uprighting the ship on April 7, holding her dynamically in position, then had to let her go as a storm was building up. The ship was uprighted again later, holes were plugged, water was pumped out, and the HFE was carried back into the harbour on April 27 without any further loss of life, or environmental disaster.

Like the salvage operation itself, the counterpollution operation presented pitfalls and difficulties that make the accident exemplary. In the context of intensifying maritime transport of chemicals and chemical wastes, growing awareness of widespread environmental deterioration, and growing publicity given by the media to threats of marine pollution, public authorities have a duty to react responsibly, decidedly and efficiently whenever a ship casualty carries a danger of accidental marine pollution. As soon as the human aspect has been dealt with, the environmental dimension requires their full attention. The problem is by no means an easy one. To an administration responsible for environmental protection it looks like this: how do we (1) evaluate the harmfulness of the cargo and the danger it represents for people and the environment; (2) monitor cargo and actual pollution; (3) take protective measures to reduce potential impact; (4) integrate those activities in the overall response (rescue operation, salvage, recovery of property, judicial enquiry)? Each of these aspects has inherent difficulties, which the HFE operation brought to light. This paper examines what these difficulties were and how they were overcome. An attempt is made at deriving some general lessons from the experience.

2 BASE OF THE INFORMATION

In the Belgian organization for dealing with disasters in the coastal zone, the overall coordinator is the Province Governor of West-Flanders. The Ministry of Public Health and Environment is the department responsible for national environmental policy and for environmental management of the sea. Within the Ministry it is the Management Unit of the North Sea and Scheldt Estuary Mathematical Models (MUMM) that deals with marine affairs. In particular, MUMM is responsible for the environmental monitoring of the sea; it co-ordinates scientific evaluations in case of pollution, and it advises the overall command on counterpollution measures. The present description of the HFE operation is based on the information that was made available to the authorities during the operation. More specifically, it draws on MUMM's records and on the experience of the Unit's personnel engaged in the operation. General accounts of the accident and salvage operation have been published (Vandenbussche, 1987) and lie beyond the subject of this paper.

3 THE FACTS

3.1 Nature of the dangerous cargo

A complete inventory of the dangerous substances carried by the HFE is given in Table 1. A first list of dangerous goods was made available to the authorities 12 h after the accident. That list was incomplete and inaccurate. For example, only 'cyanide-containing substances' were reported from lorry B, lorry C was not listed, and the load in lorry E was described as 'soluble lead compounds', quite an incorrect description since tribasic lead sulfate is very insoluble in water. It was feared initially that large quantities of tetraethyl lead could be on board. Also, the exact amount of cyanide — in reality less than 750 g — remained unclear for some time. This of course together with the difficulty of identifying recovered packages that had deteriorated in seawater, later led to considerable confusion.

The full manifest with a summary description of the entire cargo was obtained 73 h after the disaster. Out of the five lorries with dangerous goods it turned out, however, that three had way-bills lacking essential information. For lorry B the description was so inaccurate that even after additional information had been supplied by the shipper it remained impossible to make out what precisely was on board. Table 1 therefore combines information that was communicated by the shipping companies with the final inventory of recovered cargo drawn by the authorities. A large amount of work was required to verify the nature and the precise state (solid, liquid, solution, etc.) of the substances, their location on board, the type of package or container and its likely behavior in water, and how each package could be identified.

TABLE 1
The HFE Accident: Inventory of the Dangerous Cargo Based on the Documents Made Available to the Belgian Authorities and on the Salvaged Cargo

Lorry	*Substance*	*Total quantity (kg)*	*Packaging*		*Recovered*
			Type	*Number*	
A	TDI[a]	5 450	218 kg drums	25	7 drums
B	Cyanide-containing wastes (<200 ppm CN)	270 (<540 g CN)	200 liter drums 120 liter drums	2 3	1 drum?
	Cyanide-containing hardening salts	130 (<208 g CN)	200 liter drums	1	?
	CN-containing liquid		30 liter drum	?	1 drum
	Chlorine trifluoride + fluorine perchlorate	260	30 liter gas tanks 10 liter gas tanks	6 2	4 (some empty)
	12 chemicals[b] in small gas bottles		0·1, 0·25 and 0·5 liter bottles	21	~10
	Chemicals[c] in 0·1 to	2 710	12 liter buckets	150	~80

	2 liter bottles packed in buckets		25 and 30 liter buckets	30	~15 buckets
	Paint wastes	7 780	200 liter drums	40	30 drums
C	Hydroquinone	5 000	25 kg sacks[d]	200	none
D	Leatherpaint	3 500	100 kg drums	35	26 drums
	Leatherpaint with MET[e]	1 500	100 kg drums	15	13 drums
	Leatherpaint diluent	50	10 kg drums	5	3 drums
E	Tribasic lead sulfate (88% in granules)	19 925	25 kg paper sacks[f]	797	~all

[a]Toluene diisocyanate in solution.
[b]Hydrogen bromide (7 half-liter bottles), chlorine (3 half-liter), ethylene (2 half-liter), CO_2, CO, HCl, fluoromethane, ether, chlorotrifluoromethane, methylamine, tetrafluoroborate, antimony pentafluoride (shipped together with the gas tanks in three 200 liter drums; total reported weight was 260 kg).
[c]Fifty-two reported and several tens of unreported chemicals including Br, Na, K, P, aniline, acrylonitrile, acids, etc. (shipped on 12 pallets in one aluminum container).
[d]Paper sacks with polyethylene layers.
[e]Leatherpaint agent containing methoxyethanoltoluene.
[f]Twenty pallets of 40 sacks packed in polyethylene sheets.

3.2 Assessment of the harmfulness of the dangerous goods

In the first hours of the incident some basic information on the properties of the reported chemicals was supplied by the Information Center on Dangerous Substances of the Ministry of Interior (BIG). Thereafter, a number of sources were consulted in addition to the standard IMDG code and GESAMP hazard profiles of the International Maritime Organization. The most useful were found to be the works of Verschueren (1983), unfortunately limited to organic substances, and Sax (1984). These books give information on the physical and chemical properties of the substances and they report available toxicity data, including aquatic toxicities. A first complete evaluation of dangers for people and for the environment connected with the cargo was presented by MUMM on March 8. It was supplemented by the Toxicity Department of the Institute of Hygiene and Epidemiology (IHE) in Brussels, using among other sources the Institute's ISOTOX data base (IHE, 1987). Table 2 gives the concentrations at which the most worrisome of the substances could be considered hazardous to marine life.

TABLE 2
The HFE Accident: Potential Environmental Hazard Presented by the Dangerous Cargo (All concentrations in mg/liter (nd = not detectable). Toxicity data from standard reference works and from review by the Institute of Hygiene and Epidemiology. Measured concentrations in seawater as reported by the various State laboratories participating in the monitoring.)

Substance	*Concentrations hazardous to marine life*		*Concentrations measured in/around casualty*	
	Tolerance limit (sensitive species)	*Lethal to some fish species*	*Minimum*	*Maximum*
TDI[a]	1–10	164	nd	nd
Cyanides (CN)	<10	0·05	<0·005	<0·005
Hydroquinone[b]	0·05	0·044[e]	<0·5	1·8
Toluene[c]	10–100	24	<0·005	0·040
Lead[d]	0·22[f]	500	<0·001	0·076

[a]Including toluene diisocyanate (detection limit 0·001 mg/liter) and toluene diamine (detection limit 0·020 mg/liter).
[b]Measured as hydroquinone + quinone + total phenols.
[c]Taken as representative of unspecified solvents reported in the cargo.
[d]Total lead in water after removing oily phase in oil-contaminated samples.
[e]LC50 (96 h) for larval fish. Sensitive adult fish reported to be affected at 0·1 mg/liter.
[f]LC50 (28 days) for rainbow trout.

It remained difficult to properly assess the environmental hazard the dangerous cargo constituted, because so little is known of the toxicity of most chemicals to marine organisms. An important factor to be considered was the fact that once released into the marine environment many chemicals react or degrade, so that the reaction products too require attention. In the present case, substances such as quinone, the degradation product of hydroquinone, and toluene diamine, the hydrolysis product of toluene diisocyanate (TDI), were found to be no more toxic than the original chemical. Finally, an assessment of the actual danger could only be arrived at by evaluating the likely behavior of the goods after their release at sea, and by monitoring the environment to detect the presence of the chemicals. These two activities are described below.

3.3 Prediction of the behavior of cargo lost at sea

As soon as the nature of the cargo was known a major concern of MUMM was to evaluate how grave the situation would be if the toxic substances were spilled, and what measures could be taken to minimize impact and maximize the chances of recovery. Lorry A had fallen overboard as the ferry heeled over. It had been pulled out of the water empty: the drums of TDI were therefore lost at sea. Lorry B was visible on B deck at low tide and only some of its 11 tonne chemical cargo had been released. Lorry C with 5 tonnes of hydroquinone was deep in the E deck garage and could not be controlled before the ferry was uprighted. Lorry D had also fallen overboard and only the cab had been recovered. Drums of leatherpaint were adrift, but some had quickly been picked up. Lorry E was deep in the hold on B deck and not visible: the condition of the 20 tonnes of lead sulfate was unknown.

Firstly, a simplified scenario was used to calculate quickly the extent of the sea area in which concentrations considered lethal for marine organisms could be reached. This scenario assumed immediate and uniform dispersion of the quantity of each chemical that remained unaccounted for over an average depth of 10 m. The toxicities in Table 2 were used as guides in these estimates. Except for the 5 tonnes of hydroquinone none of the dangerous substances could cause real problems beyond 165 m from the source. The greatest risk thus came from the hazard drums, tanks, buckets and other containers constituted for the people who would manipulate them. It was therefore important to try and locate those objects, or predict where they could go. For the hydroquinone, the calculation indicated the possibility of a deadly cloud in the water column extending more than 2 km from the source, and therefore more precise risk evaluations were in order.

Hydroquinone is not a very dangerous product for man, but it can be extremely harmful to aquatic organisms. Using the dispersion model MU-DISPER, MUMM ran a series of mathematical simulations on a computer in order to study the fate of the substance (MUMM, 1987). The results are reproduced in Table 3. A standard run studied the effect of the tide on the extent of the contamination and showed that the affected water mass was largest for a spill starting during flood. The isoline corresponding to the LC50 for larval fish contained an area of 7 km^2. This was less than the crude calculation had suggested, but still significant. A real-time simulation using the actual meteorological forecast and wind forcing on marine currents was run on April 7 when the ferry was uprighted, because it was feared that the cargo would shift and cause a spillage. It turned out, however, that by that time the entire load of hydroquinone had dissolved away unnoticed, probably during the storms that had affected the area in the previous 2 weeks.

Since the casualty was also loosing oil through vent pipes, an oil-fate model was run to anticipate the drift of possible oil slicks (MUMM, 1987). An attempt was made at adapting the model in order to simulate the drift of floating drums. The model evidenced the dramatic effect of wind on

TABLE 3

The HFE Accident: Predicted Extent of Contamination of the Sea by 5 tonnes of Hydroquinone Released from the Casualty over a Period of 6 h (The MU-DISPER computer model was used in a standard situation to examine the effect of the tide, and in real time on April 7 during the uprighting operation.)

Time spill begins	*Maximum extent of the 0·050 mg/liter isoline (km^2)*	*Highest concentration predicted (mg/liter)*	*Time of the highest concentration (hours after begin of spill)*
Standard run[a]			
High tide	4·8	0·300	10
Ebb	3·6	0·247	10
Low tide	5·4	0·200	4
Flood	7·0	0·135	2
April 7			
06:00 UT	~5·0	0·233	11

[a]Using the M2 and S2 tide components in spring-tide regime.

the predicted trajectories, but it was not felt to be sufficiently reliable to be of much use. The difficulty lay in the uncertainty about the portions of the objects which would emerge and remain immersed, and the geometry of each. No model was available to simulate the behavior of drums lying on the seabed. To gain some insight on the fate of the TDI drums Townsend Thoresen had a dummy drum equipped with a transmitter and released where the real drums had been lost, but currents in the area vary much with weather and tide, and the tracking experiment produced little usable results.

3.4 Environmental monitoring of the casualty

3.4.1 Objectives and organization of the monitoring

The environmental monitoring pursued two main objectives: to detect the presence of dangerous substances in the air or water inside the wrecked vessel in order to control the safety of personnel involved in the operation, and to assess the extent and impact of a spillage in the surrounding marine environment if one occurred. Safety inside the casualty was the concern of both the salvage company and the authorities, the latter having to conduct the judicial inquiry on board and to recover the remains of the victims. Air and water samples were therefore taken by both concerns and analyzed separately. The State oceanographic vessel *Belgica* provided a platform for on-site monitoring, and a container-laboratory was installed in Zeebrugge harbour. Gas measurements (CN detection and explosimetry) were made inside the casualty by personnel of the Air Pollution Section of the IHE. The quantity of cyanide in the cargo was small, but because of the presence (actually prohibited) of unidentified acids on the same lorry, the formation of deadly cyanhydric acid could not be excluded. Cyanides in water were analyzed on board the *Belgica* by IHE personnel and by Navy personnel under MUMM's control. The hydroquinone was measured in the container by IHE personnel. Samples were dispatched every day to three laboratories of the Ministry of Agriculture and to the IHE's Water Pollution Section for confirmation of the field measurements and further analyses.

3.4.2 Methods of analysis

Cyanides in water were determined by colorimetry with pyridine-pyrazolone on a Technicon autoanalyzer using distillation. TDI and its hydrolysis product, toluene diamine, were determined by gas chromatography. Toluene, chosen as a typical toxic solvent likely to appear in paint and other organic products, was determined by gas chromatography coupled with mass spectrometry in order to eliminate the masking effect of oil. Hydroquinone was measured together with its degradation product — quinone — and total phenols by colorimetry with 4-amino-antipyrine in ammonia buffer on the autoanalyzer. Lead was determined by atomic absorption, after occasional separation of the organic fraction from the inorganic one by extraction.

3.4.3 Sampling strategy

Sampling was often made difficult and even dangerous by the rough sea state and instability of the wreck. When boarding the casualty was impossible, seawater was sampled downstream at a safe distance. It was realized that any spilled substance would disperse so quickly that detection in the surrounding water would be impossible unless the spill was a massive one. This represented a major limitation for the monitoring strategy. To overcome this difficulty, marine organisms were monitored to see if a slow, unnoticeable leakage had caused bio-accumulation, and sediments were analyzed to find out if lead particles had escaped and spread around the vessel. Neither were found to be contaminated (Baeteman *et al.*, 1987).

3.4.4 Results of the water analyses

The results of the water analyses are summarized in Table 2. All samples were below the detection limit for cyanides and TDI. Total lead remained low, a maximum of 0·17 mg/liter being recorded when suspended and oily matters in the water sample were included in the measurement. Solvents were detected occasionally, registering a maximum of 0·04 mg/liter of toluene, well below the toxicity limit. Hydroquinone around the casualty remained below the detection limit at all times, but one single seawater sample taken on E deck on 11 April contained 1·8 mg/liter of that substance. E deck had in fact been visited on 8 April at low tide while the ferry was held upright by the salvage vessels. Lorry C had been inspected on that occasion and found totally empty, no trace of the sacks of hydroquinone being visible. The 11 April sample indicated some residual contamination of the wreck. It is likely that the hydroquinone had dissolved away during stormy weather without being picked up in the scanty monitoring the sea state had permitted. Indeed, it can be seen from Table 3 that the highest concentration predicted in case of spillage was below the detection limit (0·5 ml/liter) of the only field method that could practically be implemented. The detection limit also lay one order of magnitude higher than the toxicity threshold of the substance, which made the monitoring useful for warning purposes, but not for correct impact assessment.

3.5 Protective measures

A number of measures were decided in order to mitigate pollution effects. They included arrangements for oil containment and recovery, recovery of the packaged goods lost at sea and containment of the remaining cargo within the casualty, and attempts at locating and securing the dangerous goods on board. A keep-off zone for ships and aircraft was imposed by the State to protect the operation. The position of the authorities was that first-line protective measures were the responsibility of the shipowner and needed to satisfy the requirements laid down by the administration. The State insured a second line of defense by keeping vessels and equipment on stand-by, by supervising the operation, and by assisting in the search and recovery of lost cargo.

Absorbent material in 4 m boom sections was laid inside the ferry to retain leaking fuel. A net was fastened to the structure across the gaping opening of the open garage to prevent parcels and wrecks from escaping. A debris-retention net and an oil boom were deployed downstream of the casualty during the uprighting operation in order to intercept oil and floating objects. Very little oil escaped from the ship and in fact none was recovered at sea. No oil dispersants were used. Little could be done to remove the cargo from the ferry before it had been refloated and towed back into the harbour: only a few gas cylinders were located and removed while the vessel was at sea.

All vessels on the scene participated in the recovery of floating objects. Navy mine hunters and salvage tugs did the search for sunken objects, but in spite of an intensive survey of the Zeebrugge ship channel and the Wielingen area only seven of the 25 TDI drums were recovered. One major difficulty was to sort out the various items among the recovered cargo and to recognize those containing harmful products. Labels peel off and drum markings quickly become obliterated in seawater. A full and precise description of the appearance of both the dangerous and the harmless packages would have been useful, but in many cases it was not available. It required a considerable amount of time and organizing to keep an accurate inventory of the recovered cargo and to verify the contents of suspicious containers. Yet it was essential to keep an updated inventory of the dangerous substances in order to correctly assess the residual danger at sea. A complete list of the dangerous goods picked up at sea or eventually removed from the casualty is given in Table 1. It can be seen that more than half of the goods known to have been shipped on board the HFE remained missing.

3.6 Integration of these activities in the operation

The integration of counterpollution activities in the salvage operation met at first with organizational and administrative difficulties that compounded the technical ones. They were due to the variety of simultaneous operations requiring coordination, to the conflicting interests of the State and the shipowner, and to a lack of correct understanding of the environmental implications of the situation by some of the parties involved.

For the owner of the HFE, the main concern was the salvage of the vessel in the shortest possible time and at the least cost. The salvage company's interest was to use simple, efficient refloating techniques with as little outside interference as possible. For the authorities the concerns were humanitarian, judicial, nautical (freeing of the waterway) and environmental. Decisions were taken in a coordination committee where all the parties involved were represented. Thus, the work of the salvage company was coordinated with the collecting of the bodily remains of the victims, the judicial inquiry on board (nothing could be disturbed before inspection by the judiciary) and ashore (by court order the recovered chemicals were held in custody), the search for, identification and recovery of the dangerous cargo, the environmental monitoring in and out of the casualty, and the protective measures against pollution. At each step of the operation an agreement had to be reached on priorities, communications, and ways of making these activities compatible.

As soon as the initial rescue operation was over and the presence of the dangerous cargo was known, the authorities announced their intention to set requirements in relation to counterpollution measures and to carry out a continuous survey of water quality. Immediately, the shipowner went to court against the State, out of fear that the proposed measures could interfere with the salvage of the ship. The court appointed an independent expert and instructed him to reconcile points of view. All decisions relating to environmental protection were thereafter made under court supervision. This slowed down the procedure initially, the State having to use persuasion rather than authority in order to implement its policy, but it also presented the advantage for the State that any counterpollution measure agreed upon during the operation could not easily be contested by the shipowner afterwards.

4 DISCUSSION

The HFE operation was long and difficult, but successful. Although more than half the dangerous cargo was lost in the accident, the ship was salvaged, and the environmental damage kept to a minimum. A number of lessons were learned by the authorities in charge of environmental protection, pointing to problems that deserve attention.

It is clear that a wide variety of packaged chemicals are transported by car ferries with completely inadequate protection in case they are lost at sea. Plastic and paper sacks have no chance of remaining intact in seawater. Partly filled drums sinking to the seabed do not resist the water pressure. It is also evident that such shipments are inadequately documented. Information is crucial in the management of chemical accidents (Jacques, 1985). The actual, not merely legal, requirements go well beyond the bill of lading to include specific data that, at this time, only direct contacts with shipping agencies and producers can supply: the form under which the substance is containerized, concentration, nature of the solvent, degree of filling and weight/volume ratio of drums, recommended method of detection. It would be helpful if that information were required on shipping documents.

Many chemicals can only be detected with sophisticated instruments, and field methods applicable to seawater often lack the desired sensitivity. For those substances, harmful concentrations cannot readily be detected at sea, and only behavior/dispersion models can provide information on the level of risk, the fate of the spilled chemical, and its likely impact. There is a great need for data on the properties, behavior in seawater and marine toxicities of many dangerous substances, to ensure that mechanisms can be simulated and dangers assessed properly. A pressing need also exists for mathematical models capable of simulating the behavior of solid objects floating at the surface of the sea or drifting on the seabed.

From the organizational point of view, the operation revealed the absolute need to coordinate the recovery of drifting and beached wrecks, and to keep a precise inventory of these goods in order to permit a correct assessment of the residual risk. The need to formally incorporate environmental protection activities in general disaster management procedures and contingency plans was confirmed by the legal and organizational difficulties the administration met with in conducting the counterpollution program. One should recognize that pollutants do threaten the safety of man as well as nature, and it is imperative to consider the marine environment as a resource, to be treated on the same footing as other resources, and with all the more care as so many ecological mechanisms remain poorly understood.

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