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Recovery of sunken oil in the Sea of Marmara

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ABSTRACT

During a storm on 29 December 1999 the Russian tanker VOLGONEFT 248 broke in two in the Sea of Marmara, off Istanbul, Turkey and spilled 1,578 tonnes of Heavy Fuel Oil. Most of the oil was cast ashore, and was subsequently cleaned up manually, whilst the remaining oil sank in shallow water. The sunken oil caused re-contamination of cleaned shorelines during storms and a decision was therefore taken to try and recover oil from the seabed.

A contractor was appointed and work started in April 2001. Manual oil recovery by divers was used in preference to dredging so as to minimise damage to the seabed. About 10 divers worked in depths of 1-15 metres and collected 150 tonnes of oil-contaminated sand per month. Roughly one quarter of the collected waste was pure oil. The oil content was determined by sampling the collected oily waste and measuring its calorific value. The oil content could then be calculated by reference to the known calorific value of the oil cargo. All collected oily waste was transported by road to a municipal disposal site for incineration.

A novel method is described for using a “no cure - no pay” contract to manage the recovery operation. The contractor was paid an agreed rate for the amount of pure oil collected. This approach proved successful and resulted in maximising the recovery of sunken oil whilst discouraging the collection of material other than oil. The commercial incentive created in this type of contract can also help to resolve the problem of determining the appropriate cut-off for the collection of widely scattered pockets of the sunken oil.

BACKGROUND

During a storm on 29th December 1999, the Russian tanker VOLGONEFT 248 (4,039 DWT) broke in two at an anchorage near Istanbul in the Sea of Marmara. The vessel was carrying 4,365 tonnes of Heavy Fuel Oil loaded in Bourgas, Bulgaria. The break occurred across tanks 5 and 6, and all the oil contained therein was spilled: 1,279 tonnes. The stern section with two intact tanks (7 & 8) containing 1,013 tonnes was driven aground in the storm, but after re-floating in early January the oil was discharged ashore without further spillage. The bow section with four full tanks (no. 1-4) containing the balance of 2,073 tonnes sank in shallow water and settled upright on the seabed. For several weeks, a small but continuous oil seepage surfaced above the sunken bow until divers were able to plug various leaks from the submerged tank vents and damaged pipe-work. Most of the oil in the bow tanks was recovered in February 2000 and the entire bow section was lifted from the seabed in May 2000. In light of these events, the best estimate of the total spill quantity is 1,578 tonnes.

The storm-force south-westerly winds which precipitated the incident also quickly cast the spilled oil ashore along about five kilometres of shorelines in the Istanbul suburb of Florya. The coastline consists of sandy beaches, rocks and concrete promenades with many seaside resorts, restaurants and cafés (Figure 1). The oil was mainly deposited at or above high water mark, forming a continuous band of oil between 2 and 10 metres wide, and up to 5 centimetres in thickness. In the prevailing low temperatures, the oil was thick and viscous, but gradually penetrated into the beach, forming sheets of stiff oil-saturated sand. Much of the oil stranded on beaches quickly became buried underneath fresh deposits of sand.

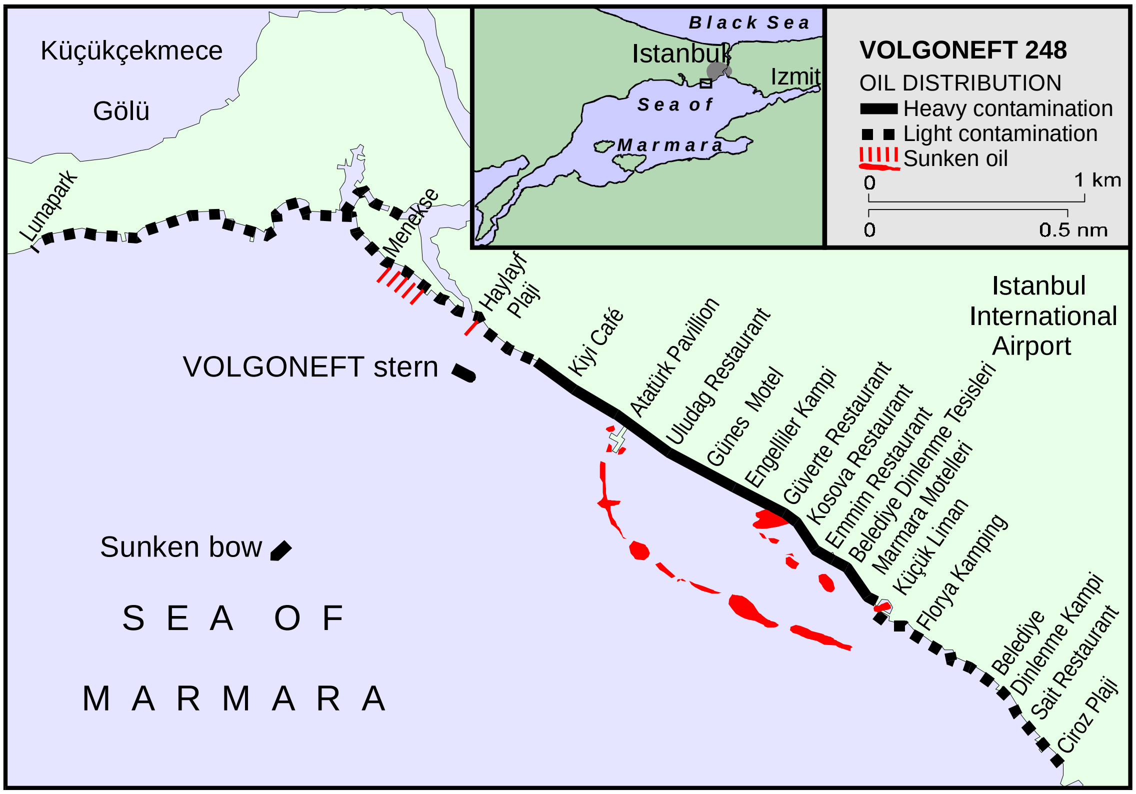

Figure 1. Location of wreckage and distribution of stranded and sunken oil.

Considerable quantities of the spilled oil became mixed with sand, mussel shells and other debris, and sank in shallow water at or near the shoreline. The Heavy Fuel Oil cargo had a specific gravity of 0.9914 g/cm³ @ 15°C, so the incorporation of sand particles and debris quickly led to the oil loosing buoyancy. The largest accumulations of sunken oil were located between Atatürk Pavilion and Küçük Liman in depths of 1–15 metres (Figure 1). In some places the deposit of sunken oil/sand mixture was later found to be up to 30 centimetres thick. During subsequent episodes of strong southerly winds large amounts of sunken oil and oily mussel shells were cast ashore or brought to the waters edge by wave action.

Although this incident involved the loss of a substantial quantity of oil, the length of coastline affected was very limited and only two clean-up contractors with small workforces were engaged, allowing both the shoreline clean-up operation and the recovery of sunken oil to be closely monitored and controlled. The fact that all waste recovered was transported to a single disposal site also facilitated the collection of relevant data. As a result, more reliable information on the progress of cleanup and the relative effectiveness of different techniques is available than for any other oil spill attended by ITOPF.

SHORELINE CLEANUP RESPONSE

As in previous major oil spills in Turkey, the Governor of Istanbul established a Crisis Committee to oversee the response to the VOLGONEFT 248 spill, with representatives of the National Salvage Administration, Ministry of Environment, Istanbul City, Istanbul Port Authority and Istanbul University. The Committee met regularly with P&I insurance representatives and ITOPF to discuss and agree clean-up strategies.

In early January 2000 a local clean-up contractor was appointed by the P&I Club to carry out the shoreline clean-up operation in accordance with a plan prepared by ITOPF and implemented with the agreement of the Crisis Committee. The arrangement was initially a lump-sum contract, but was later converted to a daily-rate agreement because of unforeseen problems generated by sunken oil. In Phase 1 of the operation the work was performed manually with a workforce of 133 men with little or no prior experience, and using simple hand tools. For the purpose of statistical analysis, the workforce has been taken to include workers and supervisors in the field, but not off-site administrative staff.

Steady progress was made collecting oily sand and water-in-oil emulsion in plastic bags and storing these temporarily in piles on plastic lining. In a little over two months the bulk of the oil had been collected and 4,556 tonnes of waste removed for disposal. The individual rate of waste collection by cleanup workers was 511 kg/manday. Clean-up progress was quickest on the concrete promenade surfaces: 50 m^2/manday. On sandy beaches the corresponding rate was 33 m^2/manday.

All collected oily waste was transported by truck to a disposal facility in Izmit where the oil-rich waste was incinerated, whilst the lightly contaminated waste was deposited at a landfill site. On arrival at the disposal facility each truck load of oily waste was logged (date), tagged (truck number plate) and weighed (±20 kg). The waste was sampled for routine analysis of key parameters including *inter alia* calorific value, following ISO 1928 / DIN 51577 methods. The sampling procedure consisted of slitting around 20 bags to expose the contents and taking a sample of about 1 kg from parts of the load considered to be representative. Six replicate samples from each load were taken in this way.

In the laboratory a subsample of a few grammes was placed in a metal crucible, sealed under pure oxygen and ignited in a bomb calorimeter (IKA C 7000) to measure the heat generated during flash combustion. The data for the six replicate samples were averaged and converted to energy units (kilojoules per kilogramme). The normal spread of results for the six replicates was about 20%. The errors introduced by this level of accuracy and by the rough sampling procedure were considered acceptable and self-cancelling since more than 3,000 data points were obtained over the duration of the spill response.

By analysing the calorific value of the collected waste and comparing the results with the known calorific value of the loaded cargo (40,380 kJ/kg) it was possible to calculate the amount of pure oil recovered. This calculation was made on the assumption that the calorific value of the waste was directly proportional to its oil content, and that the calorific value of solids and water in the waste was nil. The combustible biogenic content of the waste was judged to be negligible. The results of these calculations performed on 410 truck loads of waste (of which 316 were delivered in Phase 1) are given in Figure 2.

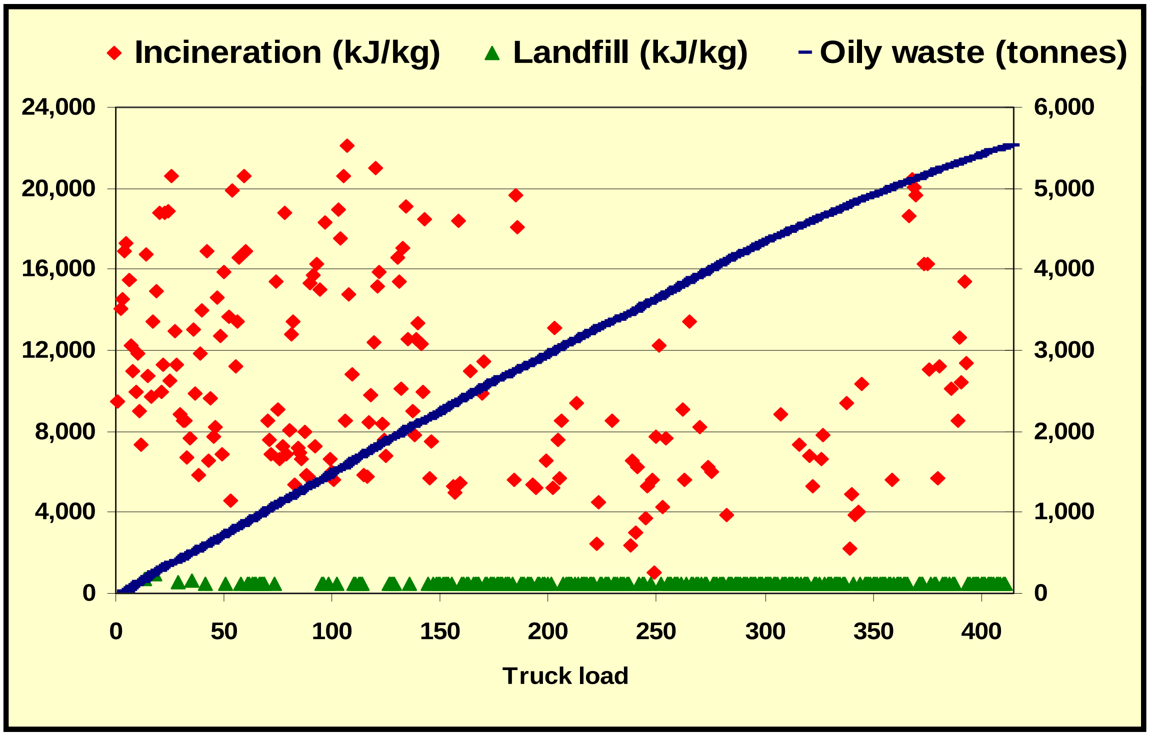

Figure 2. Calorific values and cumulative recoveries of oily waste from shorelines.

Interestingly, the highest calorific value recorded was 22,070 kJ/kg, implying an oil content of 22,070 ÷ 40,380 = 55%. This particular consignment appeared visually to consist of pure black oil with no admixture of sand or other debris. The balance of 45% must therefore have been water in the form of droplets entrained in the oil ("water-in-oil emulsion"). The oil content and frequency of waste oil consignments destined for incineration gradually reduced over time, which was to be expected as the bulk of the oil was removed first. The average oil content in the waste sent for incineration was 29% (11,627 kJ/kg). Conversely, more low-grade waste consigned to landfill was generated towards the end of the cleanup operation. Any waste with a calorific value of less than 1,000 kJ/kg was consigned to landfill, and so the average value was assumed to be 500 kJ/kg, equivalent to 1% oil.

By these calculations, the equivalent of 654 tonnes of pure oil was collected in Phase 1, which represents 41% of the spilled oil quantity. The average oil content for all the recovered waste in phase 1 was 14%. The results of Phase 1 & 2 of the shoreline cleanup operation are summarised in Table 1.

In Phase 2 the beaches were systematically cleaned, using rakes and manual sieving techniques in some areas. Contaminated man-made surfaces were cleaned to a reasonable standard using hot water washing machines. Manual sieving of sand and hot water washing generally proceeded at about 25 m^2/manday. As is to be expected during fine-cleaning, less oily waste was collected in this phase: 968 tonnes, of which 73 tonnes (7.5%) consisted of pure oil. This represents just 5% of the spill volume. The individual waste collection rate had dropped to 282 kg/manday (Table 1). The individual rate of pure oil recovery was 21 kg/manday, as against 73 kg/manday in Phase 1.

Phase 2 involved reduced effort (8-9 men on average) lasting over a year, partly because attempts to finalise the shoreline cleanup work were frustrated by cleaned areas becoming re-contaminated. Sunken oil was cast ashore during periods of onshore winds, generating additional pollution and necessitating repeated cleaning. The calculations summarised in Table 1 revealed that some 50% of the spilled oil volume was unaccounted for, much of which was probably lying on the seabed, close to shore.

Table 1 – Shoreline clean-up

Oil type	Heavy Fuel Oil		
Volume of oil spilled	1,578 tonnes		
Specific gravity @ 15°C	0.9914 g/cm³		
Calorific value	40,380 kJ/kg		
Coastline polluted	5 km		
SHORELINE CLEANUP	PHASE 1	PHASE 2	TOTAL
Period of operation (days)	67	404	471
Average labour force (no. men)	133	8.5	
Cleanup effort (mandays)	8,919	3,436	12,355
Waste collection rate on concrete (m^2/manday)	50		
Waste collection rate on beaches (m^2/manday)	33		
Manual sieving rate on beaches (m^2/manday)		25	

Hot water washing rate (m^2/manday)		25	
Quantity of oily waste collected (tonnes)	4,556	968	5,524
Quantity of pure oil collected (tonnes)	654	73	727
Average oil content of oily waste	14%	7.5%	13%
Oily waste collection rate (kg/manday)	511	282	447
Pure oil collection rate (kg/manday)	73	21	59
Proportion of waste incinerated	52%	27%	48%
Proportion of waste landfilled	48%	73%	52%
Proportion of spill volume recovered	41%	5%	46%
Shoreline clean-up costs (US$ million)	2	1	3

To summarise, the shoreline cleanup operation involved 12,355 mandays and the recovery of 5,524 tonnes of oily waste (13% oil) representing 46% of the spilled quantity at a cost of US$ 3 million.

RECOVERY OF SUNKEN OIL

The presence of sunken oil in shallow water and within reach of wave motion in rough weather created serious problems. Events soon showed that fresh oiling on the coast could be expected after every onshore gale or storm, making it impossible to bring shoreline cleanup work to a satisfactory conclusion. Diving surveys at depths of 1-15 metres confirmed that oil lay in deposits of varying thickness scattered on the seabed, between rocks and in some places buried under layers of sand up to one metre thick. There were clearly several hundred tonnes of sunken oil present, but it was not possible to determine the quantity with any degree of precision, or to judge how much of it could be recovered.

As in any oil recovery operation the issue arose as to how far the work should be pursued, since a 100% recovery rate was unlikely. This problem was particularly difficult to resolve since the oil in question was on the seabed, hidden from general view and, in part, buried under sand.

Nevertheless, a high rate of recovery was called for in this case, since residual oil accumulations on the seabed could be expected to affect these shorelines in the future.

The consistency of the oil was another problem. During the shoreline cleanup operation, workers could wade to accessible patches of sunken oil in the shallows and remove them piece by piece with spades. The oil was extremely viscous and progress was slow. On days with particularly low water, some success was achieved using a front-end loader to pull sunken oil ashore, but a different approach was needed for oil lying in deeper water.

Dredging was deemed too damaging to fauna and flora on the seabed and was therefore not considered acceptable by the Crisis Committee. Simple trials carried out by a French contractor using a mechanical device based on the airlift system proved unsuccessful, probably due to the high viscosity of the sunken oil material. Manual recovery by divers was the approach advocated by the Committee, but there was a problem of creating sufficient incentive for a commercial contractor, firstly to accept the assignment to work for fair financial reward, and secondly to work efficiently without the risk of the operation dragging on indefinitely. With very little experience of sunken oil recovery existing world-wide, there was merit in giving the appointed contractor maximum scope for innovative approaches whilst at the same time guarding against inappropriate ones.

The solution adopted by the P&I Club was to invite contractors to submit work proposals within the framework of a “no cure – no pay” contract. In principle, it would be for the appointed contractor to decide the work schedule and how long to pursue the work. Payment would be made strictly in accordance with the amount of pure oil collected, by reference to the calorific value of recovered waste. The payment rate selected was US$ 7,000 per tonne, based loosely on the shoreline cleanup costs. The contractor would be responsible for transporting the recovered waste to the disposal site, thereby creating a further incentive to keep the collection of non-oil waste to an absolute minimum.

Recognising that the recovery of sunken oil would become increasingly difficult over time, an escalator was built into the payment schedule. The rate of payment would increase in defined steps once a certain quantity of pure oil had been recovered. This served to provide a financial incentive for the contractor to embark on the more complex and time-consuming recovery of sunken oil deposits buried under sand.

After eight local and foreign contractors had been approached, the assignment was awarded to a Turkish salvage company. The contractual terms included an allowance to be paid in the event of rough weather preventing diving work. The recovery operation started in April 2001 with a team of about ten divers tackling the easiest deposits first. The work consisted of cutting chunks of oil with hand tools and placing the oil in plastic bags which were then lifted to the surface and to a work boat. In places where the oil was buried, the overburden of sand was first shifted out of the way using an airlift system. A diver support vessel was on hand to provide back-up, equipment and materials. A boom was generally positioned above the work site in case of surface oil pollution from oily bags and contaminated equipment being lifted out of the water.

Working conditions were taxing with diving suits and equipment becoming severely contaminated. From time to time, and depending on weather conditions, the waste water discharged from an out-fall at Marmara Motelleri added to the divers' discomfort. However, the financial inducement to work was substantial and the only interruptions in the operation were caused by onshore winds creating choppy seas. In the first nine months of operations (April 2001 to January 2002) the time lost to rough weather conditions amounted to 47 days (17%). Predictably, most of the enforced idleness occurred during the winter months.

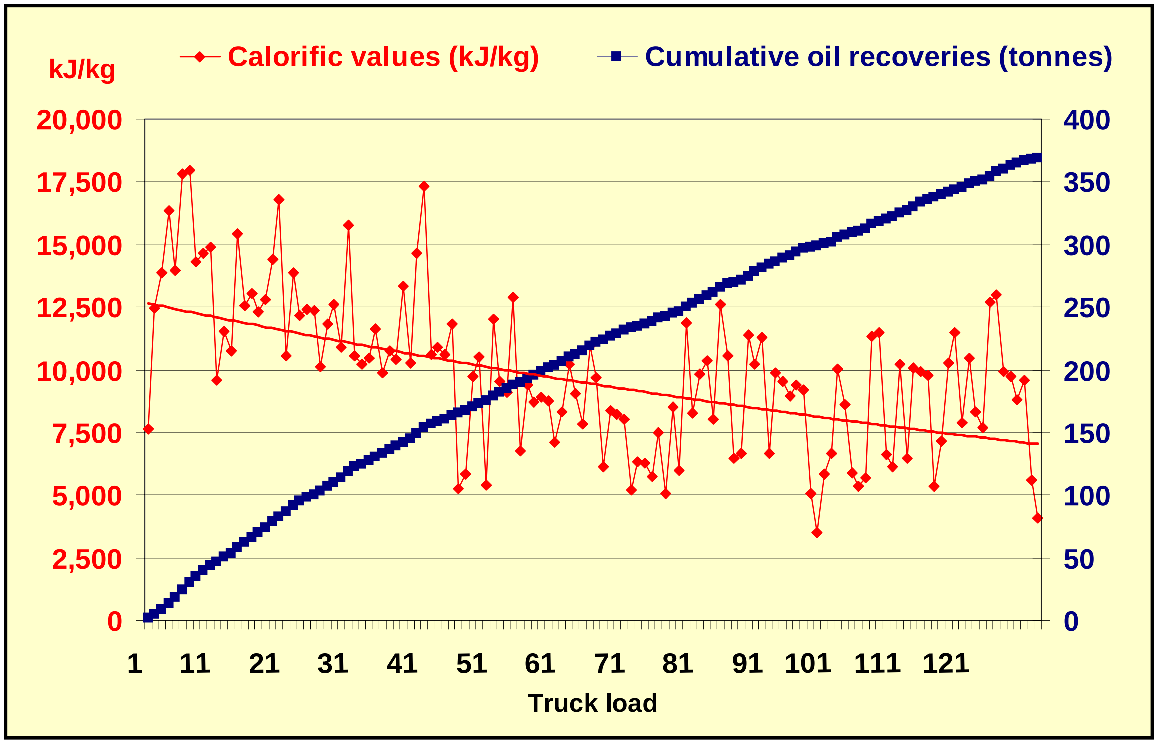

Figure 3. Calorific values and cumulative recoveries of oil from the seabed.

Figure 3 shows the progress during this period (275 days). The gradual decrease in the calorific value (oil content) of the recovered waste confirmed the expected trend whereby the return on invested effort fell as the work focused on buried and more fragmented oil deposits. A total of 1,488 tonnes of waste has been recovered from the seabed, with an oil content of 25%. This is appreciably higher than the 14% achieved in the shoreline cleanup. Based on analyses of the calorific value of each waste oil consignment the corresponding amount of pure oil was 368 tonnes, i.e. 23% of the spill volume (Table 2). The oily waste collection rate (466 kg/manday) compared favourably with the shoreline cleanup operation (447 kg/manday – Table 1). Whereas the individual collection rate of pure oil was 59 kg per day for shoreline workers, the divers achieved 107 kg/manday. This was a good result considering the more arduous conditions of operating underwater. It also reflects the fact that the sunken oil lay concentrated in thicker deposits and often more accessible than on the shorelines.

Table 2 – Sunken oil recoveries	
Period of operation (days)	275
Weather down-time (days)	47
Average labour force (no. men)	14
Cleanup effort (mandays)	3,192
Quantity of oily waste collected (tonnes)	1,488
Quantity of pure oil collected (tonnes)	368
Average oil content of oily waste	23%
Oily waste collection rate (kg/manday)	466
Pure oil collection rate (kg/manday)	107
Proportion of spill volume recovered	23%

DISCUSSION AND CONCLUSION

Whilst the elements of shoreline cleanup operations are well known, there is very little experience available concerning the recovery of sunken oil. Isolated occurrences of sunken oil were described by Moller (1992) and the behaviour of such oil was reviewed by Michel *et al.* (1995). Kaperick (1997) compiled an annotated bibliography of literature on oil sinking.

The problems of sunken oil have been tackled in very few incidents world-wide, and then often in an experimental way. The Swedish Coast Guard has tested sub-sea pumping systems in two separate incidents, and similar attempts have been performed in the United States (Ploen, 1995). A review by the US National Research Council summarises the limited experience available (National Research Council, 1999). The state of the art of sunken oil studies and recovery work are reported by Cabioc'h (*ibid.*).

The method of measuring the calorific value of oily waste has proved to be a useful tool in judging the performance of the oil pollution response operation following the VOLGONEFT 248 incident. At the time of writing the operation was in its final stages and about 70% (1,095 tonnes) of the spilled oil had been recovered. The remainder is likely to have dissipated at sea or become buried and fragmented beyond practical recovery.

The circumstances of this incident have provided an opportunity to gain further insights to the unusual problems posed by sunken oil. The detailed and relatively precise data on calorific values of collected oily waste have allowed the costs and benefits of the different facets of the cleanup response to be compared. In Figure 4 the relative values of key factors are presented in percentage terms.

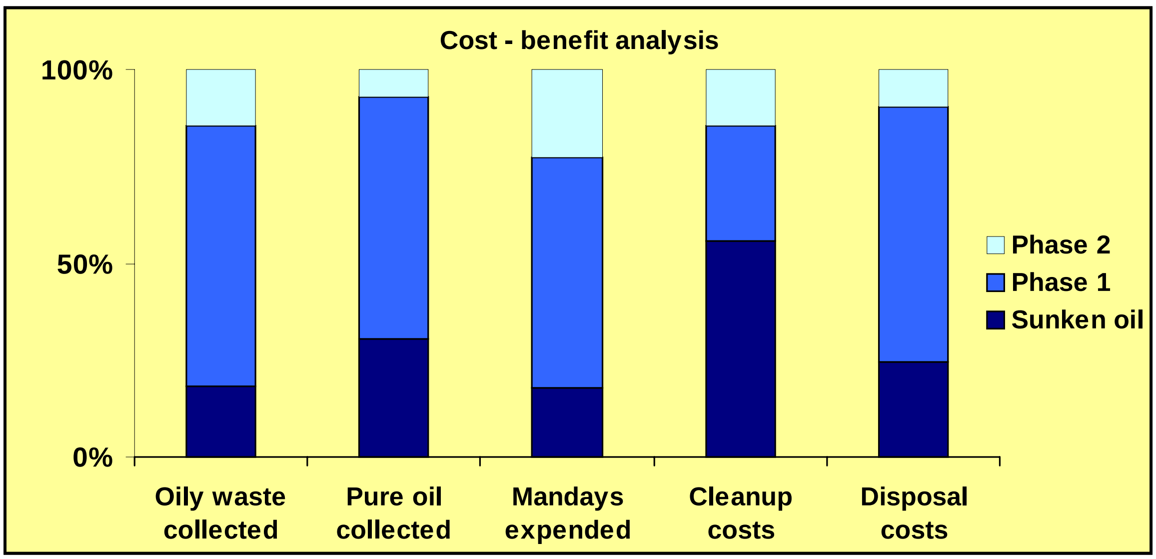

Figure 4. Comparison of costs and benefits of each shoreline and sub-sea cleanup phase.

The main points arising out of the cost-benefit analysis can be summarised as follows:

- Most of the oily waste and pure oil was collected during the first phase of the shoreline cleanup.

- In terms of pure oil collected, Phase 2 cleaning gave less return on effort expended, although the aim at this stage was fine-cleaning, not bulk oil removal.

- The highest individual recovery rate of pure oil (kg/manday) was achieved by divers.

- The costs for the sunken oil recovery operation were slightly higher than the combined shoreline cleanup costs (Phases 1 & 2).

- The disposal costs for the oily waste collected during shoreline cleanup were three times greater than for the recovered sunken oil.

- The overall costs of oil recovery plus disposal on-land versus sub-sea were roughly equal.

In conclusion, the convenient means of measuring the calorific value of oily waste opened the way to employing a "no cure – no pay" formula for tackling the sunken oil problem. The basic aim of maximising the amount of oil recovered, and thereby reducing greatly the risk of chronic shoreline pollution during periods of strong onshore winds was accomplished. The approach allowed the financial implications for both contracting parties to be defined in advance and could be used as a model in future incidents in similar circumstances. It would also be possible to consider this method for the removal of bulk oil on shorelines (such as Phase 1) but it does not lend itself to being applied during the fine-cleaning phase since the end-point is usually a visual standard and the quantity of recovered oil is a less relevant yardstick.

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BIOGRAPHY

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A marine biologist by training, Dr Moller is a Technical Team Manager at The International Tanker Owners Pollution Federation. In the course of his 23 years at ITOPF he has attended some 80 oil pollution incidents in 30 countries.

Although living and working in the United Kingdom, Dr Moller is a citizen of Sweden and studied at Gothenburg University before completing his national service in Sweden and continuing his postgraduate studies in fisheries biology at the University of Wales in Bangor, North Wales UK. He was awarded a Ph.D. there in 1977 and held a postdoctoral research post at Liverpool University until 1979.