ENVIRONMENTAL CONTAMINANTS ENCYCLOPEDIA

PHENANTHRENE ENTRY

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Like a library or many 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 without 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).

Phenanthrene (Phenanthren, CAS number 85-01-8)

Brief Introduction:

Br.Class: General Introduction and Classification Information:

Phenanthrene is a low molecular weight, 3-ring polyaromatic hydrocarbon (PAH), and an EPA Priority Pollutant [697,634]. Although historically classified by EPA (for modeling purposes only) as a carcinogen, [302,446], other sources, including more recent ones, have determined that phenanthrene is not classifiable as to its carcinogenicity to humans [788,847,893].

Phenanthrene is a toxic pollutant designated pursuant to section 307(a)(1) of the Clean Water Act and is subject to effluent limitations /Polynuclear aromatic hydrocarbons [40 CFR 401.15 (7/1/87)] [366].

Phenanthrene occurs as a major component of the total content of PAH compounds in the environment [847]. Phenanthrene is an important petroleum-source PAH, usually found in higher amounts in refined oil products than crude oil [770].

The most abundant aromatic hydrocarbon families in oil products have two and three fused rings with one to four carbon atom alkyl group substitutions [773]. Phenanthrene is a 3-ring PAH. Phenanthrene is called the parent compound, while phenanthrenes with alkyl group substitutions added to phenanthrene are called alkyl phenanthrenes.

Alkyl phenanthrene and alkyl anthracene compounds cannot be differentiated with current (1996) analytical techniques. Phenanthrene, anthracene, and the phenanthrenes/anthracenes alkyl homolog series are included on the NOAA recommended expanded scan for PAHs and alkyl PAHs [828]. This list includes most of the PAHs recommended by the NOAA's National Status and Trends program [680].

Phenanthrene was one of the PAHs found by NASA in 1996 on a rock alleged to be a meteorite from mars (see Uses/Sources section below for details).

Br.Haz: General Hazard/Toxicity Summary:

Acute toxicity is rarely reported in humans, fish, or wildlife, as a result of exposure to low levels of a single PAH compound such as this one. 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 (Roy Irwin, National Park Service, Personal Communication, 1996, based on an overview of literature on hand). See also "PAHs as a group" entry.

This compound often occurs together with other aromatics (sometimes including alkyl PAHs), and a typical complex mixture of aromatics may be more toxic or hazardous in general than this compound would be alone (see PAHs as a group entry).

Within an aromatic series, acute toxicity increases with increasing alkyl substitution on the aromatic nucleus [851]. For example, there is an increase in toxicity as alkylation of the naphthalene structure increases. The order of most toxic to least in a study using grass shrimp (Palaemonetes pugio) and brown shrimp (Penaeus aztecus) was dimethylnaphthalenes > methylnaphthalenes > naphthalenes [853].

Studies conclude that the toxicity of an oil appears to be a function of its di-aromatic and tri-aromatic hydrocarbons, which includes three-ring hydrocarbons such as phenanthrene [770].

No enhanced toxicity to Daphnia magna was photoinduced by solar radiation of phenanthrene [887; Reprinted with permission from Environmental Toxicology and Chemistry, Volume 6, Newstead, J.L. and J.P. Geisy. Predictive models for photoinduced acute toxicity of polycyclic aromatic hydrocarbons to Daphnia magna. Copyright 1987 SETAC].

For additional details on immunological effects of PAHs in general, see ATSDR [881].

Potential effects of PAHs on humans were summarized by the Agency for Toxic Substances and Disease Registry in a 1995 toxicological profile for polycyclic aromatic hydrocarbons [881], so no lengthy summary will be attempted here.

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

EPA 1996 IRIS database information [893]:

Evidence for classification as to human carcinogenicity; weight-of-evidence classification

Classification: D; not classifiable as to human carcinogenicity

BASIS: Based on no human data and inadequate data from a single gavage study in rats and skin painting and injection studies in mice.

HUMAN CARCINOGENICITY DATA: None.

ANIMAL CARCINOGENICITY DATA: Inadequate. Available data are inadequate to permit an evaluation of the carcinogenicity of phenanthrene to experimental animals [847]. The International Agency for Research on Cancer (IARC) and recent (1994) EPA weight-of-evidence evaluations have determined that phenanthrene is not classifiable as to its carcinogenicity to humans [788,847,881].

EPA Historical (modeling purposes only) Classification: Carcinogen [302,446].

Several references [888,891,887] do not include phenanthrene among PAHs found to be phototoxic, but one reference does list it as phototoxic [494]. Although not definitive, as discussed above, phototoxicity represents one clue suggesting possible carcinogenicity.

In general, the heavier (4-, 5-, and 6-ring) PAHs tend to be more carcinogenic than the lighter (2- and 3-ring) PAHs (such as the 3-ringed phenanthrene) [796].

This compound often occurs together with other aromatics (often including various alkyl PAHs), and a typical complex mixture of aromatics may be more carcinogenic in general than this compound would be alone (see "PAHs as a group" entry). The debates on exactly how to perform both ecological and human risk assessments on the complex mixtures of PAHs typically found at contaminated sites, are likely to continue. There are some clearly wrong ways to go about it, but defining clearly right ways is more difficult. One of the few things that seems clear is that complex mixtures of PAHs and other aromatics in water, sediments, and organism internal tissues may be carcinogenic and/or phototoxic (Roy Irwin, National Park Service, personal communication, 1996; see also "PAHs as a group" entry and Arfsten et al [911]).

One way to approach site specific risk assessments is to collect the complex mixture of PAHs and other lipophilic organic contaminants in a semipermeable membrane device (SPMD, also known as a fat bag) [894,895,896], retrieve the organic contaminant mixture from the SPMD, then test the mixture for carcinogenicity, toxicity, and phototoxicity (James Huckins, National Biological Survey, and Roy Irwin, National Park Service, personal communication, 1996).

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

Benzo(a)pyrene hydroxylase activity of the rat placenta can be induced by phenanthrene [847].

A test for forward mutation in Chinese hamster ovary cells exposed to 1 ug/mL was not positive [893].

Phenanthrene induced/ mutation in one experiment in human cells in culture in the presence of an exogenous metabolic system ... (IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V32 426, 1983) [366].

Genotoxicity studies for this compound have yielded mixed results [366].

Phenanthrene induced/ sister chromatid exchange in Chinese hamster bone-marrow cells in vivo. [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V32 426 (1983) [366].

Enhancement of mutagenicity occurs with 11 polycyclic aromatic hydrocarbons when 3-methylcholanthrene induced guinea pig liver s9 is substituted for aroclor induced rat liver s9 in ames test. Phenanthrene which is considered noncarcinogenic was non-mutagenic in strain TA100. (Baker RS ET AL; Mutat Res 71 1: 43-52, 1980) [366].

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

The heavier (4-, 5-, and 6-ring) PAHs are more persistent than the lighter (2- and 3-ring) PAHs, including the 3-ringed phenanthrene [796]. However, increased alkylation makes phenanthrene heavier and changes other fate characteristics, including increasing bioconcentration tendencies [347]. Whereas phenanthrene (parent compound, no methyl groups attached) had higher concentrations in soil than in earth worms, the concentrations for 3,6,-dimethylphenanthrene were higher in earthworms than in soil [347]. This is not surprising since alkylation increases Kow. For details, see Bio.Detail section below and the "PAHs as a group" entry.

Low molecular weight parent compound PAHs (naphthalenes through phenanthrenes) are removed from the water column primarily by evaporation, microbial oxidation, and sedimentation [851].

Partitioning of phenanthrene to sediment is generally expected whenever phenanthrene is released to water [336].

Two significant processes which can influence the fate of phenanthrene in the sediment are sorption and biodegradation. Oxidation, hydrolysis and volatilization processes were found to have no effect on the fate of phenanthrene in sediment [862].

Phenanthrene was found in groundwater at a coal and oil gasification plant some 30 years after the plant shut down [788].

For several PAH families (naphthalenes, fluorenes, phenanthrenes, dibenzothiophenes, and chrysenes) if the unsubstituted parent PAH is less abundant than the sum of its counterpart alkyl homologues, the source is more likely petrogenic (from crude oil or other petroleum sources) rather than pyrogenic (from high temperature sources) [942].

Since alkyl versions of this compound are often found in even greater concentrations than the parent compound, the following generalizations concerning alkyl vs. parent compound PAHs should be kept in mind:

> Some alkyl PAHs tend to be less volatile than parent compound PAHs [867]. Alkyl substitution usually also decreases water solubility [754].
>
> Introduction or extension of an alkyl group increases not only persistence but also lipophilicity; increased lipophilicity is often associated with increased absorption [856]. Alkyl PAHs tend to bioaccumulate to a greater degree than parent compound PAHs [347,885].
>
> Alkylated PAHs are often more abundant than parent compounds [468], at least those alkyl PAHs originating from petrogenic sources [942].
>
> Alkyl PAHs also tend to persist for a longer time than the parent PAHs [468, 856]. PAH persistence tends to increase with increasing alkyl substitution; for example, methyl naphthalene is more persistent than naphthalene (the parent compound) and dimethyl naphthalene is still more

persistent than methyl naphthalene in sediments and amphipod tissues [885].

Comparing PAHs and alkyl PAHs, the parent compound is typically the first to degrade. Thus, as mixed composition petroleum products age, the percentage of alkyl PAHs vs. PAHs increases, yet most standard EPA scans (even 8270) do not pick up alkyl PAHs [796]. This, coupled with the need for lower detection limits and the general hazards presented by alkyl PAHs, is one reason the NOAA protocol expanded scan [828] or other rigorous scans using Selected Ion Monitoring (SIM) [942] are often recommended rather than the older standard EPA scans.

Environmental Fate/Exposure Summary [366]:

Release of phenanthrene most likely results from the incomplete combustion of a variety of organic compounds including wood and fossil fuels. Release to the soil will likely result in biodegradation. Volatilization is not expected to be significant. Phenanthrene is expected to bind strongly to soil and not leach extensively to groundwater. When released to water, adsorption of phenanthrene to suspended sediments is expected to remove most of the compound from solution. Photolysis is expected to occur near the water surface and biodegradation of phenanthrene in the water column is expected. Oxidation, volatilization and bioconcentration are not expected to be significant. Phenanthrene released to the atmosphere is expected to rapidly adsorb to particulate matter. Phenanthrene adsorbed on fly ash has been shown to photolyze rapidly (half-life 49 hr) and phenanthrene adsorbed on particulate matter will be subject to wet and dry deposition. Vapor phase phenanthrene will react with photochemically generated, atmospheric hydroxyl radicals with an estimated half-life of 1.67 days. phenanthrene is a contaminant in air, water, sediment, soil, fish and other aquatic organisms and food. Human exposure results primarily from ingestion of food contaminated with phenanthrene.

Synonyms/Substance Identification:

Phenanthren (GERMAN) [366,847]
Phenantrin [847]

Molecular Formula [366]:

C14-H10

Associated Chemicals or Topics (Includes Transformation Products):

See individual entries:

PAHs as a group
PAHs, Alkyl Homologs of
Phenanthrene, 1-Methyl
Phenanthrene, 3,6-Dimethyl
Phenanthrenes/Anthracenes, C1-
Phenanthrenes/Anthracenes, C2-
Phenanthrenes/Anthracenes, C3-
Phenanthrenes/Anthracenes, C4-

Related Compounds include [366]:

(Analog) Anthracene
(Analog) Fluoranthene

See also individual entry for combination products containing this compound:

Petroleum, General

Metabolism/Metabolites [366]:

Phenanthrene yields trans-9,10-dihydro-9,10-dihydroxyphenanthrene in rat & rabbit: Boyland, E et al, Biochem J, 84, 571 (1962); Boyland E & Wolf, G, Biochem J, 47, 64 (1950); & in rat: Boyland E, & Wolf G; Biochem J 42 32p (1948). /From table/ [Goodwin, B.L. Handbook of Intermediary Metabolism of Aromatic Compounds. New York: Wiley, 1976.,p. P-4].

Phenanthrene yields trans-1,2-dihydro-1,2-dihydroxyphenanthrene, trans-3,4-dihydro-3,4-dihydroxyphenanthrene, and s-(9,10-dihydro-9-hydroxyphenanthr-10-yl) glutathione in rabbit & in rat; Boyland E, and Sims P; Biochem J 84 571 (1962). /From table/ [Goodwin, B.L. Handbook of Intermediary Metabolism of Aromatic Compounds. New York: Wiley, 1976.,p. P-4].

Phenanthrene yields 1-hydroxy-, 2-hydroxy-, 3-hydroxy-, & 4-hydroxyphenanthrene in rat & in rabbit: Boyland E et al; Biochem J 84: 571 (1962); Sims P; Biochem J 84: 558 (1962). /From table/ [Goodwin, B.L. Handbook of Intermediary Metabolism of Aromatic Compounds. New York: Wiley, 1976.,p. P-4].

Phenanthrene yields 9-hydroxyphenanthrene in rat & rabbit: Sims P; Biochem J 84: 558 (1962); & phenanthrene-9,10-oxide; Grover PL, Hewer A, & Sims P; febs letters 18: 76 (1971). /From table/ [Goodwin, B.L. Handbook of Intermediary Metabolism of Aromatic Compounds. New York:

Wiley, 1976.,p. P-4].

Metabolites 48 hr after intragastric admin of 75 mg/kg to coalfish were all 5 of possible monohydroxy deriv & trans-phenanthrene-1,2-dihydrodiol & trans-phenanthrene-9,10-dihydrodiol. Trans-phenanthrene-1,2-dihydrodiol was excreted as glucuronide &/or sulfate conjugate. [Solbakken JE et al; Acta Pharmacol Toxicol 46 (2): 127-32 (1980)].

The metabolism of (14)C-phenanthrene in vitro by untreated, sodium phenobarbital (PhB) and 3-methylcholanthrene pre-treated rat, guinea pig, and mouse hepatic microsomes has been studied. The major metabolite, except with microsomes from 3-methylcholanthrene pre-treated guinea pigs, was trans-9,10-dihydro-9,10-dihydroxyphenanthrene. In the case of 3-methylcholanthrene pre-treated guinea pig microsomes, the trans-1,2-dihydrodiol was the major product. [The Royal Society of Chemistry. Foreign Compound Metabolism in Mammals. Volume 6: A Review of the Literature Published during 1978 and 1979. London: The Royal Society of Chemistry, 1981. 345].

The 1,2-, 3,4-, and 9,10-dihydrodiols are excreted either free or conjugated with glucuronic acid in the urine of rats and rabbits following IP admin of phenanthrene. These metabolites have also been detected in vitro following incubation of phenanthrene with liver preparations from guinea pigs, rats and mice. Further oxidative metabolism of the 1,2-dihydrodiol by rat-liver preparations to the 1,2-diol-3,4-epoxide has also been reported. [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V32 423 (1983)].

Pseudomonas /(bacterial)/ degradation of phenanthrene is as follows: Phenanthrene to phenanthrene cis-3,4-dihydrodiol to 3,4-dihydroxyphenanthrene to cis-4-(1-hydroxynaphth-2-yl)-2-oxobut-3-enoic acid to 4-(1-hydroxynaphth-2-yl) -2-oxo-4-hydroxybutyrate. [Verschueren, K. Handbook of Environmental Data of Organic Chemicals. 2nd ed. New York, NY: Van Nostrand Reinhold Co., 1983. 971].

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

W.Low (Water Concentrations Considered Low):

No information found.

W.High (Water Concentrations Considered High):

Groundwater samples taken near wood treatment/ storage sites in Canada contained between 0.52 and 0.73 mg/L phenanthrene. Other sites contained between 0.020 and 40 mg/L combined anthracene/ phenanthrene [864].

Information from ATSDR on PAHs in water (for information on embedded references, see ATSDR) [881]:

> PAHs have been detected in urban runoff generally at concentrations much higher than those reported for surface water. Data collected as part of the Nationwide Urban Runoff Program indicate concentrations of individual PAHs in the range of 300-10,000 ng/L, with the concentrations of most PAHs above 1,000 ng/L [881].
>
> Industrial effluents also have elevated PAH levels. There are elevated PAH levels in refinery waste waters, with concentrations for most PAHs in the range of 400 ng/L (benzo[b]fluoranthene) to 16,000 ng/L (phenanthrene) [881].
>
> In an analysis of STORET data covering the period 1980-88, Staples et al. (1985) reported median concentrations in industrial effluents of less than 10 ug/L) for 15 PAHs. The number of samples ranged from 1,182 (benzo[b]fluoranthene) to 1,288 (phenanthrene); the percentage of samples in which PAHs were detected ranged from 1.5 (benzo[g,h,i]perylene) to 7.0 (fluoranthene) [881].
>
> Few data are available on the concentrations of PAHs in U.S. groundwater. Basu and Saxena (1978b) reported total PAH concentrations in groundwater from three sites in Illinois, Indiana, and Ohio to be in the range of 3-20 ng/L. Groundwater levels of PAHs near a coal and oil gasification plant and U.S. wood treatment facilities have been found to be elevated. Groundwater samples from the site of a Seattle coal and oil gasification plant which ceased operation in 1956 were found to contain acenaphthylene, acenaphthene, fluorene, phenanthrene, fluoranthene, pyrene, and chrysene at concentrations ranging from not detected (detection limit 0.005 mg/L) to 0.25, 0.18, 0.14, 0.13, 0.05, 0.08, and 0.01 mg/L, respectively [881].
>
> Individual PAHs in the groundwater from 5 U.S. wood treatment facilities were reported at average concentrations of 57 ppb (0.057 mg/L) for benzo[a]pyrene to 1,825 ppb (1.8 mg/L) for

phenanthrene [788,881].

W.Typical (Water Concentrations Considered Typical):

Trace amounts of phenanthrene were found in samples of rain and snow from Norway, probably originating from combustion of fossil fuels [500].

Information from ATSDR on PAHs in water (for information on embedded references, see ATSDR) [881]:

> PAHs have been detected in surface waters of the United States. In an assessment of STORET data covering the period 1980-82, Staples et al. (1985) reported median concentrations in ambient water of less than 10 ug/L for 15 PAHs (acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, benzo[a]pyrene, chrysene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, naphthalene, phenanthrene, and pyrene). The percentage of samples in which these PAHs were detected ranged from 1.0 (benzo[g,h,i]perylene) to 5.0 (phenanthrene) and 7.0 (naphthalene) [881].
>
> DeLeon et al. (1986) analyzed surface water from 11 locations in the Mississippi River. Seventeen PAHs were identified in the samples at levels ranging from 1 ng/L for 6 compounds to a high of 34 ng/L for phenanthrene. The highest concentration of phenanthrene was detected in a sample collected near New Orleans, Louisiana, near an industrial area, implicating industrial effluent or surface runoff from this area as a possible source [881].
>
> During April and May 1990, Hall et al. (1993) analyzed 48-hour composite samples from three locations in the Potomac River and three locations in the upper Chesapeake Bay for eight PAHs: perylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, and chrysene. Pyrene was the only PAH found (0.42 ug/L) in these samples; it was detected in only one of nine Chesapeake Bay samples and not detected in any of the Potomac River samples (detection limit, 0.04 ug/L) [881].
>
> In a more recent study by Pham et al. (1993), raw water samples from 5 areas in the St. Lawrence River and its tributaries were analyzed for 12 PAHs. The highest mean total PAH concentrations were observed in samples collected in the spring (27.3 ng/L) and autumn (21.03 ng/L), which was

attributed to snow melt and increased runoff during these respective seasons. The lowest mean total PAH concentration was observed in summer (14.63 ng/L). High molecular weight PAHs were detected more frequently in the spring and autumn samples. Phenanthrene, benzo[b]fluoranthene, fluoranthene, and pyrene were predominant, comprising on average 33.8%, 17.4%, 17.1% and 12.8% of the total PAHs, respectively. With the exception of anthracene and benzo[b]fluoranthene, a general decrease in concentration with increasing molecular weight was observed [881].

Data summarized by Sorrel et al. (1980) indicate low levels of PAHs in finished drinking waters of the United States. Reported maximum concentrations for total PAHs (based on measurement of 15 PAHs) in the drinking water of 10 cities ranged from 4 to 24 ng/L; concentrations in untreated water ranged from 6 to 125 ng/L. The low concentrations of PAHs in finished drinking water were attributed to efficient water treatment processes. Shiraishi et al. (1985) found PAHs in tap water at concentrations of 0.1-1.0 ng/L, primarily as chlorinated derivatives of naphthalene, phenanthrene, fluorene, and fluoranthene. The significance to human health of these compounds is not known (Eisler 1987) [881].

Water Concentrations [366]:

Has been identified in ... surface water (0.1300 ng/l); tap water (3.1-90 ng/l); waste water (780 ug/l) ... [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V32 421 (1983)].

SURFACE WATER: Raw water - various US sites, 6-20 ng/l(1); Lake Quinsinamond, MA, Glen Ellyn, IL, Little Rock, AR, Bellevue, WA, and Eugene, OR - 12% pos, 0.3-10 ug/l(2). Five percent of 865 water samples had a median PHEN concentration of < 10.000 ug/l (STORET Database)(3). Great Britain (Tamar Estuary) - 8.8 ng/l(4). Tsukuba Japan - 0.34 ng/l(5). PHEN was detected but not quantified in Lakes Ontario, Erie, Michigan and Superior(6) and combined PHEN/anthracene residues were detected but not quantified in Mississippi River water(7) and in the Rhine and Maas Rivers in the Netherlands(8). [(1) Sorrell RK et al; Environ Intern 4: 245-54 (1980) (2) Cole RH et al; J Water Pollut Control Fed 56: 898-908 (1984) (3) Staples

CA et al; Environ Toxicol Chem 4: 131-42 (1985) (4) Readman JW et al; Estuarine Coastal Shelf Sci 14: 369-89 (1982) (5) Shiraishi H et al; Environ Sci Technol 19: 585-9 (1985) (6) Great Lakes Quality Board; Report to the Great Lakes Water Quality Board, Windsor, Ontario, Canada (1983) (7) Overton EB et al; Chemosphere 9: 629-33 (1980) (8) Meijers AP, Van Der Leer RC; Water Res 10: 597-604 (1976)].

DRINKING WATER: Athens, GA - 24-90 ng/l(1). Tsukuba, Japan - 0.45-1.41 ng/l(2). Combined phenanthrene (PHEN) and anthracene residues were as follows: New York - public water system wells, 39 wells tested, 17.9% pos, 21.0 ppb max(3); Great Lakes (various locations) - 0.6-1269 ng/l(4); Japan - tap water, 0.7 ng/l (5) and 1.7 ppb(6). PHEN was detected but not quantified in drinking water from an unspecified location(7). [(1) Thruston AD Jr; J Chromat Sci 16: 254-9 (1978) (2) Sharaishi H et al; Environ Sci Technol 19: 585-9 (1985) (3) Council on Environmental Quality; 11th Annual Report (1980) (4) Williams DT et al; Chemosphere 11: 263-76 (1982) (5) Akiyama T et al; J UOEH 2: 285-300 (1980) (6) Shinohara R et al; Water Res 15: 535-42 (1981) (7) Kool HJ et al; Crit Rev Env Control 12: 307-57 (1982)].

GROUNDWATER: Pensacola, FL - 0.76 and 0.78 mg/l at 12 and 6 m depths, respectively, and at 18 m, 0.07 mg/l (different site than above)(1). Phenanthrene was detected but not quantified in groundwater in Minnesota(2). [(1) Goerlitz DF et al; Environ Sci Technol 19: 955-61 (1985) (2) Rostad CE et al; Chemosphere 14: 1023-36 (1985)].

RAIN/SNOW: Portland, OR - 61-130 ng/l, 90.1 ng avg(1). Oregon Graduate Center (southeast of Portland, OR) - 3.1-51 ng/l, 24 ng/l; Portland, OR - 62-280 ng/l, 140 ng/l avg(2). Netherlands - 30-133 ng/l(3). Combined phenanthrene (PHEN)/anthracene residues in Portland, OR were 1.3-10.0 ng/l in particulates, 4.1 ng/l avg and 0.08-0.93 ng/cu m aerosol-associated, 0.37 ng/cu m (4). Combined PHEN/anthracene residues were detected but not quantified in Norway (particulates and dissolved)(5). [(1) Ligocki MP et al; Atmos Environ 19: 1609-17 (1985) (2) Pankow JF et al; Environ Sci Technol 18: 310-18 (1984) (3) Van Noort PCM, Wondergem E; Environ Sci Technol 19: 1044-8 (1985) (4) Ligocki MP et al; Atmos Environ 19: 1619-26 (1985) (5) Lunde G et al; Organic Micropollutants in Precipitation in Norway SNSF Project, FR-9/76 (1979)].

Effluents Concentrations [366]:

Phenanthrene (PHEN) residues in treated wastewater effluents from a variety of industries were as follows(1): Auto and other laundries - 3 samples, 100% pos, < 10-66 ug/l, < 29 avg; coal mining - 46 samples, 13% pos, 3-35 ug/l, 13 ug/l avg; leather tanning and finishing - 6 samples, 67% pos, 1.4-7.3 ug/l. < 6.2 ug/l avg; aluminum forming - 26 samples, 42.3% pos, < 1-110,000 ug/l, < 14,200 ug/l avg; battery manufacturing - 9 samples, 44.4% pos, < 10-< 10 ug/l, < 10 ug/l avg; coil coating - 32 samples, 53.1% pos, 7-25 ug/l, 11 ug/l avg; electrical/electronic components - 1 sample, 100% pos, < 10 ug/l max; foundries - 12 samples, 100% pos, 4-3200 ug/l, 290 ug/l avg; photographic equipment/supplies - 4 samples, 50% pos, minimum = maximum = 10 ug/l, 10 ug/l avg; nonferrous metals manufacturing - 60 samples, 11.7% pos, ND-140 ug/l, 11 ug/l avg; organic chemicals manufacturing/plastics - 26 detections, 7.2 ug/l avg; paint and ink formulation - 10 ug/l max; timber products processing - 9 samples, 88.9% pos, 10-37,000 ug/l, 59 ug/l avg(1). Sediment and water samples taken from the effluent channel from a coking plant in an unspecified location were 3.6 ug/g dry sediment and 0.40 ug/l, respectively(2). Gasoline engine exhaust contained 2359-2930 ug/l burnt fuel(3) and 2.1 ug/cu m(4). Diesel fuel exhaust contained 6.4 ug/cu m(4). Phenanthrene was detected but not quantified in diesel fuel exhaust(9). Of 1288 samples listed in the STORET data base, 5.1% were positive for PHEN with a median concentration of < 10.000 ug/l(5). Japanese sewage effluent samples contained combined PHEN/anthracene residues at 8.3 ng/l(6). PHEN was detected but not quantified in secondary effluents from wastewater treatment plants(7), a biomass gasifier(8), oil- and coal-fired power plants, industrial coal stoker fired broilers, and coke plants(9). [(1) USEPA; Treatability Manual Vol 1 Treatability Data USEPA-600/2-81-001a (1981) (2) Griest GH; pp 173-83 in Hydrocarbons and Halogenated Hydrocarbons in the Aquatic Environment Plenum Press NY (1980) (3) IARC; Polynuclear Aromatic Compounds Part 1, Chemical, Environmental and Experimental Data 32: 419-30 (1983) (4) Kerkhoff M et al; Environ Sci Technol 19: 695-99 (1985) (5) Staples CA et al; Environ Toxicol Chem 4: 131-42 (1985) (6) Akiyama T et al; J UOEH 2: 285-300 (1980) (7) Ellis DD et al; Arch Environ Contam Toxicol 11: 373-82 (1982) (8) Desilets DJ et al; Environ Sci Technol 18: 386-91 (1984) (9) Daisey JM et al; J Air Pollut Cont Assoc

36: 17-33 (1986)].

W.Concern Levels, Water Quality Criteria, LC50 Values, Water Quality Standards, Screening Levels, 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):

Important Note: Initial indications are that phenanthrene does not appear to be phototoxic [888,891,887].

General Water Quality Criteria in ug/L [446,689]:

Freshwater Acute Criteria: Proposed Criterion 30.0

Freshwater Chronic Criteria: Proposed Criterion 6.3

Note: one author asserted that the criterion was that phenanthrene in water should not exceed 6.3 ug/L more than once every three years, but that this EPA criterion does not take into account photo-induced toxicity of the PAH or subacute effects [894]. Both assertions appear to be wrong, since this is a chronic rather than an acute criterion and since phenanthrene does not appear to be phototoxic [888,891,887]. However, phototoxicity of other PAHs typically found in the same fuel mixtures as phenanthrene could indeed play a major role in PAH effects in clear waters, very shallow waters, or for any biota (for example amphibian or fish eggs or larvae) living in habitats receiving significant solar radiation (see "PAHs as a group" entry for details).

Marine Acute Criteria: Proposed Criterion 7.7

Marine Chronic Criteria: Proposed Criterion 4.6

Oak Ridge National Lab, 1994: Ecological Risk Assessment Freshwater Screening Benchmarks for concentrations of contaminants in water [649]. To be considered unlikely to represent an ecological risk, field concentrations should be below all of the following benchmarks [649]:

Phenanthrene (ug/L) [649]:

37.1 = Secondary acute value

3.23 = Secondary chronic value

200 = Lowest chronic value - daphnids

110 = Lowest test ec20 - daphnids

No value given for the following benchmarks:

National ambient water quality criterion - acute

National ambient water quality criterion - chronic

Lowest chronic value - fish

Lowest chronic value - non-daphnid invertebrates

Lowest chronic value - aquatic plants

Lowest test EC20 - fish

Sensitive species test EC20

Population EC2O

Acute and Chronic Criteria for Aquatic and Wildlife Uses in Arizona are 30 ug/L and 6.3 ug/L, respectively [881].

The Final Acute Value (FAV) for freshwater organisms, derived from fourteen standard acute toxicity tests on eight freshwater genera, was determined to be 59.63 ug/L. The FAV for saltwater organisms, derived from fourteen standard acute tests on eleven saltwater genera, was 16.61 ug/L [862]. See the below W.Invertebrate and W.Fish sections.

Chronic toxicity test were conducted with phenanthrene using a freshwater invertebrate, freshwater fish, and saltwater invertebrate. The Final Chronic Value (FCV) for freshwater organisms was determined to be 6.325 ug/L. The FCV for saltwater organisms was 8.255 ug/L. The invertebrate mean Acute-Chronic Ratio (ACR) was

2.012 for both freshwater and saltwater organisms [862].

Canada's interim assessment criteria (similar to screening benchmarks) and remediation criteria provide another indication that the consensus is going in the direction of lower standards and detection limits for PAHs. The interim assessment criteria (that is, approximate background concentration or approximate analytical detection limit) for phenanthrene in water is 0.2 ug/L (ppb) [656]. There is currently no listed remediation criteria for phenanthrene in water [656].

W.Plants (Water Concentrations vs. Plants):

No information found.

W.Invertebrates (Water Concentrations vs. Invertebrates):

LC50/ EC50 96-hour acute values, ug/L (ppb) [862]:

Freshwater invertebrates [862]:
Hydra (Hydra sp.) - 96 ppb, FT
Annelid (Lumbriculus variegatus) - > 419 ppb, FT
Cladoceran (Daphnia magma, 1st instar) - 700 ppb, S
Cladoceran (Daphnia magma, 4-6 days) - 207 ppb, S
Cladoceran (Daphnia pulex, <24 hours)- 734 ppb, S
Amphipod (Gammarus pseudolimnaeus) - 126 ppb, FT
Midge (Chironomous tentans, larval) - 490 ppb, S

Saltwater invertebrates [862]:
Archiannelid (Dinophilus gyrociliatus)-185.4 ppb, R
Polychaete worm (Neanthes arenaceodentata) - 600 ppb, S
Mud snail (Nassarius obsoletus) - > 245 ppb, R
Blue mussel (Mytilus edulis) - > 245 ppb, R
Soft-shell clam (Mya arenaria) - > 245 ppb, R
Mysid (Mysidopsis bahia) - 17.7 ppb, FT
Amphipod (Leptocheirus plumulosus) - 198.4 ppb, FT
Grass shrimp (Palaemonetes pugio) - 145.4 ppb, R
Hermit crab (Pagurus longicarpus) - 163.7 ppb, FT

NOTES: Test methods: FT = flow-through, R = renewal, S= static

Other LC50 Values [851]:

Neanthes arenaceodentata
  (marine polychaete) - 0.6 ppm, 96 h
Palaemonetes pugio
  (grass shrimp) - 0.37 ppm, 24 h

W.Fish (Water Concentrations vs. Fish):

Acute Criteria for Cold-Water Fisheries in Arizona are each 30 ug/L [881].

Acute Criteria for Warm-Water Fisheries in Arizona are each 540 ug/L [881].

Chronic Criteria for Cold- and Warm-Water Fisheries in Arizona are each 6.3 ug/L [881].

One study reports that phenanthrene concentrations of 1.02 to 2.0 mg/L killed sunfish in one hour, while another report gives 4.0 to 5.0 mg/L as the lethal concentration for fish during one hour exposure [224].

In Lake Huron water at 12 degrees C, 5.0 mg/L killed rainbow trout and bluegill sunfish in 24 hours, but had no effect on the sea lamprey [224].

In continuous-flow toxicity tests with embryo-larval stages of rainbow trout and largemouth bass, the LC50 values for phenanthrene were 0.04 and 0.18 mg/L, respectively [754].

Fish: TLm (median lethal dose) Neanthes arenaceodentata 0.6 ppm/96 hr in seawater at 22 deg C in a static bioassay [154].

LC50/ EC50 96-hour acute values, ug/L (ppb) [862]:

Freshwater fish [862]:
- Rainbow trout (Oncorhynchus mykiss) - 375 ppb, FT
- Fathead minnow (Pimephales promelas)- >1150 ppb, S
- Bluegill (Lepomis macrochirus) - 234 ppb, FT

Saltwater fish [862]:
- Sheepshead minnow (Cyprinodon variegatus) - > 245 ppb, R
- Sheepshead minnow (Cyprinodon variegatus) - 429.4 ppb, FT
- Atlantic silverside (Menidia menidia) - 108 ppb, FT

NOTES: Test methods: FT = flow-through, R = renewal, S= static

Other LC50 Values [851]:

Gambusia affinis

(mosquito fish) - 150 ppm, 96 h

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

Acute and Chronic Criteria for Aquatic and Wildlife Uses in Arizona are 30 ug/L and 6.3 ug/L, respectively [881].

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

EPA 1996 IRIS database information [893]:

Ambient Water Quality Criteria for Human Health

Water & Fish: 2.8E-3 ug/liter [893].

Older References:

Human Health (10-6) Risk Level for Carcinogens): Published Criteria for Water and Organisms in ug/L: 0.0028 [689].

For the maximum protection of human health from the potential carcinogenic effects due to exposure of polynuclear aromatic hydrocarbons through ingestion of contaminated water and contaminated aquatic organisms, ... therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 1x10-5, 1x10-6, and 1x10-7. The corresponding criteria /for ambient water/ are 28.0 ng/l, 2.8 ng/l, and 0.28 ng/l, respectively [366].

Fish Only: 3.11E-2 ug/liter [893].

Older References:

Human Health (10-6) Risk Level for Carcinogens): Published Criteria for Organisms Only in ug/L: 0.0311 [689].

The levels which may result in

incremental increase of cancer risk over the lifetime are estimated at 1x10-5, 1x10-6, and 1x10-7. The corresponding criteria for organism consumption only are 311.0 ng/l, 31.1 ng/l, and 3.11 ng/l respectively. /Polynuclear aromatic hydrocarbons based on benzo(a)pyrene as the model PAH/ [USEPA; Ambient Water Quality Criteria Doc: Polynuclear Aromatic Hydrocarbons p.C-121 (1980) [366].

Reference: 45 FR 79318 (11/28/80)

Contact: Criteria and Standards Division / OWRS / (202)260-1315

Discussion: For the maximum protection from the potential carcinogenic properties of this chemical, the ambient water concentration should be zero. However, zero may not be obtainable at this time, so the recommended criteria represents a E-6 estimated incremental increase of cancer over a lifetime. The values given represent polynuclear aromatic hydrocarbons as a class.

Drinking Water MCL. MCLG [446,893]:

None Published

Note: Before citing a concentration as EPA's water quality criteria, it is prudent to make sure you have the latest one. Work on the replacement for the Gold Book [302] was underway in March of 1996, and IRIS is updated monthly [893].

The warm water- and cold water sport fish community human cancer criteria for phenanthrene in Wisconsin public water supplies are each 0.023 mg/L [881].

The warm water- and cold water sport fish community human cancer criteria for phenanthrene in Wisconsin non-public water supplies are each 0.1 mg/L [881].

Numeric Water Quality Criteria in Arizona [881]:

Domestic water supply: 0.003 ug/L

Fish consumption: 0.0005 ug/L
Full body contact: 0.12 ug/L

Criteria for human health protection in Missouri [881]:

Fish consumption: 0.03 ug/L
Drinking water supply: 0.003 ug/L
Groundwater: 0.003 ug/L

Note: Before citing a concentration as EPA's water quality criteria, it is prudent to make sure you have the latest one. Work on the replacement for the Gold Book [302] was underway in March of 1996, and IRIS is updated monthly.

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

The toxic effect of aromatic hydrocarbons, benzene, toluene, naphthalene, 1-methylnaphthalene, anthracene, 9-methylanthracene, phenanthrene, on the productivity growth rate of various marine planktonic algae (Dunaliela biocula, Phaeodactylum tricornutum, and Isochysis galbaya) increased with increasing number of aromatic rings. The methylated compounds were most toxic. Taxonomic differences in sensitivity to aromatic hydrocarbons were not demonstrated. [Jensen K et al; Limnol 15 (2): 581-4 (1984)] [366].

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

Sed.Low (Sediment Concentrations Considered Low):

Great Lakes Harbors: The control site in one Great Lakes study had a sediment concentration of <0.01 mg/kg (dry weight) of phenanthrene [145].

Sed.High (Sediment Concentrations Considered High):

Introduction of creosote into the Hershey River in Michigan resulted in phenanthrene (PHEN) concentrations as high as 352 ng/g sediment (wet weight) 3 km downstream from the source(1). Partitioning of PHEN to sediment is generally expected whenever PHEN is released to water [336].

Sediment samples taken near wood treatment/ storage sites in Canada contained between 0.038 and 5,687 mg/kg dry weight phenanthrene [864].

Analyses of sewage sludges from 50 publicly owned treatment works by the U.S. Environmental Protection

Agency (1985): The mean concentration of phenanthrene was 5.9 ppm (dry weight) [347].

Sed.Typical (Sediment Concentrations Considered Typical):

Phenanthrene was detected in 100 percent of urban-bay samples from the Puget Sound area. The mean concentration was 2897 ug/kg dry weight (ppb), while the median concentration was 290 ug/kg (ppb) [852].

Phenanthrene was detected in 75.7 percent of non-urban-bay samples from the Puget Sound area. The mean concentration was 4036 ug/kg dry weight (ppb), while the median concentration was 99.5 ug/kg (ppb) [852].

> NOTE: The above values are not normalized for total organic carbon (TOC) content. Urban bay concentrations may be lower than non-urban bay concentrations due to more frequent dredging practices in urban bays, and also to the fact that most of the urban bays are at the mouths of rivers which are continually depositing "clean" sediment into these bays.

Information from ATSDR on PAHs in sediment (for information on embedded references, see ATSDR) [881]:

> Sediments are major sinks for PAHs, primarily because of the low solubility of these compounds and their strong affinity for organic carbon in particulate matter. PAH concentrations in sediment are generally much higher than those detected in surface water, i.e., in the range of ug/kg (ppb) rather than ng/kg (ppt) [881].
>
> In an assessment of STORET data covering the period 1980-1982, Staples et al. (1985) reported median concentrations in sediment of less than or equal to 500 ug/kg dry weight for 15 PAHs (acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, benzo[a]pyrene, chrysene, fluoranthene, fluorene, indenopyrene, naphthalene, phenanthrene, and pyrene). The number of sample ranged from 236 (anthracene) to 360 (benzo[a]pyrene, fluoranthene); the percentage of samples in which these PAHs were detected ranged from 6.0 (acenaphthene, benzo[b]fluoranthene, benzo[k]fluoranthene, indeno[1,2,3-c,d]pyrene) to 22.0 (fluoranthene, pyrene) [881].

Sediment Concentrations [366]:

Has been identified ... in dried sediment (140-2740 ug/kg). [847].

Residues of ... phenanthrene were identified from the Buffalo River, NY sediments. [Kuehl DW et al; J Great Lakes Res 10 (2): 210-214 (1984)].

SEDIMENTS: Sagamore Lake, NY - 150-15 ng/g dry weight for depths of 0-4 to 41-47 cm, respectively and 17 and 27 ng/g dry weight for depths of 51-55 and 81-81 cm, respectively; Woods Lake, NY - 320-33 ng/g dry weight for depths of 0-4 to 12-17 cm, respectively, 38-36 ng/g dry weight for depths of 24-26 and 34-38 cm, respectively and 55-22 ng/g dry weight for depths of 5-54 to 80-84 cm, respectively phenanthrene(1). Penobscot Bay ME - 17-252 ppb dry weight, surficial sediments(2). Duwamish River Delta, WA - 1200 ng/g sediment, wet weight(3). Eagle Harbor, WA - 160 to 19000 ng/g dry weight; President Point, WA - 150 ng/g dry weight(4). South Carolina - Palmetto Bar Marina, 131.0; 195.2 ug/kg dry weight; Outdoor Resorts Marina, 26.9; 1620.8 ug/kg dry weight; Fripp Island Marina, ND; 54.4 ug/g dry weight; (spring, summer measurements)(5). [(1) Tan YL, Heit M; Geochim et Cosmochim 45: 2267-79 (1981) (2) Johnson AC et al; Mar Environ Res 15: 1-16 (1985) (3) Varanasi U et al; Environ Sci Technol 19: 836-41 (1985) (4) Malins DC et al; Carcinogenesis 6: 1463-9 (1985) (5) Marcus JM, Stokes TP; Bull Environ Contam Toxicol 35: 835-44 (1985)].

SEDIMENTS: Great Britain (Tamar Estuary) - 1042 ng/g of phenanthrene in suspended solids, 368 ng/g sediments(1). Norway (Saudafjord) - 121.6-9069.4 dry weight (0-2 cm), 205.9-2781.5 ppb dry weight (2-4 cm), 34.5-3409.8 ppb dry weight (4-6 cm), and 106.2-1477.6 ppb dry weight (6-8 cm)(2). Baltic Sea - 31 ng/g; Gulf in Finland - 77 ng/g, 31-77 ug/kg, 3-30 ug/kg; Norway - 150 ug/kg(3). Combined phenanthrene/anthracene residues were as follows in sediments: sediment samples taken from the Charles River in Boston, MA and successively farther out into the Atlantic to a distance 1000 km from Boston were 3000-<0.1 ppb dry weight(4). Niagara River (Niagara-on-the-Lake) - suspended sediments, trace- 4000 ng/g(5). Charles River, MA - 5000 ppb; Gulf of Maine - 44; Buzzards Bay, MA - 8-53; Cape Cod Bay, MA - 140 ppb; Pettaquamscutt River, RI - 940 ppb; New York Bight, NY - 740 ppb; Hudson Channel, NY - 62 ppb; Hudson Canyon, NY - 74 ppb; Continental Slope, US East Coast - 7 ppb; Mono Lake, CA - 91-110 ppb; Polynesian Atolls - not detected-90 ppb; Walvis Bay, Africa - 7.6 ppb; Cariaco Trench - 18 ppb; Amazon River flood plain - 2.1 ppb; Amazon River - not detected-9.3 ppb;(6). [(1) Readman JW et al; Estuarine Coastal Shelf Sci 14: 369-89 (1982) (2) Bjorseth A et al; Sci Total Environ 13: 71-86 (1979) (3) Poutanen EL et al;

Chemosphere 10: 347-54 (1981) (4) Windsor JG Jr, Hites RA; Geochim Cosmochim Acta 43: 27-33 (1979) (5) Kuntz KW; Toxic Contaminants in the Niagara River, 1975-82, Environment Canada, Inland Waters Directorate, Water Quality Branch Tech Bull No.134 (1984) (6) Hites RA et al; Adv Chem Ser 185: 289-311 (1980)].

SEDIMENTS: Seattle, WA - Duwamish River (intertidal sediments), 170-2200 ng/g dry weight and 530 +/- 51-920 +/- 50 ng/g dry weight phenanthrene(1). Washington - Port Angeles Harbor, 43-320 ng/g dry weight(2). Maine (Casco Bay) - ND-2000 ppb wet weight(3). Michigan - Hershey River sediments, ND-23,000 ng/g wet weight(4). Sediment samples taken in a Michigan River near a coal fired power plant and 5 and 10 km away in Lake Erie were about 190, 350 and 300 ppb, respectively(5). Washington coastal sediment - 0.6-2.7 ug/g organic content(6). Cayuga Lake, NY - 320 to 560 ng/g (deep water sediments); 190 to 1200 ng/g (littoral sediments); 49-1500 ng/g (littoral sediments near power plant); 300-6600 ng/g (Ithaca, NY sediments); 810-3000 ng/g (sediments from marines)(7). Lake Pontchartrain, LA - 51 ng/g dry weight(8). [(1) MacLeod WD et al; Anal Chem 54: 386-92 (1982) (2) MacLeod WD JR et al; pp. 385-96 in Fate Eff Pet Hydrocarbons Mar Ecosyst Org Proc Symp (1977) (3) Larsen PF et al; Bull Environ Contam Toxicol 30: 5305 (1983) (4) Black JJ; Arch Environ Contam Toxicol 11: 161-6 (1982) (5) Eadie BJ et al; Chemosphere 11: 185-91 (1982) (6) Prahl FG, Carpenter R; Est Coastal Shelf Sci 18: 703-20 (1984) (7) Heit M; Water Air Soil Pollut 24: 41-61 (1985) (8) McFall JA et al; Chemosphere 14: 1561-9 (1985)].

SEDIMENTS: Sediment samples taken from the North Sea to locations in Norway and Sweden ranged from 1.51-10,700 ppb phenanthrene dry weight(1). Polycyclic aromatic hydrocarbons in general were 3.1-1.2 ug/g in sediments trapped from 50-200 m and 1.0 ug/g in bottom sediments collected in the Puget Sound, WA(2). Phenanthrene was detected but not quantified in sediments taken from Lake Washington and Puget Sound(3), the Elizabeth River in Virginia(4), Commencement Bay, WA(2), the Atlantic Ocean, the Gulf of Mexico and Southern California(5), New Brunswick, Canada(6) and Dokhai Bay, Japan(7). [(1) Sporstol S et al; Environ Sci Technol 17: 282-6 (1983) (2) Bates TS et al; Environ Sci Technol 18: 299-305 (1984) (3) Barrick RC et al; Environ Sci Technol 18: 846-54 (1984) (4) Merrill EG, Wade Tl; Environ Sci Technol 19: 597-603 (1985) (5) Overton EB, Laseter JL; Adv Chem Ser 185: 327-41 (1980) (6) New Brunswick Research and Productivity Council; Bioaccumulation of toxic compounds in sulphmill effluents by aquatic organisms in receiving waters, Report 657-1 (1978) (7) Shinohara R et al; Environ Intern 4: 163-74 (1980)].

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):

Various Sediment Concern Levels (Dry Weight):

EPA 1988: The interim sediment criteria value proposed by EPA was 1.0 mg/kg [127,145].

AET 1988: The apparent effects threshold concentrations for phenanthrene in sediments proposed for Puget Sound ranged from 1.5 mg/kg dry weight (microtox) to 6.9 mg/kg dry weight (amphipod) [416]. Although the authors of the Puget Sound AETs have cautioned that Puget Sound AETs may not be appropriate for comparison with data from other geographic areas, so few concern levels for this chemical have been published that the proposed Puget Sound concern level is included in this text as a reference item.

The Canadian AET concentration, adapted from NOAA (1990), for phenanthrene sorbed to marine sediments is 0.260 mg/kg dry weight [864]. An AET is defined as the lowest concentration of a compound in sediment at which biological effects (usually changes in composition of benthic invertebrate communities) are observed to occur [864].

NOTE: Even lower concentrations of this PAH may be of concern related to its contribution to "total PAH" sums (see "PAHs as a group" entry).

NOAA 1995: After studying its own data from the National Status and Trends Program as well as many literature references concerning different approaches to determining sediment criteria, NOAA suggested that the potential for biological effects of this contaminant sorbed to sediments was highest in sediments where its concentration exceeded the 1500 ppb dry weight Effects Range-Median (ERM) concentration and was lowest in sediments where its concentration was less than the 240 ppb dry weight Effects Range-Low (ERL) concentration [664]. To improve the original 1990 guidelines [233], the 1995 report included percent (ratios) incidence of effects for ranges below, above, and between the

ERL and ERM values. These numbers represent the number of data entries within each concentration range in which biological effects were observed divided by the total number of entries within each range [664]:

<ERL	18.5
ERL-ERM	46.2
>ERM	90.3

The 1995 NOAA study also compared these derived ERM values to criteria developed with other methods. For example, the national sediment quality criteria proposed by the US EPA (1993) for phenanthrene is 240 ug/gram organic carbon (goc), with 95% confidence limits of 110 and 510 ug/goc [664]. Assuming a total organic carbon (TOC) concentration of 1%, this is equivalent to 2400 (1100 - 5100) ppb dry weight. This exceeds the ERM value of 1500 ppb by a factor of 1.6. Note that increasing the percent TOC would increase the EPA criteria value [664].

Ontario Ministry of the Environment Freshwater Sediment Guidelines, 1993. Lowest effect level: 560 ug/kg dry weight. Severe effect level: 950 ug/kg organic carbon [761].

St. Lawrence River Interim Freshwater Sediment Criteria, 1992. No effect level: 30-70 ug/kg dry weight. Minimal effect level: 400 ug/kg dry weight. Toxic effect level: 80 mg/kg organic carbon [761].

Environment Canada Interim Sediment Quality Assessment Values, 1994. Threshold Effect Level: 41.9 ug/kg dry weight. Probable effect level: 514.9 ug/kg dry weight [761].

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Sediment Concentrations. To be considered unlikely to represent an ecological risk, field concentrations should be below all of the following benchmarks [652]:

1.8 mg/kg (ppm) dry weight is the sediment quality criterion for phenanthrene- 1% Organic Carbon (EPA).

Various Sediment Concern Levels (organic carbon (OC) basis]:

The Sediment Quality Criteria on a sediment organic carbon basis (SQC OC) was determined to be 180 ug/g OC in freshwater, and 240 ug/g OC in saltwater. These values were derived from phenanthrene Final Chronic Values (FCV) of 6.325 ug/L for freshwater and 8.255 ug/L for saltwater, and an organic carbon partition coefficient (Log 10 K oc) of 4.46 [862]. Dry weight concentrations can be converted to organic carbon normalized concentrations with the following formula [862]:

ug/g OC = ug/g dry weight x 100 / % TOC

NOTES: TOC = total organic carbon content. The use of the FCV (that is, the chronic effects-based water quality criteria) as the effects concentration for calculation of the equilibrium partition (EqP)-based SQC assumes that benthic species as a group have sensitivities similar to the benthic and water column species tested to derive the FCV concentrations (see reference [862] values in the above W.General, W.Invertebrates, and W.Fish sections). This method also assumes that the partitioning of the chemical between sediment organic carbon and interstitial water is at equilibrium. Therefore, SQC values may also need to be adjusted because of site specific considerations. In spill situations, where chemical equilibrium between water and sediments has not yet been reached, sediment chemical concentrations less than the SQC may pose risks to benthic organisms because disequilibrium concentrations in interstitial and overlying water may be proportionally higher relative to sediment concentrations.

Sed.Plants (Sediment Concentrations vs. Plants):

No information found.

Sed.Invertebrates (Sediment Concentrations vs. Invertebrates):

The acute toxicity of phenanthrene spiked into sediments was tested with two saltwater amphipod species. Test results follow and include both pore water toxicities and organic carbon conditions of the tests [863]:

LC50s [863]:

Amphipod (Eohaustorius estuarius) -
sediment toxicity = 39.2 ug/g dry weight
pore water toxicity = 138 ug/L
Organic carbon conditions: 0.82% TOC

Amphipod (Eohaustorius estuarius) -
sediment toxicity = 97.2 ug/g dry weight
pore water toxicity = 139 ug/L
Organic carbon conditions: 2.47% TOC

Amphipod (Eohaustorius estuarius) -
sediment toxicity = 122 ug/g dry weight
pore water toxicity = 146 ug/L
Organic carbon conditions: 2.97% TOC

Amphipod (Leptocheirus plumulosus) -
sediment toxicity = 92.4 ug/g dry weight
pore water toxicity = 387 ug/L
Organic carbon conditions: 0.82% TOC

Amphipod (Leptocheirus plumulosus) -
sediment toxicity = 162 ug/g dry weight
pore water toxicity = 306 ug/L
Organic carbon conditions: 2.50% TOC

Amphipod (Leptocheirus plumulosus) -
sediment toxicity = 255 ug/g dry weight
pore water toxicity = 360 ug/L
Organic carbon conditions: 2.97% TOC

NOTE: TOC = total organic carbon content; All tests were static, 10-day tests.

Sed.Fish (Sediment Concentrations vs. Fish):

No information found.

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

No information found.

Sed.Human (Sediment Concentrations vs. Human):

No information found.

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

In a study of the effects of motor boat activity on the water and sediment quality of a drinking water reservoir near Washington, D.C., only a few PAHs (like phenanthrene, pyrene, and fluoranthene) were commonly found in the sediments, unlike the water samples, in which all 11 of the PAHs monitored were frequently found [653].

Information from HSDB [366]:

> Buffalo river sediment extracts contained polynuclear aromatic hydrocarbons (PAH) which caused skin darkening, hyperplasia, skin papillomas, mild coarsening and local pigmentations in the brown bullhead (Ictalurus nebulosus). Sixteen polynuclear aromatic hydrocarbons were identified in the sediment extract: fluorene, phenanthrene, anthracene, fluoranthene, 2-methylphenanthrene, pyrene, 2-methylanthracene, benzanthracene, chrysene, perylene, benzo(f)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, benzo(g,h,i)perylene, and indeno(1,2,3-c,d)pyrene. [Black JJ; Polynucl Aromat Hydrocarbons Int Symp 7th 99-11 (1983)].

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

Soil.Low (Soil Concentrations Considered Low):

No information found.

Soil.High (Soil Concentrations Considered High):

Soil samples taken near wood treatment/ storage sites in Canada contained between 5.6 and 7,200 mg/kg dry weight phenanthrene. Other sites contained between 34.91 and 5,300 mg/dry weight phenanthrene/ anthracene [864].

Soil Concentrations (mg/kg dry weight) Polycyclic Aromatic Hydrocarbons (PAHs) at Contaminated Sites. Highest values found at wood preserving, gas works, and coking site plants (mg/kg dry weight) [881]:

Phenanthrene	4,434

Soil.Typical (Soil Concentrations Considered Typical):

Information from ATSDR on PAHs in soil (for information on embedded references, see ATSDR) [881]:

> PAHs are ubiquitous in soil. Because anthropogenic combustion processes are a major source of PAHs in soils, soil concentrations have tended to increase

over the last 100-150 years, especially in urban areas (Jones et al. 1989a, 1989b). Background concentrations for rural, agricultural, and urban soils (from the United States and other countries) are below.

Recent data on PAH concentrations in soil at contaminated sites are summarized in the table below. Because of the different sampling methods and locations at each site, this tabulation does not provide a reliable inter-site comparison. Additional studies indicate significantly elevated concentrations of PAHs at contaminated sites. Soil samples collected from the Fountain Avenue Landfill in New York City contained PAH concentrations ranging from 400 to 10,000 ug/kg (Black et al. 1989). In a 1988 study at a hazardous waste land treatment site for refinery process wastes, which had been operative since 1958, average PAH concentrations in surface soils (0-30 cm) ranged from not detected (detection limits 0.1-2.0 mg/kg dry weight) for acenaphthylene, acenaphthene, anthracene, benz[a]anthracene, and benzo[k]fluoranthene to 340 mg/kg dry weight for dibenz[a,h]anthracene (Loehr et al. 1993). In addition to dibenz[a,h]anthracene, the three most prevalent compounds at this depth were benzo[a]pyrene (204 mg/kg), benzo[b]fluoranthene (130 mg/kg), and chrysene (100 mg/kg). PAH concentrations decreased with increasing depth and the majority of PAHs were not detected at depths below 60 cm. At 90-135 cm, only phenanthrene (1.4 mg/kg), pyrene (4.0 mg/kg), chrysene (0.9 mg/kg), and dibenz[a,h]anthracene (0.8 mg/kg) were found [881].

Background Soil Concentrations of Polycyclic Aromatic Hydrocarbons (PAH concentration in ug/kg) [881]:

(The below table is not indented to allow it to fit the margins):

Compound	Rural soil	Agricultural Soil	Urban Soil
Acenaphthene	1.7	6	
Acenaphthylene		5	
Anthracene		11-13	
Benzo(a)anthracene	5-20	56-110	169-59,000
Benzo(a)pyrene	2-1,300	4.6-900	165-220
Benzo(b)fluoranthene	0-30	58-200	5,000-62,000
Benzo(e)pyrene		53-130	60-14,000
Benzo(g,h,i)perylene	10-70	66	900-47,000
Benzo(k)fluoranthene	0-110	58-250	300-26,000
Chrysene	38.3	78-120	251-640

Fluoranthene	0.3-40	120-210	200-166,000
Fluorene		9.7	
Ideno(1,2,3-c,d)pyrene	10-15	63-100	8,000-61,000
Phenanthrene	30.0	48-140	

HSDB information on typical soil concentrations [366]:

SOILS: Combined phenanthrene/ anthracene residues were as follows in a variety of soils. Nova Scotia - <0.1-110 ppb(1); Maine - 63 ppb, Stoneham, MA (urban soil) - 120 ppb; Springfield, MA - 33 ppb, South Carolina - 78 ppb, Nebraska - 4.4-8.0 ppb, Wyoming - 4.8-30 ppb, California - 7.0-9.5 ppb, Alaska - 2.5-67 ppb, Hawaii - 3.6 ppb, Enewetok Atoll - 130 ppb, Wake Island - 31 ppb, Samona - Not detected-0.3 ppb dry weight(2). Phenanthrene was collected near a roadway in Canada(3). [(1) Windsor JG Jr, Hites RA: Geochim Cosmochin Acta 43: 27-33 (1979) (2) Hites RA et al; Adv Chem Ser 185: 289-311 (1980) (3) Daisey JM et al; J Air Pollut Cont Assoc 36: 17-33 (1986)].

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):

Canada's interim assessment criteria (similar to screening benchmarks) and remediation criteria provide another indication that the consensus is going in the direction of lower standards and detection limits for PAHs. The interim assessment criteria (that is, approximate background concentration or approximate analytical detection limit) for phenanthrene in soil is 0.1 ug/L (ppb) [656]. The interim remediation criteria (considered generally protective of human and environmental health) for phenanthrene in soil is 0.1 ug/g (ppm) for agricultural land, 5 ug/g for residential/ parkland, and 50 ug/g for commercial/ industrial land. All values are in dry weight [656].

Soil criteria for evaluating the severity of contamination under the Dutch Soil Cleanup (Interim) Act (1982): 0.1 ppm indicates a background concentration of phenanthrene. 5 ppm indicates a moderate soil contamination. 50 ppm indicates a threshold contamination that requires immediate cleanup [347].

Acceptable on-site concentrations approved by the Ontario Ministry of the Environment for the Texaco and Shell refinery sites (1987): The acceptable soil concentration for phenanthrene is 1,870 ppm [347].

Soil.Plants (Soil Concentrations vs. Plants):

No information found.

Soil.Invertebrates (Soil Concentrations vs. Invertebrates):

No information found.

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

No information found.

Soil.Human (Soil Concentrations vs. Human):

No information found.

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

No information found.

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.

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

No information found.

Tis.Invertebrates:

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

No information found.

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

No information found.

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

Details of phenanthrene content (ug/kg or ppb) in whole body samples of mussels) from Snug Harbor, Alaska, an area heavily oiled by the Exxon Valdez Crude Oil, 4/15/89 [971]:

Note: Concurrent measurements of water quality, as well as equilibrium partitioning estimates of water quality based on concentrations in fish and mussels, both confirm that PAH concentrations did not exceed water quality criteria at the time these concentrations were measured in mussel tissues [971]. These values are wet weight (Jerry Neff, Battelle Ocean Sciences, Duxbury, MA, personal communication 1996):

phenanthrene:	356 ug/kg = ppb
C1-phenanthrene:	1924 ug/kg = ppb
C2-phenanthrene:	3834 ug/kg = ppb
C3-phenanthrene:	2438 ug/kg = ppb
C4-phenanthrene:	796 ug/kg = ppb

Measured phenanthrene concentrations were (in wet weight) 0.03 to 0.1 ug/g in oysters, 0.19 ug/g in snails, 0.520 in insects, 0.45 ug/g in crayfish, and 0.028 in clams from Canadian and American creosote-contaminated sites [864].

See Tis.Fish, C) section below.

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.

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

No information found.

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

Details of phenanthrene content (mg/kg or ppm) in salmon carcass (fatty viscera removed, so the concentrations may have been higher from whole body samples) from Snug Harbor, Alaska, an area heavily oiled by the Exxon Valdez Crude Oil, 4/15/89 [971]:

> Note: Concurrent measurements of water quality, as well as equilibrium partitioning estimates of water quality based on concentrations in fish and mussels, both confirm that PAH concentrations did not exceed water quality criteria at the time these concentrations were measured in fish tissues [971]. These values are wet weight (Jerry Neff, Battelle Ocean Sciences, Duxbury, MA, personal communication 1996):
>
> phenanthrene: 22.97 ug/kg = ppb
> C1-phenanthrene: 28.48 ug/kg = ppb
> C2-phenanthrene: 20.45 ug/kg = ppb
> C3-phenanthrene: 12.43 ug/kg = ppb
> C4-phenanthrene: 1.71 ug/kg = ppb

The phenanthrene concentration in mosquitofish with extremely elevated total PAH concentrations (60.79 mg/kg) was 7.2 mg/kg [201].

Measured phenanthrene concentrations were (in wet weight) 0.038 ug/g in lamprey and 0.029 in trout from Canadian and American creosote-contaminated sites [864]. Other concentrations were 0.03 ug/g in fish muscle, 0.200 in fish fat, and 50 ug/ml naphthalene/ phenanthrene metabolites in fish bile [864].

Fish/Seafood Concentrations [366]:

> Fish - Lake Erie, 3 sites, stomach contents of bottom feeders, 23.37-43.07 ng/g wet weight(1). Oysters - variety of US sites, 0-1.0 ug/g dry weight(2). Fish - Eagle Harbor and President Point, WA, liver, < 34-96 ng/g; muscle, < 2.9 ng/g dry weight (Eagle Harbor only)(3). Oysters - South Carolina: Outdoor Resorts Marina, 4.9-16.0 ug/kg wet weight mean; Palmetto Bay Marina, 6.0-76.5 ug/kg wet weight mean(4). Mussels - Yaquina Bay, OR, two sites, 45.9-178.4 ug/kg wet weight, 107.6 ug/kg avg; 173.3-284.3 ug/kg wet weight, 216.3 ug/kg avg(5). Softshell clams - Coos Bay, OR, two sites, 9.4-17.4 ug/kg, 12.2 ug/kg avg (site adjacent to highway); 144.4-162.3 ug/kg, 154.8 ug/kg avg (site proximal to industry)(6). Galveston Bay, MD - 2.2 ug/kg in oysters taken from areas not approved for

harvesting(7). Lake Pontchartrain, LA - oysters, 220 ng/g wet weight; clams, 72 ng/g wet weight(8). Mussels - Saudafjord, Norway, 20-1130 ppb dry weight(9). Norway - common mussels, 41-792 ug/kg dry weight; common periwinkle, 115-258 ug/kg dry weight; common limpet, 55-2542 ug/kg dry weight; starfish, 32-50 ug/kg dry weight(10). Thailand - oysters, 6.7 ng/g; green mussel, 4.4 ng/g; scallop, 4.4 ng/g(11). Mussels - Thermaikos Gulf, Greece, 52.6% pos, 9 ppb wet weight(12). Phenanthrene was detected but not quantified in fish from Louisiana(13), the Gulf of Mexico(14), and Puget Sound, WA(15). [(1) Maccubin AE et al; Bull Environ Contam Toxicol 34: 876-82 (1985) (2) Pittinger CA et al; Environ Toxicol Chem 4: 379-87 (1985) (3) Malins DC et al; Carcinogenesis 6: 1463-9 (1985) (4) Marcus JM, Stokes TP; Bull Environ Contam Toxiol 35: 835-44 (1985) (5) Mix MC, Schaffer RL; Marine Environ Res 9: 193-209 (1983) (6) Mix MC, Schaffer RL; Marine Pollut Bull 14: 94-7 (1983) (7) Howard JW, Fazio T; J Assoc Off Anal Chem 63: 1077-104 (1980) (8) McFall JA et al; Chemosphere 14: 1561-9 (1985) (9) Bjorseth A et al; Sci Total Environ 13: 71-86 (1979) (10) Knutzen J, Sortland B; Water Res 16: 421-8 (1982) (11) Hungspreugs M et al; Marine Pollut Bull 15: 213-8 (1984) (12) Iosifidou HG et al; Bull Environ Contam Toxicol 28: 535-41 (1982) (13) Bieri RH et al; Proc Oil Spill Conference, New Orleans, LA American Petroleum Institute (1977) (14) Nulton CP, Johnson DE; J Environ Sci Health A16: 271-88 (1981) (15) Malins DC et al; Environ Sci Technol 18: 705-13 (1984)].

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.

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):

The LD50 for the mouse is 700 mg/kg body weight [847].

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

After the Exxon Valdez spill, one yearling brown bear (Ursus arctos) found dead had elevated bile naphthalene and phenanthrene concentrations (160,000 ppb and 18,000 ppb respectively) [713].

Tis.Human:

A) Typical Concentrations in Human Food Survey Items:

See also Tis.Fish section C) above.

Food Survey Results [366]:

Phenanthrene (PHEN) has been detected in charcoal broiled steaks - 11 ug/kg(1), smoked eel - 37 ppb, smoked lumpfish - 10 ppb, smoked trout - 52 ppb, smoked redfish - 4.1 ppb, electric smoked mackerel - 9 ppb, gas smoked mackerel - 11 ppb, barbecued ribs - 58.0 ppb, smoked mutton - 104.0 ppb, smoked mutton sausages - 17.0 ppb(2). A variety of Nigerian fish were variably prepared and found to contain PHEN as follows: traditional smoked (heavy wood smoking) - 115.14-189.28 ng/g fish dry weight; traditional solar dried - 9.02-34.10 ng/g fish dry weight; oven dried - 10.32-20.75 ng.g fish dry weight(3). Phenanthrene was detected but not quantified in smoked salami, smoked martadella and heavily smoked bacon(2). [(1) IARC; Polynuclear Aromatic Compounds Part 1, Chemical, Environmental and Experimental Data 32: 419-30 (1983) (2) Santodonato J et al; Health and Ecological Assessment of Polynuclear Aromatic Hydrocarbons Lee SD, Grant L eds; Pathotox Publ Park Forest South IL (1981) (3) Afolabi O et al; J Agric Food Chem 31: 1083-90 (1983)].

The following lists phenanthrene concentration in meat products as follows: Charcoal broiled steaks: 21.0 ppb. /Data derived from table/ [USEPA; Ambient Water Quality Crit Doc: Polynuclear Aromatic Hydrocarbons (Draft) p.C-21 (1980)].

Baker's yeast concentrations of phenanthrene is as follows: French: 17.8-34.6 ppb; German: 67.0 ppb; Scottish: 1,620 ppb; Russian: 7.2

ppb. /Data derived from table/ [Grimmer G; Dtsch Lebensm Rundsch 70: 394 (1974) as cited in USEPA; Ambient Water Quality Criteria Doc: Polynuclear Aromatic Hydrocarbons (Draft) p.C-28 (1980)].

Phenanthrene concentration of 51 ppb was found in coconut oil. /Data derived from table/ [USEPA; Ambient Water Quality Criteria Doc: Polynuclear Aromatic Hydrocarbons (Draft) p.C-12 (1980)].

Kale: 70-586 ppb [USEPA; Ambient Water Quality Crit Doc: Polynuclear Aromatic Hydrocarbons (Draft) p.C-23 (1980)].

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.

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

Body Burdens [366]:

Semi-quantitative analyses revealed phenanthrene in atherosclerotic aortas at 8-10 ng/g anthracene equivalents(1). [(1) Ferrario JB et al; Arch Environ Contam Toxicol 14: 529-34 (1985)].

Tis.Misc. (Other Tissue Information):

No information found.

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

Bioconcentration Factor, log BCF [848]:

3.42 - Pimephales promelas
2.51 - Daphnia pulex
3.42 - Fathead minnow

During the Exxon Valdez spill, bioconcentration explained the buildup of PAHs in tissues better than biomagnification; most accumulation was of an equilibrium partitioning nature across the gills rather than from the food chain [971]. Immature fish seem to have higher bioconcentration of PAHs than adults, perhaps because their PAH breakdown systems are not fully developed and at times perhaps because of a higher percentage of lipid tissues (yolk tissues, etc) [971] (confirmed by Jerry Neff, Battelle Ocean

Sciences, Duxbury, MA, personal communication 1996).

Analyses of soft tissue of three species of unionidae mussels from northern Lake George showed these organisms concentrated phenanthrene. It was detected in some but not all mussel samples [849].

Increased alkylation in phenanthrene appears to increase bioconcentration tendencies [347]. Whereas phenanthrene (parent compound, no methyl groups attached) had higher concentrations in soil than in earth worms, the concentrations for 3,6,-dimethylphenanthrene were higher in earthworms than in soil [347]. This is not surprising since alkylation increases Kow. For additional details on alkyl PAHs, see "PAHs as a group" entry.

> Concentrations of PAH's in bioassay earthworms and bioassay soil from 15 sites at the Times Beach Confined Disposal Facility in Buffalo, N.Y. (1987):
>
> > The mean concentration of 3,6-dimethylphenanthrene in the soil was <0.04 ppm (dry weight), the range was <0.04-0.72 ppm. The mean concentration of 3,6,-dimethylphenanthrene in the earthworm was 0.10 ppm (ash-free dry weight), the range was <0.004-0.51 ppm [347]. By contrast, at the Times Beach Confined Disposal Facility in Buffalo, N.Y. (1987): The mean concentration of phenanthrene in the soil was 2.3 ppm (dry weight), the range was 0.41-4.8 ppm. The mean concentration of phenanthrene in the earthworms was 0.28 ppm (ash-free dry weight), the range was 0.091-1.4 ppm [347].
>
> Bioconcentration [366]:
>
> > Analyses of soft tissues of 3 species of unionidae mussels (lampsillis radiata, elliptio complanatus & anodonata grandis) from northern lake george showed these organisms concentrated phenanthrene. It was detected in some but not all of the mussel samples. [HEIT M ET AL; ENVIRON SCI TECHNOL 14 (4): 465-8 (1980)].
> >
> > The measured log octanol/water partition coefficient of phenanthrene (PHEN) is 4.57(1). A Kow of this magnitude suggests significant bioconcentration should occur in aquatic organisms(SRC). By the action of microsomal oxidase, however, fish are capable of rapidly metabolizing polycyclic aromatic hydrocarbons(2). PHEN is expected to be similarly degraded in fish, and therefore, may not bioconcentrate significantly(SRC). [(1) Karickhoff SW; Chemosphere 10: 833-46 (1981) (2) Santodonato J et al; Health and Ecological Assessment of Polynuclear Aromatic Hydrocarbons; Lee SD, Grant L eds; Pathotox Publ Park Forest South IL (1981)].
> >
> > Polycyclic aromatic hydrocarbons (pah) were analyzed in surfacial sediments & benthic organisms in southeastern lake erie, near a large coal-fired power plant. Sediment

concn (530-770 ppb pah) were relatively homogenous throughout most of the 150 square km area, although river & nearshore concentrations reached 4 ppm. Oligochaete worms did not bioconcentrate (on wet wt basis) any of the pah. Chironomide midges collected 1 km offshore exhibited bioconcentration of 5 pah one of which was pyrene. Further offshore, these apparent bioconcentrations disappeared, with midges at near equilibrium with sediments. /Polycyclic aromatic hydrocarbons/ [EADIE BJ ET AL; CHEMOSPHERE 11 (2): 185-92 (1982)].

Interactions:

No information found.

Uses/Sources:

See Chem.Detail section below for phenanthrene concentrations in various petroleum products.

Phenanthrene is present in products of incomplete combustion; it also occurs in fossil fuels. It is found in relatively high concentrations of coal-tar [847].

According to one source, there is no commercial production or known use of this compound. Its derivative, cyclopentenophenanthrene, has been used as a starting material for synthesizing bile acids, cholesterol and other steroids [847].

Another source states that phenanthrene is produced by fractional distillation of high-boiling coal-tar oil and the subsequent purification of the crystalline solid. Some of the uses of phenanthrene are in the manufacturing of dyestuffs and explosives, in the synthesis of drugs and in biochemical research [862].

Of the polynuclear aromatic hydrocarbons, naphthalene, 2-methylnaphthalene, and phenanthrene are the most commonly found in diesel and are the individual compounds posing the highest calculable risk due to ingestion [497].

Naphthalene, benzo(a)pyrene, fluorene, and phenanthrene are common PAH components of used motor oil [75].

Phenanthrene was found in groundwater at a coal and oil gasification plant some 30 years after the plant shut down [788].

To study water soluble leachates from out-of service railway ties, one gram of wood was shaved from the surface of the railroad ties and agitated in water for 24 hours. Up to 119 ug/L of phenanthrene was found in the water [864].

During the summer of 1996, NASA announced that PAHs had been found on a martian meteorite. Three to 6 ring PAHs found included phenanthrene, pyrene, chrysene, perylene, and benzo(a)pyrene, with less than 10% of the mass being alkyl PAHs. It was said that the meteorite PAHs were typified by little alkylation and a lack a dibenzothiophene, making the PAH mixture different than typically found in the earth's atmosphere. However, another unidentified mass of alkyl PAH compounds were also found and NASA acknowledged that PAHs have been found in a wide range of extraterrestrial materials [McKay et.al. 1996, manuscript entitled "Search for Life on Mars: Possible Biogenic Activity in Martian Meteorite ALH84001," a NASA paper available at the time of the NASA press release].

> Note from Roy Irwin: This represents and interesting and somewhat speculative attempt to link fingerprinting of PAH combinations to possible life on mars. NASA admits that the PAHs alone do not prove there was life on mars.

In a 1985-86 study, reported average ambient concentrations (combined particle- and vapor-phase) of eight PAHs in Denver ranged between 0.83 ng/m3 for benzo[k]fluoranthene and 39 ng/m3 for phenanthrene [881].

In a study conducted in Hamilton, Ontario, between May 1990 and June 1991, the concentrations of PAHs in respirable air particulate samples were found to range from 0.6 ng/m3 for phenanthrene to 4.3 ng/m3 for benzo[g,h,i]perylene, and 5.1 ng/m3 for combined benzo[b,j,k]fluoranthenes [881]. Concentrations of PAHs in a typical vapor-phase sample from the Boston Harbor Tunnel for four PAHs included in this profile: anthracene (32.3 ng/m3), fluoranthene (25.6 ng/m3), phenanthrene (184 ng/m3), and pyrene (28.3 ng/m3 [881].

Natural Sources [366]:

> Occurs in fossil fuels. [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V32 420 (1983)].
>
> Kuwait crude oil: 26 ppm; South Louisiana crude oil: 70 ppm. [Verschueren, K. Handbook of Environmental Data of Organic Chemicals. 2nd ed. New York, NY: Van Nostrand Reinhold Co., 1983. 970].
>
> ..Phenanthrene is a component of/ shale oil. [DOE; Identification and Toxicity of Fractionated-Shale-Oil Components 17pp Report No. DOE/EV/10404-TI (1982)].

Artificial Sources [366]:

> Phenanthrene (PHEN) is a product of incomplete combustion of organic materials and so has been detected in sidestream cigarette smoke, mainstream smoke of marijuana cigarettes, gasoline engine exhaust and charcoal broiled steaks(1). PHEN has also been detected in used motor oil (157.85 mg/kg), crude oils (>128.7 mg/kg), and lubricating fuels (>7.09 mg/kg)(1). Diesel and gasoline exhaust contained 6.4 and 2.1 ug/cu m PHEN, respectively(2). Combined residues of PHEN and anthracene were 155,000 and 76,500 ppb dry weight in crude oil and soot samples, respectively(3). Phenanthrene was detected

but not quantified in diesel exhaust(4). [(1) IARC; Polynuclear Aromatic Compounds Part 1. 32: 419-30 (1983) (2) Kerkhoff MJ et al; Environ Sci Technol 19: 695-99 (1985) (3) Sporstot S et al; Environ Sci Technol 17: 282-86 (1983) (4) Daisey JM et al; J Air Pollut Control Assoc 36: 17-33 (1986)].

Misc. Environmental Concentrations [366]:

Sidestream cigarette smoke - 6.0-8.5 ug/100 cigarettes, mainstream marijuana smoke - 8.9 ug/100 cigarettes (1). Sewage influent in Japan contained 400 ng/l phenanthrene/anthracene (2). [(1) IARC; Polynuclear Aromatic Compounds Part 1, Chemical, Environmental and Experimental Data 32: 419-30 (1983) (2) Akiyama T et al; J UOEH 2: 285-300 (1980)].

Phenanthrene ... has been identified in ... used motor oil (157.85 mg/kg) ... [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V32 421 (1983)].

Coke oven emissions: 163.5-2,828.5 ug/g of sample; coal tar pitch fumes: 36.4 weight % (phenanthrene and/or anthracene). [Verschueren, K. Handbook of Environmental Data of Organic Chemicals. 2nd ed. New York, NY: Van Nostrand Reinhold Co., 1983. 971].

Phenanthrene /concn/ in gasoline (high octane): 20.5 mg/l; gasoline: 15.7 mg/l. [Verschueren, K. Handbook of Environmental Data of Organic Chemicals. 2nd ed. New York, NY: Van Nostrand Reinhold Co., 1983. 970].

Exhaust condensate of gasoline engine: 2.3-2.9 mg/l gasoline consumed. [Verschueren, K. Handbook of Environmental Data of Organic Chemicals. 2nd ed. New York, NY: Van Nostrand Reinhold Co., 1983. 970].

The loading of phenanthrene (PHEN) in metric tons per year to each of the Great Lakes were estimated to be: Lake Superior - 4.8; Lake Michigan - 3.4; Lake Huron - 3.5; Lake Erie - 1.5; Lake Ontario - 1.1(1). Inputs of PHEN to the Narragansett Bay watershed in kg/yr were as follows: residential - 1.7; commercial - 2.1; industrial - 32.4; and highway - 32.8(2). [(1) Eisenreich SJ et al; Environ Sci Technol 15: 30-8 (1981) (2) Hoffman EJ et al; Environ Sci Technol 18: 580-7(1984)].

Forms/Preparations/Formulations:

No information found.

Chem.Detail: Detailed Information on Chemical/Physical Properties:

Solubility [848]: 1.18-1.65 mg/L at 25 degrees C.

Solubilities [609]:

1 G in 60 ml cold or 10 ml boiling 95% alcohol; in 25 ml absolute alcohol; 2.4 Ml toluene or carbon tetrachloride; 2.0 Ml benzene; 1.0 Ml carbon disulfide; 3.3 Ml anhyd ether; sol in glacial acetic acid; org solvents, especially in aromatic hydrocarbons [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1037].

Sol in hot pyridine, in chloroform [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. C-402].

1.6 mg/l at 15 deg C; 0.423 ppm at 8.5 deg C; 0.816 ppm at 21 deg C; 0.6 + or - 0.1 ppm at 22 deg C 1.277 ppm at 30 deg C [Verschueren, K. Handbook of Environmental Data of Organic Chemicals. 2nd ed. New York, NY: Van Nostrand Reinhold Co., 1983. 970].

Density [848]: 1.174 g/cm3 at 20 degrees C.

Density [849]: 0.98 at 4 degrees C.

Density/Specific Gravity [609]:

0.9800 @ 4 DEG C [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. C-402].

Melting point [848]: 97-101 degrees C.

Melting Point [609]:

101 DEG C [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. C-402].

Boiling point [848]: 338-340 degrees C.

Boiling Point [609]:

340 DEG C [Weast, R.C. (ed.) Handbook of Chemistry and

Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. C-402

Vapor pressure [848]: 0.0187-0.106 Pa at 25 degrees C.

Vapor Pressure [609]:

1 mm Hg @ 118.2 deg C; 10 mm Hg @ 173.0 deg C; 40 mm Hg @ 215.8 deg C; 100 mm Hg @ 249.0 deg C; 400 mm Hg @ 308.0 deg C [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. D-209

Vapor Density [609]:

6.15 (air= 1 at boiling point of phenanthrene) [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2

Octanol/Water partition coefficient (log Kow) [609,848,849]: 4.57

Log Kow values for phenanthrenes [971]:

phenanthrene:	4.57
C1-phenanthrene:	5.14
C2-phenanthrene:	5.51
C3-phenanthrene:	6
C4-phenanthrene:	6.51

Sorption partition coefficient (log Koc) [848]: 4.36

Henry's Law Constant [848]: 3.97 Pa m3/mol

Molecular Weight [609]:

178.22 [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1037

Color/Form [609]:

MONOCLINIC PLATES FROM ALCOHOL [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1037

COLORLESS SHINING CRYSTALS [Hawley, G.G. The Condensed Chemical Dictionary. 10th ed. New York: Van Nostrand Reinhold Co., 1981. 794

LEAFLETS [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. C-402

Odor [609]:

Faint aromatic odor [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 1

Heat of Combustion [609]:

1,685.6 kcal @ 25 deg C [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. D-276

Heat of Vaporization [609]:

14,184.0 gcal/g mole [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. C-675

Details of phenanthrene content (ng/mg or ppm) in one fresh sample of NSFO (Fuel Oil 5, Chuck Rafkind, National Park Service, Personal Communication, 1996):

Phenanthrene:	778.2
C1-Phenanthrene/anthracene:	2116.3 (includes both)
C2-Phenanthrene/anthracene:	2716.7 "
C3-Phenanthrene/anthracene:	1923.3 "
C4-Phenanthrene/anthracene:	820.5 "

NOTE: The above PAHs and alkyl PAHs were analyzed by a GC/MS/SIM NOAA protocol [828] modified with methylene chloride extraction for use with water samples (Guy Denoux, Geochemical and Environmental Research Group, Texas A&M University, personal communication 1996).

Phenanthrene concentrations in Used Engine Oil [519]: 200.0 ppm

Concentrations of PAHs in a reference Bunker C residual oil versus Two Crude Oils and Another Refined Oil [177]:

NOTE: The following concentrations in mg/kg (ppm) are from API reference oils:

PAH	South LA crude	Kuwait crude	No. 2 fuel oil	Bunker C residual
Phenanthrene	70	26	429	482
1-Methylphenanthrene	111	-	173	43
2-Methylphenanthrene	144	89	7,677	828

For comparison, the following table lists some of the specific naphthalene contents (ppm) of water soluble fraction (WSF) from 10% oil-in-water solution of four test oils (measured by gas chromatography) [770]:

COMPOUNDS	SOUTH LA CRUDE	KUWAIT CRUDE	NO. 2 FUEL OIL	BUNKER C RESIDUAL
Phenanthrene	0.001	0.001	0.010	0.009
Methylphenanthrenes	0.002	0.001	0.007	0.011
Dimethylphenanthrenes	0.001	0.001	0.003	0.003

Aromatic hydrocarbons concentrations (ug/g, ppb) measured in a study using Prudhoe Bay Crude oil [854]:

COMPOUNDS	CONCENTRATION (ppb)
Phenanthrene	431
1-Methylphenanthrene	221

For comparison, capillary gas chromatograph analyses of aromatic hydrocarbon concentrations (uL/L, ppb) in the water soluble fractions (WSF) of a fresh Prudhoe Bay Crude oil [854]:

COMPOUNDS	CONCENTRATION (ppb)
Phenanthrene	1.18
Methylphenanthrene	<0.08
Dimethylphenanthrene	<0.08
TOTAL PHENANTHRENES	1.18

Phenanthrene concentrations were determined for three different crude oil sample types taken from the Exxon Valdez oil spill. Concentrations in 1) unweathered oil from the tanker itself (March 1989), 2) oil skimmed from the water immediately after the spill and held in the skimmer barge for about 90 days (July 1989), and 3) weathered oil from Prince William Sound shorelines (May 1989) were, respectively [790; Reprinted with permission from Environmental Toxicology and Chemistry, Vol.14(11), W.A. Stubblefield, G.A. Hancock, W.H. Ford, and R.K. Ringer, "Acute and Subchronic Toxicity of Naturally Weathered Exxon Valdez Crude Oil in Mallards and Ferrets." Copyright 1995 SETAC]:

Phenanthrene: 222, 200, 124
C1-Phenanthrene/anthracene: 488, 660, 410
C2-Phenanthrene/anthracene: 629, 870, 564
C3-Phenanthrene/anthracene: 456, 640, 507
C4-Phenanthrene/anthracene: 256, 370, 263

Details of phenanthrene content (mg/kg or ppm) in one fresh sample of Exxon Valdez Crude Oil [971]:

Phenanthrene: 262 mg/kg = ppm
C1-Phenanthrene: 572 mg/kg = ppm
C2-Phenanthrene: 722 mg/kg = ppm
C3-Phenanthrene: 576 mg/kg = ppm
C4-Phenanthrene: 446 mg/kg = ppm

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

Volatilization of acenaphthene, anthracene, fluorene, and phenanthrene (low molecular weight PAHs) from soil may be substantial. Lower molecular weight compounds may also volatilize from sediments; this process is not significant for the higher molecular weight compounds [788].

One study showed how biodegradation of PAHs was related to molecular weight. The 2- and 3-ring PAHs (naphthalene, fluorene, and phenanthrene) degraded rapidly. The 4-ring PAHs generally biodegraded 50% in a few months. The 5-ring PAHs decreased slowly over a period of years [815].

Environmental Fate [366]:

TERRESTRIAL FATE: The phenanthrene (PHEN) content of dried sludge added to soil decreased by 98.8% after 1280 days(1). The loss of PHEN was attributed to biodegradation and unidentified abiotic processes(1). The PHEN content of secondary wastewater decreased by 80-90% following percolation through treatment basins(2). The residence time in the basins was 8 hr(2). When wastewater containing 0.05-100 ug/l polycyclic aromatic hydrocarbons (PAH) and pretreated by oil separation was applied to grass covered soil at 4300 gallons per day/acre, water samples taken in November from downgradient wells contained 13-61 ng/l PHEN(3). PAH's were non-detectable in July well water samples(3). The wells were located an unspecified distance from the application site(3). Migration of PHEN through the soil is indicated by this study and, therefore, PHEN may leach to groundwater. Because of the high measured Koc value of PHEN (22,909), however, it is suggested that leaching of PHEN to groundwater should be limited in most circumstances(SRC). [(1) Bossert I et al; Appl Environ Microbiol 48: 463-7 (1984) (2) Bouwer EJ et al; Water Res 18: 463-72 (1984) (3) Middleton AC; Basic Life Sci 28: 137-49 (1984)].

AQUATIC FATE: Introduction of creosote into the Hershey River in Michigan resulted in phenanthrene (PHEN) concentrations as high as 352 ng/g sediment (wet weight) 3 km downstream from the source(1). Partitioning of PHEN to sediment is generally expected whenever PHEN is released to water. Biodegradation of PHEN by water- and sediment-dwelling bacteria is expected. Volatilization of PHEN can also occur, but is not expected to be significant due to the anticipated adsorption to sediments(SRC). Bioconcentration of PHEN is not expected to be significant since the compound will probably be easily metabolized via microsomal oxidase in fish(SRC). Photolysis and photooxidation of dissolved PHEN may occur (estimated half-life 8.4 hr). These processes, however, are expected to be severely attenuated, if not eliminated entirely, by the anticipated adsorption of PHEN to particulate matter and sediments(SRC). [(1) Black JJ; Arch Environ Contam Toxicol 11: 161-6 (1982)].

ATMOSPHERIC FATE: The half-life for the reaction of vapor phase phenanthrene (PHEN) with photochemically generated hydroxyl radicals in the atmosphere was estimated to be 1.67 days(1) but this process is expected to be considerably slower for particle-adsorbed PHEN. Photolysis of PHEN adsorbed to fly ash has been shown to occur (half-life 49 hr) and any vapor phase PHEN may also photolyze directly since it absorbs irradiation above 290 nm. Wet and dry deposition of PHEN-adsorbed on particulates is expected(SRC). [(1) GEMS; Graphical Exposure Modeling System. Fate of Atmospheric Pollutants (FAP) Data Base. Office of Toxic Substances. USEPA (1986)].

AQUATIC FATE: ... Empirical evidence suggests that phenanthrene ... will be adsorbed onto suspended particulates and biota and that their transport will be determined by the hydrogeologic conditions of the aquatic system. That portion dissolved in the water column may undergo direct photolysis. [Callahan, M.A., M.W. Slimak, N.W. Gabel, et al. Water-Related Environmental Fate of 129 Priority Pollutants. Volume I. EPA-440/4 79-029a. Washington, DC: U.S.Environmental Protection Agency, December 1979.,p. 96-1].

Biodegradation [366]:

Biodegradation of phenanthrene (PHEN) in water samples taken from several sites in the Center Hill Reservoir in Tennessee incubated at 25 deg C for 28 days was 55.52% (Feb), 65.86 to 90.25% (Mar), 80.39% to 91.75% (Apr), 79.76% to 85.76% (Jun), 49.58% to 58.84% (Aug), 67.61% to 78.46% (Sept), and 92.26% to 94.60% (Dec)(1). PHEN added to water samples from two Center Hill Reservoir sites incubated at 25 deg C was 90.12 and 86.70, 90.36 and 95.04, 94.02 and 93.55, 94.81 and 90.84% degraded after 1, 2, 3, and 4 weeks, respectively(1). When PHEN was added to Center Hill Reservoir water at 100 ug/l, the compound was 0, 66.4, 60.08, and 43.9% degraded following incubation at 25 deg C for 1, 2, 5, and 7 days respectively(1). PHEN added at 1000 ug/l was 2.3%, 13.5%, 39.6%, 22.8%, and 46.1% degraded after 1, 2, 3, 4, and 5 days of incubation at 25 deg C, respectively(1). Maximum biodegradation occurred at 25 and 37 deg C when PHEN was added to Center Hill Reservoir samples at 100 and 1000 ug/l, respectively(1). [(1) Saylor GS, Sherrill TW; Bacterial Degradation of Coal Conversion By-Products (polycyclic aromatic hydrocarbons) in Aquatic Environments. p.90 USNTIS PB 83-187161 (1981)].

To investigate the mineralization rate of phenanthrene (PHEN) in aquatic sediments, the kinetics of mineralization of PHEN by bacteria in sediment slurries were determined(1). Incubation with sediments for 6 and 60 days yielded constants of 6.6X10-5 to 1.1X10-5 1/hr, respectively, and biodegradation half-lives of 437.5 and 2625 days, respectively(1). Microcosms consisting of natural sediments and sterilized pond water in 1 L Erlenmeyer flasks were prepared. The dependence of mineralization rates upon incubation temperature was determined for untreated microcosms and those treated with synthetic oil (SO) at 0.01% in the slurry. The sediments in the microcosms were acclimated prior to addition of PHEN, which was added at 1 ug/g sediment. The optimal temperatures were 15 and 23 deg C for the untreated and SO treated sediments, respectively; mineralization rates of the SO treated sediments were higher than the untreated sediments at all temperatures(1). The rate of mineralization was inversely dependent upon the weight/volume sediment slurry composition(1). When natural and sterilized sediments were inoculated with Beijerinckia sp., biodegradation rates of PHEN were higher than in uninoculated natural sediments(1). [(1) Saylor GS, Sherrill TW; Bacterial Degradation of Coal Conversion By-Products (polycyclic aromatic hydrocarbons) in Aquatic Environments. p.90 USNTIS PB 83-187161 (1981)].

Bacteria were obtained from Eastern Bay in the Chesapeake Bay(1). Incubation of bacteria from Colgate Creek in Eastern Bay and Colgate Creek water resulted in 63.4% and 50.2% phenanthrene (PHEN) degradation respectively(1). Incubation of Eastern Bay bacteria in Colgate Creek and Eastern Bay water resulted in 85.0% and 92.4% PHEN degradation, respectively(1). The greater percentage of PHEN degradation observed in the Colgate Creek sediment bacteria was said to reflect the higher degree of organic pollution to which the bacteria were exposed(1). Phenanthrene incubated in Rhode Island water at 25 ug/l degraded with half-lives of 11000, 180, and 79 days at 2, 8, and 18 deg C, respectively(2). PHEN incubated in water from South Carolina degraded with half-lives 210, 19, 24, and 36 days at temperatures of 8,27,28 and 27 deg C, respectively(2). The biodegradation half-lives of PHEN in water obtained from the Gulf of Thailand and Chao Phraya River were 35 and 37 days, respectively(3). [(1) Walker JD, Colwell RR; Prog Water Technol 7: 783-91 (1975) (2) Lee RF, Ryan C; Can J Fish Aquat Sci 40: 86-94 (1983) (3) Hungspreuge M et al; Marine Pollut Bull 15: 213-28 (1984)].

The half-life of phenanthrene (PHEN) applied to soil at 2.1 ug/g soil and incubated at 15-25 deg C was 26 days(1). The half-life when applied at 25,000 ug/g soil and incubated at > 25 deg C was 2.5 days(1). [(1) Sims RC, Overcash MR; Res Rev 88: 1-68 (1983)].

Abiotic Degradation [366]:

After 5 hr and 10 hr irradiation of phenanthrene (PHEN) with a 250 W, high pressure mercury lamp, 43% and 64.1% of the initial amount of PHEN remained in seawater(1). The direct photolysis half-life of PHEN in water was estimated to be 8.4 hr(2). Sunlight intensity in both estimations was assumed to be that of a clear day at latitude 40 degrees N at midday in midsummer and it was assumed that the chemical was near the surface of the water and fully exposed to the sunlight(2). The half-life for the reaction of polycyclic aromatic hydrocarbons (PAH) with RO2 radicals is about 21,917 years, so the oxidation of PHEN by these radicals is not expected to be a major fate process(3). The rate constants for the reaction of PHEN with ozone at pH values of 1 and 7 are 1.33X10+4 and 1.57X10+4 cu dm 1/mol 1/s at 25 deg C(4). Assuming a tropospheric ozone concentration of 2X10-9 M in clean air, the half-life of PHEN in the atmosphere was estimated to be 6 hr(4). [(1) Nagata S, Kondo G; pp 617-20 in Proc 1977 Oil Spill Conf (1977) (2) Zepp RG, Schlotzhauer PF; pp 141-58 in Polynuclear Aromatic Hydrocarbons Jones PW, Leber P eds Ann Arbor Sci Publ Inc, Ann Arbor MI (1979) (3) Callahan MA et al; Water-Related Environmental Fate of 129 Priority Pollutants Vol II p 96-16 USEPA-440/4-79-029b (1979) (4) Butkovic V et al; Environ Sci Technol 17: 546-8 (1983)].

Adsorption of PHEN to fly ash is rapid and irreversible at concentrations of < 30 ug/g fly ash(1). PHEN is expected, therefore, to be largely adsorbed to atmospheric particulates. The direct photolysis half-life of PHEN adsorbed to fly ash irradiated at > 300 nm is 49 hr(2). Since photolysis of PAH is attenuated by adsorption to particulates(3), any PHEN in the vapor phase is expected to photolyze faster. [(1) Eiceman GA, Vandiver VJ; Atmos Environ 17: 461-5 (1983) (2) Behymer TD, Hites RA; Environ Sci Technol 19: 1004-6 (1985) (3) Korfmacher WA et al; Environ Sci Technol 14: 1094-9 (1980)].

Soil Adsorption/Mobility [366]:

The log soil-sorption coefficient (Koc) of phenanthrene (PHEN) in coarse silt fractions from sediments from Doe Run and Hickory Hill, Georgia, is 4.36(1). A log Koc of this magnitude suggests that PHEN will be strongly adsorbed to the soil and is not, therefore, expected to leach extensively(SRC). [(1) Karickhoff SW et al; Water Res 13: 241-8 (1979)].

Volatilization from Water/Soil [366]:

Using a water solubility of 1.29 mg/l and a vapor pressure of 6.80X10-4 mm Hg(1), a Henry's Law constant of 1.24X10-4 atm cu m/mol at 25 deg C was estimated(2). The half-life values for the volatilization of phenanthrene (PHEN) from streams, rivers and lakes were estimated from these parameters(2). The wind velocity was assumed to be 3 m/sec, the current velocities of the streams, rivers and lakes, 2, 1 and 0.01 m/sec, respectively, the depths of the lakes 50 m and that of the streams and rivers 1 m. The half-life values were 9.4 hr, 13.15 hr and 4696.13 hr (195.7 day) for the streams, rivers and lakes, respectively. These values apply strictly to dissolved PHEN. Any process which limits the amount of dissolved PHEN, such as adsorption to sediments or biota, will increase these half-lives. Volatilization from water and soil is not expected to be significant, since most of the PHEN is expected to be adsorbed(SRC). [(1) Sims RC, Overcash MR; Res

Rev 88: 1-68 (1983) (2) Lyman WJ et al; Handbook of Chemical Property Estimation Methods Environmental Behavior of Organic Compounds. McGraw-Hill NY p 15-11, 15-21 (1982)].

Absorption, Distribution and Excretion [366]:

1. Radioactivity accumulation by coalfish administered 15.8 Ug 9-(14)c- labeled coalfish, radioactivity was greater in liver than in gallbladder or muscle following intragastric admin of 15.8 Ug. Max accum occurred from 10-24 hr after dosing & approx 72% was present in liver after 17 hr. In gallbladder highest level occurred 24-48 hr after admin. [SOLBAKKEN JE ET AL; BULL ENVIRON CONTAM TOXICOL 23 (1-2): 100-3 (1979)].

2. Following intragastric admin in norway lobster of (14)c-labeled phenanthrene, highest amt of radioactivity was found in hepatopancreas system & muscle. In all tissues, except intestine, highest levels were measured 1 day after dosing, after 28 days only minute amt remained in tissues. The low content of radioactivity in stomach & intestine 1 day after administration indicated that most of it was absorbed from intestine. Norway lobster accum radioactivity at high rate & is able to eliminate most of radioactivity within a few wk after a single dose. [PALMORK KH, SOLBAKKEN JE; BULL ENVIRON CONTAM TOXICOL 25 (4): 668-71 (1980)].

3. Polynuclear aromatic hydrocarbons are highly soluble in adipose tissue and lipids. /Polynuclear aromatic hydrocarbons/ [Sittig, M. Handbook of Toxic And Hazardous Chemicals. Park Ridge, NJ: Noyes Data Corporation, 1981. 564].

4. Polynuclear aromatic hydrocarbons (PAH), some of which are potent carcinogens, are common environmental pollutants. The transport processes for these hydrophobic compounds into cells and between intracellular membranes are diverse and are not well understood. A common mechanism of transport is by spontaneous desorption and transfer through the aqueous phase. From the partitioning parameters, ... the rate limiting step involves solvation of the transfer species in the interfacial water at the phospholipid surface. Transfer of 10 PAH ... out of phosphatidylcholine vesicles has been examined. ... Results show that the molecular volume of the PAH is a rate-determining factor. Moreover, high performance liquid chromatography (HPLC) data confirms the hypothesis that the rate of transfer is correlated with the size of the molecule and with the partitioning of the molecule between a polar and hydrocarbon phase. The kinetics and characteristics of the spontaneous transfer of carcinogens are likely to have a major impact on the competitive processes of PAH metabolism within cells. [Plant AL et al; Chem-biol Interact 44 (3): 237-46 (1983)].

Laboratory and/or Field Analyses:

Many methods have been used to analyze for PAHs [861]. For risk assessment or drinking water purposes, low detection limits should be specified using Selective Ion Mode (SIM) methods [828] or other rigorous methods.

When potential biological effects are being considered, many of the methods historically used have been determined to be inferior to the NOAA protocol expanded scan [828] being recommended by some risk assessment experts in 1996. Most of the historically used methods, including EPA standard semi-volatile scan number 8270, do not cover important alkyl PAHs and do not utilize low-enough detection limits (10 ppt for water, 0.3 to 1 ppb for tissues, sediments, and soil) to use in ecological risk assessments.

> Note: Utilizing up to date techniques, many of the better labs can use detection limits of 0.3 to 1 ppb for tissues, sediments, and soils, and these lower detection limits are far better for risk or hazard assessment, but in all cases detection limits for these media should not be above 10 ppb.

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]. 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].

If a Park Service groundwater investigation at Colonial National Historical Park performed in response to contamination by Fuel Oil 5 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 typically utilize detection limits in the 170-600 ppb range, the false conclusion reached would have been that no PAHs were present in significant (detection limit) amounts. This false negative conclusion would have been made because the parent compound PAHs present constituted only 7.6% of the PAHs detected in groundwater by the expanded scan [828], and the highest concentration found for any parent compound was 8.4 ppb, far below the detection limits used on the older standard EPA scans. Utilizing the NOAA protocol expanded scan [828], it was determined that 92.4% of the total concentration values of the PAHs detected in groundwater were alkyl PAHs, and that all 39 PAHs and alkyl PAHs were present. Of course, all 39 PAHs were also present in the fresh product, in much higher concentrations, and also having alkyl compounds with the highest percentage of higher values compared to parent compounds (see Chem.Detail section in separate "PAHs as a group" entry for more details).

In a similar vein, if the Park Service sediment investigation at Petersburg National Historical Battlefield (see Chem.Detail section in separate "PAHs as a group" entry; this study was performed in response to contamination by Diesel) 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.

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.

Less rigorous scanning methods for various PAHs in drinking water have included High pressure liquid chromatography (EPA 550, 550.1); gas chromatographic/mass spectrometry (EPA 525): PQL= 0.0002 mg/L [893].