Pollution in the Gulf: Monitoring the marine environment

Two years after the Gulf conflict, IAEA marine scientists are continuing to assess the serious effects of oil contamination

by S. W. Fowler

More than 2 years after the Gulf conflict, scientists are continuing to keep a close watch on marine pollution stemming from the war.

Following the conflict in early 1991, major concern was raised worldwide when an estimated four to eight million barrels of crude oil were directly released into the Persian Gulf from the Sea Island terminal in Kuwait. Such amounts clearly made it the largest oil spill in history. The catastrophe was exacerbated when Kuwaiti oil fields were ignited. They burned for 250 days, sending enormous smoke plumes into the air. From the best available estimates, some 500 million barrels (67 million tonnes) of emitted or ignited oil were added to the Gulf as aerosols, soot, toxic combustion products, and gases. Even if only a few percent of these emissions were deposited in the coastal marine environment, it would far surpass the amounts of crude oil that actually were spilled. The commonly held belief was that the pollution could readily spread far beyond the Gulf.

The magnitude of the pollution, and the types of toxic contaminants involved, led to a worldwide response through the United Nations system. An inter-agency plan of action was developed quickly to address the immediate problems and the potential impact of war-related contaminants in the Gulf environment. As one of its steps, the co-ordinating agency — the United Nations Environment Programme (UNEP) — asked the IAEA's Marine Environment Laboratory (MEL) in Monaco to help make a preliminary assessment of the situation. The Laboratory's main goal in initial surveys was to map the extent and general degree of the war-related pollution throughout the Gulf. In carrying out the work, scientists drew upon the IAEA-MEL's previous extensive experience in monitoring hydrocarbons and heavy metal contaminants in the region.

Since the initial surveys were done, IAEA-MEL scientists have been engaged in regional follow-up activities in ongoing attempts to obtain a clearer picture of the oil pollution's effects on the Gulf's marine environment. This article highlights the Laboratory's work in the Gulf following the 1991 conflict, within the context of co-operative programmes and projects. *

The context of actions

The Persian Gulf historically has been vulnerable to pollution, mainly because of its unique oceanographic characteristics.

The Gulf is a relatively small, shallow, semi-enclosed body of water bordered by the Arabian peninsula and Iran. Its average depth is only 35 metres and the deepest parts located along the Iranian coast are about 100 metres. Surface seawater temperatures vary widely between approximately 12° to 35° Celsius; however, in some coastal areas under certain conditions, they can reach nearly 40° Celsius. Normal seawater salinity usually ranges between 30 to 35 parts per thousand; however, because of the high rate of evaporation in the Gulf region, salinities often exceed 40 parts per thousand in the northwestern portion and can surpass 70 parts per thousand in various shallow, intertidal lagoons on the Arabian side of the Gulf. Such extremes pose enormous environmental stress on many coastal marine species against which any additional impact from pollution must be gauged.

The Gulf's vulnerability to pollution — coupled with the rapid development and urbanization of the coastal zone during the 1970s

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*Also see "Oil and combustion product contamination of the Gulf marine environment following the war", by J.W. Readman, S.W. Fowler, J.-P. Villeneuve, C. Cattini, B. Oregioni, and L.D. Mee, *Nature*, 358 (1992).

— led to a series of regional actions in the 1980s. One was the establishment of the Kuwait Action Plan (KAP), a regional convention aimed at safeguarding the Gulf from the impact of human activities. Then in early 1980, the UNEP — which was responsible for implementing a Regional Seas Programme for the Gulf within the framework of KAP — asked the IAEA-MEL for assistance. Specifically, the Laboratory's participation was requested in a 3-month multidisciplinary UN mission to assess the marine capabilities in the region for surveying, studying, and combatting marine pollution. Immediately following this assessment, the UNEP Regional Seas Programme held a series of meetings with the eight countries around the Gulf in order to establish a regional marine monitoring and research programme that would act as a focal point for pollutant baseline monitoring activities in each country. Because of lack of trained personnel in environmental analyses in Oman, Bahrain, and the United Arab Emirates (UAE), IAEA-MEL was asked especially to assist these countries in obtaining baseline data on pollutant levels in environmental samples (sediments and biota) required by the KAP Regional Monitoring Programme.

The first KAP quarterly sampling missions in those countries undertaken by IAEA-MEL began in early 1983 and continued through 1986. This was a period of rapid development of environmental awareness in the region. It culminated in the creation of a regional secretariat for marine environmental affairs called the Regional Organization for the Protection of the Marine Environment (ROPME). It was headquartered in Kuwait and took over the responsibility for carrying out the KAP programme previously overseen by UNEP. During this time, IAEA-MEL increased its technical assistance activities in the region by training nationals in pollutant analyses, overseeing regional workshops in various aspects of marine pollution, and managing a quality assurance project. This project involved a thorough intercalibration of analytical techniques used by the participating Gulf institutions.

Throughout the 1980s, a database of considerable size was built up. The result was a much clearer picture of existing pollutant levels, distributions, and trends in the coastal zone both inside and outside the Strait of Hormuz. Furthermore, these surveys carried out in the regional

Along the northwestern Saudi Arabian coast, a typical beach and bay area lies heavily contaminated with crude oil spilled during the Gulf war. *At left*: Scientists sample sea surface waters for petroleum hydrocarbons at Khafji, Saudi Arabia.

KAP networks were considered useful in gauging possible perturbations of pollution inputs from the Iran-Iraq war such as the Nowruz oil spill.

With the occupation of Kuwait in late 1990 and the outbreak of hostilities in early 1991, regional KAP activities came to a virtual halt. However, scientists at IAEA-MEL were able to draw upon that work in developing their response for assessing the war's pollution. The basic strategy chosen was to return to the same stations occupied in previous years in Bahrain, UAE, and Oman, to obtain similar samples for the purpose of making realistic comparisons. In addition, more intense sampling took place in the northwestern sector along the Kuwait and Saudi Arabian coasts where the coastal ecosystem was reported to be at most risk from the spilled oil.

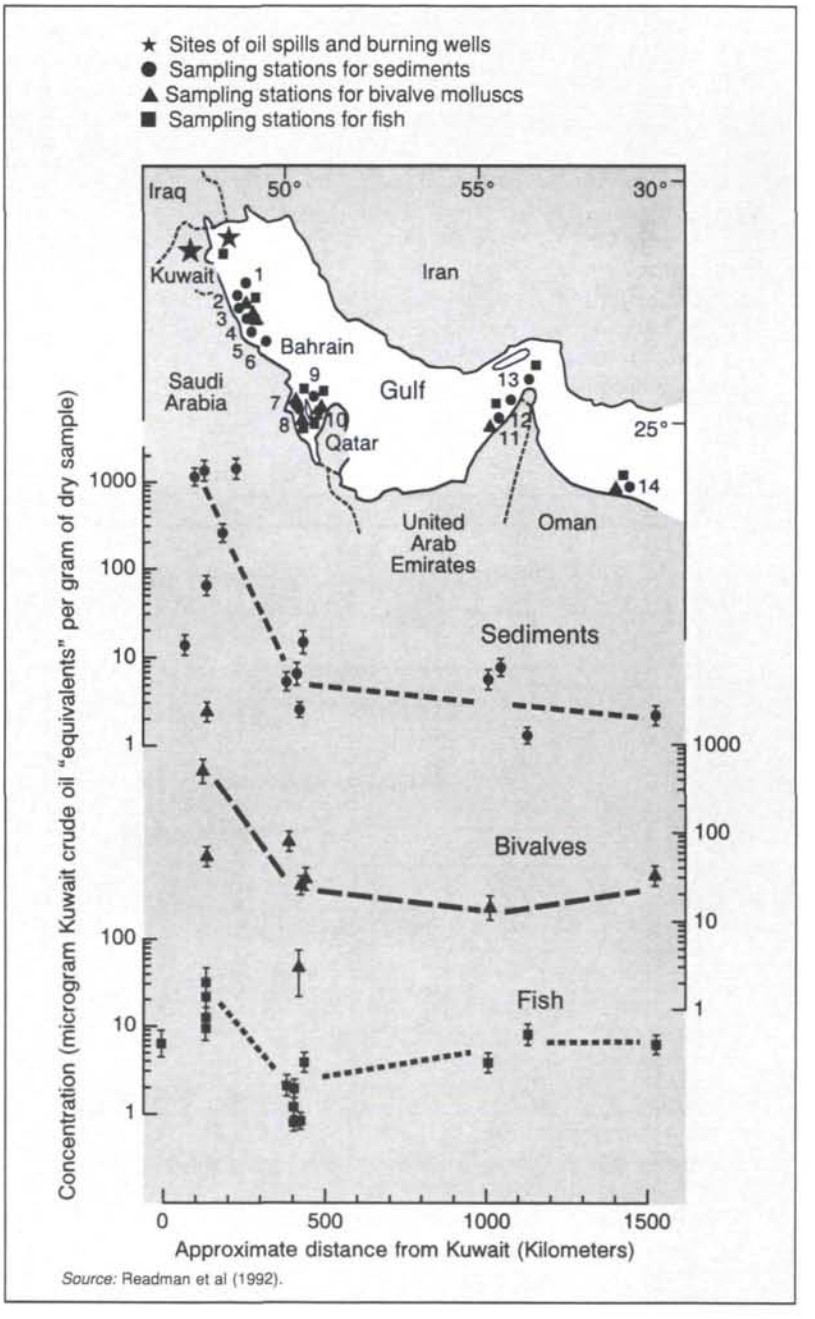
Post-war pollution survey

Field sampling began in June 1991 and continued periodically until the following October; the work was done in co-operation with the International Union for the Conservation of Nature (IUCN) and the Intergovernmental Oceanographic Commission (IOC). During June in Kuwait, access to the entire coastline and nearshore waters was forbidden owing to ordnance and unexploded mines. However, thanks to the Kuwait Environmental Protection Department, it was possible to fly by helicopter to an offshore island to survey the beach for tar and collect sediments near the shore for analysis. In addition, with the aid of a local fisherman, a sample of fresh fish was obtained near Kuwait City approximately 20 kilometers from the source of the oil spills. In order to have an idea of source-term contaminant levels in the fallout from the smoke plumes, soil samples also were taken in the vicinity of the oil well fires. Only about 25% of them had been extinguished by this time.

In Saudi Arabia, whose coastline IAEA-MEL had not previously sampled, sites were chosen based on previous surveys in the country as well as the visible impact of beach oil in this region. In the northern sector of Saudi Arabia where there was heavy fallout from the smoke plume, the top few microns of sea water, the "surface microlayer, or SML" were laboriously collected by a glass plate adhesion technique. In Bahrain, UAE and Oman, teams returned to the sites studied since 1983 so that samples from the same sediments and populations of organisms were obtained for purposes of comparison.

Typical of other pollutant monitoring programmes throughout the world, the Gulf assessment focused on bivalve molluscs which are considered excellent bio-indicators of metal and hydrocarbon contaminants, and common species of fish which are widely eaten in these countries. The molluscs included clams from the northern sector, pearl oysters, and rock scallops from the central region, and rock oysters from the coast of Oman. Fish obtained were principally species of grouper and bream which are common throughout the entire region. The clams and fish were dissected in the field and the tissues stored frozen until analyzed. In addition, sediments near the shore were collected by diver or from a boat using a small sediment grab. All materials were processed and analyzed at IAEA-MEL in

Concentrations of petroleum hydrocarbons in Gulf samples



Source: Readman et al (1992).

Monaco by the same analysts using the same methodologies as in previous years.

During a helicopter flight along the southern Kuwait coast in June, many slicks were observed, especially near the terminals which had suffered damage. However, except for some localized oil patches which came ashore, the beaches downstream from the Sea Island terminal appeared to be relatively clean. Beach surveys of tar balls on the offshore island of Qaruh surprisingly showed levels (approximately 380 grams per meter of beach) which were similar to amounts recorded during pre-war surveys in Kuwait and other Gulf States. This suggested that the nearby massive oil spill had not perturbated this particular nearby region.

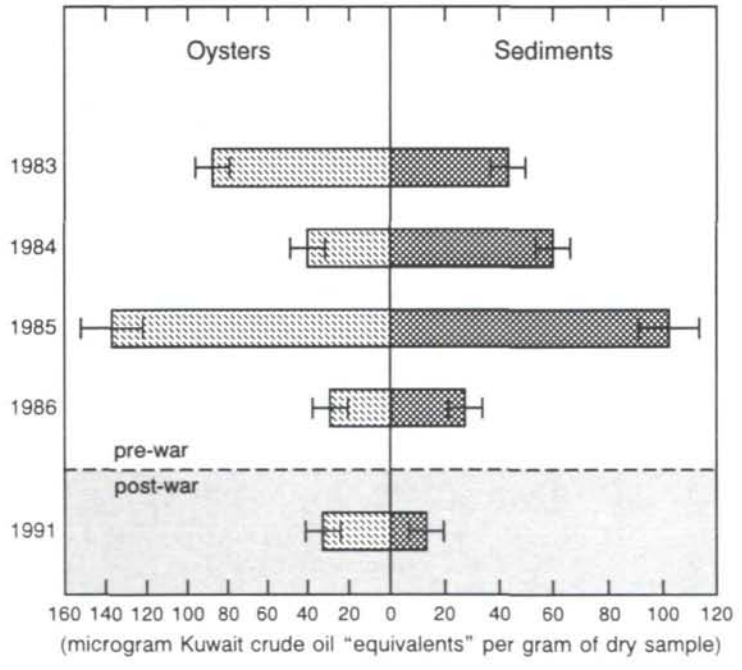
Many areas along the north central portion of the Saudi Arabia coastline were heavily impacted by oil. At Khafji near the Kuwaiti border, atmospheric pollution was very severe and large amounts of greasy soot in the coastal waters were noted. This resulted in extremely high petroleum hydrocarbon concentrations of 18 000 micrograms per liter in the surface microlayer. Even the subsurface seawater at that site contained more oil (260 micrograms per liter) than had been measured previously in other waters of the Gulf. Further south along the coast at Manifa Bay, the levels in the SML dropped by two orders to around 200 micrograms per liter. Beyond this sector of the coast little, if any, fresh oil and tar were seen on the beaches surveyed.

To obtain a Gulf-wide view of the potential impact of pollution stemming from the war, all the survey data for oil hydrocarbons were plotted on a map. *(See map.)* Sediment and bivalve mollusc analyses clearly showed that the major oil contamination was restricted to the Saudi Arabian coastline within approximately 400 kilometers of the source at Sea Island terminal. Sites outside of this area, including Muscat on the Indian Ocean shoreline of Oman, all exhibited similar, comparatively low levels of contamination. This contaminant distribution trend is most clearly delineated with sediment samples. However, it is mirrored by the bivalve data which also show an overall decrease with distance from the area of impact. While concentrations in fish appeared marginally elevated in the most northerly samples, their relative degree of contamination was lower than that observed for the bivalve molluscs.

If the area outside of the directly affected locations of Kuwait and Saudi Arabia is considered, the relative degree of oil pollution from the war can be evaluated by comparison with IAEA-MEL data obtained in previous years. For example, at a sampling site off Askar, Bahrain, not too far from the area of major oil impact, hydrocarbon contamination was similar or less than that measured in the 1980s. *(See graph.)* It is important to note that "normal" oil pollution input into the northern Gulf from oil production and transport activities averages about 2 million barrels per year. This represents up to half of the quantity spilled during the conflict. Given the drastic reduction in these activities during the period between late 1990 and early 1991, the low petroleum hydrocarbon levels recorded in the mid-1991 survey probably resulted from reduced chronic inputs during that period.

Several specific gas chromatographic and mass spectrometric analyses were undertaken to try and learn more about the state of the oil and its potential toxicity. Oil is a composite of many thousands of individual compounds with differing chemical properties and, once released into seawater, these are subject to weathering at different rates. Basically, solubilization and biodegradation act to reduce rapidly the concentrations of these various compounds. Although the survey took place within only a few months of the oil spill, an analysis of key compound ratios in sediments indicated that most of the spilled oil had substantially degraded. High temperatures and enhanced microbial degradation could have caused the rapid weathering that was observed.

Concentrations of petroleum hydrocarbons in a composite sample of pearl oysters and sub-tidal surface sediments



Note: Samples taken from a single site near Askar, Bahrain.
Source: Readman et al (1992).

The toxic polycyclic aromatic hydrocarbons (PAH compounds) were the major resolved aromatic components in the survey samples. PAHs such as pyrene are associated with combustion and could have arisen from the burning wells. Nevertheless, concentrations in the Gulf sediments (3 to 450 nanograms per gram dry weight) were well within the range of those reported for other coastal areas such as Buzzards Bay and New York Bight in the United States (7 to 1300 nanograms per gram dry weight) and United Kingdom estuaries (60 to 1510 nanograms per gram dry weight). Furthermore, the median value for the Gulf sediments (12.5 nanograms per gram dry weight) was somewhat lower than that for a survey of similar scope and sediment type in the Southern Baltic Sea (72.5 nanogram per gram dry weight, with a range of 1.7 to 150 nanogram per gram dry weight).

Thus, from the initial survey it seems that PAHs emanating from the burning oil wells did not broadly contaminate the coastal areas of the Gulf.

Many of the samples collected during the 1991 survey are being examined for potential pollutants by other nuclear and non-nuclear analytical techniques. For example, a suite of oil-related heavy metals including nickel, vanadium, and lead have been analyzed by inductively coupled plasma mass spectrometry (ICP-MS). In some soil samples taken in the oil fields, there was a covariance between vanadium and hydrocarbon content; however, in the coastal zone samples including those from Kuwait near the fires, metal levels did not suggest any impact from the fire fallout. Natural radionuclides such as polonium-210 are also enriched in crude oil and were therefore analyzed in fish and bivalve molluscs from the region. The levels of polonium-210 measured were similar to concentrations typically found in coastal fish and shellfish from other marine areas. They therefore gave no indication of major contamination from either the fires or oil spill.

The magnitude of the environmental catastrophe in the Gulf highlighted the need to be able to fingerprint oils under routine conditions to learn something about the origin of the spills. Therefore, since previous research has shown that petroleum contains a wide range of stable isotope signals which differ substantially from those in the present marine environment, select samples were analyzed for stable light isotopes to examine their potential in tracing, quantifying, and fingerprinting marine oil. The different sample types were clearly reflected by variations in signals of the different isotopes. Relatively strong correlations were found between the various isotopes, most notably between sulphur-34 and deuterium for Kuwait crude oil samples. Furthermore, significant trends were noted between deuterium and the hydrocarbon content of desert sands and nitrogen-15 and oil in biota samples.

Nevertheless, the number of samples examined was limited, and far more need to be analyzed before any definitive interpretation of these trends can be made. Plans are under way to further examine these isotope trends in co-operation with Scientists from the Japan Atomic Energy Research Institute.

Follow-up activities

Clearly, pollution of this magnitude must be examined in greater detail before definite conclusions can be drawn about long-term effects in the region. During the first half of 1992, a 3-month oceanographic cruise aboard the *Mt. Mitchell* was carried out to further investigate the impact of the 1991 oil spills; the survey was done under ROPME, in co-operation with the IOC, the US National Oceanic and Atmospheric Administration (NOAA), and UNEP. This multidisciplinary cruise saw the participation of more than 140 scientists from within and outside the region.

In August 1992, a follow-up coastal pollution survey was carried out by IAEA-MEL in Kuwait and Saudi Arabia in collaboration with IUCN, IOC, and ROPME. The team returned to the most heavily impacted areas to re-examine the same sites surveyed in 1991 to note any changes in contaminant levels that may have occurred during the previous 12 months. Some 60 samples of sediment, biota, and seawater were collected from 12 stations and are presently being analyzed by IAEA-MEL. While temporal trend assessments must await the outcome of these critical analyses, from visual observations made at the most heavily polluted areas, there appears to be less tar and oil in the zone near the shore than was observed a year earlier. Degradation and burial by drifting sand and sediment are believed to be mainly responsible for this improvement.

Nevertheless, it will no doubt be several years before the coastal zone in this region is completely free of war-derived oil contamination. Under the current ROPME/IAEA co-operative project, IAEA-MEL scientists will continue to keep a close watch on the status of marine pollution in the Gulf. ❐