5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

JP-4 and JP-7 are complex mixtures of hydrocarbons whose environmental fate depends primarily on the specific chemical and physical properties of their individual components. The individual components can be categorized into basic groups (paraffins, cycloparaffins, aromatics, and olefins), and these groups are common to both jet fuels. No information on the environmental fate of JP-7 was located. However, since the hydrocarbon groups making up the two compounds are similar, JP-7 can be expected to behave similarly to JP-4.

Jet fuel may be released to the environment by in-flight jettisoning of fuel and from spills or leaks to soil or water. Jet fuel jettisoned from planes can be transported by the wind. Some of it is transformed photochemically to ozone and other components of smog. It has been shown to form aerosols as a result of reactions with atmospheric chemicals, but the specific composition of the particulate material is not known. Most of the jet fuel released to water evaporates to the air. The components with the lowest boiling points volatilize most rapidly (e.g., short-chain alkanes, aromatics). Those with higher boiling points (e.g., branched alkanes, long-chain alkanes) persist longer in the water. Some of the hydrocarbons making up jet fuel are soluble in water (e.g., the aromaticsbenzene, toluene, and xylene). Under turbulent water conditions, the more soluble hydrocarbons remain dissolved longer and may partition to sediment or be biodegraded. The primary degradative fate process for jet fuel components in soil is biodegradation. While volatilization is expected to be the dominant fate process for these fuels from soil surfaces, biodegradation will become increasingly dominant as the soil depth increases. Some components of these fuels also migrate through the soil to groundwater.

Hydrocarbons associated with JP-4 and JP-7 have been detected in air in closed buildings where the fuels were being used or burned. Organic compounds found in JP-4 have been detected in groundwater following JP-4 leaks and spills. Hydrocarbons associated with JP-4 have also been found in soil surrounding fuel spill and leak sites. No data were located on the contamination of food, fish, shellfish, or terrestrial plants or animals.

The National Occupational Exposure Survey conducted by NIOSH between 1980 and 1983 estimated that 4,866 employees had the potential to be exposed to JP-4 in the workplace (NOES 1990). Populations most likely to be exposed to JP-4 and JP-7 include those involved in jet fuel manufacturing or refueling operations, populations working or living on Air Force bases where the fuels are used and stored (and where leaks or spills are likely to occur), and those living or working near waste sites where the fuels are dumped.

JP-4 has been found in at least 4 of the 1,397 NPL hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (HazDat 1994). JP-7 has not been found in any NPL site. However, the number of NPL sites evaluated for JP-4 and JP-7 is not known. The frequency of these sites within the United States can be seen in Figure 5-1.

5.2 RELEASES TO THE ENVIRONMENT

JP-4 and JP-7 are fuel mixtures used by the U.S. military as aviation fuels. As a result of normal aircraft operations and fuel storage, JP-4 and JP-7 can be released into the environment. Under some conditions, it is common practice for aircraft to jettison excess fuel, releasing it into the environment (IARC 1989).

Since JP-4 and JP-7 releases are not required to be reported under SARA Section 313, there are no data for JP-4 and JP-7 in the Toxics Release Inventory (TRI 1993).

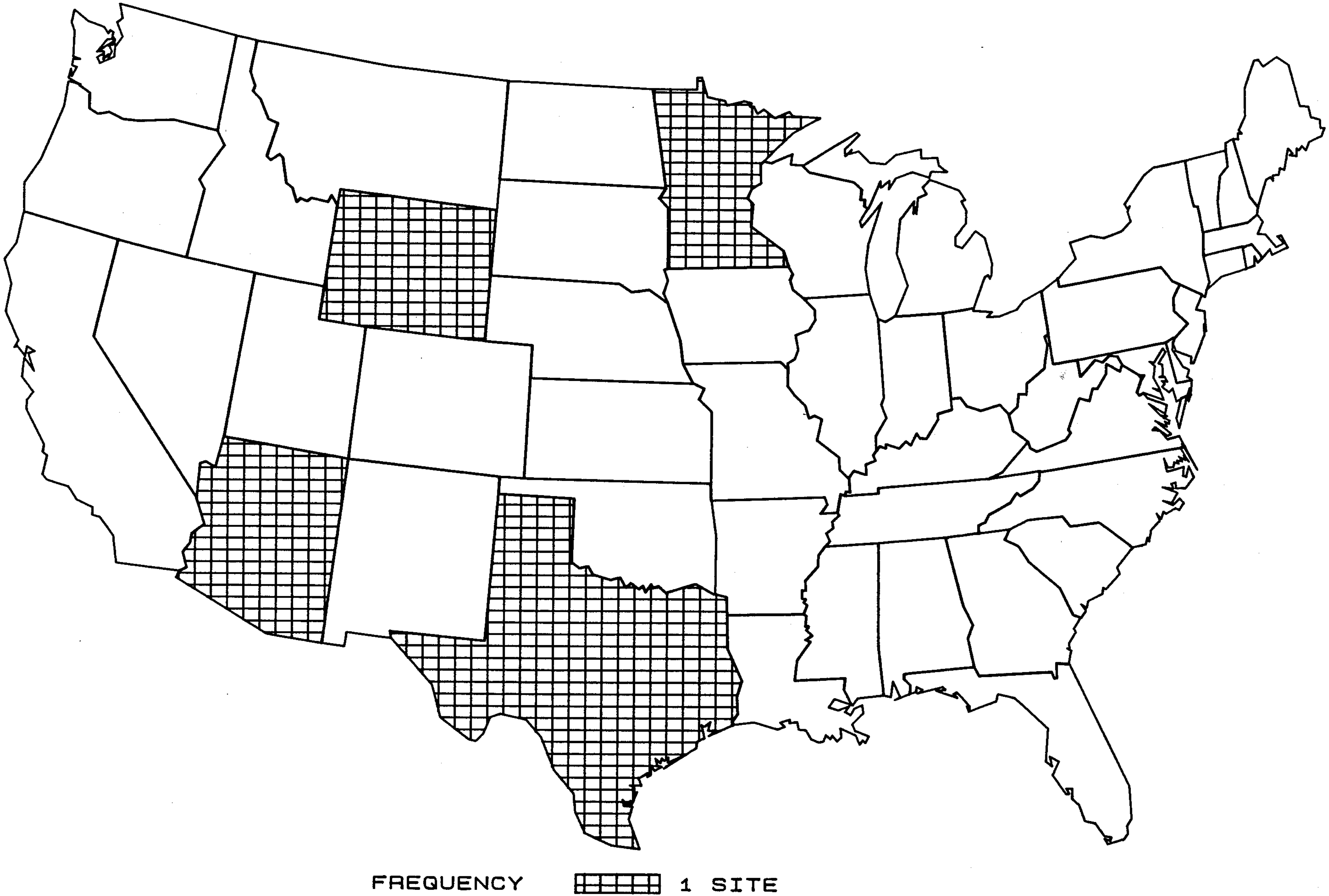
5.2.1 Air

JP-4 may be released into the atmosphere as vapors in loading and unloading operations in closed aircraft shelters (Air Force 1981h; NIOSH 1989). Releases into the air may also occur as a result of evaporation of JP-4 from contaminated soils or other spill sites (Air Force 1984b).

5.2.2 Water

JP-4 and JP-7 may be released into groundwaters as a result of seepage from contaminated soils during storage, aircraft maintenance, and fuel storage and dispensing operations (Twenter et al. 1985). A fuel layer of approximately 2 feet was identified in groundwater from shallow wells at Robins Air Force

FIGURE 5-1. FREQUENCY OF NPL SITES WITH JET FUEL (JP-4) CONTAMINATION *



*Derived from HazDat 1994

Base (Georgia) on a site where an undetermined amount of JP-4 was released into the soil from an underground fuel supply line in the 1960s (Air Force 1985a).

Groundwater intrusions of JP-4 were reported to have occurred as a result of cracks in the gunnite lining of the diked area surrounding three aboveground storage. tanks at the Niagara Falls Air Force Reserve Facility in New York (Air Force 1983a). Additional JP-4 was found in storm water drainings at the facility from underground inlet pipe, and in&t and outlet pipe leaks discovered in 1979 and 1982, respectively. Hydrocarbon groundwater contamination from leaking pipes in a JP-4 fuel farm occurred in a residential area surrounding the U.S. Navy air station in Traverse City, Michigan (Sammons and Armstrong 1986).

5.2.3 Soil

JP-4 and JP-7 may be released into soil as a result of leaks in underground or aboveground storage tank systems. In October 1975, approximately 83,000 gallons of JP-4 were lost from the bottom of a newly cleaned, aboveground storage tank at the Defense Fuel Supply Center in Charleston, South Carolina (Talts et al. 1977). Investigation of the soil revealed that JP-4 had moved through porous soil to a depth of approximately 7-14 feet. In 1972, approximately 42,000 gallons of JP-4 were released into the soil as a result of an external pipe leak at O'Hare Air Reserve Forces Facility, Illinois (Air Force 1983b). The dike had accumulated excess water as a result of heavy rains, and a drop in temperature caused the water to freeze and crush external piping to the tank. An undetermined amount of JP-4 was released into the soil from a leak in a 4-inch diameter pipe in 1965 at Robins Air Force Base (Air Force 1985a). Approximately 27,000 gallons of JP-4 were released into the soil in January 1985 as a result of an automatic filling system malfunction which caused underground storage tanks to overfill at Hill Air Force Base in Utah (Elliot and DePaoli 1990).

5.3 ENVIRONMENTAL FATE

5.3.1. Transport and Partitioning

Since JP-4 and JP-7 are mixtures of hydrocarbons, their movement in the environment is actually a function of the chemical and physical properties of the component hydrocarbons. Following release of jet fuel to air, water, or soil, the component hydrocarbons partition relatively independently of each other based on their respective vapor pressures, solubilities, and Henry's law and sorption constants. For JP-4 and JP-7 mixtures, these values are ranges based on the component hydrocarbons. Information on the specific physical and chemical properties of several of the component hydrocarbons (e.g., benzene, toluene, xylene, naphthalene, etc.) can be found in the ATSDR toxicological profiles for these chemicals. The hundreds of hydrocarbons making up JP-4 and JP-7 fuel mixtures can be divided into a few groups of hydrocarbon classes with similar properties (Air Force 1989b; CRC 1984). These include paraffins (saturated straight-chain hydrocarbons), cycloparaffins (saturated cyclic hydrocarbons), aromatics (fully unsaturated six-carbon ring compounds), and olefins (unsaturated straight-chain and cyclic hydrocarbons). Paraffins and cycloparaffins are the major components and comprise about 90% of JP-4 by volume (79% by weight) (Air Force 1989b). Aromatics make up about 10-25% by volume of JP-4 but only about 5% of JP-7 (Air Force 1989b; IARC 1989); however, the specific composition of these fuels varies among manufacturers and probably between batches (Cooper et al. 1982). Jet fuel may also contain low and variable levels of nonhydrocarbon contaminants and additives such as sulfur compounds, gums, alcohols, naphthenic acids, antioxidants, metal deactivators, and icing and corrosion inhibitors (CRC 1984; IARC 1989). The variability in the composition contributes to the difficulty in making general conclusions about the fate and transport processes of these fuels in the environment.

Most of the principal JP-4 component hydrocarbons rapidly evaporate from water following a spill. Tests with both petroleum- and shale-derived JP-4 under various environmental conditions all showed volatilization of JP-4 component hydrocarbons to be the dominant fate process (Air Force 1987b, 1988b; EPA 1985). Complete evaporation of benzene, toluene, and *p*-xylene occurred within 24 hours in shake-flask experiments using water from three natural sources (EPA 1985). Ninety percent of the JP-4 evaporated within 6 days under the laboratory conditions used (Air Force 1988b). As expected, the hydrocarbons with the lowest boiling points evaporated most rapidly. Simulated spills of JP-4 to water suggested that most JP-4 component hydrocarbons evaporated within l-2 weeks following release (Air Force 1981f). In a model petroleum-derived JP-4 fuel spill into a natural freshwater sample, initial concentrations of total dissolved hydrocarbons were about 1 mg/L. At 1 and 2 weeks following the simulated spill, concentrations did not exceed 0.005 mg/L for any of the measured fuel components. This was attributed to the high volatility of the fuel. Shake-flask experiments have shown that increased dissolved organic carbon decreases the rate of hydrocarbon evaporation (Air Force 1988b). Laboratory experiments have shown that the evaporation rate of jet fuel and its components increases with wind velocity and, to a lesser extent, with temperature and fuel-layer thickness (Air Force 1988d). Comparisons of dissolution and evaporation rates under several windspeed and mixing conditions showed that evaporation was the dominant fate process for jet fuel components in water.

JP-4 also evaporates from soil, although evaporation is not as important a fate process in soil as it is in water. A model soil core ecosystem was treated with JP-4 to simulate a spill (Air Force 1981e, 1982c). Headspace above the soil core revealed hydrocarbons from the JP-4 indicating that evaporation of component hydrocarbons had occurred. In model soil core ecosystems, volatilization accounted for 7% of the hydrocarbon loss compared to 93% for biodegradation (Coho 1990).

Some downward migration of JP-4 component hydrocarbons occurred in model soil core ecosystems treated with JP-4 to mimic a spill and watered to simulate rainfall (Air Force 1982c). Of nine hydrocarbons monitored for vertical migration through the core, only *n*-pentadecane and *n*-heptane migrated the 50 cm to the bottom of the core. They were first found at this depth 197 days following initiation of the experiment. These two compounds also persisted in the soil longer than the other hydrocarbons monitored. *n*-Decane, *n*-undecane, dodecane, *n*-tridecane, and *n*-tetradecane were found only at 10 cm below the surface. They were observed for 50-134 days following onset of the experiment and were not detected again. Additional data obtained by leachate collection indicated that the migration of hydrocarbons was best explained by channeling effects caused by biota and/or physical stresses since there was no direct correlation between leachate collection and hydrocarbon transport. Additional evidence for vertical migration of jet fuel hydrocarbons through soil comes from their detection in groundwater following leaks and spills to surface soil (EPA 1990b; Talts et al. 1977). Horizontal and vertical migration through soil has been confirmed by detection of JP-4 hydrocarbons in soil several meters from the spill site (EPA 1988a, 1990b).

The difficulties of determining the fate of JP-4 and its components are epitomized by the problems in determining the composition of its water-soluble fraction. Various results are likely to be obtained by different investigators even when the fuel tested and the methods used appear to be similar. Seventeen hydrocarbons were detected in an analysis of the water-soluble fractions of shale-derived and petroleum-derived JP-4, with the most abundant hydrocarbons being benzene, methylbenzene, and 3-methylhexane (Air Force 1988b). In contrast, only benzene, toluene, and p-xylene were found in significant concentrations in the water-soluble fraction of JP-4 (origin not specified) in laboratory simulations of field conditions, although other hydrocarbons could be detected (EPA 1985). The aqueous concentration of JP-4 components under spill conditions was found to depend on the solubility of the individual components, the mixing of the mixture due to wind speed, the thickness of the fuel layer, the ionic strength of the aqueous solution, and the rate of evaporation of components (Air Force 198%). Laboratory experiments simulating a JP-4 spill to water measured both evaporation and dissolution of components under slow and fast wind speeds and under conditions that enhanced complete mixing. Under both conditions, only the component aromatics (benzene, toluene, ethylbenzene, and xylene) were soluble enough to-be detected in the aqueous phase before evaporative processes reduced their concentrations below detectable limits. Concentration measurements of these components in both the fuel and water suggested that, in general, the concentration of the lighter aromatics decreased in the fuel layer and increased in the water phase until evaporation began to substantially affect their concentration in the aqueous phase. Heavier aromatics initially decreased in the fuel but then increased as the lighter aromatics decreased. Aqueous concentrations increased over time and generally reached higher levels, and their evaporation was not as rapid. Increased wind speed increased both dissolution and evaporation of JP-4 components, but evaporation was increased substantially more than dissolution (a 5fold increase for evaporation compared to a 2-3-fold increase for dissolution). At both wind speeds, evaporation was dominant with rates on the order of mg/minute compared to dissolution rates in the pg/minute range. When sea water was used as the test medium, results were similar; however, the concentrations of the hydrocarbons dissolved in sea water were considerably less than when distilled water was used. This was attributed to the effect of high ionic strength on the solubility of the hydrocarbons. Increased thickness of the fuel layer increased the concentration of the dissolved hydrocarbons because evaporation was reduced. This increased the contact time between fuel components and the water. Solubility has also been found to increase with increasing concentrations of dissolved organic carbon (Air Force 1988b).

Movement of JP-4 on and in water was found to affect the important processes of evaporation and dissolution of JP-4 components. Variations in wind speed, the force responsible for mixing of fuel, created eddies in the aqueous medium that caused non-uniform variations in concentration of fuel components with water depth and increased evaporation. Experiments that examined spreading rate of a fuel film on water indicated that spreading was very rapid (Air Force 1988d). Tests showed that spreading was initially uniform, but as evaporative effects became noticeable, spreading became less uniform and the film eventually disintegrated. Rapid spreading reduced dissolution of the fuel by increasing evaporation and decreasing contact time.

The data on the role of sediments in the fate of JP-4 and its components are contradictory. However, partitioning of jet fuel hydrocarbons to sediment does not seem to be an important fate process (Air Force 1981f; EPA 1985). Some data suggest that, under certain conditions, JP-4 hydrocarbons may adsorb to sediment and reduce volatilization (Air Force 1988b; EPA 1985). Quiescent bottle tests using natural water from a salt water marsh, a brackish polluted bay, and a freshwater river showed that volatility was reduced in sterile controls containing water and sediment compared to sterile controls containing only water (Air Force 1988b). "In contrast, when undisturbed or shaken gently, flasks containing water and sediment, or water only, and sterile control flasks containing water from the same sources exhibited no difference in the rate of disappearance of components (EPA 1985). When the flasks were shaken vigorously to imitate turbulent water conditions, volatilization of some components was reduced in the flasks with sediment and water compared to the flasks containing water only. Field and laboratory data on sediment that was dosed with JP-4 and then either returned to the pond or introduced to model laboratory systems indicate that sediment interaction of JP-4 components occurs and affects the volatility of JP-4. Sediment interactions increased persistence of JP-4 components to as much as 20 days in the field tests. Differences between laboratory and field data indicated that laboratory data were not good predictors of what would occur in the field. Evidence acquired using simulated petroleum- and shale-derived jet fuels indicates that neither the major representative components nor the JP-4 mixture have strong adsorption to standard clays or to sediments from natural fresh, brackish, or salt water sources (Air Force 1981f). The data also indicated that the magnitude of the adsorption constant on a particular sediment was dependent on the size and complexity of the dissolved hydrocarbon, the nature of the sediment, and the salinity of the water and inversely correlated with the water solubility of the dissolved hydrocarbon. Temperature and pH did not appear to have an effect on adsorption.

There are no bioconcentration data on JP-4 or JP-7; however, JP-8 was found to accumulate in flagfish exposed to concentrations ranging from 1.0 to 6.8 mg/L in the surrounding water from the egg stage to 128 days after hatching (Klein and Jenkins 1983). Similar results would be expected for JP-4 because of the similarity in composition and chemical and physical properties of these two fuels. The mean concentration of JP-8 in the whole-body tissue samples increased with increasing concentration of the water-soluble fraction (WSF) of the fuel. The bioconcentration factor (BCF), expressed as the ratio of the concentration in fish tissue to the concentration of the WSF of JP-8 in the aqueous environment, was found to be 159 (log value = 2.2). An additional experiment in adult flagfish exposed to 2.54 mg/L for a 14-day period yielded a BCF of 130 (log value = 2.1). The concentrations in liver, muscle, and whole-body tissue following the 14-day exposure were 448, 165, and 329 mglkg wet weight of tissue. Placement of the fish in uncontaminated water showed a depuration rate similar to the accumulation rate. In 14 days, whole-body tissue levels of JP-8 were reduced by about 10%. Similar experiments in rainbow trout did not show a relationship between concentrations of JP-8 in the surrounding water and the whole-body concentration in the fish. The calculated BCF for trout was only 63-112 (log value of 1.8-2.1) indicating that the WSF of JP-8 does not concentrate as readily in this species.

5.3.2 Transformation and Degradation

5.3.2.1 Air

JP-4 has been found to react photochemically in air in the presence of nitrogen oxide compounds to form ozone (Air Force 1981b, 1982e; Carter et al. 1984). The formation of ozone decreased with increasing altitude, decreasing temperature, and decreasing ultraviolet light intensity. Initial experiments suggested that the nitrous oxide oxidation rates decreased with increasing pressure and decreasing temperature. However, further tests indicated that the temperature effect may have been an artifact of the radical source used in the simulation and that the nitrous oxide oxidation rate caused by JP-4 may actually increase with altitude. Therefore, the effect of temperature on the nitrous oxide oxidation rate is uncertain. Reactions of JP-4 in the air resulted in the formation of large amounts of aerosol material (Air Force 1981b).

5.3.2.2 Water

Data on the biodegradation of JP-4 components are mixed. Evidence from experiments using the WSF of JP-4 and water from three different natural sources (a pristine salt water marsh, a polluted brackish bay, and a pristine freshwater river) did not show any biodegradation (Air Force 1983f; EPA 1985). The authors of these studies attributed this to the rapid evaporation of the components from the water. In quiescent tests on the WSF of JP-4, biodegradation was observed in several flasks, but different results were obtained with water and/or sediment from different sources. In most tests, ethylbenzene, trimethylbenzene, and 1,4-dimethylethylbenzene were degraded. Benzene, cyclohexane, and toluene seemed to be more resistant to biodegradation. When the sample flasks were vigorously shaken to enhance hydrocarbon-sediment interactions, evidence of biodegradation of some of the component hydrocarbons was observed. In general, the more substituted benzenes (e.g., p-xylene, ethylbenzene, methylethylbenzene, trimethylbenzene) and less volatile hydrocarbons seemed to be biodegraded. Some components were also biodegraded in similarly shaken, water-only flasks. There were some differences in biodegradation among the three water samples used, and biodegradation could not be detected in the polluted bay water. The variable results obtained with the three water sources, varying conditions, and inclusion or exclusion of sediment make it difficult to assess the relative importance of biodegradation of jet fuel in water. It is apparent, ‘however, that biodegradation of at least some of the JP-4 hydrocarbons does occur. Sediment appeared to decrease biodegradation. Similar experiments using water from the same three sources supported evidence that biodegradation of JP-4 component hydrocarbons did occur (Air Force 1988b). Disappearance of hydrocarbons from the experimental flasks was compared to sterile flasks containing the same type of water or water/sediment. Measurement of biodegradation rates was difficult to determine because evaporation rates were so rapid. However, some differences between experimental and control flasks were observed and inclusion of selected radiolabeled hydrocarbons supported the assertion that biodegradation did occur and could play a role in removal of JP-4 hydrocarbons from aquatic systems, particularly under conditions that reduce volatility.

A comparison of field and laboratory data obtained from experiments on natural sediment dosed with JP-4 suggested that biodegradation did not occur in the field (Air Force 1987b). This was in contrast to laboratory data with the same sediment in which biodegradation was observed. The study authors determined that the conflicting results indicated that laboratory tests (quiescent bottles and plexiglass trays) were not good predictors of field behavior of JP-4 and its components. Studies of shallow water aquifers contaminated with JP-4 indicate that the mixture does not inhibit microbial activity and that selective aerobic biodegradation of component hydrocarbons may occur (Aelion and Bradley 1991). Results indicated that biodegradation might be limited by the available nitrogen in the ecosystem. Samples from a contaminated aquifer have also been shown to degrade aromatic JP-4 components under denitrifying (anaerobic) conditions, although at a very low rate (Hutchins et al. 1991).

5.3.2.3 Sediment and Soil

Considerable evidence exists to indicate that jet fuel is biodegraded in the soil. This is not unexpected since several components of jet fuel are known to be degraded by soil microorganisms. Application of shale-derived JP-4 to model soil core ecosystems resulted in increased production of carbon dioxide in the system (Air Force 1981e, 1982c). Increased activity following addition of JP-4 to soil has been associated with increased microbial growth and decreased hydrocarbon residues (Song and Bartha 1990; Wang and Bartha 1990). The likely reason for this increase was increased activity of microorganisms that use the JP-4 component hydrocarbons. Laboratory comparisons of soil contaminated with JP-4 and uncontaminated soil showed that both degraded JP-4 hydrocarbons under aerobic conditions when nitrogen, phosphorus, and trace minerals were added (Yong and Mourato 1987). The uncontaminated soil had a lag time before biodegradation was initiated, whereas the contaminated soil showed immediate initiation of biodegradation. These data indicate the importance of microbial adaptation to biological breakdown of jet fuel in soil. Additional experiments in nonaerated soils showed that biodegradation of JP-4 hydrocarbons occurred under these conditions but was considerably reduced compared to degradation in aerated soils. Other studies have supported the evidence that most JP-4 degradation is aerobic (Song and Bartha 1990). In these experiments, decreased biodegradation in subsurface soils was associated with decreased oxygen. Model soil core ecosystems composed of contaminated soil taken from the site of a JP-4 spill were tested for biodegradation under a range of soil and water content conditions (Coho 1990). Two columns were vented with a mix of oxygen and nitrogen, and a control column was vented with nitrogen only. The venting rates were kept low to reduce losses through volatilization. An average of 44% of the original mass of JP-4 present in the soil (3,560 mg/kg moist soil; 4,590 mg/kg dry soil) was removed over the Sl-89-day experimental period. Biodegradation accounted for 93% of the total removed and volatilization accounted for 7%. The maximum rate of biodegradation, 14.3 mg/kg moist soil/day, occurred at a soil/water content of 72% saturation. The average rate of degradation due to microbial activity was about 10.6 mg/kg moist soil/day. Biodegradation of JP-4 has also been shown to be affected by soil type, temperature, and jet fuel concentration (Song et al. 1990). Biodegradation was greater in clay soil than sand or loam. The optimum temperature was 27 °C, with decreased degradation at higher and lower temperatures. The half-life of JP-4 in clay at 27 ºC was 3.5 weeks. Bioremediation treatment to increase the oxygen and mineral content of the soil decreased the half-life to 1.7 weeks. Some products of JP-4 metabolism appeared to be inhibitory to the microbiota, resulting in slightly decreased biodegradation rates at higher fuel concentrations (Song and Bartha 1990). At a concentration of 50 mg/g dry soil, 85% of the JP-4 had disappeared in 4 weeks, and with a concentration of 135 mg/g dry soil, 75% was degraded in 4 weeks. The components of JP-4 fuel found to be biodegradable in soil were tridecane, tetradecane and pentadecane, but undecane, dodecane and hexadecane were resistant to aerobic biodegradation (Dean-Ross 1993). Although anaerobic biodegradation of components in JP-4 fuel is slower than aerobic biodegradation, anaerobic biodegradation of JP-4 fuel was observed in sediments. The carbon mineralization rate was most favorable at an added nitrate concentration of approximately 1 mmol and a pH of 6-7 (Bradley et al. 1992).

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

JP-4 and JP-7 consist of various hydrocarbon components such as benzene, toluene, and xylene. These components can be measured in high concentrations in air, water, and soil.

5.4.1 Air

JP-4 and JP-7 enter the atmosphere through various mechanisms such as evaporation of spills, vaporization in loading and unloading operations, and burning in engines. JP-4 was detected in samples in a closed aircraft shelter that housed F-4 aircraft (Air Force 1981h). The JP-4 concentrations in the air ranged from 533 mg/m^3 (in the area of the shelter) to 1,160 mg/m^3 (in the vicinity of the refueler technician).

5.4.2 Water

Between 1986 and 1988, a hydrocarbon plume of JP-4 was discovered floating on the water table at the Federal Aviation Administration (FAA) Technical Center (Atlantic County, New Jersey) after JP-4 fuel contamination was discovered (EPA 1990b). The organic contaminants benzene, toluene, and naphthalene (identical to the components in jet fuel) were detected in groundwater samples at concentrations of 4,000, 3,100, and 1,000 ppb, respectively. The total volume of jet fuel-contaminated groundwater at the site was estimated to be 13.3 million gallons. In October of 1975, JP-4 was detected in water samples taken from the Defense Fuel Supply Center (Charleston, South Carolina) at a depth of 15 feet and at distances of 2.5 feet, 40 feet, and 50 feet from an 83,000-gallon fuel spill (Talts et al. 1977). From a distance of 25 feet, pure fuel was measured, while a concentration of 33 μg/mL was measured at 40 feet, and 22 μg/mL was measured at 50 feet.

Groundwater contamination was reported in East Bay Township, Michigan, in the vicinity of a U.S. Coast Guard Air Station (Twenter et al. 1985). The amount of toluene detected in groundwater samples was 74 μg/L. This concentration may possibly be attributed to JP-4 contamination, although there were many other organics used on the base that could be sources of major groundwater contamination.

5.4.3 Soil

JP-4 as determined by total hydrocarbons in soil samples was detected at Robins Air Force Base (Georgia) at a depth of 1 meter in the soil around the site of a 20-year-old JP-4 spill; concentrations ranged from <0.1 µg/L at an approximate distance of 90 meters from the spill site to 180,000 µg/L within the vicinity of the fuel spill (EPA 1988a). Soil gas samples taken at 2 meters revealed a concentration ranging from <0.05 µg/L at an approximate distance of 50 meters from the fuel spill to a concentration of 310,000 µg/L in the vicinity of the fuel spill. Soil contamination of JP-4 hydrocarbons was also measured at the FAA Technical Center (Atlantic County, New Jersey); the maximum petroleum hydrocarbon concentration detected in surface soils was 284 ppm and the maximum concentration in subsurface soils was 18,500 ppm (EPA 1990b).

5.4.4 Other Environmental Media

No data were located that discussed concentrations of JP-4 or JP-7 in other environmental media such as food, fish and shellfish, or terrestrial plants and animals.

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The National Occupational Exposure Survey, conducted by NIOSH between 1981 and 1983, estimated that 4,866 employees were exposed to JP-4 in the workplace (NOES 1990). No workplace exposure data were available for JP-7.

General population exposure to JP-4 and JP-7 is likely. However, exposure would be limited to populations living on or near Air Force bases where JP-4 and JP-7 are used in aircraft. These populations could be exposed to JP-4 and JP-7 from hydrocarbon release into air from aircraft or groundwater contaminated with spilled JP-4 or JP-7.

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Air Force base workers engaged in fuel cell maintenance operations such as defueling and fueling aircraft and cleaning jet fuel spills are exposed to higher levels of JP-4 and JP-7 than those to which the general population is exposed (Bishop 1982). Other workers that are exposed to higher levels of JP-4 and JP-7 than the general population are component testers, engine testers, and mechanics (Knave et al. 1978). Maintenance workers who monitor fuel storage tanks may be exposed to jet fuels by inhalation or dermal exposure to draining water (due to condensation) from the fuel tanks (NIOSH 1989). Potentially high exposure through inhalation and dermal route may also occur for workers in petroleum plants that manufacture JP-4 and JP-7. Populations living on or very near Air Force bases, populations living near hazardous waste disposal sites for JP-4 and JP-7, and populations exposed as a result of spills and leaks that may occur during storage, transfer, and use of the these jet fuels are potentially exposed to higher levels of JP-4 and JP-7 than those to which the general population is exposed. However, data correlating the levels of these fuels or their biomarkers in body tissues and fluids (e.g., blood) with levels of exposure among these groups of population were not located.

Military pilots have a potentially higher risk of exposure to JP-4 and JP-7 than the general population. The concentration of JP-4 vapors sampled from the cockpit of an F-4 was 1,110 mg/m3 (Air Force 1981h).

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of JP-4 and JP-7 is available. Where adequate information is not available, ATSDR, in conjunction with NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of JP-4 and JP-7.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met, would reduce or eliminate the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda may be proposed.

5.7.1 Identification of Data Needs

Physical and Chemical Properties. The values for many of the physicochemical parameters (e.g., K_{ow} K_{oc} and Henry's law constants) needed to model the fate and transport processes of JP-4 and JP-7 in the environment have not been determined. However, since these fuels are complex mixtures of hydrocarbons with small amounts of non-hydrocarbon additives, their behavior in the environment is determined by both the characteristics of the mixture and the characteristics of the individual components, making modeling based on physical and chemical properties difficult.

Production, Import/Export, Use, and Release and Disposal. Current production and import/export data are lacking and would aid in determining how pervasive the risk of exposure to JP-4 and JP-7 is to the general population. The uses of JP-4 and JP-7 are restricted to military aircraft (Air Force 1989b; IARC 1989). The primary releases to the environment come from in-flight jettisoning of fuel and from leaks and spills during storage, transfer, and use (IARC 1989; Talts et al. 1977; Twenter et al. 1985). Several disposal methods have been proposed, tested, and/or used (Elliot and DePaoli 1990; EPA 1990b; NIOSH 1989). However, data are needed on the risk posed by past disposal methods and improper disposal of the fuels.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1992, became available in May of 1994. This database will be updated yearly and should provide a list of industrial production facilities and emissions. However, since JP-4 and JP-7 are not reported under SARA Section 313, there are no data in the TRI.

Environmental Fate. The environmental fate of JP-4 has been studied extensively by the Air Force, EPA, and independent researchers. No data were located on the environmental fate of JP-7, although it can be assumed to behave in a manner similar to JP-4. Most JP-4 jettisoned in the atmosphere probably reacts photochemically to form ozone and particulates (Air Force 1981b, 1981e). Some of the fuel components or reactant products are probably transported by wind currents. The primary fate process for JP-4 in water is volatilization, although some biodegradation and partitioning to sediment may occur (Air Force 1983f, 1988b; EPA 1985). The primary fate process for JP-4 spilled to soil is biodegradation (Air Force 1982c; Coho 1990; Song and Bartha 1990). A small fraction is likely to volatilize and some components may bind to soil particles. JP-4 that spills or leaks to soil migrates both horizontally and vertically, but that migration does not seem to be due primarily to leaching. Information on the degradation products of some of the components of JP-4 and JP-7 may be found in ATSDR profiles on benzene (ATSDR 1991a), toluene (ATSDR 1990), total xylenes (ATSDR 1991c), and polycyclic aromatic hydrocarbons (ATSDR 1991b). Components of jet fuel that migrate through the soil may contaminate groundwater (EPA 1990b; Talts et al. 1977). More information on chemical and light-mediated reactions of jet fuel components would help in assessing the persistence of jet fuel hydrocarbons in water and soil. In addition, more studies on the environmental fate of jet fuel under various water and soil conditions might provide insight into the variations in the fate of components that have been found under varying environmental conditions. Specifically, data pertaining to the interaction of JP-4 or JP-7 with various types of soils, including clays, sands, and mixtures would be useful, in order to determine horizontal and vertical migration patterns for assessing groundwater contamination in the vicinity of Air Force bases and hazardous waste sites. This information could also help in determining which jet fuel components persist in the environment and under what conditions.

Bioavailability from Environmental Media. There are no data on the absorption of JP-4 or JP-7 by the inhalation, oral, or dermal routes. However, several of the components of these fuels are known to be absorbed. For more information on absorption of individual components (e.g., benzene, xylene, toluene), see the ATSDR toxicological profiles on these compounds.

Food Chain Bioaccumulation. There are no data on the bioaccumulation or biomagnification of JP-4 or JP-7 in plants, aquatic organisms, or animals. Studies on the bioaccumulation of JP-4 and JP-7 are needed for plants, animals, and aquatic organisms, especially shellfish which, historically, have exhibited sensitivity to hydrocarbons. Data on a similar jet fuel, JP-8, suggest that bioaccumulation and biomagnification are low (Klein and Jenkins 1983). The mixtures are expected to separate into the individual components in the environment and these components are expected behave independently and differently in terms of their ability to accumulate in the food chain. For information on the bioaccumulation of the different components of JP-4 and JP-7 (e.g., benzene, xylene, toluene, ethylbenzene), see the ATSDR toxicological profiles for these compounds.

Exposure Levels in Environmental Media. Some information exists on the levels of JP-4 and JP-7 in the air in closed buildings where the fuel is used (Air Force 1981h). Limited information was also located on levels in water and soil following spills or leaks (EPA 1988a, 1990b; Talts et al. 1977). No data were located on levels of jet fuels or component hydrocarbons in food, fish and shellfish, or terrestrial animals and plants. More data on levels in all environmental media are needed to fully assess the extent of exposure for populations with a high probability of exposure to jet fuels or their component hydrocarbons.

Exposure Levels in Humans. Certain populations are known to have a higher risk of exposure to JP-4, JP-7, and/or their component hydrocarbons. These are workers who manufacture or use the fuel; people living or working on Air Force bases where the fuel is stored and used; and populations living or working in the vicinity of a spill, leak, or dump site (Air Force 1981h; Bishop 1982; NIOSH 1989). More data are needed to assess the approximate levels of intermediate and chronic exposure for these populations.

Exposure Registries. No exposure registries for JP-4 and JP-7 were located. Components of JP-4 and JP-7 will be considered for inclusion in the National Exposure Registry in the future. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to these compounds.

5.7.2 Ongoing Studies

Investigations into the bioremediation of sites contaminated with jet fuels are providing information on the biodegradation of these compounds. Bioremediation studies are being conducted by the Department of the Interior, U.S. Geological Survey at a spill site in Charleston, South Carolina (FEDRIP 1994).

As part of the Third National Health and Nutrition Evaluation Survey (NHANES III), the Environmental Health Laboratory Sciences Division of the Center for Environmental Health and Injury Control, Centers for Disease Control and Prevention, will be analyzing human blood samples for certain components of JP-4 and JP-7 and other volatile organic compounds. These data will give an indication of the frequency of occurrence and background levels of these compounds in the general population.