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Assessment and Remediation of Oil Contaminated Soils`

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EDITORS
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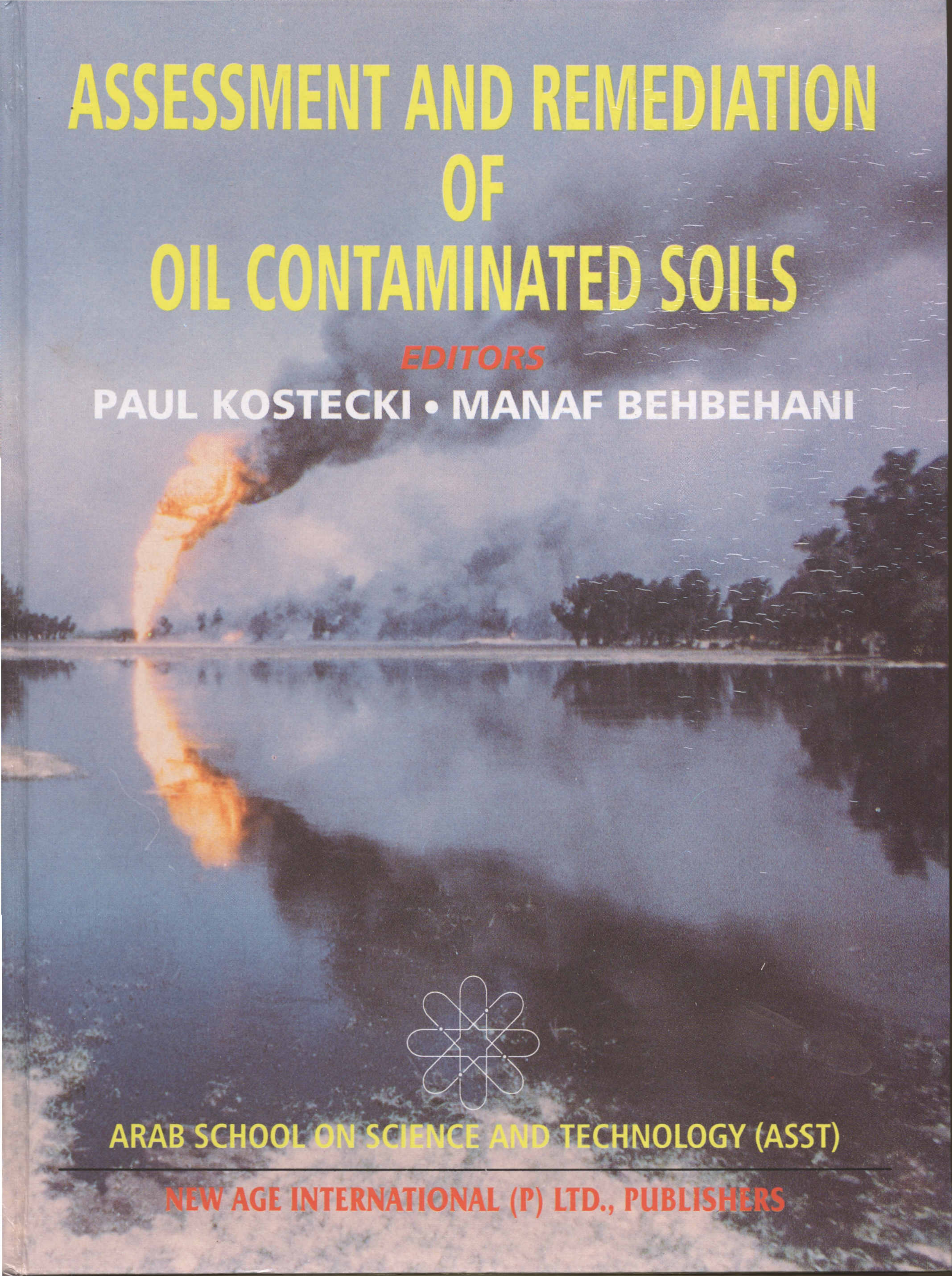

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PREFACE

In August 1990, Iraq invaded Kuwait and created one of the worst environmental disasters involving petroleum known to mankind. Retreating Iraqi troops broke pipelines, destroyed pumps and set fire to oil-well heads. Uncontrolled flows of crude oil continued for months after the Iraqi withdrawal and when the last burning well was capped on 6th November 1991, over 3,000 hectares of Kuwait landscape were covered with crude. The oil lakes that were formed ranged from a few centimeters to several meters in depth and represented over 60 million barrels of crude. In total 660 million barrels of crude oil were released to the environment resulting in 40 million tons of contaminated soil. No other petroleum release in history came close to equalling the magnitude of this event. The next largest reported release prior to 1991 was about 3 million barrels in Mexico in 1979. The Exxon Valdez spill in 1989 which commanded so much attention in the U.S. represented only about 0.2 million barrels.

The magnitude of the environmental problems facing the State of Kuwait was staggering. But the first step towards any solution is understanding the problem. In the case of the oil lakes, the problem has to be put into perspective and the technical and scientific issues discussed within that context. This book is the proceedings of the Workshop on Assessment and Remediation of Oil Contaminated Soils, held at the Kuwait Foundation for the Advancement of Sciences, March 18 – 22, 1995, and organized by the Arab School on Science & Technology. The book provides a comprehensive understanding of the oil-lake problems as well as the technical areas necessary for their cleanup: analytical, environmental fate, human and ecological risk assessment, and remediation. The international contributors provide the reader not only with a historical sense of the problem, but also with practical approaches for their solutions within the context of technical and scientific discussion.

This book will, therefore, be of considerable value to those concerned with the challenge of effectively dealing with the problem of petroleum-contaminated soils wherever they exist. Regulatory personnel, public health officials, affected parties as well as the environmental consulting community will find the information in this book essential to their professional development. In addition, this book provides students with a unique academic perspective by integrating the multidisciplinary subject areas into a real world problem.

Since the workshop was held, very little has changed. The oil lakes are in large part still there, although some of them have been covered with fresh soil to allow for Kuwait Oil Company operations, specially in drilling new wells. Some progress has been achieved with bioremediation of the oil-contaminated soils at the site but much more work is needed in other aspects of the problem particularly in the areas of groundwater contamination and community recovery.

This book represents the first and the only comprehensive publication on the problem of oil-contaminated soil resulting from damaged and burning oil wells in Kuwait as well as advanced methodologies to assess the contamination of the soil with oil and advanced technologies to deal with the problem. Therefore, it was the wish of the Editors and the Arab School on Science & Technology to have the contributions throughly reviewed and the book extensively edited, a process which took a couple of years to achieve.

24 January, 1998 Editors

A PERSPECTIVE ON PETROLEUM CONTAMINATED SOIL ISSUES

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Petroleum, crude oil and its refined products, is a major global resource. It serves as a major energy source for most, if not all, developed countries in the world. In the U.S., demand for petroleum grew in the 1970's peaking in 1978 at 18.1 million barrels per day from a low of 14.7 million barrels per day in 1970(1,2). The U.S. usage for refined petroleum products was 17 million barrels per day in 1992 which required 13.4 million barrels of crude oil. Crude oil imports accounted for 6.08 million barrels (Figure 1). Gasoline is the most important petroleum product accounting for ap-

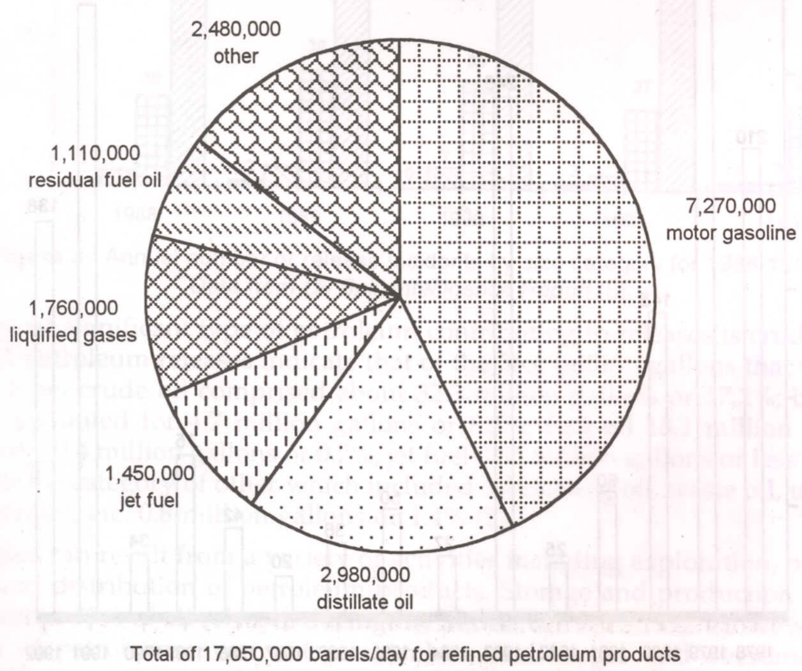

Figure 1 : U.S. daily demand for petroleum products. From *Petroleum Supply Annual*-1993(1).

proximately 42% of all petroleum products consumed from 1985 to 1992 averaging over 7 million barrels per day (2). Precise figures are not readily available for all developed countries, however, the U.S. figures are indicative of the enormous importance of petroleum utilization worldwide.

The above noted consumption statistics suggest an enormous level of support activities including production, transport, storage, and refining. These activities are potential sources for spills or releases to the environment and with them pose a high risk of contamination to soil and ground water systems.

It is estimated that four billion tons of hazardous materials are shipped each year in the U.S. with about 90% of this total being comprised of gasoline, fuel oil, and jet fuel (3). About 17% of all U.S. highway accidents hazardous materials involve petroleum products. The Massachusetts Department of Environmental Protection reported in 1984 that 58% of all highway spills involved petroleum products (4).

The quantities of petroleum released to the environment annually worldwide are enormous. Figure 2 indicates that over 1.7 billion gallons of petroleum were released

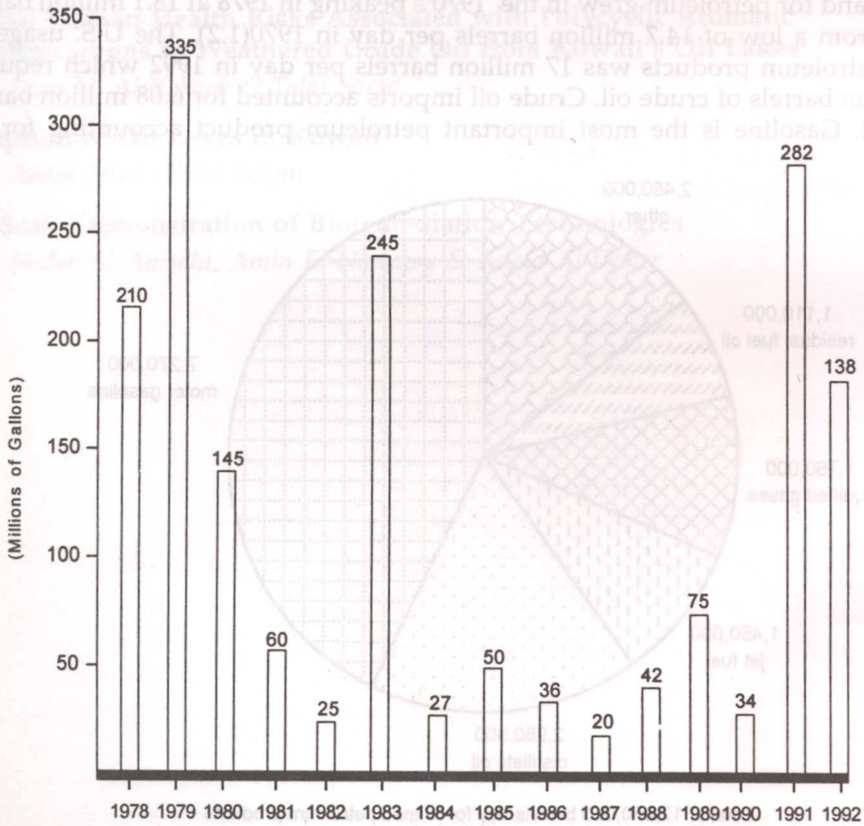

Figure 2 : Amount of petroleum released to the environment annually. Data from *Oil Spill Intelligence Report* (5).

to the aquatic and soil environs between 1978 to 1992. Annual figures range from a low of 20 million gallons in 1987 to a high of 335 million gallons in 1979 (5,6,7).

The size of individual releases can vary from less than 10,000 gallons to over 240 million. The frequency of different sized releases remains fairly equal from year to year (1988 - 1992) within four categories: greater than 10 million gallons per incident; greater than 1 million gallons but less than 10 million gallons per incident; greater than 100,000 gallons but less than 1 million gallons per incident; and greater than 10,000 gallons but less than 100,000 gallons per incident (Figure 3).

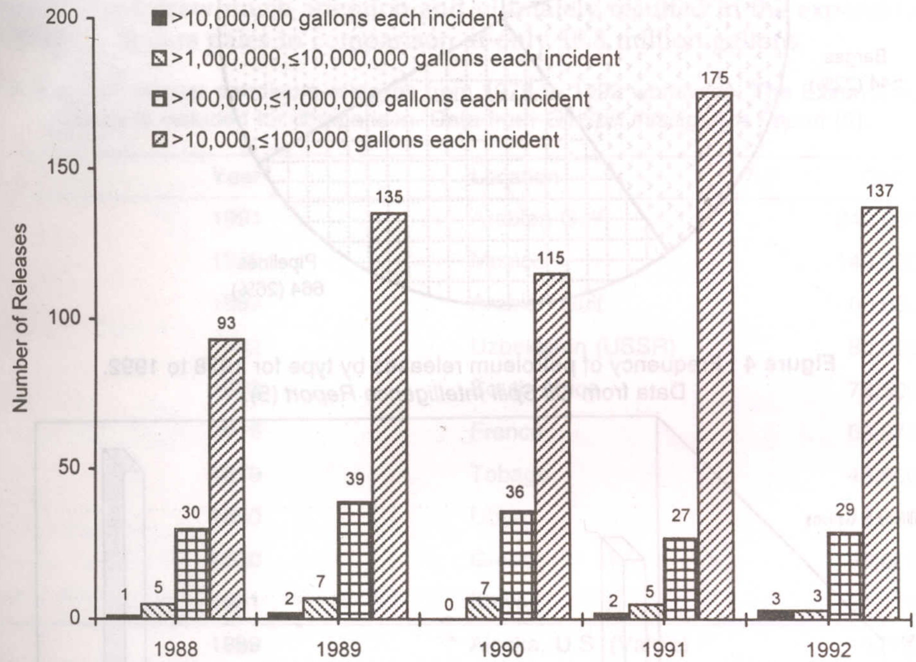

Figure 3 : Annual number or release incidents by size category for 1988-1992. Data from *Oil Spill Intelligence Report* (5).

The most significant type of petroleum contributing to releases is crude oil. Data from 1992 petroleum releases indicate that of the 56.4 million gallons that were identified by type, crude oil comprised about 32.3 million gallons or 57.2%; by contrast gasoline accounted for 4.7 million gallons or 8.3%; fuel oil 18.1 million gallons or 32.1%; diesel 0.4 million gallons or 0.7%; jet fuel 0.05 million gallons or less than .01%; and under the category of other which included lubricating oil, waste oil, used motor oil, mineral oil, etc. 0.8 million gallons or 1.4% (5).

Releases can result from a variety of activities including exploration, production, storage, and distribution of petroleum products. Storage and production accounted for only about 33% of all releases during the period of 1978 - 1992. However, it is the transport of petroleum over water in tankers and barges and overland through pipelines that contribute to the majority, as well as total quantity, of releases (Figures 4 & 5).

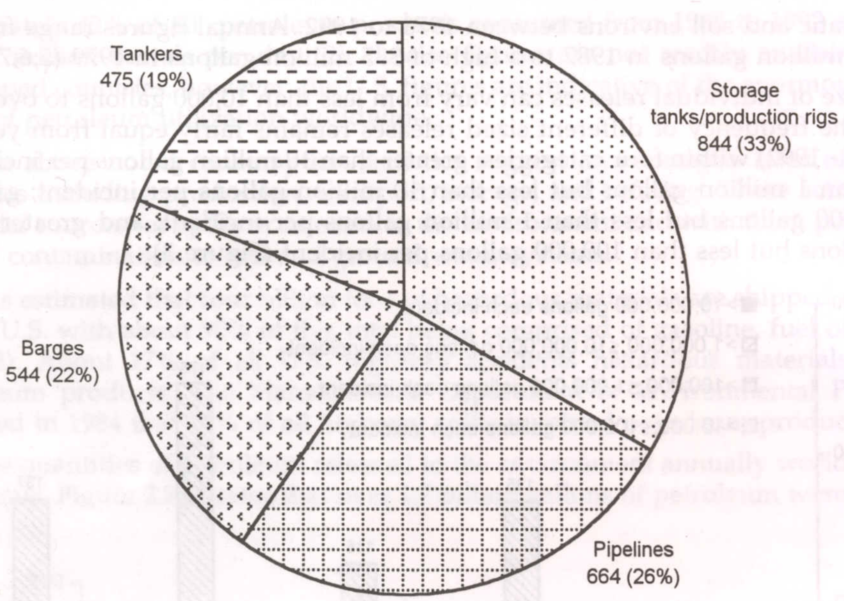

Figure 4 : Frequency of petroleum releases by type for 1978 to 1992. Data from *Oil Spill Intelligence Report* (5).

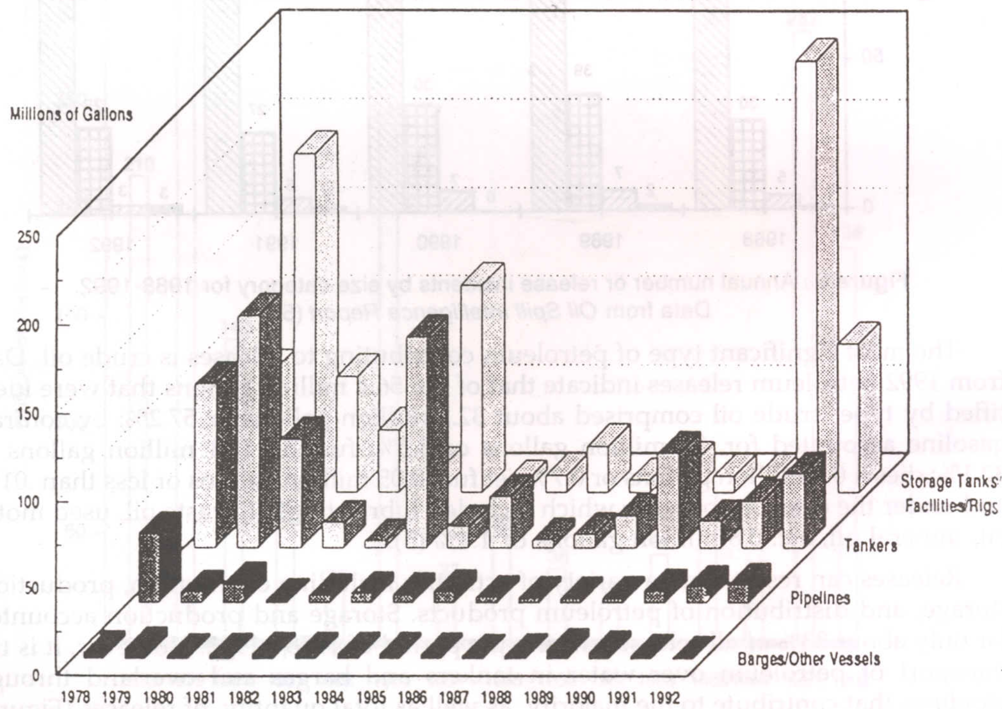

Figure 5 : Annual amount of releases by type 1978-1992. From *Oil Spill Intelligence Report* (5).

The risk of contamination to soil systems would most likely come from storage tank, production rig, and pipeline activities. These activities account for about 59% of all releases during the 1978-1992 time period.

The Gulf War, primarily the Iraqi destruction of Kuwaiti oil fields, resulted in the largest known petroleum release since 1978 when worldwide record-keeping of such events was started (Table 1). A listing of the ten largest petroleum releases between 1978 and 1992 shows the Gulf War at 240 million gallons which is approximately 175% larger than the second largest release. The Exxon Valdiz incident in Alaska which drew much attention and ultimately resulted in the expenditure of over 4 billion dollars pales in comparison at only 10.8 million gallons.

Table 1 : Ten largest petroleum releases from 1978 to 1992 worldwide. The Exxon Valdiz release is included for comparison. Data from *Oil Spill Intelligence Report* (5).

	Year	Location	Gallons
1.	1991	Arabian Gulf	240,000,000
2.	1979	Mexico	140,000,000
3.	1983	Arabian Gulf	80,000,000
4.	1992	Uzbekistan (USSR)	80,000,000
5.	1983	South Africa	78,500,000
6.	1978	France	68,670,000
7.	1979	Tobago	48,800,000
8.	1980	Libya	42,000,000
9.	1980	Greece	36,600,000
10.	1981	Kuwait	31,170,000
	1989	Alaska, U.S. (Valdiz)	10,800,000

To put the Gulf War petroleum release in proper perspective, one must consider that the incident contributed to about 86.3% of all the petroleum released worldwide in 1991 (Figure 6) or over 6 times the amount of petroleum released by all pipeline, tanker, barge, storage tank, and production rig release incidents throughout the rest of the world.

Underground storage of petroleum products can also result in serious environmental and economic problems. There are over 2 million underground storage tanks in the U.S.; of this number there are 1.2 million active and 0.9 million closed tanks (8). This total obviously does not account for unknown abandoned tanks which some experts believe may be significant.

Many of the underground storage tanks are employed for retail purposes or private use. Large petroleum companies, mid-size marketeers, small service stations, transit authorities, airports, schools, utilities, military installations, and farms all use underground storage tanks (9).

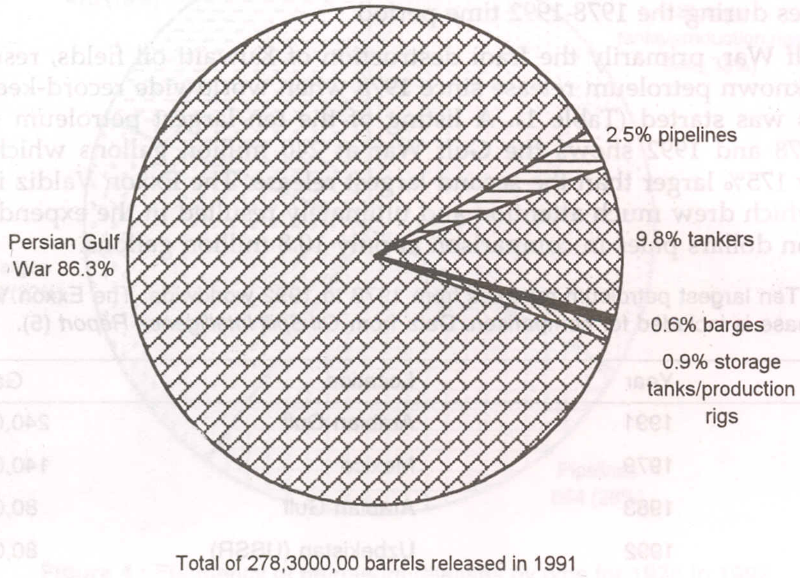

Figure 6 : Contribution of Gulf War releases to 1991 global oil releases by source. Data from *Oil Spill Intelligence Report* (6).

It is estimated that 20% to as high as 40% of all underground tanks may be leaking. This estimate would indicate there are 400,000 to 800,000 potential petroleum contaminated sites (8, 10). Leaks result from tank deterioration, improperly installed pipes, overfills, and spillage related to poor management practices.

As of the last quarter of 1994 the U.S. EPA Office of Underground Storage Tanks reported over 270,000 confirmed petroleum releases nationally since 1988. Only 39% or 107,000 of these confirmed leaks have been cleaned up (Figure 7) (8).

Clean-ups of leaking underground storage tank sites can be extremely costly in terms of time and money from the perspective of both the public and private sectors. A survey of selected U.S. states conducted by the University of Massachusetts in 1989 revealed that state environmental agencies were expending between 40% and 90% of their resources (time and money) in the oversight of petroleum contaminated sites (11).

The cost of cleaning up a leaking underground storage tank site in the U.S. generally varies between $10,000 and $200,000 for sites with only soil contamination and $100,000 to well over $1,000,000 for sites with soil and ground water contamination. Figures from one major U.S. oil company indicate that the average clean-up cost per site for leaking underground storage tanks at over 300 of its retail facilities from 1988 to 1991 was $300,000. The average length of time for each clean-up was ap-

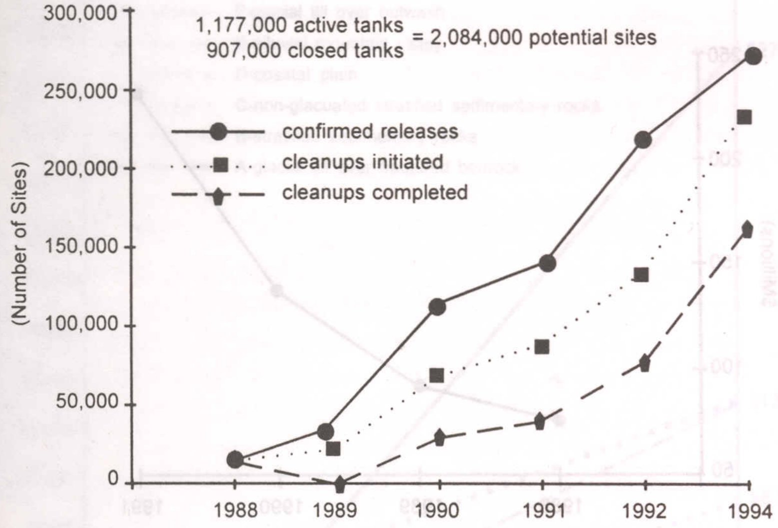

Figure 7 : Status of actions for underground storage tanks in the U.S. Data from U.S. EPA/Office of Underground Tanks (8).

proximately 3 years (Figure 8). Total annual clean-up cost over the time period for the company ranged from 70 to 210 million dollars (Figure 9).

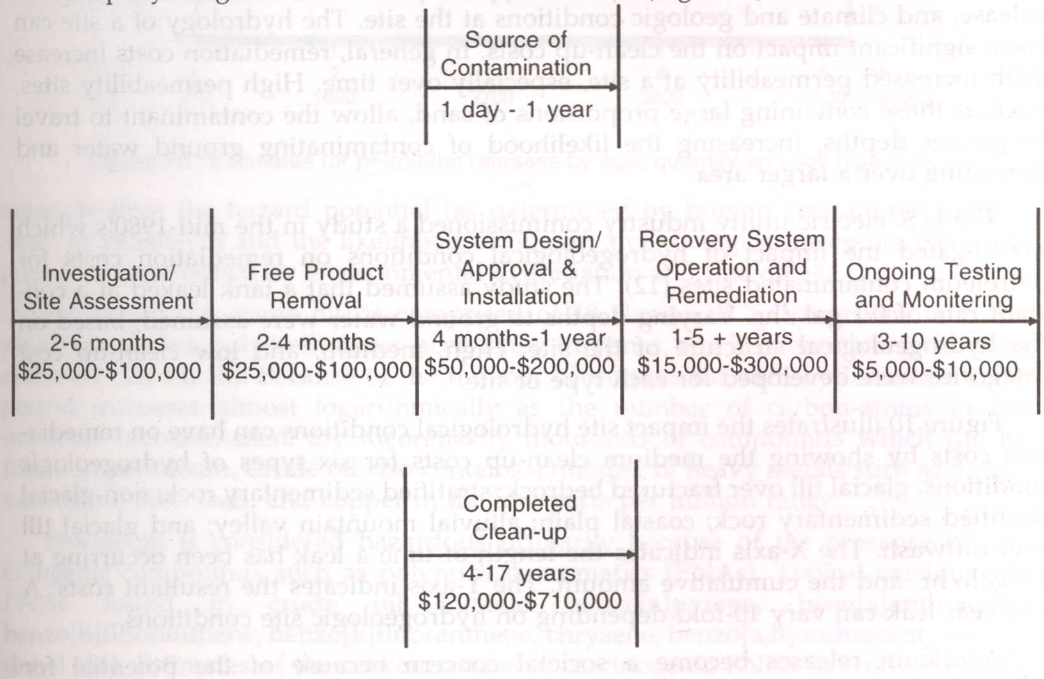

Figure 8 : Typical remediation project time and cost line for a retail gas station site in the U.S.

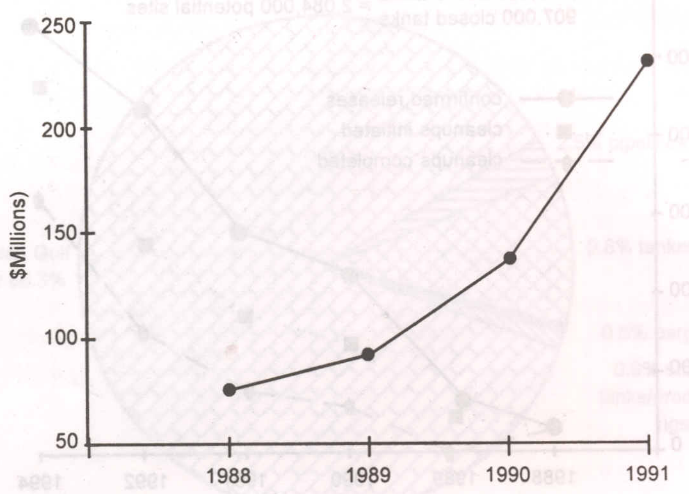

Figure 9 : Annual clean-up costs for underground storage site for a major U.S. Oil Company, 1988-1991.

There are a number of factors which influence remediation costs for petroleum contaminated sites. These factors include: type of petroleum, mass of release, age of release, and climate and geologic conditions at the site. The hydrology of a site can have significant impact on the clean-up costs. In general, remediation costs increase with increased permeability at a site, especially over time. High permeability sites, such as those containing large proportions of sand, allow the contaminant to travel to greater depths, increasing the likelihood of contaminating ground water and spreading over a larger area.

The U.S. electric utility industry commissioned a study in the mid-1980's which investigated the impact of hydrogeological conditions on remediation costs for petroleum contaminated sites (12). The study assumed that a tank leaked at a constant rate of 0.1 gal./hr. Varying depths to ground water were assumed, based on the hydrogeological structure of the site. High, medium, and low clean-up cost categories were developed for each type of site.

Figure 10 illustrates the impact site hydrological conditions can have on remediation costs by showing the medium clean-up costs for six types of hydrogeologic conditions: glacial till over fractured bedrock; stratified sedimentary rock; non-glacial stratified sedimentary rock; coastal plain; alluvial mountain valley; and glacial till over outwash. The X-axis indicates the length of time a leak has been occurring at 0.1 gal./hr. and the cumulative amount. The Y-axis indicates the resultant costs. A five year leak can vary 10-fold depending on hydrogeologic site conditions.

Petroleum releases become a societal concern because of the potential for detrimental impact on human and environmental health. The detrimental impact

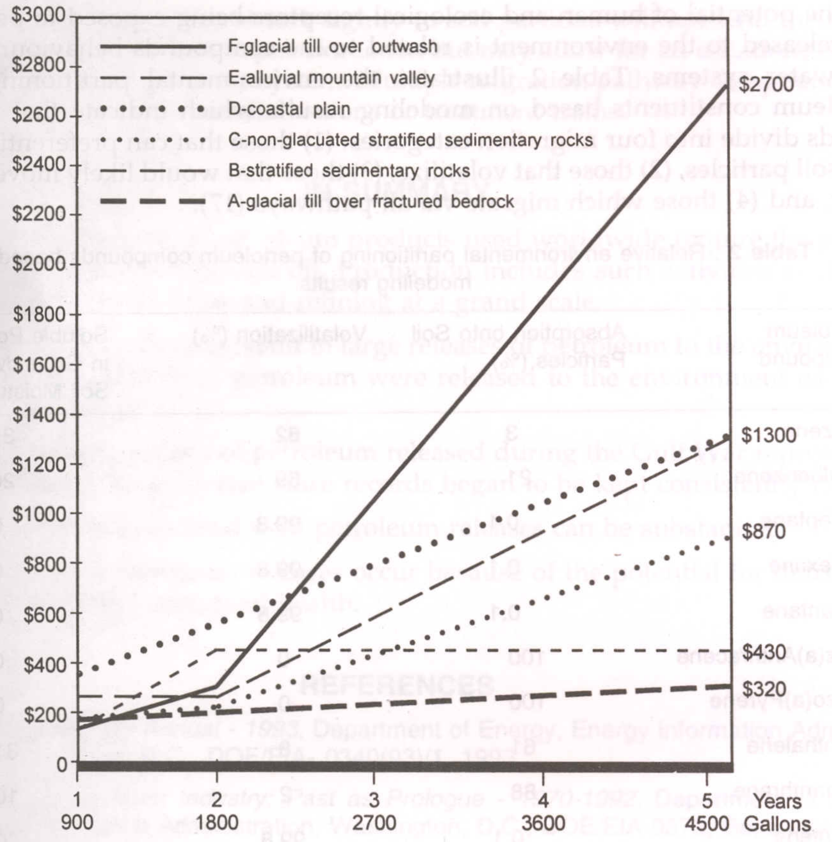

Figure 10 : Estimates for petroleum releases by age, quantity and soil type (12).

emanate from the hazard potential (as determined by human and animal toxicity data) of petroleum and the likelihood of human and ecological receptors being exposed (as determined by environmental degradation and fate data).

Petroleum (*i.e.* crude oil) is comprised of 18 classes of hydrocarbons with the paraffins, olefins, polymethylenes, acetylenes, turpenes, and benzenes being the most common (13, 14, 15). Because of the number of isomers for each hydrocarbon compound increases almost logarithmically as the number of carbon-atoms in the molecule increase, there are theoretically thousands of compounds which can be found in petroleum. Crude oil also contains a number of heavy metals such as nickel, vanadium, zinc, lead, and copper in the low parts per million range.

Petroleum is considered hazardous primarily because of the presence of carcinogenic compounds such as polynuclear aromatics (PNAs). Typical carcinogenic PNAs found in crude oil include benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, benzo[a,h]anthracene, and indenol (16). Estimates of the concentrations of carcinogenic PNAs in crude oil range between 10 and 100 ppm.

The potential of human and ecological receptors being exposed to petroleum as it is released to the environment is related to the compounds behaviour in the soil and water systems. Table 2 illustrates the environmental partitioning of some petroleum constituents based on modeling results which indicate that these compounds divide into four migration categories: (1) those that can preferentially absorb onto soil particles, (2) those that volatilize, (3) those that would likely move to ground water, and (4) those which migrate via all pathways (17).

Table 2 : Relative environmental partitioning of pertoleum compounds based on modeling results.

Petroleum Compound	Absorption onto Soil Particles (%)	Volatilization (%)	Soluble Portion in Groundwater and Soil Moisture (%)
Benzene	3	62	35
Ethylbenzene	21	59	20
(n)Heptane	0.1	99.8	0.1
(n)Hexane	0.1	99.8	0.1
(n)Pentane	0.1	99.8	0.1
Benz(a)Anthracene	100	0	0
Benzo(a)Pyrene	100	0	0
Naphthalene	61	8	31
Phenanthrene	88	2	10
1-Pentene	0.1	99.8	0.1
Phenol	9	0.01	91
Toluene	3	77	20
(o)Xylene	15	54	31

Determining the risk of petroleum releases requires a synthesis of both hazard and exposure information. The risk of exposure through skin contact or ingestion is related to the tendency of a particular compound to absorb onto soil particles and also into vegetation through root uptake which may enter the food chain. In addition, the risk of exposure through inhalation is related to the tendency of a compound to volatilize either directly from the soil or from water sources that have become impacted subsequent to the release. Also, the solubility and the specific gravity of a compound influence the way and degree to which a chemical can impact surface or ground water supplies, thereby influencing the risk of exposure through these pathways.

The environmental partitioning information has implications regarding remedial activities as well. For those compounds that volatilize rapidly, as effective remedial action would be one that takes advantage of their volatile nature such as vapor extraction. Compounds that absorb tightly to soil particles will not lend themselves to a remedial action such as vapor extraction but may allow for an isolation/containment strategy utilizing a cover system. Multiple migration pathway compounds may require several types of remedial actions or treatment trains.

IN SUMMARY

The enormous amounts of petroleum products used worldwide require the production of large quantities of crude oil. Production includes such activities as drilling, pumping, transport, storage, and refining at a grand scale.

Production activities can result in large releases of petroleum to the environment: 20 to 335 million gallons of petroleum were released to the environment each year between 1978 and 1992.

The 240 million gallons of petroleum released during the Gulf War represent the largest petroleum release event since records began to be kept consistently in 1978.

Clean-up costs associated with petroleum releases can be substantial.

Concerns over petroleum releases occur because of the potential for detrimental effects to human and ecological health.

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