JET FUEL

1. Chemical and Physical Data

1.1 Synonyms and trade names

Chem. Abstr. Services Reg. No.: not assigned (kerosene, 8008-20-6)
Chem. Abstr. Name: not assigned
Synonyms: Aviation kerosene; AVCAT (JP-5); AVTAG (JP-4); AVTUR (JP-8); Jet A; Jet A-1; Jet B; jet kerosine; JP-7; kerosine; turbo fuel A; turbo fuel A-1; wide-cut jet fuel

1.2 Description

Many commercial jet fuels have basically the same composition as kerosene, but they are made under more stringent specifications than those for kerosene. Other commercial and military jet fuels are referred to as wide-cut fuels and are usually made by blending kerosene fractions with lower boiling streams to include more volatile hydrocarbons. Because the chemical composition of kerosene and most jet fuels is approximately similar, except for the additives, kerosene used for aviation purposes is described in this monograph. The other uses of kerosene, e.g., as a fuel oil or lamp oil, are described in the monograph on fuel oils (Fuel Oil No. 1).

Readily available commercial illuminating kerosene was the fuel chosen for early jet engines, largely because its use would not interfere with needs for gasoline, which was in short supply during wartime. The development of commercial jet aircraft following the Second World War centred primarily on the use of kerosene-type fuels. High-altitude flying requires fuel with a very low freezing-point; also, the fuel must be extremely clean (free of foreign matter), have a very low moisture content, burn cleanly (essentially free of smoke) and not cause corrosion of engine parts in prolonged service. Different types of engines used for different types of service require fuels with specific chemical and physical properties, and individual specifications have evolved to meet these needs. As international jet service increased, fuels with similar characteristics had to be available worldwide. Thus, steps were taken to meet these needs, although some variation in specifications still exists among different countries. Specifications of several common jet fuels are given in Table 1 (Dukek, 1978).

Table 1. Selected specification properties of aviation gas turbine fuels[a]

Characteristic	Civil ASTM D 1655		Military[b]			
	Jet A kerosene	Jet B wide-cut	Mil-T-5624-K		Mil-T-38219	Mil-T-83133
			JP-4 wide-cut USAF	JP-5 kerosene USN	JP-7[c] kerosene USAF	JP-8 kerosene USAF
Composition						
aromatics, vol. % max	20[d]	20[d]	25	25	5	25
sulfur, wt % max	0.3	0.3	0.4	0.4	0.1	0.4
Volatility						
distillation temperature max °C: 10% received	204			205	196	205
distillation temperature max °C: 50% received		188	190			
distillation temperature max °C: endpoint	300		270	290	288	300
flash-point, °C min	38			60	60	38
vapour pressure at 38°C kPa max (psi)		21 (3)	14–21 (2–3)			
density at 15°C, kg/m^3	775–840	751–802	751–802	788–845	779–806	775–840
Fluidity						
freezing-point, °C max	−40[e]	−50	−58	−46	−43	−50
viscosity at −20°C, mm^3/s max (= cSt)	8.0			8.5	8.0	8.0
Combustion						
heat content, MJ/kg, min	42.8	42.8	42.8	42.6	43.5	42.8
smoke point, mm, min	20[f]	20[f]	20	19	35[c]	20
H_2 content, wt % min			13.6	13.5	14.2[c]	13.6
Stability						
test temperature[g], °C min	245	245	260	260	350[b]	260

[a] From Dukek (1978); full specification requires other tests.

[b] USAF, US Air Force; USN, US Navy

[c] Estimated properties for advanced supersonic fuel

[d] Fuel up to 25 vol % aromatics may be supplied on notification (22 vol % for Jet A-1, Jet B).

[e] International airlines use Jet A-1 with −50°C freeze-point.

[f] Fuel with 18 smoke point may be supplied on notification (19 for Jet A-1, Jet B).

[g] Thermal stability test by D3241 to meet 3.3 kPa (25 mm Hg) pressure drop and Code 3 deposit rating

The early development of jet fuels differed in Europe and the USA. The wide-range distillate-type turbine fuel originated in the USA and evolved to the current jet propulsion, JP-4 military fuel; readily available gasoline fractions were used to supplement the basic kerosene type of fuel. In Europe, however, where gasoline was less readily available, kerosene was used to help conserve gasoline, particularly for the gasoline-fuelled aircraft used in the Second World War. In the postwar years, and particularly in the interests of standardization under the North Atlantic Treaty Organization (NATO), the British AVTAG wide-cut fuel has been brought closely in line with JP-4 (Boldt & Hall, 1977). A recent development with NATO forces in Europe has been the decision to convert military aircraft fuel completely from JP-4 to JP-8 kerosene fuel. The conversion is scheduled to be completed by 1990.

Naval aircraft have somewhat different requirements from those for land-based planes. Less volatile, higher flash-point fuels are needed to minimize vapour exposure of personnel and to reduce fire risk, particularly in enclosed areas below decks. This led to the development of JP-5, a 60°C minimum flash-point kerosene-type fuel for use in shipboard service. Supersonic aircraft also have certain special fuel needs, including low volatility and greater thermal stability than conventional kerosene. JP-7 has been developed to meet these needs. Smaller volumes of these special low-volatility fuels are produced than of the more conventional kerosene-type fuels.

1.3 Chemical composition and physical properties of technical products

The basic component of kerosene used for aviation is the straight-run kerosene stream [5] (refer to Table 2 and Figure 1 of the monograph on occupational exposures in petroleum refining) which consists of hydrocarbons with carbon numbers predominantly in the range of C_9–C_{16} (C_4–C_{16} for wide-cut fuels) and which boil in the range of approximately 150–290°C (CONCAWE, 1985). In the early 1980s, the final boiling-point specification was raised to 300°C maximum in order to allow increased availability of kerosene for jet fuel use (American Society for Testing and Materials (ASTM) D 3699).

Kerosene and jet fuels may actually be blends of heavy straight-run naphtha [4], derived from atmospheric distillation as a more volatile fraction than straight-run kerosene, plus one or more kerosene fractions, such as chemically neutralized kerosene [5C], hydrodesulfurized kerosene [5B] or hydrotreated kerosene [5A]. Some kerosene is made by including hydrocracked fractions which have a very low sulfur content and are otherwise suitable to be made a part of the kerosene product. Such blending permits the refiner increased flexibility in tailoring products to meet a variety of requirements. A net result of the special requirements of jet fuel is that nearly all of it is derived from treated stocks.

The chemical composition of kerosene depends upon the source of crude oil or blend streams from which it is derived. It consists of a complex combination of hydrocarbons, including alkanes (paraffins) and cycloalkanes (naphthenes), aromatics and small amounts of olefins (CONCAWE, 1985).

Alkanes and cycloalkanes are saturated with respect to hydrogen and are chemically stable, clean-burning components, which, together, constitute the major part of kerosene.

Aromatics are also present and represent usually anywhere from about 10% to 20% of the product, depending on the source of crude oil (Dickson & Woodward, 1987). While aromatics are a good source of energy, they tend to smoke when burned and also contribute to the odour of the product. Kerosene in the C_9-C_{16} range normally has a boiling range well above the boiling-point of benzene; accordingly, the benzene (see IARC, 1982, 1987) content of such kerosenes is normally below 0.02%. However, wide-cut products (45–280°C), such as those used for JP-4 and Jet B, are usually made by blending and may contain more benzene, normally $<0.5\%$ (CONCAWE, 1985). Dinuclear aromatic naphthalenes, with two benzene rings in a condensed structure, are also likely to be present in kerosene, at concentrations ranging from 0.1% to 3%, depending on the source of crude oil (Dickson & Woodward, 1987); however, the maximum final boiling range of approximately 300°C tends to exclude the presence of high-boiling polycyclic aromatic hydrocarbons such as the three- to seven-ring condensed aromatic structures (Dukek, 1978)

Olefins are normally present in straight-run kerosene at concentrations of about 1% or less (CONCAWE, 1985). Olefins are essentially eliminated by the hydrotreating processes used in finishing kerosene.

In the USA, the National Institute for Petroleum and Energy Research conducts annual surveys for the American Petroleum Institute and the US Department of Energy on various products, including aviation turbine fuels. The reports provide limited data on composition but include mercaptans, total sulfur, aromatic content and olefin content for JP-4 (wide-cut product) and JP-5 (60°C minimum flash-point) military jet fuels. In addition, the report for Jet A commercial jet fuel includes naphthalene content. These data, together with additional data gathered in the survey for 1986 are given in Table 2 (Dickson & Woodward, 1987). The composition data for commercial Jet A can be considered generally representative of kerosene in the USA, and the data in Table 2 for commercial Jet A-1 are typical of the European product.

ASTM standard D 1655 lists a number of additives that may be used with jet fuels, as agreed by the supplier and purchaser (ASTM D 1655). The International Air Transport Association recommendations require the addition of antioxidant immediately after processing for fuel which has been finished by hydrotreating.

Jet fuels are often transported through pipelines to terminals from which further distribution is made. Because of the risk of loss of some of the additives to pipeline surfaces in entrained water in these systems, some or most of the additives are added at terminals or final distribution centres to ensure correct concentrations in the product delivered to aircraft. The antioxidants approved under ASTM D 1655 for addition to jet fuels at concentrations not exceeding 24.0 mg/l are, e.g., 75% min 2,6-di-*tert*-butylphenol plus 25% max *tert*- and tri-*tert*-butylphenols; 72% min 2,4-dimethyl-6-*tert*-butylphenol plus 28% max monomethyl- and dimethyl-*tert*-butylphenols; and 55% min 2,4-dimethyl-6-*tert*-butylphenol plus 45% max mixed *tert*- and di-*tert*-butylphenols. Metal deactivators — such as *N*,*N*-disalicylidene-1,2-propanediamine, which is approved under ASTM D 1655 — may be added at concentrations not exceeding 5.7 mg/l. Electrical conductivity additives permitted as antistatic additives are ASA-3 (a Shell product) at concentrations up to 1 mg/l and 'Stadis' 450 (a DuPont product) at concentrations up to 3 mg/l (American Society for

Table 2. Physical properties and composition of various samples of jet fuels

Property and composition	USA[a]			Europe[b]
	Military aviation turbine fuel JP-4 (wide-cut)[c]	Military aviation turbine fuel JP-5	Commercial Jet fuel A	Commercial Jet fuel A-1
Gravity, °API	54.8	41.0	42.3	45.2
Distillation temperature				
10% evaporated, °C	92	198	188	169
50% evaporated, °C	138	215	213	194
90% evaporated, °C	198	242	246	236
Reid vapour pressure, psi [atm]	2.6 [0.18]	–	–	–
Freezing-point, °C	–61	–49	–45	–52
Viscosity, kinematic, –20°C, cSt	–	–	5.48	3.85
Aniline point, °C	53	59	60	–
Aniline-gravity product, no.	7007	5646	5976	6141
Water tolerance, ml	0.6	–	0.7	–
Sulfur: total wt %	0.018	0.020	0.035	0.054
mercaptan, wt %	0.000	–	0.001	0.001
Naphthalenes, wt %	–	–	1.59	1.74
Aromatic content, vol. %	13.4	19.1	18.5	18.5
Olefin content, vol. %	0.7	0.8	1.0	0.5
Smoke point, mm	25.6	21.2	22.6	24.2
Gum, mg/100 ml at 232°C	0.8	1.0	1.0	1.0
Heat of combustion, net, kJ/kg	43 024	42 564	42 709	42 757
Thermal stability:				
pressure drop, in mm Hg	0.2	0.0	0.2	–
Water separometer index no.	90	95	97	94

[a] From Dickson & Woodward (1987), based on analysis of samples collected in 1986

[b] Data provided by CONCAWE

[c] Similar to Jet B, with special additives

Testing and Materials, 1986). A fuel system icing inhibitor may also be added; ethylene glycol monomethyl ether, which conforms to ASTM specification D 4171 may be used in concentrations of 0.1–0.15 vol %.

In addition to those approved under ASTM D 1655, other special-purpose additives may be used, such as corrosion inhibitors (American Society for Testing and Materials, 1986), lubrication improvers, biocides (Dukek, 1978) and thermal stability improvers. The use and concentrations of such additives are agreed upon by the supplier and purchaser.

2. Production, Use, Occurrence and Analysis

2.1 Production and use

(*a*) *Production*

Kerosene is derived from crude oil, normally as the third product stream category from an atmospheric distillation tower, following removal of gases, light ends and naphtha streams (see Figure 1, monograph on occupational exposures in petroleum refining). Any need for further processing at this point depends on the type of crude oil from which the kerosene stream is derived. The principal impurities are generally nitrogen and sulfur compounds, which affect odour and overall product quality. The olefin and aromatic content is also an important consideration for some applications, particularly where the end use is as jet fuel. Kerosene derived from sweet crude oils (very low nitrogen and sulfur content) may be used without further treatment for noncritical applications; however, because the major use of kerosene is as jet fuel, most refiners sweeten the stream chemically, such as by caustic washing or other caustic or chemical treatments. Kerosene from sour crude oils, i.e., with higher sulfur content, is often hydrotreated, which markedly lowers the nitrogen and sulfur contents and saturates any olefins that may be present (Dukek, 1978).

When kerosene is finished by a hydrotreating process, it normally contains an oxidation inhibitor; use of further additives is usually agreed between the refiner and purchaser. Some years ago, addition of small amounts of blue dyes was sometimes used to enhance or 'brighten' the appearance of the product, but this practice is seldom used today, if at all. Additives may be required more extensively in jet fuels, in both kerosene types and wide-cut types.

The demand for kerosene, which had earlier been a major petroleum product, has gradually declined with time, whereas that for jet fuels has steadily increased. As a result of trends in demand, many refiners have found it more economical in recent years to produce Jet A-1 as the basic product and simply divert a portion of the product for marketing as kerosene.

Data on production and consumption of jet fuels, including both the kerosene-type and wide-cut fuels, for the USA and for the 24 countries included in the Organisation for Economic Cooperation and Development (OECD) combined for the period 1970–85 are presented in Table 3 (International Energy Agency, 1987), from which the appreciable increase in volumes of jet fuels are evident. Data on production and consumption of jet fuel for 1985 are given by geographical area or organization in Table 4.

(*b*) *Use*

A British patent application filed in 1930 for a turbojet engine resulted in an acceptable working model by 1937 (Dukek, 1978); however, Germans working from the British concept are credited with the first successful test flight of a jet plane that same year. Jet-powered aircraft came into only limited use during the Second World War; however, both military

Table 3. Production and consumption (in thousands of tonnes) of jet fuel in the USA and countries of the Organisation for Economic Cooperation and Development (OECD), 1970-85[a]

Area	Production/ consumption	1970	1975	1980	1985
OECD	Production	57 659	68 002	81 217	90 280
	Consumption	61 810	70 557	79 748	88 880
USA	Production	37 636	41 690	48 580	56 939
	Consumption	43 950	46 497	51 020	58 179

[a] From International Energy Agency (1987)

Table 4. Production and consumption (in thousands of tonnes) of jet fuel by geographical area, 1985[a]

Region/organization	Production	Consumption
North America	60 460	61 616
USA	56 939	58 179
Canada	3 521	3 437
OECD[b] (Europe)	24 376	22 787
European Economic Community	22 438	20 199
Pacific[c]	5 444	4 447
OECD (All)	90 280	88 880

[a] From International Energy Agency (1987)

[b] Organisation for Economic Cooperation and Development

[c] Australia, Japan, New Zealand

and commercial development accelerated in the ensuing years to the point that jet engines began to dominate power sources for aircraft in the 1960s. In turbojet aircraft, the exhaust gases drive the compressor and create the thrust to power the aircraft. In turboprop aircraft, turbine power is used to drive a propeller.

Jet fuels A, A-1 and B (wide-cut) are generally used in civil aviation and jet fuels JP-4–JP-8 in military aviation.

(*c*) *Regulatory status and guidelines*

In Sweden, the occupational exposure limit (1984) for jet fuel has been set at 380 mg/m^3 (8-h time-weighted average (TWA)) and 500 mg/m^3 (15-min short-term exposure limit (STEL)) (Holm *et al.*, 1987). In the USA, a recommendation has been issued on an 8-h TWA limit of 100 mg/m³ for kerosene (National Institute for Occupational Safety and Health, 1977). Recommended values of 700 mg/m³ (8-h TWA) and 1050 mg/m³ (15-min STEL) for wide-cut jet fuels, evaluated as total hydrocarbon and expressed as *n*-hexane, have been developed by the US Air Force (Bishop *et al.*, 1983).

2.2 Occurrence

(*a*) *Occupational exposure*

Potential exposure to jet fuel in the work environment has been reported in association with the following operations: manually handled filling and discharge, including fuel filling of airplanes (CONCAWE, 1985; Døssing *et al.*, 1985; Holm *et al.*, 1987); tank dipping, pipeline pump repairs and filter cleaning in refineries, distribution terminals and depots (CONCAWE, 1985); maintenance, inspection and cleaning of jet fuel storage tanks, servicing of pump units (Fardell & Houghton, 1975/76; CONCAWE, 1985; Holm *et al.*, 1987); production and installation of aircraft fuel systems (Knave *et al.*, 1976); component testing and engine testing in a jet motor factory (Knave *et al.*, 1978); maintenance and service of aircraft fuel tanks, fuel systems and engines (Thomas & Richardson, 1981; CONCAWE, 1985; Holm *et al.*, 1987); routine sampling and laboratory analysis of jet fuel (CONCAWE, 1985); and use of high-pressure kerosene sprays for washing engines and other parts during maintenance or repairs (CONCAWE, 1985).

Available quantitative exposure data are summarized in Table 5. Those data refer mostly to exposure to wide-cut aviation turbine fuel, which, by its more volatile nature, is more likely to give rise to high vapour concentrations than regular kerosene jet fuel types. Inspection and maintenance of aircraft wing fuel tanks may, as a result of the confined working space, present opportunities for much higher exposures to jet fuel than most of the other operations listed above. Wide-cut jet fuel vapours may contain small concentrations of benzene and *n*-hexane (CONCAWE, 1985). Maximal overall 8-h TWA values of 16 and 4 mg/m³ for *n*-hexane and benzene, respectively, have been measured for aircraft unit personnel in Sweden (Holm *et al.*, 1987), with maximal 15-min STEL values at about 157 and 39 mg/m³ for these same two compounds.

(*b*) *Environmental occurrence*

An accidental spill of more than 14 tonnes of JP-5 jet fuel mixed with No. 2 fuel oil from a storage facility in Searsport, ME, USA, in March–June 1971 was reported (Dow *et al.*, 1975). In October 1975, 83 000 gallons [314 000 l] of JP-4 jet fuel were spilled in Charleston, SC, USA (Talts *et al.*, 1977). It is also noted that it is common practice for aircraft to jettison excess fuel in the air under some conditions.

2.3 Analysis

Since jet fuel or kerosene is composed of a complex mixture of hydrocarbons, there are few methods for the environmental analysis of 'jet fuel' or 'kerosene' as an entity, but many

Table 5. Concentrations of jet fuel vapours in various operations and occupations (personal samples)

Operation or occupation	Type of fuel	Duration of sampling (no. of samples)	Mean/median concentration (mg/m^3)	Reference
Fuel filling attendants	Unspecified (military)	Several hours (69)	31 (median) 1–1020 (range)	Døssing *et al.* (1985)
Fuel systems component testing (jet motor factory)	Wide-cut	19–97 min (9)	423 mg/m^3 (average of means)[a] 85–925 (range of means)	Knave *et al.* (1978)
Engine testing (jet motor factory)	Wide-cut	30–54 min (3)	128 mg/m^3 (average of means)[a] 110–147 (range of means)	Knave *et al.* (1978)
Mechanics (jet motor factory)	Wide-cut	10–55 min (4)	149–974 (range of means)[a]	Knave *et al.*, 1978
Inspection and repair of aircraft fuel tanks	Wide-cut (JP-4)	0.5–4 h (21)	<0.3–3014 (range)[b]	Thomas & Richardson (1981)
Jet fuel handling	Wide-cut (MC-77) military	8 h (12)	0.9 GM[c] 2.7 GSD[d]	Holm *et al.* (1987)
		15 min (6)	6.0 GM 6.9 GSD	
Flight service	Wide-cut	8 h (56)	3.3 GM 5.0 GSD	Holm *et al.* (1987)
		15 min (28)	9.3 GM 10.0 GSD	
Workshop service	Wide-cut	8 h (24)	2.1 GM 5.3 GSD	Holm *et al.* (1987)
		15 min (12)	5.8 GM 12.3 GSD	

[a] Time-weighted average of time-integrated means corresponding to measurements performed during various tasks involving exposure. These tasks cover ~50% of workers' time in testing activities and 35% for mechanics.

[b] Charcoal tube samples analysed by gas chromatography only. Nine samples above 800 mg/m^3

[c] GM, geometric mean

[d] GSD, geometric standard deviation

methods are reported for the analysis of its component hydrocarbons. These methods are used to identify or 'fingerprint' the origin of a specific jet fuel or kerosene sample on the basis of the proportions of its component hydrocarbons. For a further discussion of analytical methods for component hydrocarbons of petroleum and petroleum products in environmental samples, see section 2.3 of the monograph on crude oil.

Selected methods applicable to the analysis of jet fuel are identified in Table 6.

Table 6. Methods applicable to the analysis of jet fuel in air

Sample preparation	Assay procedure[a]	Limit of detection	Remarks	Reference
Adsorb (charcoal); desorb (carbon disulfide); inject aliquot	GC/FID	5 mg/m³	Applies to kerosene vapours	Eller (1984)
Adsorb (charcoal or passive organic vapour monitor); desorb	IR	0.4 mg/m³	Applies to JP-4	Thomas & Richardson (1981)

[a] GC/FID, gas chromatography/flame ionization detection; IR, infra-red spectrophotometry

3. Biological Data Relevant to the Evaluation of Carcinogenic Risk to Humans

3.1 Carcinogenicity studies in animals

Studies on straight-run [5] and hydrotreated kerosene [5A], which are components of jet fuel, are described in the monograph on occupational exposures in petroleum refining, p. 72.

Skin application

Mouse: Groups of 50 male and 50 female B6C3F1 mice, eight weeks old, were given applications of 0, 250 or 500 mg/kg bw JP-5 navy fuel (52.8% cycloalkanes, 30.8% paraffins, 15.9% aromatics and 0.5% olefins) in 0.1 ml acetone on the skin on five days per week for 103 weeks. High-dose females were killed after 90 weeks because of the occurrence of non-neoplastic skin lesions. Survival at 105 weeks was: males — controls, 36/50; low-dose, 33/50; high-dose, 28/50; females — controls, 44/50, low-dose, 33/50; high dose, 17/50 (90 weeks). No neoplasm of the skin occurred at the application site in treated or vehicle-control mice of either sex. Carcinomas of the skin at the inguinal site occurred in one low-dose male, one high-dose male and one high-dose female. One papilloma of the skin occurred in a low-dose male. The incidence of malignant lymphomas was increased in low-dose female mice: controls, 7/48; low-dose, 19/49; high-dose, 5/47 (National Toxicology Program, 1986). [The Working Group noted that the incidence of lymphomas in low-dose female mice was within the range for historical untreated control female B6C3F1 mice in this laboratory.]

3.2 Other relevant data

(*a*) *Experimental systems*

Absorption, distribution, excretion and metabolism

No data were available to the Working Group.

Toxic effects

The oral LD_{50} in male Sprague-Dawley rats of jet propulsion fuel (JP-5) was >60 ml/kg bw. Male Sprague-Dawley rats treated with a single dose of 24 ml/kg bw JP-5 by gavage showed moderate renal and hepatic functional alterations, renal hyaline droplet formation, and renal and hepatic fatty change one to three days later (Parker *et al.*, 1981). Slight behavioural disturbances were observed after single oral administration of 1, 3 or 5 ml/kg bw JP-5 by gavage to male Sprague-Dawley rats 2.5–6 h after dosing (Bogo *et al.*, 1984).

Exposure of C57Bl/6 mice to 500 and 1000 mg/m^3 JP-4 for 90 days caused centrilobular fatty change in the livers of females (MacNaughton & Uddin, 1984). Male Fischer 344 rats exposed continuously to JP-4 fuel vapour (500 and 1000 mg/m^3) or JP-5 vapour (150 and 750 mg/m^3) for 90 days developed dose-related nephropathy with cytoplasmic hyaline droplets, necrosis of proximal tubular cells and accumulation of intratubular necrotic debris (Bruner, 1984; Gaworski *et al.*, 1984). Rats held for life after the 90-day exposure to JP-5 showed abundant renal mineralized casts, papillary hyperplasia of pelvic urothelium and tubular degeneration (Bruner, 1984).

Male and female $C3H_f/Bd_f$ mice developed renal lesions after receiving dermal applications of 50 μl JP-5 and JP-8 jet fuel on their clipped backs thrice weekly for 60 weeks; atrophied and degenerating nephrons, as well as papillary necrosis, were observed (Easley *et al.*, 1982). Groups of male and female B6C3F1 mice were administered 0, 250 or 500 mg/kg bw JP-5 in acetone by dermal application on five days per week for 103 weeks (90 weeks for high-dose females due to ulceration of the skin). A marked increase in the incidence of ulceration, inflammation and epithelial hyperplasia was observed. No nephrotoxicity was seen, but the high-dose males and females had amyloidosis in multiple organs, possibly in response to the dermal ulcerations (National Toxicology Program, 1986).

Effects on reproduction and prenatal toxicity

No embryotoxic, fetotoxic or teratogenic effect was observed following exposure of Charles River CD rats by inhalation from day 6 to 15 of gestation for 6 h per day to 100 and 400 ppm jet fuel A (Beliles & Mecler, 1982). No toxic effect was detected on duck embryos after an application on the shell surface of weathered or unweathered aviation kerosene (1–20 μl per egg) on day 6 of incubation (Albers & Gay, 1982).

Genetic and related effects

Jet fuel A (boiling range, 163–282°C; 17.9% aromatics) was not mutagenic to *Salmonella typhimurium* TA1535, TA1537, TA1538, TA98 or TA100 [0.25–40 mg/plate] in the presence or absence of an exogenous metabolic system from rat liver (Conaway *et al.*, 1984). Similarly, jet fuel JP-5 was not mutagenic to *S. typhimurium* TA1535, TA97, TA98 or TA100 (100–10 000 μg/plate) in the presence or absence of an Aroclor 1254-induced rat or hamster liver preparation (National Toxicology Program, 1986). Jet fuel A induced mutation in mouse lymphoma L5178Y $TK^{+/-}$ cells only in the presence of an exogenous metabolic system from either rat or mouse liver. It induced chromosomal aberrations in the bone marrow of male and female Sprague-Dawley CD rats exposed by dynamic inhalation for 20 days to 100 ppm or for five days to 400 ppm (Conaway *et al.*, 1984).

(*b*) *Humans*

Absorption, distribution, excretion and metabolism

No data were available to the Working Group.

Toxic effects

Exposure to jet fuel vapours has been reported to cause a number of neurobehavioural symptoms, including dizziness, headache, nausea and fatigue (Davies, 1964; Knave *et al.*, 1976, 1978, 1979).

In a cross-sectional study of 30 workers exposed to jet fuel vapour (average, 300 mg/m³; mean employment, 17 years) and 30 or 60 unexposed controls, a higher prevalence of psychiatric symptoms, poorer performance in some psychological tests and reduced sensorimotor speed were reported among the exposed group (Knave *et al.*, 1978, 1979).

Among 91 jet fuel-filling attendants in Denmark (exposure, 1–1020 mg/m³; median, 31 mg/m³), antipyrine clearance was higher during exposure than after an exposure-free period of two or four weeks; a similar, but smaller effect was reported in a control group of office workers (Døssing *et al.*, 1985). [The Working Group noted that no conclusion with respect to exposure to jet fuel can be made.]

Effects on reproduction and prenatal toxicity

No data were available to the Working Group.

Genetic and related effects

No data were available to the Working Group.

3.3 Epidemiological studies and case reports of carcinogenicity to humans

A cohort of 2182 men exposed to jet fuel in the Swedish armed forces was established in 1974 (Seldén & Ahlborg, 1986). Most of the men (86%) were employed in the Air Force, where exposure had been primarily to aviation kerosene, jet fuel, isopropyl nitrate (a starter fuel) and aviation gasoline (for piston engines). Measurements of jet fuel in air at some work places in 1975 and 1976 showed concentrations exceeding 350 mg/m³. Cancer morbidity and mortality in the cohort were followed until 1981 and 1982, respectively, in central registers, with loss to follow-up of less than 0.2%. For Air Force personnel, there was significantly lower total mortality than expected on the basis of national rates (44 observed, 81.1 expected), due to low mortality from cardiovascular diseases. There were 25 malignant neoplasms compared with 29.4 expected. No clear increase in the frequency of cancers at specific sites was seen, even when duration of employment, latency, occupation or type of exposure were taken into consideration. These results were confirmed when the follow-up was continued for a further two years (Seldén & Ahlborg, 1987). [The Working Group noted the short duration of follow-up.]

In a case-control study of cancer at many sites in Montréal, Québec, Canada, which is described in detail in the monograph on gasoline (p. 185), among men exposed to jet fuel (kerosene-type and wide-cut), an increased risk was seen for kidney cancer only (adjusted odds ratio, 3.1; 90% confidence interval, 1.5–6.6) (Siemiatycki *et al.*, 1987). In subjects in jobs which were estimated to result in substantial exposure, the adjusted odds ratio was 3.4 (1.5–7.6). Aircraft mechanics and repairmen constituted the largest occupational group, and there was an overlap between groups exposed to aviation gasoline and jet fuel, resulting from combined exposures.

4. Summary of Data Reported and Evaluation[1]

4.1 Exposure data

Jet fuels are produced mainly from straight-run [5] and hydrotreated kerosene [5A] or kerosene blended with heavy naphtha streams [4 and derived streams] from the atmospheric distillation of crude oil. Jet fuels are composed mainly of aliphatic and aromatic hydrocarbons with boiling ranges of 150–300°C (kerosene type) and 45–280°C (wide-cut type). The formulated products are used in turbine engines of civil and military aircraft. Exposures to jet fuel may occur during its production, transport and storage as well as during refuelling and maintenance of aircraft. Heavier exposures may occur during inspection and repair of aircraft wing tanks owing to the confined working space.

4.2 Experimental data[2]

One sample of jet fuel was tested by skin application in one experiment in male and female mice. No skin tumour occurred at the application site.

Two samples of straight-run kerosene [5] and one sample of hydrotreated kerosene [5A] produced skin tumours in mice. (See the monograph on occupational exposures in petroleum refining.)

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[1] The numbers in square brackets are those assigned to the major process streams of petroleum refining in Table 2 of the monograph on occupational exposures in petroleum refining (p. 44).

[2] Subsequent to the meeting, the Secretariat became aware of a study in which skin tumours were reported in mice after application to the skin of jet fuel A [kerosene type] and JP-4 [wide-cut type] (Clark *et al.*, 1988).

4.3 Human data

A cohort of men exposed to jet fuel, aviation kerosene and other fuels in the Swedish Air Force had no increased cancer risk during ten years of follow-up. A case-control study of cancer at many sites in Canada revealed an elevated risk for kidney cancer, with some indication of a positive dose-response relationship, in men exposed to jet fuel.

4.4 Other relevant data

In single studies, one sample of jet fuel induced chromosomal aberrations in bone-marrow cells of rats and mutations in cultured mammalian cells in the presence of an exogenous metabolic system but did not induce mutation in bacteria. A further sample was also not mutagenic to bacteria. (See Appendix 1.)

4.5 Evaluation[1]

There is *inadequate evidence* for the carcinogenicity in humans of jet fuel.

There is *inadequate evidence* for the carcinogenicity in experimental animals of jet fuel.

In formulating the overall evaluation, the Working Group also took note of the following supporting evidence from the monograph on occupational exposures in petroleum refining. There is *limited evidence* for the carcinogenicity in experimental animals of straight-run kerosene and of hydrotreated kerosene.

Overall evaluation

Jet fuel *is not classifiable as to its carcinogenicity to humans (Group 3).*

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[1] For definition of the italicized terms, see Preamble, pp. 25–28.

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