POLYCYCLIC AROMATIC HYDROCARBONS, 15 LISTINGS

First Listed in the *Second Annual Report on Carcinogens*

CARCINOGENICITY

The following polycyclic aromatic hydrocarbons (PAHs): benz[*a*]anthracene (56-55-3), benzo[*b*]fluoranthene (205-99-2), benzo[*j*]fluoranthene (205-82-3), benzo[*k*]fluoranthene (207-08-9), benzo[*a*]pyrene (50-32-8), dibenz[*a,h*]acridine (226-36-8), dibenz[*a,j*]acridine (224-42-0), dibenz[*a,h*]anthracene (53-70-3), 7*H*-dibenzo[*c,g*]carbazole (194-59-2), dibenzo[*a,e*]pyrene (192-65-4), dibenzo[*a,h*]pyrene (189-64-0), dibenzo[*a,i*]pyrene (189-55-9), dibenzo[*a,l*]pyrene (191-30-0), indeno[1,2,3-*cd*]pyrene (193-39-5), and 5-methylchrysene (3697-24-3) are *reasonably anticipated to be human carcinogens* based on sufficient evidence of carcinogenicity in experimental animals (IARC 1973, 1983, 1987).

When administered by gavage, benz[*a*]anthracene induced papillomas of the forestomach in mice. In another gavage study, benz[*a*]anthracene induced lung adenomas and hepatomas in mice. When administered topically, benzo[*a*]anthracene induced skin papillomas in mice. When administered by a single subcutaneous injection, benz[*a*]anthracene induced sarcomas in adult mice and pulmonary adenomas and adenocarcinomas in newborn mice. When administered by bladder implantation, benz[*a*]anthracene induced local carcinomas in mice (IARC 1973).

When administered topically, benzo[*j*]fluoranthene induced skin papillomas and carcinomas in female mice. When injected directly into the pulmonary tissues of female rats, benzo[*j*]fluoroanthene and benzo[*k*]fluoranthene induced squamous cell carcinomas. When administered topically, benzo[*k*]fluoranthene was active as an initiator of skin tumors in female mice. When administered by subcutaneous injection, benzo[*k*]fluoranthene induced local sarcomas in mice of both sexes (IARC 1983).

When administered by gavage, benzo[*a*]pyrene induced malignant and benign forestomach tumors in mice and hamsters, and mammary tumors in female rats. When administered in the diet, benzo[*a*]pyrene increased the incidence of forestomach tumors and induced lung adenomas in mice. When administered topically, benzo[*a*]pyrene induced skin carcinomas and papillomas in mice, rats, guinea pigs, and rabbits. When administered by inhalation, benzo[*a*]pyrene induced tracheal papillomas and carcinomas in hamsters and squamous cell carcinomas of the lung in rats. When administered by intratracheal instillation, benzo[*a*]pyrene induced lung tumors in rats, tracheobronchial tumors in hamsters, and squamous carcinomas of the lung in two of six subhuman primates. When administered by subcutaneous injection, benzo[*a*]pyrene induced local sarcomas in rats, hamsters, guinea pigs, newts, subhuman primates, and adult mice; hepatomas and lung adenomas were produced in newborn mice. When administered by intraperitoneal injection, benzo[*a*]pyrene induced abdominal fibrosarcomas in mice of both sexes, and mammary and uterine carcinomas in rats. When administered by intravenous injection, benzo[*a*]pyrene induced mammary carcinomas in female rats. When administered by intrabronchial implantation, benzo[*a*]pyrene induced local tumors in rats. When administered by subcutaneous or intraperitoneal injections to mice at the 11th, 13th, and 15th day of pregnancy, benzo[*a*]pyrene increased the incidence of lung adenomas and initiated skin carcinogenesis in the offspring (IARC 1973). When administered topically, benzo[*b*]fluoranthene induced skin tumors in mice (IARC 1973). When administered by subcutaneous injection, benzo[*b*]fluoranthene induced local sarcomas in mice. When administered topically, dibenz[*a,h*]acridine induced skin tumors. When administered by intravenous injection, dibenz[*a,h*]acridine increased the incidence of lung tumors in mice (IARC 1973).

When administered topically, dibenz[*a,j*]acridine induced skin tumors in mice. When administered by subcutaneous injection, dibenz[*a,j*]acridine induced local sarcomas and increased the incidence of lung tumors in mice (IARC 1973).

When administered in the diet, dibenz[*a,h*]anthracene induced squamous cell carcinomas and papillomas of the forestomach in mice. When administered as an olive oil emulsion in place of the drinking water, dibenz[*a,h*]anthracene induced alveologenic carcinomas of the lung and hemangioendotheliomas in mice of both sexes and mammary carcinomas in female mice. When administered by intratracheal injection, dibenz[*a,h*]anthracene induced lung squamous cell carcinomas in rats. When administered by subcutaneous injection, dibenz[*a,h*]anthracene induced local sarcomas in rats, guinea pigs, pigeons, fowl, adult mice, and newborn mice; the incidence of lung adenomas was increased in newborn mice. When injected directly into lung tissues, dibenz[*a,h*]anthracene induced lung adenomas. When injected into the kidney of frogs, dibenz[*a,h*]anthracene induced renal adenocarcinomas (IARC 1973).

7*H*-Dibenzo[*c,g*]carbazole induced subcutaneous injection site tumors in rats. When administered by gavage, 7*H*-dibenzo[*c,g*]carbazole induced forestomach papillomas and carcinomas and benign and malignant hepatomas in mice. When administered by intratracheal injection, 7*H*-dibenzo[*c,g*]carbazole induced respiratory tract tumors in hamsters (IARC 1973).

When administered topically, dibenzo[*a,e*]pyrene, dibenzo[*a,h*]pyrene, dibenzo[*a,i*] pyrene, and 5-methylchrysene induced skin tumors in mice. Dibenzo[*a,h*]pyrene also induced skin tumors in rats. These four compounds and dibenzo[*a,l*]pyrene induced local sarcomas in mice when administered by subcutaneous injection (IARC 1973).

There is inadequate evidence for the carcinogenicity of PAHs in humans (IARC 1973, 1983). However, there are a number of epidemiologic and mortality studies that show increased incidences of cancer in humans exposed to mixtures of PAHs (ATSDR 1995). Mortality studies have demonstrated that exposure to coke oven emissions, which contain a variety of PAHs, caused increased incidences of lung and genitourinary cancer mortality in coke oven workers (see Coke Oven Emissions) (IARC 1984, Lloyd 1971, Redmond *et al*. 1972). Workers exposed to creosote containing numerous PAHs developed skin tumors (see Coal Tars and Coal tar Pitches). Exposures to other chemical mixtures that contain PAHs, such as cigarette smoke, coal tar, coal tar pitch, and bitumens, have been associated with increased incidences of lung cancer in humans. Dermal exposure to coal tar and shale oils containing PAHs have been associated with increased incidences of skin tumors in humans (IARC 1985, ATSDR 1995).

PROPERTIES

The 15 PAHs listed occur as needles, plates, crystals, leaflets, or prisms ranging from colorless to pale yellow to golden yellow. Four of the 15 PAHs, benz[*a*]anthracene, dibenzo[*a,i*]pyrene, indeno[1,2,3-*cd*]pyrene, and 5-methylchrysene, show fluorescence ranging from greenish yellow to brilliant bluish violet to brown. Solubility characteristics vary for each PAH, but in general, they are slightly soluble to insoluble in ethanol, and are soluble to slightly soluble in acetic acid, benzene, and acetone. Several PAHs are soluble in toluene, xylene, 1,4-dioxane, and other organic solvents. Some of the PAHs are soluble in mineral and/or olive oil, and dibenz[*a,h*]anthracene is soluble in cyclohexane. PAHs are insoluble in diethyl ether and petroleum ether, and most are insoluble in water (IARC 1973).

USE

Twelve of the 15 PAHs are used only in biochemical, biomedical, laboratory, and/or cancer research. There are no known uses or applications for the remaining three PAHs, dibenzo[*a,h*]pyrene, dibenzo[*a,i*]pyrene, and 5-methylchrysene (IARC 1983).

At least 8 of the 15 PAHs are present in coal tar, which is used as a fuel in the steel industry in open-hearth and blast furnaces. Coal tar is also used in the clinical treatment of skin disorders such as eczema, dermatitis, and psoriasis. Coal tar is distilled to produce a variety of coal tar products including coal tar pitch and creosote. At least 6 of the 15 PAHs are present in coal tar pitch, which is used primarily as a binder for aluminum smelting electrodes in the aluminum reduction process. Coal tar pitch is also used in roofing, surface coatings, for pitch coke production, and a variety of other applications (IARC 1985). At least 2 of the 15 PAHs are found in creosote, which is used to preserve railroad ties, marine pilings, and telephone poles. Some creosote is used for fuel by steel producers (NIOSH 1977). At least 3 of the 15 PAHs are present in bitumens and asphalt which are used for paving roads, for sound- and water-proofing, and coating pipes.

PRODUCTION

PAHs are not currently produced for commercial use in the United States (IARC 1983, HSDB 2000a, 2000b, 2000c, 2000d, 2000e, 2000f, 2000g). The 1979 TSCA Inventory reported one producer with no stated production volumes of benz[*a*]anthracene and dibenz[*a,h*]anthracene in 1977 (TSCA 1979). Indeno[1,2,3-*cd*]pyrene is listed in the TSCA Inventory, but production and import volumes were not provided. Analytical grade indeno[1,2,3-*cd*]pyrene is produced by one domestic company for use in laboratory investigations (Chem Sources 1986). The TSCA Inventory reported one U.S. manufacturer of benzo[*a*]pyrene with a CBI Aggregate production of less than 1 million lb. Several specialty chemical companies distribute benz[*a*]anthracene for research purposes in quantities ranging from 1 to 5 g. Benzo[*b*]fluoranthene is available from some specialty chemical firms in quantities of 25 to 100 mg. Dibenz[*a,h*]anthracene and benzo[*a*]pyrene are also available from some specialty chemical companies in quantities of 100 to 500 mg and 100 to 1,000 mg, respectively. Benzo[*k*]fluoranthene is produced in the United States by one company for use as a research chemical (TSCA 1979, Chem Sources 1986). Chem Sources (2001) identified current U.S. suppliers for all 15 of the PAHs ranging from two suppliers for 7*H*-dibenzo[*c,g*]carbazole and dibenzo[*a,l*]pyrene to 20 suppliers for dibenz[*a,h*]anthracene.

PAHs form as a result of incomplete combustion of organic compounds. The primary source of PAHs in air is the incomplete combustion of wood and fuel for residential heating. The PAHs are found in gasoline or diesel motor vehicle exhaust, by-products of open fires or refuse burning, coal tar, coal tar pitch, coke tars or coke oven emissions, creosote, mineral oils, bitumens, industrial smoke and soot, cigarette and cigar tobacco and smoke, tar, or smoke condensates, and charcoal-broiled foods. Benzo[*a*]anthracene is found in gasoline and diesel exhaust, cigarette smoke and smoke condensate, amino acid, fatty acid, and carbohydrate pyrolysis products, coal tar and coal tar pitch, asphalt, soot and smoke, wood smoke, coal combustion emissions, commercial solvents, waxes, mineral oil, and creosote. Benzo[*b*]fluoranthene is found in gasoline exhaust, tobacco leaves, cigarette smoke, carbohydrates, amino acid and fatty acid pyrolysis products, coal tar, and soot. Benzo[*j*]fluoranthene is found in cigarette smoke, gasoline exhaust, coal smoke, oil heat emissions, used motor oils, crude oils, and coal tar. Benzo[*k*]fluoranthene is found in cigarette smoke, gasoline exhaust, coal and oil combustion emissions, coal tar, lubricating oils, used motor oils, and crude oils. Benzo[*a*]pyrene is found in gasoline and diesel exhaust, cigarette smoke and smoke condensate, pyrolysis products of carbohydrates, amino acids, and fatty acids, coal tar and coal tar pitch, soot and smoke, petroleum asphalt, creosote oil, shale oil, and commercial solvents. Dibenz[*a,h*]acridine is found in cigarette smoke condensate, coal combustion emissions, petroleum refinery incinerator emissions, and coal tar pitch. Dibenz[*a,j*]acridine is found in gasoline exhaust, cigarettes and cigarette smoke condensates, coal combustion stack effluents, petroleum refinery incinerator effluents, and coal tar pitch. Dibenz[*a,h*]anthracene is found in gasoline exhaust, cigarette smoke condensate, soot, and coal tar. 7*H*-Dibenzo[*c,g*]carbazole is found in cigarette tar. Dibenzo[*a,e*]pyrene is found in fossil fuels, tobacco smoke, and gasoline exhaust. Dibenzo[*a,h*]pyrene may be found in engine exhaust, cigarette tar, and coal tar pitch. Dibenzo[*a,i*]pyrene may be found in automobile exhaust, cigarette smoke, and coal tar. Dibenzo[*a,l*]pyrene is found in fossil fuels, cigarette smoke, and coal gasification products. Indeno[1,2,3-*cd*]pyrene is found in automobile and diesel exhaust, cigarette smoke condensate, benzene and pyrene pyrolysis products, soot, coal tar and coal tar pitch, and petroleum asphalt. 5-Methylchrysene is found in gasoline exhaust and tobacco smoke. Other sources of incidentally generated PAHs include coal and coal combustion, petroleum refinery incinerators, forest fires, incomplete combustion of diesel and kerosene, soot, and marijuana smoke, volcanoes, shale oil, and crude oil (IARC 1983, Kirk-Othmer 1980, ATSDR 1995).

Production data for tar, tar pitch, creosote, mineral oils, and coke which contain various PAHs are included in their respective profiles in this Report (see Coal Tars and Coal Tar Pitches, Coke Oven Emissions, and Mineral Oils).

EXPOSURE

The primary routes of potential human exposure to PAHs are inhalation of polluted air, wood smoke, and tobacco smoke, as well as ingestion of contaminated water, and foods normally containing microgram quantities of PAHs. Foods found to contain minute quantities of benz[*a*]anthracene, benzo[*j*]fluoranthene, benzo[*a*]pyrene, dibenz[*a,h*]anthracene, or indeno[1,2,3-*cd*]pyrene include: smoked, barbecued, or charcoal-broiled foods, vegetables and vegetable oils, margarines, roast coffee and coffee powders, fresh sausages, cereals, grains, flour, breads, meats, seafood, fruits, processed foods, and beverages. PAHs have been detected at low levels in some drinking water supplies as well as in fresh and sea water in the United States (IARC 1984). Inhalation of dust, soot, or vehicle exhaust contaminated by PAHs is another route of possible exposure. Potential human exposure to PAHs may also occur by dermal contact with PAH-containing products such as creosote-treated wood products, asphalt roads, or coal tar. Consumers may be exposed to PAHs that are present in dermatological preparations containing coal tar (IARC 1985). PAHs do not usually enter the body through the skin under normal conditions; however, small amounts could enter the body if there is contact with products or oils containing high concentrations of PAHs.

Benzo[*a*]pyrene occurs as a product of combustion, with stationary sources releasing an estimated 1.8 million lb per year. The sources for 96% of the benzo[*a*]pyrene released are coal refuse piles, outcrops, abandoned coal mines, coke manufacture, and residential external combustion of bituminous and anthracite coals (Kirk-Othmer 1980). The monitoring of several air pollution sources of dibenz[*a,h*]acridine showed concentrations of 17 mg/1,000 m^3 in coal combustion stack effluents, 0.01 mg/1,000 m^3 in air polluted by coal tar pitch, <0.12 to 0.7 mg/1,000 m^3 in petroleum refinery incinerator effluents, and 0.01 μg/100 cigarettes smoked in cigarette smoke condensate (IARC 1973). Dibenz[*a,j*]acridine has been detected in concentrations of 2 mg/1,000 m^3 in coal combustion stack effluents, 0.15 to 1.8 mg/1,000 m^3 in petroleum refinery incinerator effluents, 0.001 mg/1,000 m^3 in air polluted by coal tar pitch, up to 300 µg/kg in automobile exhaust, and 0.27 µg/100 cigarettes smoked. Benzo[*b*]fluoranthene has been detected in a fixed bed gasifier of a coal gasification plant at a concentration of 140 µg/g. It has also been found in cigarette smoke at 4 to 22 mg/cigarette smoked. Benz[*a*]anthracene and dibenz[*a,h*]anthracene have been detected in cigarette smoke at concentrations of 20 to 70 mg/cigarette smoked and 4 mg/cigarette smoked, respectively (IARC 1983). 7*H*-Dibenzo[*c,g*]carbazole is found in cigarette tar in concentrations of 0.07 µg/100 cigarettes smoked (IARC 1973).

There is potential occupational exposure to PAHs for workers at coal tar production plants, coking plants, coal gasification sites, smoke houses, foundries, aluminum production plants, bitumen and asphalt production plants, road and roof tarring operations, municipal waste incineration sites, other facilities that burn carbonaceous materials, and cooking fume sources in the food and catering industries (ATSDR 1995). The National Occupational Exposure Survey (1981-1983) estimated that 28 workers potentially were exposed to benz[*a*]anthracene through actual use of the compound; 896 total workers, including 299 females, potentially were exposed to benzo[*a*]pyrene through actual use of the compound (NIOSH 1984). The National Occupational Hazard Survey, conducted by NIOSH from 1972 to 1974, estimated that about 210,000 workers were potentially exposed to dibenzo[*a,h*]pyrene, dibenzo[*a,i*]pyrene, and indeno[1,2,3-*cd*]pyrene from inhalation of asphalt volatiles, coal tar pitch volatiles, and coke oven emissions. An unspecified additional number of workers may have been exposed to PAHs by combustion products from fuel oil, diesel fuel, kerosene, and wood (NIOSH 1976).

The U.S. Department of Agriculture estimated that about 100 commercial thermal and dip-treatment workers have consistently high potential inhalation exposure to creosote, which contains benz[*a*]anthracene, benzo[*a*]pyrene, and dibenz[*a,h*]anthracene. About 4,000 commercial pressure-treatment workers were estimated to have occasional high potential inhalation exposure to creosote. Skin contact with creosote was classified as minimal, except among maintenance workers who were estimated to have occasional high exposure (IARC 1985). Additional exposure information may be found in the ATSDR Toxicological Profile for Creosote (ATSDR 2000). The National Occupational Hazard Survey estimated that 2 million workers were potentially exposed to bitumens and 33,000 were potentially exposed to bitumen fumes in the workplace. The majority of the workers potentially exposed to bitumens are employed in highway and street construction, roofing and sheet-metal operations, and steel mills (NIOSH 1976).

EPA's Toxic Chemical Release Inventory (TRI) listed the top 100 reporting facilities (of 276) that produced, processed, or otherwise used polycyclic aromatic compounds in 1999. Total releases to the environment were estimated to be 1,578,210 lb with total air emissions and releases to land comprising 87% and 13%, respectively (TRI99 2001).

REGULATIONS

The Carcinogen Assessment Group at EPA has designated many of the PAHs as potential carcinogens. As a result, EPA regulates the PAHs under the hazardous waste disposal rule of the Resource Conservation and Recovery Act (RCRA). The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) has established reportable quantities (RQs) for most of the PAHs. Water quality criteria set by the Clean Water Act (CWA) also address all PAHs. EPA has included some PAHs on a list of priority hazardous chemicals subject to reporting requirements under the Superfund Amendments and Reauthorization Act (SARA).

NIOSH has a recommended exposure limit (REL) of 0.1 mg/m^3 as a 10-hr time-weighted average (TWA) for coal tar products, which contain several PAHs. OSHA indirectly limits exposure to PAHs by requiring that occupational exposure to coal tar pitch volatiles not exceed 0.2 mg/m^3 as an 8-hr TWA. In another attempt to minimize the risk of workplace exposure to PAHs, OSHA promulgated a permissible exposure limit (PEL) of ≤0.15 mg/m^3 as an 8-hr TWA for coke oven emissions. OSHA also regulates PAHs under the Hazard Communication Standard and as chemical hazards in laboratories. Regulations are summarized in Volume II, Table 150.

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