ENVIRONMENTAL CONTAMINANTS ENCYCLOPEDIA

JET FUEL, GENERAL ENTRY

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COMPILERS/EDITORS:

ROY J. IRWIN, NATIONAL PARK SERVICE

WITH ASSISTANCE FROM COLORADO STATE UNIVERSITY
STUDENT ASSISTANT CONTAMINANTS SPECIALISTS:

MARK VAN MOUWERIK
LYNETTE STEVENS
MARION DUBLER SEESE
WENDY BASHAM

NATIONAL PARK SERVICE
WATER RESOURCES DIVISIONS, WATER OPERATIONS BRANCH
1201 Oakridge Drive, Suite 250
FORT COLLINS, COLORADO 80525

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Like a library or most large databases (such as EPA's national STORET water quality database), this document contains information of variable quality from very diverse sources. In compiling this document, mistakes were found in peer reviewed journal articles, as well as in databases with relatively elaborate quality control mechanisms [366,649,940]. A few of these were caught and marked with a "[sic]" notation, but undoubtedly others slipped through. The [sic] notation was inserted by the editors to indicate information or spelling that seemed wrong or misleading, but which was nevertheless cited verbatim rather than arbitrarily changing what the author said.

Most likely additional transcription errors and typos have been added in some of our efforts. Furthermore, with such complex subject matter, it is not always easy to determine what is correct and what is incorrect, especially with the "experts" often disagreeing. It is not uncommon in scientific research for two different researchers to come up with different results which lead them to different conclusions. In compiling the Encyclopedia, the editors did not try to resolve such conflicts, but rather simply reported it all.

It should be kept in mind that data comparability is a major problem in environmental toxicology since laboratory and field methods are constantly changing and since there are so many different "standard methods" published by EPA, other federal agencies, state agencies, and various private groups. What some laboratory and field investigators actually do for standard operating practice is often a unique combination of various standard protocols and impromptu "improvements." In fact, the interagency task force on water methods concluded that [1014]:

> It is the exception rather than the rule that water-quality monitoring data from different programs or time periods can be compared on a scientifically sound basis, and that...
>
> No nationally accepted standard definitions exist for water quality parameters. The different organizations may collect data using identical or standard methods, but identify them by different names, or use the same names for data collected by different methods [1014].

Differences in field and laboratory methods are also major issues related to (the lack of) data comparability from media other than water: soil, sediments, tissues, and air.

In spite of numerous problems and complexities, knowledge is often power in decisions related to chemical contamination. It is therefore often helpful to be aware of a broad universe of conflicting results or conflicting expert opinions rather than having a portion of this information arbitrarily censored by someone else. Frequently one wants to know of the existence of information, even if one later decides not to use it for a particular application. Many would like to see a high percentage of the information available and decide for themselves what to throw out, partly because they don't want to seem uniformed or be caught by surprise by potentially important information. They are in a better position if they can say: "I knew about that data, assessed it based on the following quality assurance criteria, and decided not to use it for this application." This is especially true for users near the end of long decision processes, such as hazardous site cleanups, lengthy ecological risk assessments, or complex natural resource damage assessments.

For some categories, the editors found no information and inserted the phrase "no information found." This does not necessarily mean that no information exists; it simply means that during our efforts, the editors found none. For many topics, there is probably information "out there" that is not in the Encyclopedia. The more time that passes without encyclopedia updates (none are planned at the moment), the more true this statement will become. Still, the Encyclopedia is unique in that it contains broad ecotoxicology information from more sources than many other reference documents. No updates of this document are currently planned. However, it is hoped that most of the information in the encyclopedia will be useful for some time to come even with out updates, just as one can still find information in the 1972 EPA Blue Book [12] that does not seem well summarized anywhere else.

Although the editors of this document have done their best in the limited time available to insure accuracy of quotes or summaries as being "what the original author said," the proposed interagency funding of a bigger project with more elaborate peer review and quality control steps never materialized.

> The bottom line: The editors hope users find this document useful, but don't expect or depend on perfection herein. Neither the U.S. Government nor the National Park Service make any claims that this document is free of mistakes.

The following is one chemical topic entry (one file among 118). Before utilizing this entry, the reader is strongly encouraged to read the README file (in this subdirectory) for an introduction, an explanation of how to use this document in general, an explanation of how to search for power key section headings, an explanation of the organization of each entry, an information quality discussion, a discussion of copyright issues, and a listing of other entries (other topics) covered.

See the separate file entitled REFERENC for the identity of numbered references in brackets.

HOW TO CITE THIS DOCUMENT: As mentioned above, for critical applications it is better to obtain and cite the original publication after first verifying various data quality assurance concerns. For more routine applications, this document may be cited as:

> **Irwin, R.J., M. VanMouwerik, L. Stevens, M.D. Seese**, and **W. Basham.** 1997. Environmental Contaminants Encyclopedia. National Park Service, Water Resources Division, Fort Collins, Colorado. Distributed within the Federal Government as an Electronic Document (Projected public availability

on the internet or NTIS: 1998).

Jet Fuel, General

Brief Introduction/overview:

Br.Class: General Introduction and Classification Information:

Jet fuels, or turbine fuels, are one of the primary fuels for internal combustion engines worldwide, and are the most widely available aviation fuel [743]. Jet fuels are forms of fuel oils. "JP" stands for "jet propulsion." The classification jet fuel is applied to fuels meeting the required properties for use in jet engines and aircraft turbine engines.

Jet Fuel 1 (JP-1) is the same thing as kerosene or Fuel Oil No. 1; Fuel Oil 1 is the same thing as Diesel 1 except for additives. See also Kerosene, Fuel Oil 1, and Diesel 1 entries.

Because of its availability compared to gasoline during wartime, commercial illuminating kerosene was the fuel chosen for early jet engines. Consequently, the development of commercial jet aircraft following World War II centered primarily on the use of kerosene-type fuels [747].

Many commercial jet fuels have basically the same composition as kerosene, but they are under more stringent specifications than those for kerosene. Other commercial and military jet fuels, such as jet B and JP-4, are referred to as wide-cut fuels and are usually made by blending kerosene fractions with lower boiling streams, such as the gasoline and naphtha fractions, to include more volatile hydrocarbons [747].

Different types of engines used for different types of service require fuels with specific chemical and physical properties, and individual specifications have evolved to meet these needs [747]. Therefore, there are several categories of jet fuels (please see the Forms/Preparations/Formulations section below, as well as individual entries starting with "Jet Fuel," for details). The most prevalent turbine fuels are: Jet-A and Jet A-1, used for commercial and general aviation; JP-4, the standard fuel of the US Air Force and Army Aviation; and JP-5, the naval equivalent of JP-4 [743]. Naval aircraft have somewhat different requirements from those for land-based planes, such as less volatility and higher flash points, in order to minimize vapor exposure of personnel as well as reduce fire risk in enclosed areas below decks [747]. JP-8 is a new fuel proposed as the standard for all military vehicles using turbine engines [743]. A recent development with the North Atlantic Treaty Organization (NATO) forces in Europe has been the decision to convert miliary aircraft fuel completely from JP-4 to JP-8 kerosene fuel. The schedule was to be completed by 1990 [747].

According to the US Coast Guard Emergency Response Notification System (ERNS), jet fuels JP-1 (kerosene), JP-4, and JP-5 are among the top spilled petroleum products in the United States [635].

In terms of refining crude oil, jet fuels are middle distillates. The middle distillates include kerosene, aviation fuels, diesel fuels, and fuel oil #1 and 2. These fuels contain paraffins (alkenes), cycloparaffins (cycloalkanes), aromatics, and olefins from approximately C9 to C20. Aromatic compounds of concern included alkylbenzenes, toluene, naphthalenes, and polycyclic aromatic hydrocarbons (PAHs). Compositions range from avgas and JP-4, which are similar to gasoline, to Jet A and JP-8, which are kerosene-based fuels. JP-4 and JP-5 are volatile, complex mixtures of aliphatic and aromatic hydrocarbons and are principally used in military aircraft. The volatility means that inhalation exposure is a potential problem near fueling facilities, either from spills or leaks. Once the soil has become saturated, remedial activities create both fire and inhalation hazards. Toxic effects are similar to those described for gasoline. Chronic effects associated with middle distillates are mainly due to exposure to aromatic compounds, which are found primarily in JP-4 and JP-5 [661].

JP-4 and JP-7 are U.S Air Force fuels which contain many of the same hydrocarbons and additives [876]. JP-7 is a high flash point special kerosene used in advanced supersonic aircraft [560].

Br.Haz: General Hazard/Toxicity Summary:

Jet fuel can be directly toxic to some forms of aquatic life, can coat birds, and is of concern as a potential source of PAHs, a potentially harmful class of aromatic hydrocarbons (see "PAHs as a group" entry). Concerning toxicity testing, jet fuels tend to be less explosive and less volatile than gasoline, making the materials easier and safer to use. Also, because of their use as aviation fuel, turbine fuels are produced to stringent specifications designed to ensure safety of flight [743]. For example, high-altitude flying requires fuel with a very low freezing-point; also, the fuel must be extremely clean (free of foreign matter), have a very low moisture content, burn cleanly (essentially free of smoke) and not cause corrosion of engine parts in prolonged service [747]. Therefore, the overall general properties of these materials are tightly controlled. However, like all petroleum products, the exact identity of the constituents varies according to the original crude and the refining process [743].

Short-term hazards of the some of the lighter, more volatile and water soluble compounds (such as benzene compounds and toluene) in jet fuels include potential acute toxicity to aquatic life in the water column (especially in relatively confined areas) as well as potential inhalation hazards. Jet fuels have moderate volatility and moderate solubility [777]. Jet fuels possess moderate to high acute toxicity to biota with product-specific toxicity related to the type and concentration of aromatic compounds [777]. Jet fuel spills could result in potential acute toxicity to some forms of aquatic life. Oil coating of birds, sea otters, or other aquatic life which come in direct contact with the spilled oil is another potential short term hazard. Some of the same compounds found in gasoline are also found in jet fuels. As might be expected, there is therefore some overlap between the toxic effects potentially resulting from jet fuel spills and gasoline spills (see Gasoline, General entry). In the short term, spilled oil will tend to float on the surface; water uses threatened by spills include: recreation; fisheries; industrial, potable supply; and irrigation [608].

Long-term potential hazards of the some of the lighter, more volatile and water soluble compounds (such as benzenes, toluene, xylenes) in jet fuels would include contamination of groundwater. Long-term water uses threatened by spills include potable (ground) water supply.

Long-term effects are also associated with PAHs, alkyl PAHs, and alkyl benzene (such as xylene) constituents of jet fuel. Although PAHs, particularly heavy PAHs, do not make up a large percentage of jet fuels by weight, there are some PAHs in jet fuels, including naphthalene and alkyl naphthalenes [636,744]. Due to their relative persistence and potential for various chronic effects, PAHs (and particularly the alkyl PAHs) can contribute to long term (chronic) hazards of jet fuels in contaminated soils, sediments, and groundwaters. Chronic effects of some of the constituents in jet fuel (benzene, toluene, xylene, naphthalenes, alkyl benzenes, and various alkyl PAHs) include changes in the liver and harmful effects on the kidneys, heart, lungs, and nervous system. Increased rates of cancer, immunological, reproductive, fetotoxic, genotoxic effects have also been associated with some of the compounds found in jet fuel (see entries on individual compounds for more details).

> Further detail on potential risks for PAHs in this product: Acute toxicity is rarely reported in humans, fish, or wildlife, as a result of exposure to low levels of a single PAH compound. PAHs in general are more frequently associated with chronic risks. These risks include cancer and often are the result of exposures to complex mixtures of chronic-risk aromatics (such as PAHs, alkyl PAHs, benzenes, and alkyl benzenes), rather than exposures to low levels of a single compound. This product is an example of such a complex mixture (Roy Irwin, National Park Service, Personal Communication, 1996, based on an overview of literature on hand). See also: PAHs as a group entry.

Exposure to jet fuel vapors has been reported to cause neurobehavioral symptoms, including dizziness, headache, nausea and fatigue [747].

One source states that methylcyclohexane may be one of the more toxic components of jet fuel [606]. This compound (cyclohexane, methyl, also known as toluene hexahydride, CAS# 108-87-2) can account for 2-16% of jet fuel 4 by weight [636,744].

Some of the PAHs in this product can move into plants and some have either harmful or positive effects on plants (see PAHs as a group entry).

Many of the PAHs found in this product (see Chem.Detail section below) are phototoxic, that is they display greatly enhanced toxicity in sunlight or other UV source than elsewhere (see PAHs as a group entry).

JP-4 and JP-7 are U.S Air Force fuels which are similar enough to pose many of the same hazards to humans [876].

Additional human health issues related to this topic have been summarized by ATSDR in the toxicity profile for kerosene (JP-1) [962] and the profile for JP-4 and JP-7 [876]. Due to lack of time, important highlights from these ATSDR documents have not yet been completely incorporated into this entry.

> Editor's note: synonyms for Jet Fuels can be confusing and are sometimes incorrect in the literature; for example, JP-5 is given as an exact synonym for kerosene and Fuel Oil 1 in ATSDR [962], but this is not 100% correct (see Kerosene entry). It is more precise to say that Jet fuel 5 (JP-5) is

one particular form of no. 1 fuel oil [635]. JP-1 is kerosene, while JP-5 is a specially refined kerosene, a high flash point kerosene [560]. Nevertheless, the products are similar enough that the reader is encouraged to read the entries of products similar to the one being researched.

Br.Car: Brief Summary of Carcinogenicity/Cancer Information:

There is inadequate evidence for carcinogenicity in humans or experimental animals as a result of exposure to jet fuel. There is limited evidence for carcinogenicity in experimental animals due to straight-run kerosene and/or hydrotreated kerosene [747].

Distillate fuel oils are not classifiable as to the carcinogenicity to humans [747]. However, certain carcinogenic effects have been associated with benzene and (possibly) some of the other compounds found in jet fuel [609,766,767] (see entries on individual compounds for more details).

The debates on which PAHs, alkyl PAHs, and other aromatics typically in complex mixtures (such as this product) to classify as carcinogens, and the details of exactly how to perform both ecological and human risk assessments on such complex mixtures, are likely to continue. There are some clearly wrong ways to go about it, but defining clearly right ways is more difficult. Perhaps the most unambiguous thing that can be said about complex mixtures of PAHs, alkyl PAHs, and benzenes, is that such mixtures are often carcinogenic and possibly phototoxic. One way to approach site specific risk assessments would be to collect the complex mixture of PAHs and other lipophilic contaminants in a semipermeable membrane device (SPMD, also known as a fat bag) [894,895,896], retrieve the contaminant mixture from the SPMD, then test the mixture for carcinogenicity, general toxicity, phototoxicity, and other hazards (James Huckins, National Biological Service, and Roy Irwin, National Park Service, personal communication, 1996).

Additional human health issues related to this topic have been summarized by ATSDR in the toxicity profile for kerosene (JP-1) [962] and the profile for JP-4 and JP-7 [876].

See Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.
See also: PAHs as a group entry.

Br.Dev: Brief Summary of Developmental, Reproductive, Endocrine and Genotoxicity Information:

The results are mixed, but some immunological, reproductive, fetotoxic, and genotoxic effects have been associated with a few of the compounds found in jet fuel [609,764,765,766,767] (see entries on individual compounds for more details).

Additional human health issues related to this topic have been summarized by ATSDR in the toxicity profile for kerosene (JP-1) [962] and the profile for JP-4 and JP-7 [876].

See Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.
See also: PAHs as a group entry.

Br.Fate: Brief Summary of Key Bioconcentration, Fate, Transport, Persistence, Pathway and Chemical/Physical Information:

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 [876]. 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 [876].

Some fuel additives may contribute to environmental problems. In the past, additives containing lead were documented [608].

Jet fuel may be released to the environment by in-flight jettisoning of fuel and from spills or leaks to soil or water [876]. 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 aromatics--benzene, toluene, and xylene). Under turbulent water conditions, the more soluble hydrocarbons remain dissolved longer and may partition to sediment or be biodegraded [876]. 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 [876].

Jet fuels and diesels are middle distillate petroleum hydrocarbon products of intermediate volatility and mobility [661]. As intermediate products, jet fuels have a combination of (mostly) lighter, less persistent and more mobile compounds as well as (some) heavier, more persistent and less mobile compounds. These two different groups are associated with two distinctly different patterns of fate/pathway concerns:

> The relatively lighter, more volatile, mobile, and water soluble compounds in jet fuels will tend to fairly quickly evaporate into the atmosphere or migrate to groundwater. When exposed to oxygen and sunlight, most of these compounds will tend to break down relatively quickly. However, in groundwater, many of these compounds tend to be more persistent than in surface water, and readily partition on an equilibria basis back and forth between water and solids (soil and sediment) media. Cleaning up groundwater without cleaning up soil contamination will usually result in a rebound of higher concentrations of these compounds partitioning from contaminated soils into groundwater (Roy Irwin, personal communication).
>
> The compounds in jet fuel which will tend to be somewhat more persistent and more bound to solids particles will include the PAHs, alkyl PAHs, and alkyl benzenes. Higher concentrations of heavier PAHs will tend to be in adjacent contaminated soils than in groundwater, but cleaning up groundwater without cleaning up soil contamination will nevertheless usually result in at least some rebound of higher concentrations of these compounds partitioning from contaminated soils into groundwater (Roy Irwin, personal communication).

Concerning clean-up issues, jet fuels in general fall between two categories (that is, "Very Light Oils" for wide-cut jet fuels such as JP-4, and "Diesel-like Products" for kerosene-based jet fuels such as jet fuel A and JP-8). The following groupings are used by NOAA to identify basic cleanup options [741,771,777]:

The variability in the composition of jet fuels 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 [876].

Gasoline Products (Very Light Oils):

- -Highly volatile.
- -Evaporates quickly, often completely within 1 to 2 days.
- -Highly soluble.
- -Narrow cut fraction with no residue.
- -Low viscosity, spreads rapidly to a thin sheen.
- -High acute toxicity to biota.
- -Do not emulsify.
- -Will penetrate substrate; nonadhesive.

Diesel-like Products and Light Crudes (Jet Fuels, Diesel, No. 2 Fuel Oil, Kerosene, West Texas Crude):

- -Moderately volatile.
- -Refined products can evaporate with no residue.
- -Light crude will leave residue (up to one-third of spill amount) after a few days.
- -Moderately soluble, especially distilled products.
- -Low and moderate viscosity; spread rapidly into thin slicks.
- -Can form stable emulsions.
- -Moderate to high acute toxicity to biota; product-specific toxicity related to type and concentration of aromatic compounds.
- -Will "oil" intertidal resources with long-term contamination potential.
- -Has potential for subtidal impacts (dissolution, mixing, sorption onto suspended sediments).
- -Tend to penetrate substrate; fresh spills are not adhesive.
- -Stranded light crudes tends to smother organisms.
- -No dispersion necessary.
- -Cleanup can be very effective.

Additional information on this topic has been summarized by ATSDR in the toxicity profile for kerosene (JP-1) [962] and the profile for JP-4 and JP-7 [876].

See Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture. See also: PAHs as a group entry.

Synonyms/Substance Identification:

See Br.Class section above and Forms/Preparations section below. Editor's note: synonyms for Jet Fuels can be confusing and are sometimes incorrect in the literature; for example, JP-5 is given as an exact synonym for kerosene and Fuel Oil 1 in ATSDR [962], but this is not 100% correct (see Kerosene entry). It is more precise to say that Jet fuel 5 (JP-5) is one particular form of no. 1 fuel oil [635]. JP-1 is kerosene, while JP-5 is a specially refined kerosene, a high flash point kerosene [560].

Associated Chemicals or Topics (Includes Transformation Products):

See also individual entries:

- Kerosene (Fuel Oil No. 1, JP-1)
- Jet Fuel A
- Jet Fuel 4
- Jet Fuel 5
- Jet Fuel 8
- Petroleum, General
- Oil Spills
- Naphthalene
- Methyl Naphthalenes (various entries)
- Xylenes, Total
- Benzene
- Toluene
- Ethylbenzene
- PAHs as a group

Jet Fuel 1 (JP-1) is an exact synonym for kerosene according to several sources [366,367,560].

> NOTE: Discrimination between fuel oil no. 1, jet fuel 1 and kerosene may be solely based on end use. Compositionally, they are often the same. For example, in the US Coast Guard CHRIS Manual [367], the only difference in the synonyms between Jet Fuel 1 and Kerosene is that kerosene also lists "illuminating oil." Therefore, if an end use is illumination, the oil product may be labeled "kerosene" or "fuel oil no. 1" whereas if the end use is jet propulsion, a similar oil product may be labeled "JP-1" or "jet fuel 1." The word "kerosene" is also used to refer to the kerosene fraction removed during the distillation of petroleum at boiling point 175 to 330 degrees C [746]. Thus, many petroleum products, including the majority of jet fuels, are labelled "kerosene-based" since they are derived from this petroleum fraction. For the purposes of this document, we are putting specific information found on either JP-1, Fuel Oil No.1, and/or kerosene under the Kerosene entry. See the Kerosene entry for more details.
>
> Editor's note: JP-5 is given as an exact synonym for

kerosene and Fuel Oil 1 in ATSDR [962], but this is not 100% correct (see Kerosene entry). It is more precise to say that Jet fuel 5 (JP-5) is one particular form of no. 1 fuel oil [635]. JP-1 is kerosene, while JP-5 is a specially refined kerosene, a high flash point kerosene [560].

Site Assessment-Related Information Provided by Shineldecker (Potential Site-Specific Contaminants that May be Associated with a Property Based on Current or Historical Use of the Property) [490]:

Raw Materials, Intermediate Products, Final Products, and Waste Products Generated During Manufacture and Use:

- Benzene
- Ethyl benzene
- Hydrazine and derivatives
- Mercaptans
- Polynuclear aromatic hydrocarbons
- Toluene
- Xylenes

Water Data Interpretation, Concentrations and Toxicity (All Water Data Subsections Start with "W."):

W.Low (Water Concentrations Considered Low):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.High (Water Concentrations Considered High):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Typical (Water Concentrations Considered Typical):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Concern Levels, Water Quality Criteria, LC50 Values, Water Quality Standards, Screening Levels, Dose/Response Data, and Other Water Benchmarks:

W.General (General Water Quality Standards, Criteria, and Benchmarks Related to Protection of Aquatic Biota in

General; Includes Water Concentrations Versus Mixed or General Aquatic Biota):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Plants (Water Concentrations vs. Plants):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Invertebrates (Water Concentrations vs. Invertebrates):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Fish (Water Concentrations vs. Fish):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Wildlife (Water Concentrations vs. Wildlife or Domestic Animals):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Human (Drinking Water and Other Human Concern Levels):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

W.Misc. (Other Non-concentration Water Information):

In November 1976, jet propulsion fuel (JP-5) leaked from a storage tank, flooded a catchment basin and dischargeed into Ensenada Honda, Puerto Rico where 59,000 gallons of it collected in two mangrove forest areas. Petroleum hydrocarbons were not detectable in water samples collected 152 days and 328 days after the discharge [622]. Sediment samples collected at the same time (collected 152 days and 328 days after the discharge) contained low levels of residual hydrocarbons [622].

No other information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sediment Data Interpretation, Concentrations and Toxicity (All Sediment Data Subsections Start with "Sed."):

Sed.Low (Sediment Concentrations Considered Low):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.High (Sediment Concentrations Considered High):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Typical (Sediment Concentrations Considered Typical):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Concern Levels, Sediment Quality Criteria, LC50 Values, Sediment Quality Standards, Screening Levels, Dose/Response Data and Other Sediment Benchmarks:

Sed.General (General Sediment Quality Standards, Criteria, and Benchmarks Related to Protection of Aquatic Biota in General; Includes Sediment Concentrations Versus Mixed or General Aquatic Biota):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Plants (Sediment Concentrations vs. Plants):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Invertebrates (Sediment Concentrations vs. Invertebrates):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Fish (Sediment Concentrations vs. Fish):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Wildlife (Sediment Concentrations vs. Wildlife or Domestic Animals):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Human (Sediment Concentrations vs. Human):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Sed.Misc. (Other Non-concentration Sediment Information):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil Data Interpretation, Concentrations and Toxicity (All Soil Data Subsections Start with "Soil."):

Soil.Low (Soil Concentrations Considered Low):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.High (Soil Concentrations Considered High):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.Typical (Soil Concentrations Considered Typical):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.Concern Levels, Soil Quality Criteria, LC50 Values, Soil Quality Standards, Screening Levels, Dose/Response Data and Other Soil Benchmarks:

Soil.General (General Soil Quality Standards, Criteria, and Benchmarks Related to Protection of Soil-dwelling Biota in General; Includes Soil Concentrations Versus Mixed or General Soil-dwelling Biota):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.Plants (Soil Concentrations vs. Plants):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.Invertebrates (Soil Concentrations vs. Invertebrates):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.Wildlife (Soil Concentrations vs. Wildlife or Domestic Animals):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Soil.Human (Soil Concentrations vs. Human):

No information found on this complex and variable mixture. See Chem.Detail section for chemicals found in this product, then look up information on each hazardous compound. Some individual compounds found in petroleum products have low-concentration human health benchmarks for soil (see individual entries).

Soil.Misc. (Other Non-concentration Soil Information):

As of 1996, several States were considering allowing natural attenuation (the "do nothing and let nature clean up the mess through bioremediation" option) to proceed near leaking storage tanks in situations where drinking water was not being impacted and where human rather than environmental resources were the main resources in the immediate area (Roy Irwin, National Park Service, personal communication, 1996).

The trend of thinking towards natural attenuation was given a boost by a Lawrence Livermore National Laboratory (LLNL) report entitled "Recommendations to Improve the Cleanup Process for California's Leaking Underground Fuel Tanks;" which stressed the use of passive bioremediation for petroleum product contaminated soils, whenever possible, based on the relatively low number of cases where drinking water was impacted [969]. EPA has pointed out some limitations of the LLNL report, including the lack of adequate consideration of PAHs and additives such as MTBE, as well limited consideration of (non-human) exposure pathways and various geologic conditions [969].

Others would point out that petroleum product spills into soils are not necessarily a trivial environmental threat related to ecotoxicology (emphasis on living things other than humans), due to the many hazardous compounds in the product (see Chem.Detail section below).

Exposure to petroleum-source contamination in soils is predominantly of concern through a number of possible exposure pathways, including dermal contact with soil, ingestion of soil, inhalation of soil particulates, and ingestion of contaminated groundwater [824].

No other information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Tissue and Food Concentrations (All Tissue Data Interpretation Subsections Start with "Tis."):

Tis.Plants:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Plants:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

B) Body Burden Residues in Plants: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Tis.Invertebrates:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Invertebrates:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

B) Concentrations or Doses of Concern in Food Items Eaten by Invertebrates:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

C) Body Burden Residues in Invertebrates: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Tis.Fish:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Fish (Includes FDA Action Levels for Fish and Similar Benchmark Levels From Other Countries):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

B) Concentrations or Doses of Concern in Food Items Eaten by Fish:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

C) Body Burden Residues in Fish: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Tis.Wildlife: Terrestrial and Aquatic Wildlife, Domestic Animals and all Birds Whether Aquatic or not:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Wildlife, Domestic Animals, or Birds:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

B) Concentrations or Doses of Concern in Food Items Eaten by Wildlife, Birds, or Domestic Animals (Includes LD50 Values Which do not Fit Well into Other Categories, Includes Oral Doses Administered in Laboratory Experiments):

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

C) Body Burden Residues in Wildlife, Birds, or Domestic Animals: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Tis.Human:

A) Typical Concentrations in Human Food Survey Items:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

B) Concentrations or Doses of Concern in Food Items Eaten by Humans (Includes Allowable Tolerances in Human Food, FDA, State and Standards of Other Countries:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

C) Body Burden Residues in Humans: Typical, Elevated, or of Concern Related to the Well-being of Humans:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Tis.Misc. (Other Tissue Information):

In November 1976, jet propulsion fuel (JP-5) leaked from a storage tank, flooded a catchment basin and dischargeed (sic. discharged) into Ensenada Honda, Puerto Rico where 59,000 gallons of it collected in two mangrove forest areas. One of the affected areas, a mixed species assemblage of red, black, and white mangroves, was surveyed 152 days and 328 days after the discharge [622].

Aerial surveys revealed that immediately following the discharge, 5.5 ha of mangrove forest were completely defoliated and 0.8 ha were partially defoliated. There were also extensive injuries in tidal creek forest north of the principal impacted area. Seedling mortality was variable among the oiled transect stations, and appeared to be correlated with degree of exposure to open water [622].

It was conculed (sic. concluded?) that the mechanism of toxicity was direct poisoning of mangroves by the jet fuel. They proposed that recolonization of the affected mangrove forest depends on an adequate supply of new seeds in combination with acceptable growing conditions. Seeds were available from adjacent unaffected areas, and colonization was evident about one year after the discharge. A 10-year recovery was predicted under the natural recovery scenario [622].

No other information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Bio.Detail: Detailed Information on Bioconcentration, Biomagnification, or Bioavailability:

Bioconcentration information from ATSDR [876] (for information on embedded references, see ATSDR):

> 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 mg/kg 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 [876].

No other information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Interactions:

Many of the PAH compounds in jetfuel are photoxic (see PAHs entry).

No other information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Uses/Sources:

No information found; see Chem.Detail section for compounds in this product, then see individual compound entries for summaries of information on individual components of this mixture.

Forms/Preparations/Formulations:

The following summary briefly explains some of the main uses and formulations of various jet fuel products [560]. For more details, please see the individual entries:

JP-1 -- Kerosene.
JP-4 -- 65% gasoline, 35% light petroleum distillates. U.S. Air Force wide-cut aviation turbine fuel.
JP-5 -- Specially refined kerosene. A high flash point kerosene.
JP-6 -- A higher kerosene cut than JP-4 with fewer impurities.
JP-7 -- A high flash point special kerosene used in advanced supersonic aircraft.
JP-8 -- A kerosene modelled on Jet A-1 which is used in new military aircraft.
Jet Fuel A -- A petroleum distillate blended from kerosene fractions and used in civil aviation. Operational fuel for commercial turboprop and turbojet aircraft in the U.S.
Jet Fuel A-1-- A petroleum distillate blended from kerosene fractions and used in civil aviation. Jet A-1 is similar to Jet A except for a lower freezing point. Operational fuel for all turboprop and turbojet aircraft requiring a low freezing point product.
Jet Fuel B -- A wide-boiling-range petroleum distillate blended from gasoline and kerosene fractions. Operational fuel for U.S. and NATO military aircraft and for many commercial turboprop and turbojet aircraft.

Chem.Detail: Detailed Information on Bioconcentration, Biomagnification, or Bioavailability:

> NOTE: For more information on the chemical components of a particular type of jet fuel, please refer to the specific product entry as well.

Jet fuel is a mixture primarily of saturated hydrocarbons and aromatic hydrocarbons [783]. Many of the components of jet fuel are also in diesel [783]. Thin-layer chromatography (TLC) patterns for jet fuel appear to be similar to that of diesel fuel [783]. Diesel fuel contains all the PAHs and alkyl PAHs found in the NOAA expanded scan (see Diesel entries).

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 [876]. 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) [876]. Aromatics make up about 10-25% by volume of JP-4 but only about 5% of JP-7 [876]; however, the specific composition of these fuels varies among manufacturers and probably between batches [876]. 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 [876].

As stated in the introduction, PAHs (particularly heavy PAHs) do not make up a large percentage of jet fuels by weight, but there are some PAHs in jet fuels, including naphthalene and alkyl naphthalenes [636,744,747]. Since PAHs are important hazardous components of this product, risk assessments should include analyses of PAHs and alkyl PAHs utilizing the NOAA protocol expanded scan [828] or other rigorous GC/MS/SIM methods.

The basic component of kerosene used for aviation is the straight-run kerosene stream which consists of hydrocarbons with carbon numbers predominantly in the range of C9 to C16 (C4 to C16 for wide-cut fuels) and which boil at approximately 150 to 290 degrees C. The final boiling point specification was raised to 300 degrees C in the early 1980s in order to allow increased availability of kerosene for jet fuel use [747].

Alkanes and cycloalkanes are saturated with respect to hydrogen and are chemically stable, clean-burning components, which, together, constitute the major part of kerosene. Aromatics can be present from about 10 to 20% of the product, depending on the source of crude oil. Kerosene in the C9 to C16 range normally has a boiling range well above the boiling-point of benzene; accordingly, the benzene content of the kerosene fraction is usually below 0.02%. However, wide-cut products such as JP-4 and Jet B are usually made by blending with some of the gasoline fractions and, therefore, may contain more benzene (normally <0.5%). Depending of the source of crude, dinuclear aromatic naphthalenes, with two benzene rings in a condensed structure, are also likely to be present in kerosene in the concentration range of 0.1% to 3%. However, the 300 degrees C maximum final boiling range tends to exclude the presence of high-boiling three to seven-ring polycyclic aromatic hydrocarbons. Olefins are normally present in straight-run kerosene at concentrations of about 1% or less because olefins are essentially eliminated by the hydrotreating processes used in finishing kerosene [747].

Additives may also be added to jet fuels. For example, the International Air Transport Association recommendations require the addition of an antioxidant. Metal deactivators may also be added at concentrations not exceeding 5.7 mg/l. Fuel system icing inhibitors, electrical conductivity additives, corrosion inhibitors, lubrication improvers, biocides, and/or thermal stability improvers may also be added, as agree upon by the supplier and purchaser [747]. JP-4 and JP-7 both contain 0.1 to 0.15 vol% of anti-icers and also contain antioxidants, corrosion inhibitors, metal deactivators, and anti-static additives [876].

Because jet fuels can be derived from difference stocks of crude oil, these is considerable variability in the concentrations of major components between jet fuel samples from different crudes. That is why petroleum product specifications list "ranges," and "max" or "min" values, instead of absolute numbers. Since the different categories of jet fuels are designed to perform slightly different tasks, the compositions of the various jet fuel categories differ. The following table compares the specifications for four common jet fuels; namely JP-1, JP-4, JP-5, and JP-A [635, 637]:

JP-4 and JP-7 are U.S Air Force fuels which contain many of the same hydrocarbons and additives; difference in specifications were summarized by ATSDR [876]. JP-4 contains 0.50 % by weight of naphthalene, 0.56 % by weight of 2-methylnaphthalene; 0.78 % by weight of 1-methylnaphthalene; and 0.25 % by weight of 2,6-dimethylnaphthalene [876]. JP-4 also contains less than 2 % by weight of various Benzene, Toluene, Ethyl Benzene, and Toluene (BTEX) compounds as well as numerous alkyl benzene compounds [[876].

Principle Characteristics of Selected Military Aircraft Turbine Fuels [637]:

CHARACTERISTIC	JP-1	JP-4	JP-5	JP-A
API Gravity, max	35	45-57	36-48	39-51
Flash point, F, min	110	---	140	110
Viscosity, centistokes at:				
-30 F, max	---	---	16.5	15
-40 F, max	10	---	---	--
Freezing point, F, max	-76	-76	-40	-40
Total sulfur, % max	0.2	0.4	0.4	0.3
Total aromatics, % max	20	25	25	20
Olefins**, % max	---	5	5	--
Total potential residue, mg/100 ml, max	8	14	14	14

** Olefins (alkenes and cycloalkenes) are generated by cracking operations during the refining process [558]. Olefins are normally present in straight-run kerosene at concentrations of about 1% or less because olefins are essentially eliminated by the hydrotreating processes used in finishing kerosene [747].

The following table also lists some measured physical properties and compositions of representative samples of jet fuels [747]:

CHARACTERISTIC	JP-4	JP-5	JP-A
API Gravity	54.8	41.0	42.3
Viscosity, centistokes at:			
-20 C	--	--	5.48
Freezing point, degrees C	-61	-49	-45
Sulfur, % weight	0.018	0.020	0.035
Naphthalenes, % weight	--	--	1.59
Aromatic content, % vol	13.4	19.1	18.5
Olefins content, % vol	0.7	0.8	1.0

Additional information on chemical composition has been summarized by ATSDR for kerosene (JP-1) [962] and for JP-4 and JP-7 [876].

Additional chemical identity information on JP-4 and JP-7 jet fuels from ATSDR [876] (for information on embedded references, see ATSDR):

> The composition of aviation fuels has been established by the U.S. Air Force (Air Force 1977, 1981g, 1982d, 1988a, 1989c, 1990) using specifications that are based primarily on the characteristics that give the maximum performance of the aircraft for which the fuel is used (CRC 1984). JP-4 and JP-7 were developed for use by the U.S. Air Force. JP-4 is called a wide-cut fuel because it is produced from a broad distillation temperature range and contains a wide array of carbon chain-lengths, from 4 to 16 carbons long. It was initially developed for broad availability in times of need. The composition of JP-4 is approximately 13% (v/v) aromatic hydrocarbons, 1.0% olefin hydrocarbons, and 86% saturated hydrocarbons (ITC 1985). It has a distillation temperature range of 60 to 270 degrees C (MacNaughton and Uddin 1984). JP-7 was developed for use in advanced supersonic aircraft because of its thermal stability and high flashpoint (CRC 1984; Dukek 1978). It has a distillation temperature range of 182 to 288 degrees C and contains a maximum of 5% (by volume) aromatic compounds. Aviation fuels consist primarily of hydrocarbon compounds (paraffins, cycloparaffins or naphthenes, aromatics, and olefins) and contains additives that are determined by the specific uses of the fuel (CRC 1984; Dukek 1978; IARC 1989). Paraffins and cycloparaffins are the major components. Paraffins have a high hydrogen-to-carbon ratio, with a high heat release per unit of weight and a cleaner burn than other hydrocarbons. Cycloparaffins have a lower hydrogen-to-carbon ratio, which results in less heat released per unit of weight but increases the fuel's density. These components reduce the freezing point of the fuel. Aromatic hydrocarbons are a good energy source but produce smoke when burned; therefore, the maximum levels are restricted (20-25% by volume in JP-4, 5% by volume in JP-7). Finally, olefins are similar to the paraffins but are unsaturated with lower hydrogen-to-carbon ratios. They are the most reactive of the hydrocarbons and are permitted at only 5% by volume in JP-4 (CRC 1984). Benzene, present in wide-cut fuels such as JP-4, is an ineffectual contaminant usually present below 0.5% (CONCAWE 1985; IARC 1989). Nonhydrocarbon compounds such as sulfur and sulfur compounds are also found. Additives such as antioxidants, metal deactivators, fuel system icing inhibitors, corrosion inhibitors, and static dissipator additives are all present in limited quantities in jet fuels in order to improve performance (CRC 1984) [876].
>
> Depending on the origin of the crude and the production method, there could be considerable compositional variability between fuel oils of the same grade (Air Force 1988b) [876].

JP-4 is a mixed compound composed primarily of hydrocarbons (i.e., alkanes, cycloalkanes, alky-benzenes, indan/tetralins, and naphthalenes) [876].

JP-7, or jet propellant-7, is a mixed compound composed primarily of hydrocarbons (i.e., alkanes, cycloalkanes, alky-benzenes, indan/tetralins, and naphthalenes) [876].

Jet fuels are blends prepared to meet certain gross property specifications. Most characteristic data only reflect gross properties covered in the specifications. Proportions and values vary with the type of crude oil from which the final fuel is derived and the refining process used [876].

Composition (weight %) of Shale-Derived and Petroleum-Derived JP-4 [876]:

Constituents	Shale-derived	Petroleum-derived
N-alkanes		
Heptane	4.73	15.76
Octane	7.48	6.60
Nonane	7.24	2.54
Decane	11.25	2.24
Indane	0.42	0.17
Undecane	16.62	4.17
Dodecane	11.49	5.25
Tridecane	6.07	4.71
Tetradecane	3.19	1.02
Pentadecane	0.96	1.35
Total	9.45	43.81
Monosubstituted alkanes		
3-Methyl hexane	3.05	14.39
2-Methyl heptane	3.08	6.14
3-Methyl heptane	1.64	7.19
Total	7.77	27.72
Disubstituted alkane		
2,3-Dimethyl pentane	--	--
2,5-Dimethyl pentane	0.18	1.48
2,4-Dimethyl pentane	0.63	2.52
Total	0.81	4.00
Cyclohexanes		
Cyclohexane	1.52	2.13
Methyl cyclohexane	5.68	2.17
Ethyl cyclohexane	--	--
Total	7.20	4.30
Monosubstituted aromatics		
Methyl benzene	3.77	3.41

Disubstituted aromatics (xylenes)		
m -Xylene	2.60	2.71
p -Xylene	1.70	1.63
o -Xylene	2.00	1.89
Total	6.30	6.23
Multisubstituted aromatics		
1,3,5-Trimethylbenzene	1.52	1.09
1,2,4-Trimethylbenzene	2.00	3.52
1,2,3-Trimethylbenzene	0.30	1.04
Total	3.82	5.65
Overall total	99.12	

Fate.Detail: Detailed Information on Fate, Transport, Persistence, and/or Pathways:

Information on this topic has been summarized by ATSDR in the toxicity profile for kerosene (JP-1) [962]. The following information is from the ATSDR profile for JP-4 and JP-7 [876]:

> 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 [876].
>
> 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) [876].

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) [876].
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 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) [876].

Transformation in 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) [876].

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 inlet 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) [876].

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) [876].

Tranformation and partitioning in 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) [876].

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 [876].

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 1-2 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) [876].

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 wind-speed 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) [876].

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 1988c). 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 5-fold 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 ug/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 [876].

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 [876].

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 [876].

Transformation and Degradation, 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) [876].

Laboratory and/or Field Analyses:

The relative proportions of hazardous compound constituents present in petroleum-based oil contamination is typically quite variable. The lab analyses most appropriate for measuring different types of oil contamination depend upon the type of oil involved and the reason for measuring the contamination.

Since PAHs and alkyl PAHs are important hazardous components of this product, risk assessments should include analyses of PAHs and alkyl PAHs utilizing the NOAA protocol expanded scan [828] or other rigorous GC/MS/SIM methods. See PAHs as a group entry.

If the Park Service sediment investigation at Petersburg National Historical Battlefield (see Chem.Detail section above, this study was performed in response to contamination by Diesel, a fuel having similar hydrocarbons to certain jet fuels, had utilized EPA semi-volatile scan 8270 or any of the other typical EPA scans (625, etc.), all of which only include parent compounds and often utilize detection limits no lower than the 170-600 ppb range, the false conclusion reached would have been that only one PAH was present in significant (detection limit) amounts. This false negative conclusion would have been made because the parent compound PAHs present constituted only 2.4% of the PAHs detected in sediments, and the highest concentration found for any parent compound except pyrene was 85.5 ppb, far below the detection limits used on the older standard EPA scans. Pyrene was 185 ppb, which would have been non-detected on many of the EPA scans, but not all. However, utilizing the NOAA protocol expanded scan [828], it was determined that 97.6% of total quantity of PAHs detected in sediments were alkyl PAHs, and that all 39 PAHs and alkyl PAHs were present in these sediments.

For jet fuels spills, we recommend the following:

In choosing a lab method, it should be kept in mind that this product (as well as Diesel, No. 2 Fuel Oils, and Light Crudes) can be expected to exhibit the following characteristics [741]:

-Moderately volatile; will leave residue (up to 1/3 of spilled amount)
-Moderate concentrations of toxic (soluble) compounds
-Will "oil" intertidal resources with long-term contamination potential
-Has potential for subtidal impacts (dissolution, mixing, sorption onto suspended sediments)
-No dispersion necessary
-Cleanup can be very effective

At spill sites, if Natural Resource Damage Assessment (NRDA), risk assessment, scientific inquiry, or various questions which might be argued in court are being investigated, state of the art methods must be used, and many of these exceed the requirements of regulatory agencies (Roy Irwin, National Park Service, Personal Communication, 1996).

Many lab methods have been used to analyze for jet fuel contamination [861]. Volatile organic and related jet fuel compounds have often been analyzed with EPA method 8240. However, for certain risk and Natural Resource Damage Assessment (NRDA) purposes using the standard EPA method 8240 for volatile organic components is inadequate [468]. The standard EPA method 8240 detection limits are not always low enough. Natural Resource Damage Assessment or ecological risk assessment may require lower detection limits for comparison with ecological benchmarks or criteria, although higher detection limits may be acceptable for plume monitoring in an industrial area where no biological resources are at risk.

Regardless of the detection limits utilized, the standard EPA 8240 method often needs to be "enhanced" by the inclusion of analytes that would be expected in specific situations. For example, for tanks leaking jet fuel, one should include rigorous analyses for alkyl benzenes (including but not limited to toluene, ethylbenzene, and xylene). Like alkyl PAHs, alkyl benzenes are more resistant to degradation than the parent compounds benzene). Other compounds which often need to be analyzed are MTBE, 1,2 Dichloroethane, alkyl lead isomers, and other compounds consistent with risk assessment needs. Enhanced 8240 scans are available from various commercial labs (Gregory Douglas, Arthur D. Little, Inc., Cambridge, Massachusetts, personal communication, 1995).

EPA method 8240 is not the only "standard method" used for jet fuel compounds which is inadequate for assessing biological effects. Recent (1991) studies have indicated that EPA approved methods used for oil spill assessments (including total petroleum hydrocarbons method 418.1, semivolatile priority pollutant organics methods 625 and 8270, and volatile organic priority pollutant methods 602, 1624, and 8240) are all inadequate for generating scientifically defensible information for Natural Resource Damage Assessments [468]. Problems with these methods were further elucidated by Douglas et al. in 1992 [657]. These general organic chemical methods are deficient in chemical selectivity (types of constituents analyzed) and sensitivity (detection limits); the deficiencies in these two areas lead to an inability to interpret the environmental significance of the data in a scientifically defensible manner [468].

Draft decision Tree (dichotomous key) for selection of lab methods for measuring contamination from light crude oils and middle distillate petroleum products, including all jet fuels and kerosene (Roy Irwin, National Park Service, Personal Communication, 1996) :

1a. Your main concern is biological effects of petroleum products...2

1b. Your main concern is cleanup or remediation but no ecological or human resources are at risk............3

2a. The resource at risk is primarily humans via a drinking water pathway, either the contamination of groundwater used for drinking water, or the fresh* or continuing contamination of surface waters used as drinking water, or the risk is primarily to aquatic species in confined** surface waters from a fresh* spill, or the risk is to surface waters re-emerging from contaminated groundwater resources whether the spill is fresh* or not; the medium and/or pathway of concern is water rather than sediments, soil, or tissues 4

2b. The resource at risk is something else......................5

3a. The spilled substance is a fresh* oil product of known composition: If required to do so by a regulatory authority, perform whichever Total Petroleum Hydrocarbon (TPH) analysis specified by the regulator. However, keep in mind that due to its numerous limitations, the use of the common EPA method 418.1 for Total Petroleum Hydrocarbons is not recommended as a stand-alone method unless the results can first be consistently correlated (over time, as the oil ages) with the better NOAA protocol expanded scan*** for polycyclic aromatic hydrocarbons (PAHs) and alkyl PAHs. If not required to perform an EPA method 418.1-based analysis for TPH, instead perform a Gas Chromatography/Flame Ionization Detection (GC/FID) analysis for TPH using the spilled substance as a calibration standard. GC/FID methods can be sufficient for screening purposes when the oil contamination is fresh*, unweathered oil and when one is fairly sure of the source [657]. If diesel 1D was spilled, perform TPH-D (1D) using California LUFT manual methods (typically a modified EPA method 8015) [465] or a locally available GC/FID method of equal utility for the product spilled. However, no matter which TPH method is used, whether based on various GC/FID or EPA method 418.1 protocols, the investigator should keep in mind that the effectiveness of the method typically changes as oil ages, that false positives or false negatives are possible, and that the better Gas Chromatography-Mass Spectrometry-Selected Ion Mode (GC/MS/SIM) scans (such as the NOAA expanded scan***) should probably be performed at the end of remediation to be sure that the contamination has truly been cleaned up.

3b. The spilled product is not fresh* or the contamination is of unknown or mixed composition.......................6

4. Analyze for Benzene, Toluene, Ethyl Benzene, and Toluene (BTEX) compounds in water as part of a broader scan of volatiles using EPA GC/MS method 8240. The standard EPA GC/MS method 8240 protocol will be sufficient for some applications, but the standard EPA method 8240 (and especially the less rigorous EPA BTEX methods such as method 8020 for soil and

method 602 for water) are all inadequate for generating scientifically defensible information for Natural Resource Damage Assessments [468]. The standard EPA methods are also inadequate for risk assessment purposes. Thus, when collecting information for possible use in a Natural Resource Damage Assessment or risk assessment, it is best to ask the lab to analyze for BTEX compounds and other volatile oil compounds using a modified EPA GC/MS method 8240 method using the lowest possible Selected Ion Mode detection limits and increasing the analyte list to include as many alkyl BTEX compounds as possible. Also analyze surface or (if applicable) ground water samples for polycyclic aromatic hydrocarbons (PAHs) and alkyl PAHs using the NOAA protocol expanded scan*** modified for water samples using methylene chloride extraction. If the contaminated water is groundwater, before the groundwater is determined to be remediated, also analyze some contaminated sub-surface soils in contact with the groundwater for BTEX compounds (EPA GC/MS method 8240), and PAHs (NOAA protocol expanded scan***). The magnitude of any residual soil contamination will provide insight about the likelihood of recontamination of groundwater resources through equilibria partitioning mechanisms moving contamination from soil to water.

5a. The medium of concern is sediments or soils..................6

5b. The medium of concern is biological tissues..................7

6. Perform the NOAA protocol expanded scan*** for polycyclic aromatic hydrocarbons (PAHs) and alkyl PAHs. If there is any reason to suspect fresh* or continuing contamination of soils or sediments with lighter volatile compounds, also perform EPA GC/MS method 8240 using the lowest possible Selected Ion Mode (SIM) detection limits and increasing the analyte list to include as many alkyl Benzene, Toluene, Ethyl Benzene, and Xylene (BTEX) compounds as possible.

7a. The problem is direct coating (oiling) of wildlife or plants with spilled oil product.......................................8

7b. The problem is something else...............................9

8. Perform NOAA protocol expanded scan*** for polycyclic aromatic hydrocarbons (PAHs) and alkyl PAHs and/or GC/FID fingerprinting of the coating oil only if necessary to identify the source or exact oil. If the source is known and no confirmation lab studies are necessary: dispense with additional chemical laboratory analyses and instead document direct effects of coating: lethality, blinding, decreased reproduction from eggshell coating, etc., and begin cleaning activities if deemed potentially productive after consolations with the Fish and Wildlife Agencies.

9a. The concern is for impacts on water column organisms such as fish or plankton)..10

9b. The concern is for something else (including benthic organisms)..11

10. If exposure to fish is suspected, an HPLC/Fluorescence scan for polycyclic aromatic hydrocarbon (PAH) metabolites in bile may be performed to confirm exposure [844]. For bottom-dwelling fish such as flounders or catfish, also analyze the bottom sediments (see Step 6 above). Fish which spend most of their time free-swimming above the bottom in the water column can often avoid toxicity from toxic petroleum compounds in the water column, but if fish are expiring in a confined** habitat (small pond, etc.), EPA GC/MS method 8240 and the NOAA protocol expanded scan*** for PAHs could be performed to see if Benzene, Toluene, Ethyl Benzene, and Xylene (BTEX), naphthalene, and other potentially toxic compounds are above known acute toxicity benchmark concentrations. Zooplankton populations impacted by oil usually recover fairly quickly unless they are impacted in very confined** or shallow environments [835] and the above BTEX and PAH water methods are often recommended rather than direct analyses of zooplankton tissues.

11a. The concern is for benthic invertebrates: analyze invertebrate whole-body tissue samples and surrounding sediment samples for polycyclic aromatic hydrocarbons (PAHs) and alkyl PAHs using the NOAA protocol expanded scan***. If the spill is fresh* or the source continuous, risk assessment needs may also require that the sediments which form the habitat for benthic invertebrates be analyzed for Benzene, Toluene, Ethyl Benzene, and Xylene (BTEX) and other volatile compounds using EPA GC/MS method 8240 or modified EPA method 8240 in the Selected Ion Mode (SIM). Bivalve invertebrates such as clams and mussels do not break down PAHs as well or as quickly as do fish or many wildlife species. They are also less mobile. Thus, bivalve tissues are more often directly analyzed for PAH residues than are the tissues of fish or wildlife.

11b. The concern is for plants or for vertebrate wildlife including birds, mammals, reptiles, and amphibians: polycyclic aromatic hydrocarbons (PAHs) and other petroleum hydrocarbons break down fairly rapidly in many wildlife groups and tissues are not usually analyzed directly. Instead direct effects are investigated and water, soil, sediment, and food items encountered by wildlife are usually analyzed for PAHs and alkyl PAHs using the NOAA protocol expanded scan***. If the spill is fresh* or the source continuous, risk assessment needs may also require that these habitat media also be analyzed for Benzene, Toluene, Ethyl Benzene, and Xylene (BTEX) and other volatile compounds using EPA GC/MS method 8240 or modified EPA method 8240 in the Selected Ion Mode (SIM). Less is known about plant effects. However, the same methods recommended above for the analyses of water (Step 4 above) and for sediments or soils (Step 6 above) are usually also recommended for these same media in plant or wildlife habitats. If wildlife or plants are covered with oil, see also Step 8 (above) regarding oiling issues.

* Discussion of the significance of the word "fresh": The word "fresh" cannot be universally defined because oil breaks down faster in some environments than in others. In a hot, windy, sunny, oil-microbe-rich, environment in the tropics, some of the lighter and more volatile compounds (such as the Benzene, Toluene, Ethyl Benzene, and Xylene compounds) would be expected to disappear faster by evaporation into the environment and by biodegradation than in a cold, no-wind, cloudy, oil-microbe-poor environment in the arctic. In certain habitats, BTEX and other relatively water soluble compounds will tend to move to groundwater and/or subsurface soils (where degradation rates are typically slower than in a sunny well aerated surface environment). Thus, the judgement about whether or not oil contamination would be considered "fresh" is a professional judgement based on a continuum of possible scenarios. The closer in time to the original spill of non-degraded petroleum product, the greater degree the source is continuous rather than the result of a one-time event, and the more factors are present which would retard oil evaporation or breakdown (cold, no-wind, cloudy, oil-microbe-poor conditions, etc.) the more likely it would be that in the professional judgement experts the oil would be considered "fresh." In other words, the degree of freshness is a continuum which depends on the specific product spilled and the specific habitat impacted. Except for groundwater resources (where the breakdown can be much slower), the fresher the middle distillate oil contamination is, the more one has to be concerned about potential impacts of BTEX compounds, and other lighter and more volatile petroleum compounds.

To assist the reader in making decisions based on the continuum of possible degrees of freshness, the following generalizations are provided: Some of the lightest middle distillates (such as Jet Fuels, Diesel, No. 2 Fuel Oil) are moderately volatile and soluble and up to two-thirds of the spill amount could disappear from surface waters after a few days [771,835]. Even heavier petroleum substances, such as medium oils and most crude oils will evaporate about one third of the product spilled within 24 hours [771]. Typically the volatile fractions disappear mostly by evaporating into the atmosphere. However, in some cases, certain water soluble fractions of oil including Benzene, Toluene, Ethyl Benzene, and Xylene (BTEX) compounds move down into groundwater. BTEX compounds are included in the more volatile and water soluble fractions, and BTEX compounds as well as the lighter alkanes are broken down more quickly by microbes than heavier semi-volatiles such as alkyl PAHs and some of the heavier and more complex aliphatic compounds. Thus after a week, or in some cases, after a few days, there is less reason to analyze surface waters for BTEX or other volatile compounds, and such analyses should be reserved more for potentially contaminated groundwaters. In the same manner, as the product ages, there is typically less reason to analyze for alkanes using GC/FID techniques or TPH using EPA 418.1 methods, and more reason to analyze for the more persistent alkyl PAHs using the NOAA protocol expanded scan***.

** Discussion of the significance of the word "confined": Like the word "fresh" the word "confined" is difficult to define precisely as there is a continuum of various degrees to which a habitat would be considered "confined" versus "open." However, if one is concerned about the well-being of ecological resources such as fish which spend most of their time swimming freely above the bottom, it makes more sense to spend a smaller proportion of analytical funding for water column and surface water analyses of Benzene, Toluene, Ethyl Benzene, and Xylene (BTEX) and other volatile or acutely toxic compounds if the spill is in open and/or deep waters rather than shallow or "confined" waters. This is because much of the oil tends to stay with a surface slick or becomes tied up in subsurface tar balls. The petroleum compounds which do pass through the water column often tend to do so in small concentrations and/or for short periods of time, and fish and other pelagic or generally mobile species can often swim away to avoid impacts from spilled oil in "open waters." Thus in many large oil spills in open or deep waters, it has often been difficult or impossible to attribute significant impacts to fish or other pelagic or strong swimming mobile species in open waters. Lethality has most often been associated with heavy exposure of juvenile fish to large amounts of oil products moving rapidly into shallow or confined waters [835]. Different fish species vary in their sensitivity to oil [835]. However, the bottom line is that in past ecological assessments of spills, often too much money has been spent on water column analyses in open water settings, when the majority of significant impacts tended to be concentrated in other habitats, such as benthic, shoreline, and surface microlayer habitats.

*** The lab protocols for the expanded scan of polycyclic aromatic hydrocarbons (PAHs) and alkyl PAHs have been published by NOAA [828].

End of Key.

It is important to understand that contaminants data from different labs, different states, and different agencies, collected by different people, are often not very comparable (see also, discussion in the disclaimer section at the top of this entry).

As of 1997, the problem of lack of data comparability (not only for water methods but also for soil, sediment, and tissue methods) between different "standard methods" recommended by different agencies seemed to be getting worse, if anything, rather than better. The trend in quality assurance seemed to be for various agencies, including the EPA and others, to insist on quality assurance plans for each project. In addition to quality control steps (blanks, duplicates, spikes, etc.), these quality assurance plans call for a step of insuring data comparability [1015,1017]. However, the data comparability step is often not given sufficient consideration. The tendency of agency guidance (such as EPA SW-846 methods and some other new EPA methods for bio-concentratable substances) to allow more and more flexibility to select options at various points along the way, makes it harder in insure data comparability or method validity. Even volunteer monitoring programs are now strongly encouraged to develop and use quality assurance project plans [1015,1017].

At minimum, before using contaminants data from diverse sources, one should determine that field collection methods, detection limits, and lab quality control techniques were acceptable and comparable. The goal is that the analysis in the concentration range of the comparison benchmark concentration should be very precise and accurate.

It should be kept in mind that quality control field and lab blanks and duplicates will not help in the data quality assurance goal as well as intended if one is using a method prone to false negatives. Methods may be prone to false negatives due to the use of detection limits that are too high, the loss of contaminants through inappropriate handling, or the use of inappropriate methods. The use of inappropriate methods is particularly common related to oil products.

Additional Detail on Screening Methods Sometimes used for Jet Fuels:

Discussion of GC/FID Methods:

While a screening analysis such as GC/FID should be adequate for mid-range products such as diesels and possibly jet fuels, lighter gasoline fractions will be lost in a GC/FID analysis (which uses extraction and burning) [657]. Therefore, wide-cut jet fuels, such as JP-4 and Jet B which are usually made by blending with some of the gasoline fractions, would need to be analyzed for volatile organic components using EPA method 8240. Kerosene (a key component of jet fuels) in the C9 to C16 range normally has a boiling range well above the boiling-point of benzene; accordingly, the benzene content of the kerosene fraction is usually below 0.02% [747]. However, since wide-cut jet fuels are made by blending with gasoline, they may contain more benzene (normally <0.5%) and need to be analyzed for volatiles [747].

Discussion of Method 8015:

EPA Method 8015 (for Non-halogenated Volatile Organics) is a gas chromatographic method sometimes recommended for the analysis of volatile and semivolatile compounds. It can be used to characterize light and midrange petroleum distillates such as gasoline, diesel, fuel oil, and kerosene. This method can be used to obtain some gross fingerprint information for differentiation between petroleum products, as well as detailed information that can be used to differentiate between different batches of the same product. The major limitation of Method 8015 is its inability to detect nonvolatile compounds. The State of California recommends a "modified method 8015" (different from EPA's method 8015 and also different from EPA method 418.1) for gasoline, kerosene, diesel oil, or other fuels in soil and groundwater, as specified in the Leaking Underground Fuel Tank Manual [465].

Discussion of Fluorescent Scans, Method 8270 (unmodified) and Other Misc. Scans:

Aromatics can be present from about 10 to 20% of a kerosene product, depending on the source of crude oil. Depending on the source, dinuclear aromatic naphthalenes, with two benzene rings in a condensed structure, are also likely to be present in kerosene in the concentration range of 0.1% to 3%. However, the 300 degrees C maximum final boiling range tends to exclude the presence of high-boiling three to seven-ring polycyclic aromatic hydrocarbons [747] (for example, see the entry entitled Jet Fuel 4 for the composition of a representative jet fuel 4). Although large amounts of PAHs are typically not found in jet fuels, they are among the most persistent and hazardous compounds after the spill has aged. However, each situation is different, and various screening methods may sometimes be substituted for the NOAA Protocol Expanded Scan for PAHs and Alkyl Homologues of PAHs Using Gas Chromatography-Mass Spectrometry with Selective Ion Mode Enhanced Detection Limits (GC/MS/SIM), when shown to be effective at a given site.

Thin-layer chromatography (TLC) [783]:

The pattern will appear to be similar to that of diesel fuel. The thin-layer chromatography (TLC) pattern, using hexane as the eluting solvent, will show two spots, one oval-shaped with an Rf of 0.9 with iodine staining, and a second spot near Rf 0.5 visible under shortwave UV light and iodine staining. The relative intensities of the two spots will vary from batch to batch.

HPLC screening:

Some labs use screening HPLC fluorescence methods to screen for alkylated naphthalenes and dibenzothiophenes that fluoresce at naphthalene wavelengths and the alkylated phenanthrenes that fluoresce at phenanthrene wavelengths [521]. Other HPLC/fluorescence scans are used to examine fish bile directly for the presence of metabolites of PAHs such as naphthalene [523].

For additional details on protocols, including field collection protocols, see the oil spill entry.

See also: PAHs as a group entry.

Additional information on lab methods has been summarized by ATSDR for kerosene (JP-1) [962]. The following information for JP-4 and JP-7 was also summarized by ATSDR [876] (for indentification of embedded references, see ATSDR):

> BIOLOGICAL SAMPLES No analytical methods were located for detecting either JP-4 or JP-7 in biological samples. For analytical methods information on some hydrocarbon components of jet fuels, see the ATSDR toxicological profiles for benzene (ATSDR 1991a), toluene (ATSDR 1990), xylenes (ATSDR 1991c), and polycyclic aromatic hydrocarbons (ATSDR 1991b) [876].
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> ENVIRONMENTAL SAMPLES: Since JP-4 and JP-7 are composed of a complex mixture of hydrocarbons, there are few methods for the analysis of all of these components in environmental samples, but methods are reported for the analysis of some of the individual components or the amount of total hydrocarbon in the mixture (IARC 1989). The analysis of individual components usually involves separation of the components by column chromatography (i.e., packed or capillary column) followed by a suitable quantification method. These methods included gas chromatography (GC) and high-resolution gas chromatography (HRGC) combined with flame ionization detector (FID), or infrared (IR) spectroscopy. GC combined with mass spectrometry (MS) has been used to identify the principal hydrocarbon components present in jet fuels. Nuclear magnetic resonance (NMR), supercritical fluid chromatography (SFC)/FID, and laser raman spectroscopy can be used specifically to characterize the aromatic hydrocarbon makeup for JP- 4 and JP-7 (Clarke et al. 1991; Di Sanzo and Yoder 1991; DOE 1981). Although no methods were located specifically for analyzing JP-7 in environmental samples, the methods used to measure the hydrocarbon components of JP-4 can be used for measuring the hydrocarbon components of JP-7. .... Several of the jet fuel components have been discussed in detail in their individual ATSDR toxicological profiles (e.g., benzene and polycyclic aromatic hydrocarbons), which should be consulted for more information on analytical methods (ATSDR 1991a, 1991b). Analytical methods for detecting JP-4 and jet fuel (petroleum naphtha and kerosene vapors) in air include IR spectroscopy and GC/FID (IARC 1989; NIOSH 1984; Thomas and Richardson 1981). The total hydrocarbon content of JP-4 in air can be determined by IR spectroscopy. The IR technique is best adapted to pure hydrocarbon exposures, such as exposure to JP-4. For both methods, samples are collected with either charcoal

tubes or vapor monitor badges. Poor recovery (75%) was obtained with the IR method using only Freon 113 as a desorbent. Recovery was improved (86- 88%) using a mixture of Freon 113 and perchloroethylene. For the IR method, precision was excellent, ranging from 0.006% to 0.020% coefficient of variation (CV). Recoveries with the GC/FID method were excellent (97-101%) (NIOSH 1984; Thomas and Richardson 1981). For the GC/FID method, precision was also excellent (0.052% relative standard deviation [RSD]) (NIOSH 1984). Sensitivity for both methods is in the ppm range (IARC 1989; NIOSH 1984; Thomas and Richardson 1981). GC/FID, HRGC/FID, and IR spectroscopy have been used to measure JP-4 in water (Puyear et al. 1981; Roberts and Thomas 1986). GC/FID was used to measure the major water-soluble hydrocarbons, the aliphatics and alkylbenzenes, of JP-4 (Puyear et al. 1981). The average recovery of all hydrocarbons tested (aliphatics and alkylbenzenes) was 43-72%; however, the recovery of the aliphatics only was 90-94% (Puyear et al. 1981). Overall recovery was improved from 43% to 72% with the use of ethyl acetate as an extraction solvent for JP-4. Under the chromatographic conditions used, the individual aliphatics were not well resolved. However, the alkylbenzenes were well separated and quantitation of each component was possible (Puyear et al. 1981). Sensitivity and precision were not reported (Puyear et al. 1981). The total hydrocarbon content of JP-4 in water can also be determined by IR spectroscopy (EPA 1978; Roberts and Thomas 1986) and fluorescence spectroscopy (ASTM 1982). Since JP-4 has a distinctive gas chromatographic profile, it is possible to distinguish JP-4 from other fuels present in environmental samples by examining selected peak areas or peak ratios for certain hydrocarbons (Roberts and Thomas 1986) [876].

Sample preparation for GC/FID included extracting the fuel from soil with methylene chloride in an ultrasonic bath. Recovery was good (83.9%). Precision was adequate (12.6% CV). Sensitivity was in the low-ppm range (Vandegrift and Kampbell 1988). Other methods reported for the analysis of the aromatic components in aircraft fuels, including JP-4, include HRGC combined with an ultraviolet detector (UVD), photoionization detector (PID), and GC combined with a nitrogen specific alkali-flame detector (AFD) (Air Force 1982a) [876].

Sample preparation includes fractionation of the fuel into an aromatic fraction and a nonaromatic fraction. The fractionation is accomplished by using adsorption column chromatography with silica gel, alumina, or Florisil. The aromatic fraction is then eluted using moderately polar solvents such as methylene chloride, benzene, or ethyl ether. The UV detector is specific for aromatic compounds. The estimated detection limits for benzenes and naphthalenes were 10 ug/mL and 2 ug/mL, respectively. Precision ranged from 5% to 10%. The photoionization detector is about 10 times as sensitive as a UVD or FID for the detection of aromatic hydrocarbons, although it does not provide the selectivity obtainable with the UVD. Nitrogen-containing compounds in fuels are detected using a nitrogen-specific AFD. A gas chromatographic method involving the simultaneous use of a UVD, FID, and AFD was recommended as a rapid, inexpensive, and selective method for the analysis of aircraft fuels (Air Force 1982a) [876].

Identification of Data Needs: Methods for Determining Biomarkers of Exposure and Effect. No biomarkers of exposure were identified for JP-4 or JP-7. No standard procedures exist for identifying or quantifying exposure to JP-4 or JP-7 in biological media. Therefore, it is not possible to state whether existing methods are sensitive to measure background levels in the population or levels at which health effects occur. Biomonitoring studies are needed to adequately assess exposure to JP-4 and JP-7. No biomarkers of effect were found for JP-7. Potential biomarkers for neurological effects of JP-4 are mild muscular weakness, staggering gait, and decreased sensitivity to painful stimuli (Davies 1964). No standard procedures exist for identifying and quantifying these biomarkers of effect for JP-4. Methods for Determining Parent Compounds and Degradation Products in Environmental Media. Methods exist for measuring the hydrocarbon components of jet fuels, specifically JP-4, in air, water, and soil (IARC 1989; NIOSH 1984; Puyear et al. 1981; Roberts and Thomas 1986; Thomas and Richardson 1981; Vandegrift and Kampbell 1988). Although no methods were located specifically for analyzing JP-7 in environmental samples, the methods used to measure the hydrocarbon components of JP-4 can be used for measuring the hydrocarbon components of JP-7. These methods are relatively sensitive, selective, and reliable and can be used to detect the levels of jet fuel components found in the environment and levels at which health effects occur. Sensitivity and precision data are needed for measuring the components in water. These data will aid in comparison of sensitivity and precision between methods and indicate where improvements in sensitivity are needed. This information will be useful in monitoring contamination in the environment [876].

Ongoing Studies The Environmental Health Laboratory Sciences Division of the Center for Environmental Health and Injury Control, Centers for Disease Control and Prevention, is developing methods for the analysis of certain components of JP-4 and JP-7 and other volatile organic compounds in blood. These methods use purge and trap methodology and magnetic sector mass spectrometry which gives detection limits in the low parts per trillion range. No other ongoing studies were located for JP-4 or JP-7 [876].