Environment Canada Environnement Canada

Final Screening Assessment
Petroleum Sector Stream Approach

Aviation Fuels
[Fuels]

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Synopsis

The Ministers of the Environment and of Health have conducted a screening assessment of the following substances, identified as aviation fuels:

Aviation turbine fuel

CAS RN[a]	DSL[b] name
64741-86-2	Distillates (petroleum), sweetened middle

Aviation gasoline fuels

CAS RN	DSL name
64741-87-3	Naphtha (petroleum), sweetened
68527-27-5	Naphtha (petroleum), full-range alkylate butane-containing

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[b] DSL: *Domestic Substances List*

These aviation fuels were identified as high priorities for action during the categorization of the DSL, as they were determined to present greatest potential or intermediate potential for exposure of individuals in Canada, and were considered to present a high hazard to human health. These substances met the ecological categorization criteria for persistence or bioaccumulation potential and inherent toxicity to aquatic organisms. These substances were included in the Petroleum Sector Stream Approach (PSSA) because they are related to the petroleum sector and are considered to be of Unknown or Variable composition, Complex reaction products or Biological materials (UVCBs).

Aviation fuels fall under two major categories: aviation turbine fuels (jet fuels) intended for use in aviation gas turbines (compression-ignited turbine jet engines), and aviation gasoline fuels (Avgas) intended for use in spark-ignited aviation piston engines. The majority (99%) of refinery production is aviation turbine fuel. Aviation gasoline fuel is used in a much smaller quantity, representing approximately 1% of the total aviation fuels in Canada.

An analysis of Canadian aviation fuel spills data for the years 2000–2009 indicated that there is on average less than 1 spill per year for aviation turbine fuel to water during ship loading, transport and unloading that is of a sufficient size to be expected to be harmful to aquatic organisms (fish, invertebrates, algae, phytoplankton). Aviation gasoline is not transported by ship, and therefore spills to water during transport are not expected. Spills of aviation gasoline fuels and aviation turbine fuel to soil may cause adverse effects to terrestrial organisms (invertebrates, plants), with approximately 4 to 8 spills to the environment occurring per year of which the average spill volume is expected to cause harm. However, the actual number of spills is expected to be closer to the lower end of the range, and not all of the releases will be of a volume to cause significant harm. No systemic cause for the releases was identified. This analysis excluded spills taking place on the properties of commercial airports or industrial sites (e.g., refineries, bulk storage terminals), as releases at these locations are expected to undergo immediate remediation that would minimize entry into the environment.

Considering all available lines of evidence presented in this screening assessment, there is low risk of harm to organisms or the broader integrity of the environment from these substances. It is therefore concluded that the aviation turbine fuel (CAS RN 64741-86-2) and the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet the criteria under paragraphs 64(*a*) or (*b*) of the *Canadian Environmental Protection Act, 1999* (CEPA 1999), as they are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity, or that constitute or may constitute a danger to the environment on which life depends.

A critical health effect for the initial categorization of aviation fuels was carcinogenicity, based primarily on classifications by international agencies. Additionally, benzene, a component of aviation fuels, has been identified by Health Canada and several international regulatory agencies as a carcinogen, and was added to the List of Toxic Substances in Schedule 1 of CEPA 1999. As the predominant route of exposure to aviation fuels was determined to be inhalation, estimates of cancer potency for inhalation of benzene were used to characterize risk to the general population from evaporative emissions of aviation fuels.

Aviation fuels exhibited mixed results in *in vitro* and *in vivo* genotoxicity assays. Results from limited studies in laboratory animals indicated the potential for developmental health effects at high concentrations in mice but not in rats.

The potential for exposure of the general population to evaporative emissions of aviation fuel at Canadian airports and in the vicinity of bulk storage facilities was evaluated. For non-cancer effects, margins of exposure between upper-bounding estimates of exposure and critical effect levels identified in laboratory animals are considered adequate to address uncertainties in the health effects and exposure databases. For cancer, margins of exposure between upper-bounding estimates of exposure and estimates of cancer potency are considered adequate to address uncertainties related to health effects and exposure. Accordingly, it is concluded that the aviation turbine fuel (CAS RN 64741-86-2) and the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet the criteria under paragraph 64(*c*) of CEPA 1999, as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.

It is therefore concluded that the aviation turbine fuel (CAS RN 64741-86-2) and the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet any of the criteria set out in section 64 of CEPA 1999.

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1. Introduction

The *Canadian Environmental Protection Act, 1999* (CEPA 1999) (Canada 1999) requires the Minister of the Environment and the Minister of Health to conduct screening assessments of substances that have met the categorization criteria set out in the Act to determine whether these substances present or may present a risk to the environment or human health.

Based on the information obtained through the categorization process, the Ministers identified a number of substances as high priorities for action. These include substances that:

- met all of the ecological categorization criteria, including persistence (P), bioaccumulation potential (B) and inherent toxicity to aquatic organisms (iT), and were believed to be in commerce in Canada; and/or
- met the categorization criteria for greatest potential for exposure (GPE) or presented an intermediate potential for exposure (IPE) and had been identified as posing a high hazard to human health based on classifications by other national or international agencies for carcinogenicity, genotoxicity, developmental toxicity or reproductive toxicity.

A key element of the Government of Canada’s Chemicals Management Plan (CMP) is the Petroleum Sector Stream Approach (PSSA), which involves the assessment of approximately 160 petroleum substances that are considered high priorities for action (“high priority petroleum substances”). These substances are primarily related to the petroleum sector and are considered to be of Unknown or Variable composition, Complex reaction products or Biological materials (UVCBs).

Screening assessments focus on information critical to determining whether a substance meets the criteria set out in section 64 of CEPA 1999. Screening assessments examine scientific information and develop conclusions by incorporating a weight-of-evidence approach and precaution.[1]

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[1] A determination of whether one or more of the criteria in section 64 are met is based upon an assessment of potential risks to the environment and/or to human health associated with exposures in the general environment. For humans, this includes, but is not limited to, exposures from ambient and indoor air, drinking water, foodstuffs, and the use of consumer products. A conclusion under CEPA 1999 on the substances in the Chemicals Management Plan (CMP) Challenge is not relevant to, nor does it preclude, an assessment against the hazard criteria for the Workplace Hazardous Materials Information System that are specified in the *Controlled Products Regulations* for products intended for workplace use. Similarly, a conclusion based on the criteria contained in section 64 of CEPA 1999 does not preclude actions being taken under other sections of CEPA or other Acts.

1.1 Grouping of Petroleum Substances

The high-priority petroleum substances fall into nine groups of substances based on similarities in production, toxicity and physical-chemical properties (Table A-1 in Appendix A). In order to conduct the screening assessments, each high-priority petroleum substance was placed into one of five categories ("Streams") depending on its production and uses in Canada:

> Stream 0: substances not produced by the petroleum sector and/or not in commerce
> Stream 1: site-restricted substances, which are substances that are not expected to be transported off refinery, upgrader or natural gas processing facility sites[2]
> Stream 2: industry-restricted substances, which are substances that may leave a petroleum-sector facility and may be transported to other industrial facilities (for example, for use as a feedstock, fuel or blending component), but that do not reach the public market in the form originally acquired
> Stream 3: substances that are primarily used by industries and consumers as fuels
> Stream 4: substances that may be present in products available to the consumer

An analysis of the available data determined that 13 petroleum substances are fuels under Stream 3, as described above. These substances were grouped according to fuel type as follows: gasoline; diesel fuels; Fuel Oil No. 2; Fuel Oil No. 4, Fuel Oil No. 6 and Residual Fuel Oil; and aviation fuels. The Stream 3 fuels occur within three of the nine substance groups: heavy fuel oils (HFOs), gas oils and low boiling point naphthas (LBPNs). The aviation fuels considered in this assessment occur within the gas oils and LBPN substance groups.

This screening assessment addresses three aviation fuels described under Chemical Abstracts Service Registry Numbers (CAS RNs) 64741-86-2, 64741-87-3 and 68527-27-5. These aviation fuels were identified as GPE or IPE during the categorization exercise, and were considered to present a high hazard to human health. These substances met the ecological categorization criteria for persistence or bioaccumulation potential and inherent toxicity to aquatic organisms.

The analysis of exposure to aviation fuel exhaust from fuel combustion is outside the scope of this assessment. Consideration of the contribution of fuel

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[2] For the purposes of the screening assessment of PSSA substances, a site is defined as the boundaries of the property where a facility is located.

combustion to air pollution is assessed under different programs within the Government of Canada.

Included in this screening assessment is the consideration of information on chemical properties, uses, exposure and effects. Data relevant to the screening assessment of these substances were identified in original literature, review and assessment documents, stakeholder research reports and from recent literature searches, up to December 2011 for the environmental section of the document and up to September 2011 for the health effects section of the document. Key studies were critically evaluated, and modelling results were used to inform conclusions.

Characterizing risk to the environment involves the consideration of data relevant to environmental behaviour, persistence, bioaccumulation and toxicity, combined with an estimation of exposure to potentially affected non-human organisms from the major sources of releases to the environment. To predict the overall environmental behaviour and properties of complex substances such as these aviation fuels, representative structures were selected from each chemical class contained within these substances. Conclusions regarding risk to the environment were based in part on an estimation of environmental concentrations resulting from releases and the potential for these concentrations to have a negative impact on non-human organisms. Other lines of evidence including fate, temporal/spatial presence in the environment and hazardous properties of the substances were also taken into account. The ecological portion of the screening assessment summarizes the most pertinent data on environmental behaviour and effects, and does not represent an exhaustive or critical review of all available data. Environmental models and comparisons with similar petroleum substances assisted in the assessment.

Evaluation of risk to human health involved consideration of data relevant to the estimation of exposure of the general population, as well as information on health effects. Health effects were assessed using pooled toxicological data from aviation fuels and related substances, as well as for high-hazard components expected to be present in the fuels. Decisions for risk to human health were based on the nature of the critical effect and margins between conservative effect levels and estimates of exposure, taking into account confidence in the completeness of the identified databases on both exposure and effects, within a screening assessment context. The screening assessment does not represent an exhaustive or critical review of all available data. Rather, it presents a summary of the critical information upon which the conclusion is based.

This screening assessment was prepared by staff in the Existing Substances Programs at Health Canada and Environment Canada, and incorporates input from other programs within these departments. The human health and ecological portions of this assessment have undergone external written peer review/consultation. Comments on the technical portions relevant to human health were received from scientific experts selected and directed by Toxicology Excellence for Risk Assessment (TERA), including Dr. Michael Jayjock (The LifeLine Group), Mr. Darrell McCant (Texas Center for Environmental Quality [TCEQ]), Dr. Mark Whitten (Professor [retired] of Pediatrics, University of Arizona College of Medicine), and Dr. Errol Zeiger (Errol Zeiger Consulting). While external comments were taken into consideration, the final content and outcome of the screening assessment remain the responsibility of Health Canada and Environment Canada.

The critical information and considerations upon which the screening assessment is based are summarized below.

2. Substance Identity

For the purpose of this document, the three CAS RNs collectively will be referred to as “aviation fuels.”

Aviation fuels fall under two major categories: aviation turbine fuels (jet fuels) intended for use in aviation gas turbines (compression-ignited turbine jet engines), and aviation gasoline fuels (Avgas) intended for use in spark-ignited aviation piston engines.

CAS RN 64741-86-2 (Distillates [petroleum], sweetened middle) refers to a combination of hydrocarbons with a carbon range of C_9–C_{20} and a boiling point range of 150–345°C, produced by sweetening a petroleum distillate to convert undesirable mercaptans or to remove acidic impurities.

CAS RN 64741-87-3 (Naphtha [petroleum], sweetened) refers to petroleum naphtha with a carbon range of C_4–C_{12} and a boiling point range of 10–230°C, subjected to a sweetening process to convert undesirable mercaptans or to remove acidic impurities.

CAS RN 68527-27-5 (Naphtha [petroleum], full-range alkylate butane-containing) refers to a combination of hydrocarbons produced with a carbon range of C_7–C_{12} and a boiling point range of 35–200°C, produced by the distillation of the reaction products of isobutene with predominantly mono-olefinic hydrocarbons.

These UVCB substances are complex combinations of hydrocarbon molecules that originate in nature or are the result of chemical reactions and processes that take place during the upgrading and refining process. Given their complex and variable compositions, they could not practicably be formed by simply combining individual constituents.

2.1 Aviation Turbine Fuels

Aviation turbine fuels (which include CAS RN 64741-86-2) consist primarily of aliphatic hydrocarbons with a carbon range of C_9–C_{16} (Tharby 2010).These jet fuels have two principal names in civil aviation, Jet A and Jet A-1, which are made from the same base stock but vary in their additives. Jet A differs from Jet A-1 in that the freezing point of Jet A is -40°C while that of Jet A-1 is -47°C (Tharby 2010). Jet Propellant-5 (JP-5) and JP-8 are military grades of aviation turbine fuels (Tharby 2010). Due to the limited available information on aviation turbine fuel (CAS RN 64741-86-2), a read-across approach to Jet A, Jet A-1, JP-5 and JP-8 was used in this assessment. Furthermore, the read-across approach extended to kerosene and diesel fuel, based on similar boiling points and carbon ranges.

Aviation turbine fuels contain straight-chain *n*-alkanes, branched-chain isoalkanes, cycloalkanes, one-ring aromatics (alkylated benzene compounds) and very limited amounts of bicyclic aromatics (naphthalene and biphenyl). In general, there are approximately 25–30% each of *n*-alkanes and isoalkanes, 25% cycloalkanes and 15–20% aromatics (Tharby 2010). However, the actual proportions of each hydrocarbon type can differ based on the crude oil and secondary processing influences (Tharby 2010). A further compositional breakdown of aviation turbine fuels (Jet A/Jet A-1 and JP-8) is presented in Table 2-1. According to technical requirements as specified by the Canadian General Standards Board (CGSB 2009), aviation turbine fuels should not contain more than 25% aromatics. Kerosene, a substance used for read-across for aviation fuels, has a basic composition of at least 70% alkanes and cycloalkanes, up to 25% aromatic hydrocarbons and less than 5% alkenes (U.S. EPA 2011).

Table 1-1. Average hydrocarbon composition of Jet A/A-1 and JP-8 aviation turbine fuels (Tharby 2010; CRC 2006)

Hydrocarbon type	**Volume (%)**	
-	Jet A/A-1 (Tharby 2010; CRC 2006)	JP-8 (ATSDR 2005)
n- and Isoalkanes	58.8	71.4
Monoaromatics	13.3	13.0
Alkylated monocycloalkanes	10.9	8.1
Dicycloalkanes	9.3	-
Cycloalkane monoaromatics[a]	4.9	4.14
Alkylated naphthalenes	1.6	3.49
Tricycloalkanes	1.1	-
Naphthalene	0.1	-

[a] Specifically indans and tetralins.

2.2 Aviation Gasoline Fuels

Aviation gasoline fuels (which include CAS RN 64741-87-3 and 68527-27-5) are gasoline-based. A general composition of aviation gasoline fuels is presented in Table 2-2. Aviation gasoline fuels are composed of light alkylate (branched alkanes in the range of C_7–C_{10}), isomerate (isoalkanes), and other aromatic substances at lower concentrations such as benzene, toluene, ethylbenzene and xylenes (BTEX). They also contain anti-knock additives, primarily in the form of tetraethyl lead (Tharby 2010). The potential health and ecological effects of specific additives, including lead and its compounds, are not considered in this report and may be considered under different programs within the Government of Canada. Leaded aviation gasoline has an ongoing exemption under the *Regulations Respecting Concentrations of Lead and Phosphorous in Gasoline* (Canada 1990). The Government of Canada is not currently considering a change to the exemption for leaded gasoline used in aircraft until a suitable replacement to tetraethyl lead in aviation gasoline becomes available, and aircraft and their engines are certified to use it (Canada 2008). Aviation gasoline fuels are known to consist of blends of refined hydrocarbons derived from crude petroleum, natural gasoline or blends of the aforementioned. The refining industry does not readily use CAS RNs to denote product streams, but instead blends substances as needed to meet the required functional specifications. Thus, several product streams such as those listed above will be blended to meet product requirements. Furthermore, there is limited information available on the two specific aviation gasoline fuel substances assessed in this report, and thus a read-across approach to automotive gasoline was used in this assessment based on similar boiling points and carbon ranges. The primary difference between gasoline and these two aviation gasoline fuels is in the proportions of alkanes and alkenes.

Table 2-2. Composition of aviation gasoline fuel (Avgas 100LL) in Canada (Tharby 2010; Chevron 2008; Imperial Oil 2013)

Substance name	**Composition by weight (range)**
Naphtha, light alkylate[a]	70–100%
Naphtha, isomerization (isopentane/isomerate)	0–10%
Toluene	0–30%
Benzene	0–1%
Tetraethyl lead	< 0.53 g/L

[a] This substance is likely a complex combination of hydrocarbons consisting predominantly of branched alkanes in the range of C_7–C_{10} with a boiling point range of 90–160°C (CONCAWE 1992; Tharby 2010).

3. Physical-Chemical Properties

The composition and physical-chemical properties of aviation fuels vary depending on the type of use for the fuel, whether for turbine jet engines or piston-driven engines. Physical-chemical properties of aviation fuels are presented in Table 3-1.

Table 3-1. Physical-chemical properties of aviation fuels

Property	Value (substance)	Temperature (°C)	Reference
Boiling point (°C)	10–230 (CAS RN 64741-87-3) 35–200 (CAS RN 68527-27-5) 150–345 (CAS RN 64741-86-2)	-	European Commission c2000a, c2000b, c2000c
Vapour pressure (Pa)	300–3500 (JP-5/JP-8) > 1000 (Jet A/Jet A-1)	21 37.8	API 2003a
Henry's Law constant ($Pa \cdot m^3/mol$)	$2.8–4.6 \times 10^6$	-	EPI Suite 2008
Log K_{ow}[a] (octanol-water partition coefficient) (dimensionless)	3.3 – > 6	-	API 2003a
Water solubility (mg/L)	4.8–57	20	API 2003a
Density (g/mL)	0.78–0.84 (aviation turbine fuel) 0.71–0.73 (aviation gasoline fuel)	-	CONCAWE 1995; Exxon Mobil 2008[b] Environment Canada c2001

[a] Modelled data.
[b] Based on Canadian General Standards Board analysis of Jet A/A-1 in 2005.

In order to predict the overall behaviour of a complex petroleum mixture in the environment, representative structures were chosen from each chemical class within the substances (Table B-1 in Appendix B). A total of 24 structures were chosen, with some suggested by Tharby (2010). Representative structures were not chosen based on proportions in the substance, but rather on the identity of the components within the substance. Representative structures for alkanes, isoalkanes, cycloalkanes, cycloalkane aromatics and aromatics were chosen. Physical-chemical data were compiled from various sources of scientific literature and modelled using EPI Suite (2008). The results are shown in Table B-1 (Appendix B).

While Table B-1 (Appendix B) provides physical-chemical property data for the individual structures, it should be noted that some of these properties will differ when the substances are present in a mixture, such as the aviation fuels. The vapour pressures of components of a mixture will be lower than their individual vapour pressures due to Raoult's Law (the total vapour pressure of an ideal mixture is proportional to the sum of the vapour pressures of the mole fractions of each individual component). Similar to Raoult's Law, the water solubilities of components in a mixture are lower than when they are present individually (Banerjee 1984). Concurrently, however, components that are normally solid under environmental conditions may have lower melting points (and therefore be in a liquid state) and increased vapour pressure and water solubility (Banerjee 1984) when part of a mixture. This is not reflected in Table B-1.

Water solubility of the representative structures of aviation fuel ranges from extremely low (2.7×10^{-5} mg/L) for the alkanes to high (1790 mg/L) for the monoaromatics (Table B-1 in Appendix B). The components most likely to remain in water are the smallest structures from each chemical group. The larger structures from each group demonstrate an attraction to sediments based on their low water solubilities and moderate to high log octanol-water partition coefficient (log K_{ow}) and log organic carbon-water partition coefficient (log K_{oc}) values.

Experimental vapour pressure data found in the EPI Suite (2008) database for the representative structures range from low (0.03 Pa) to very high (2.8×10^{4} Pa), and typically decrease inversely with molecular weight (Table B-1 in Appendix B). This indicates that losses from soil and water will likely encompass a wide range, with air being the ultimate and most frequent receiving environment for most components of aviation fuels.

4. Sources

Aviation fuels are produced in Canadian refineries and are also imported into Canada. Statistics Canada (2012) and Environment Canada's National Enforcement Management Information System and Intelligence System (NEMISIS) database (Environment Canada 2011) show that these substances are used, produced and transported between various locations nationwide.

The volumes of aviation fuels produced in Canada in 2011, including volumes of imports and exports, were obtained from Statistics Canada reports on the supply and disposition of various fuels in Canada (Statistics Canada 2012; Table C-1 in Appendix C). No data were found regarding the three CAS RNs assessed in this report, although Statistics Canada separates its data into Aviation Gasoline and Aviation Turbo Fuel. In 2011, the total production volume of aviation fuels (aviation gasoline fuels and aviation turbine fuels) was 3918 million litres. The majority (99%) of the refinery production was aviation turbine fuel. Aviation gasoline fuel is used in a much smaller quantity than turbine fuel and represents about 1% of the total of aviation fuels in Canada. A similar use ratio is found in the United States, where the use of aviation gasoline fuel has been on the decline since 1983 (EIA 2010). In 2011, aviation gasoline fuel was not imported into Canada, but 8.4 million litres were exported. By comparison, 2218 million litres of aviation turbine fuel were imported and approximately 308 million litres were exported (Table C-1 in Appendix C).

5. Uses

These three substances either enter commerce as aviation fuels or are blending components used within refineries to produce products under different CAS RNs (Environment Canada 2008). Disposition data on aviation gasoline and aviation turbine fuels in 2008 are presented in Table C-2 in Appendix C (Statistics Canada 2009).

Aviation turbine fuel (CAS RN 64741-86-2) is used in turbine-driven engines and primarily handled at airports or on Armed Forces bases, following transport from refineries (Table C-2 in Appendix C). Canadian refineries reported selling this CAS RN as jet fuel (Environment Canada 2008). Other users include public administration (e.g., law enforcement and the Coast Guard), as well as other institutional uses including small private jet aircraft.

Aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) are used in piston-driven engines, with the majority of use by Canadian airlines and commercial/other institutions (Table C-2 in Appendix C). Canadian airlines using aviation gasoline fuels include northern/Arctic mixed passenger/cargo operations, smaller local air taxi operations and the public service (e.g., law enforcement). Private users can include flying clubs (private pilots), executive aviation and small charter operators (Tharby 2010).

6. Releases to the Environment

Aviation fuels may be released into the environment from activities associated with production, transportation and storage, as well as during refuelling and the operation of aviation turbine or piston engines.

Aviation fuels originate from distillation columns as a distillate in a refinery. Thus, the potential locations for the controlled release of aviation fuel include relief valves and venting valves or drain valves on piping or equipment (e.g., vessels) in the vicinities surrounding this equipment. Under typical operating conditions, releases of aviation fuel would be captured in a closed system, according to defined procedures, and returned to the processing facility or to the wastewater treatment plant. In both cases, exposure of the general population or the environment is not expected.

Unintentional releases (spills and leaks) of aviation fuels may occur at production facilities. Legislation affects releases of aviation fuels and includes requirements at the provincial/territorial level to prevent or manage the unintentional releases of petroleum substances and streams within a facility through the use of operating permits (SENES 2009). Such control measures include appropriate material selection during the design and set-up processes; regular inspection and maintenance of storage tanks, pipelines and other process equipment; the implementation of leak detection and repair or other equivalent programs; the use of floating roofs in above-ground storage tanks to reduce the internal gaseous zone; and the minimal use of underground tanks, which can lead to undetected leaks or spills (SENES 2009).

At the federal level, unintentional releases of some petroleum substances to water from facilities are addressed by the *Petroleum Refinery Liquid Effluent Regulations* and guidelines under the *Fisheries Act* (Canada 2010). Additionally, existing occupational health and safety legislation specifies measures to reduce occupational exposures of employees, and some of these measures also serve to reduce unintentional releases (CanLII 2001). Non-regulatory measures (e.g., guidelines, best practices) are also in place at petroleum sector facilities to reduce unintentional releases. Aviation fuel evaporative emissions are not anticipated to comprise a large proportion of overall site emissions at production facilities. Thus, on-site releases are not expected to be a significant source of exposure.

Aviation fuels may be stored in bulk prior to transport to export wharves or the marketplace. Potential exposure to evaporative releases from aviation fuels in bulk storage is considered in the human health portion of this assessment.

Aviation fuels are transported from refineries to sectors identified in Table C-2 (Appendix C). Aviation turbine fuel can be transported by ship, rail, transport trucks and pipeline, whereas aviation gasoline fuels are transported only by rail and transport trucks (Tharby 2010). In general, three operating procedures are involved in the process of transportation: loading, transit and unloading. Loading and unloading of aviation fuels is normally conducted at sites with limited access to the general public, such as bulk terminals and wharves.

The handling of aviation fuels at petroleum facilities for the purpose of transportation is regulated at both the federal and provincial levels, with legislation covering loading and unloading (SENES 2009). Collectively, this legislation establishes requirements for the safe handling of petroleum substances, and is intended to minimize or prevent potential releases during loading, transportation and unloading operations (SENES 2009).

Releases from washing or cleaning transportation vessels are not considered in this screening assessment, as tanks or containers for transferring petroleum substances are typically dedicated vessels and therefore washing or cleaning is not required on a routine basis (U.S. EPA 2008a). Cleaning facilities require processing of grey water to meet local and provincial release standards.

6.1 Release Estimation

Environment Canada's NEMISIS database (Environment Canada 2011) was used to evaluate the overall frequency and volume of releases of aviation fuels. NEMISIS provides national data on releases of substances involving or affecting a federal agency or department, a federal government facility or undertaking, or Aboriginal land; or releases that contravene CEPA 1999 or the *Fisheries Act*; releases that affect fish, migratory birds or species at risk or that impact an interprovincial or international boundary; and releases from marine vessels. Other spills may be reported to NEMISIS, but there is no legal requirement to do so. In addition, spills data provided to NEMISIS may vary depending on the provincial reporting requirements, such as spill quantity reporting thresholds.

Spills due to aircraft crash, collision, ice/frost, road conditions, subsidence or vandalism were not considered in the analysis. The remaining spills data documented 825 spills of aviation fuel between 2000 and 2009 (Table C-3 in Appendix C; Environment Canada 2011). Although approximately 1.57 million litres of aviation fuel were reported as spilled (Table C-3 in Appendix C), approximately 8% of the spills had no estimate of the volume released into the environment. To account for reported releases with no associated volumes, the reported volume released was extrapolated to estimate the total volume released, assuming that the statistical distribution of reported volumes released was representative of all releases. This estimation places the volume of aviation fuel reported to be spilled at ~1.69 million litres over ten years (Table C-3 in Appendix C). The average reported spill volume was approximately 2060 L. The provinces with the greatest volume of aviation fuel spilled were Quebec, Newfoundland and Labrador, and Ontario; however, some provinces did not participate in national data collection until 2005, so there are likely gaps in the data (Table C-4 in Appendix C) such that the total reported spilled volume is expected to be a low estimate.

Because the data from the NEMISIS database were generically classified as aviation fuel, the spill volumes were proportionally adjusted into estimated aviation gasoline fuel and aviation turbine fuel spill volumes. According to refinery production statistics in 2011 (Statistics Canada 2012; Table C-1 in Appendix C), 99% of the volume of aviation fuel produced was aviation turbine fuel, while 1% was aviation gasoline fuel. The estimated release volumes and number of spills following this proportional adjustment are shown in Table 6-1.

Table 6-1. Estimated total release volumes and number of reported spills of aviation gasoline and aviation turbine fuels based on total reported release volume from the NEMISIS database from 2000–2009 in Canada (Environment Canada 2011)[a,b]

Aviation turbine fuel

Compartment affected	Total spill volume (L)	Number of reported spills
Land	956 904	443
Freshwater	150 539	34
Marine	60 073	65

Aviation gasoline fuel

Compartment affected	Total spill volume (L)	Number of reported spills
Land	9666	4
Freshwater	1521	< 1
Marine	607	1

[a] Does not include releases due to aircraft crash, collision, ice/frost, road conditions, subsidence or vandalism.
[b] Data have been proportionally adjusted based on 2011 refinery production statistics (Statistics Canada 2012); 99% of refinery production is aviation turbine fuel and 1% of refinery production is aviation gasoline fuel.

Various environmental compartments were reported as receiving media for spills of aviation fuel (Table C-5 in Appendix C; Environment Canada 2011). The majority of spills affected land (68.8%), followed by air (15.8%), saltwater (10.2%) and freshwater (5.2%). On average, there were an estimated 45 aviation fuel spills to land, 7 spills to marine water and 3 spills to freshwater per year.

Although the total annual volume of releases is high, the statistics reflect a pattern of repeated, small quantities of aviation fuel released into the environment, with occasional large spills, especially from trains and storage facilities (Table C-3 in Appendix C). The NEMISIS database provides data on the sources, causes and reasons for many of the releases of aviation fuels (tables C-6a, C-6b and C-6c in Appendix C).

Further refinement of the analysis of frequency and volume related to the ecological significance of spills to soil is outlined in the section on Ecological Exposure Assessment.

7. Environmental Fate

When petroleum substances are released into the environment, four major fate processes will take place: dissolution in water, volatilization, biodegradation and adsorption. These processes will cause changes in the composition of these UVCB substances. In the case of spills on land or water surfaces, photodegradation—another fate process—can also be significant.

As noted previously, the solubility and vapour pressure of components within a mixture will differ from those of the component alone. These interactions are complex for complex UVCBs such as petroleum hydrocarbons.

Each of the fate processes affects hydrocarbon families differently. Aromatics tend to be more water-soluble than aliphatics of the same carbon number, whereas aliphatics tend to be more volatile (Potter and Simmons 1998). Thus, when a petroleum mixture is released into the environment, the principal water contaminants are likely to be aromatics, whereas aliphatics will be the principal air contaminants (Potter and Simmons 1998). The trend in volatility by component class is as follows: alkenes = alkanes > aromatics = cycloalkanes. The most soluble and volatile components have the lowest molecular weight; thus there is a general shift to higher molecular weight components in residual materials.

Biodegradation is almost always operative when petroleum mixtures are released into the environment. It has been widely demonstrated that nearly all soils and sediments have populations of bacteria and other organisms capable of degrading petroleum hydrocarbons (Pancirov and Brown 1975). Degradation occurs both in the presence and absence of oxygen. Two key factors that determine degradation rates are oxygen supply and molecular structure. In general, degradation is more rapid under aerobic conditions. Decreasing trends in degradation rates according to structure are as follows (Potter and Simmons 1998):

(1) *n*-alkanes, especially in the C_{10}–C_{25} range, which are degraded readily;
(2) isoalkanes;
(3) alkenes;
(4) benzene, toluene, ethylbenzene, xylenes (BTEX) (when present in concentrations that are not toxic to microorganisms);
(5) monoaromatics;
(6) polynuclear (polycyclic) aromatic hydrocarbons (PAHs); and
(7) higher molecular weight cycloalkanes (which may degrade very slowly (Pancirov and Brown 1975)).

Three weathering processes—dissolution in water, volatilization and biodegradation—typically result in the depletion of the more readily soluble, volatile and degradable compounds and the accumulation of those most resistant to these processes in residues.

Due to the complex interaction of components within a mixture that impact their physical-chemical properties and behaviour, it is difficult to predict the fate of a complex mixture. Therefore, as a general indication of the fate of aviation fuels, the physical-chemical properties of representative structures of aviation fuels (Table B-1 in Appendix B) were examined.

Based on the physical-chemical properties of representative structures of aviation fuels, the majority of components are expected to partition to air.

The C_6–C_{15} components have boiling points ranging from 60 to 338°C. The individual components of aviation fuels are characterized by low to high water solubilities (< 0.001 to 1790 mg/L), low to high vapour pressures (0.007 to 1.3×10^4 Pa), low to high Henry's Law constants (2.8 to 4.6×10^6 Pa·m^3/mol), low to moderate log K_{ow} values (2.1 to 7.7) and low to moderate log K_{oc} values (1.8 to 7.7) (Table B-1 in Appendix B).

The majority of lighter components (C_6–C_9) are highly volatile, with vapour pressures ranging from 320 to 2.8×10^4 Pa, and are likely to remain in air. The larger (> C_{12}) alkanes, cycloalkanes, and one- and two-ring alkylated aromatics are low to moderately volatile, with vapour pressures ranging from 0.009 to 165 Pa, and are expected to partition out of air. Due to these generally high vapour pressures, if released to air, aviation gasoline and most components of aviation turbine fuel are expected to remain in the air.

Aviation fuels are less dense than water (0.75–0.85 g/mL; CONCAWE 1995), so that upon entering water they will rise to the surface and spread out. Due to their high vapour pressures and Henry's Law constants, most components will likely volatilize despite some components having appreciable water solubilities or log K_{oc}. For instance, the *n*-alkanes will likely partition mainly to air rather than to sediment, despite their high log K_{oc}, though there is potential to sorb to sediments if they come into contact with sediment or particulate matter. In addition, the isoalkanes, one-ring and two-ring cycloalkanes, one-ring and two-ring aromatics, cycloalkane monoaromatics and cycloalkane diaromatics will mainly partition to air, though there is potential for partitioning to water based on their water solubilities. The aromatic structures, with their lower vapour pressures and higher water solubilities, will likely remain in water. The C_{12} isoalkanes and polycycloalkanes, in addition to the heavier structures (> C_{15}), will partition to sediment if released to water. Therefore, when released to water, aviation gasoline and the lighter (< C_{12}) components of aviation turbine fuels are expected to partition mainly to air, with some partitioning of some components to water and sediments. Heavier (> C_{12}) components of aviation turbine fuels will mainly partition to sediments.

If released solely to soil, many of the heavier components are expected to remain in the soil, with the alkanes, isoalkanes, one-ring cycloalkanes and other, lighter components (< C_{10}) partitioning to air based on their high Henry's Law constants.

Empirical data on the degradation (fate) of gasoline are available and can be used as read-across for aviation gasoline. Solano-Serena et al. (1999) reported that in liquid cultures using microflorae from urban-wastewater-activated sludge, 74% of gasoline degrades within 40 hours, and 94% degrades within 25 days. Gasoline also degrades at different rates in different soils, with an ultimate degradation rate ranging from 89% in spruce forest soil to 96% in activated sludge within 28 days (Marchal et al. 2003).

For the aviation turbine fuel (CAS RN 64741-86-2), a read-across approach to diesel fuel was used, due to similar boiling point and carbon range. Experimental biodegradation values for several streams used in the production of diesel fuels were considered (Penet et al. 2004) (Table D-2 in Appendix D). These data indicate that diesel fuel, and thus aviation turbine fuel, is quickly degraded when released to the environment.

When large quantities of a hydrocarbon mixture enter the soil compartment, soil organic matter and other sorption sites in soil are fully saturated and the hydrocarbons will begin to form a separate phase (a non-aqueous phase liquid, or NAPL) in the soil. At concentrations below the retention capacity for the hydrocarbon in the soil, the NAPL will be immobile (Arthurs et al. 1995); this is referred to as residual NAPL (Brost and DeVaull 2000). Above the retention capacity, the NAPL becomes mobile and will move within the soil (Arthurs et al. 1995; Brost and DeVaull 2000).

8. Persistence and Bioaccumulation Potential

Due to the complex nature of petroleum substances such as aviation fuels, the persistence and bioaccumulation potential of components of these substances were characterized based on empirical and/or modelled data for a suite of petroleum hydrocarbon structures.

8.1 Environmental Persistence

Persistence was characterized based on empirical and/or modelled data for a suite of petroleum hydrocarbons expected to occur in petroleum substances.

Model results and the weighing of information are reported in the petroleum substances persistence and bioaccumulation supporting documentation (Environment Canada 2014). These data are summarized in Table D-3 (Appendix D).

For the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5), a read-across approach with gasoline was used, due to similar carbon and boiling point ranges. Experimental aerobic half-lives of some hydrocarbons present in formulated gasoline in water are presented in Table D-1 (Appendix D). All median and mean half-lives were < 182 days in water (Prince et al. 2007a). Prince et al. (2007a) also reported a median half-life of 5 days for components of gasoline in saltwater, pond water and sewage water, without accounting for volatilization. As well, all detectable components of gasoline had degraded within 57 days, although different components of gasoline degraded at different rates (Prince et al. 2007a). The hydrocarbon components of gasoline were also considered to be intrinsically biodegradable (CONCAWE 2001).

Empirical and modelled half-lives in the atmosphere for many components of aviation fuels are less than 2 days (Environment Canada 2014). However, some components, such as C_4–C_6 *n*-alkanes and isoalkanes and C_6–C_8 monoaromatics, can have half-lives greater than 2 days, and thus may travel considerable distances from the source. In addition, some three-ring PAHs can undergo long-range transport to remote regions due to sorption to particulate matter (Environment Canada 2014).

Considering biodegradation in water, soil and sediment, the following components are expected to have half-lives greater than 6 months in water and soils and ≥ 365 days in sediments: C_{15}–C_{20} two-ring cycloalkanes, C_{18} polycycloalkanes, C_{12} one-ring aromatics, C_9-C_{20} cycloalkane monoaromatics, C_{10}-C_{20} two-ring aromatics, C_{12} cycloalkane diaromatics, and C_{14} three-ring PAHs. The C_5 alkenes, ≥ C_9 dicycloalkanes, C_{14} polycycloalkanes, and generally the ≥ C_9 one-ring aromatics, also have half-lives greater than a year in sediments.

8.2 Potential for Bioaccumulation

Bioaccumulation potential was characterized based on empirical and/or modelled data for a suite of petroleum hydrocarbons expected to occur in petroleum substances. Bioaccumulation factors (BAFs) are the preferred metric for assessing the bioaccumulation potential of substances, as the bioconcentration factor (BCF) may not adequately account for the bioaccumulation potential of substances via the diet, which predominates for substances with log K_{ow} > ~4.5 (Arnot and Gobas 2003).

In addition to fish BCF and BAF data, bioaccumulation data for aquatic invertebrate species were also considered. Biota-sediment/soil accumulation factors (BSAFs), trophic magnification factors and biomagnification factors were also considered in characterizing bioaccumulation potential.

Empirical and modelled bioaccumulation data for petroleum hydrocarbons, as well as the weighing of information, can be found in the supporting document for this assessment (Environment Canada 2014). A summary of the results for bioaccumulation potential is presented below and in Table D-4 in Appendix D.

Overall, there is consistent empirical and predicted evidence to suggest that the following components have the potential for high bioaccumulation, with BAF/BCF values greater than 5000: C_{13}–C_{15} isoalkanes, C_{12} alkenes, C_{12}–C_{15} one-ring cycloalkanes, C_{12} and C_{15} two-ring cycloalkanes, C_{14} polycycloalkanes, C_{15} one-ring aromatics, C_{15} and C_{20} cycloalkane monoaromatics, C_{12}–C_{13} diaromatics, C_{20} cycloalkane diaromatics, and C_{14} and C_{20} three-ring PAHs (Table D-4, Appendix D). These components are associated with a slow rate of metabolism and are highly lipophilic. Exposures from water and diet, when combined, suggest that the rate of uptake would exceed that of the total elimination rate. Most of these components are not expected to biomagnify in aquatic or terrestrial foodwebs, largely because a combination of metabolism, low dietary assimilation efficiency and growth dilution allows the elimination rate to exceed the uptake rate from the diet (Environment Canada 2014); however, one study (Harris et al. 2011) suggests that some alkyl-PAHs may biomagnify. While only BSAFs were found for some PAHs, it is possible that BSAFs will be > 1 for invertebrates, given that they do not have the same metabolic competency as fish. Of the bioaccumulative components, only the C_{12} alkenes and the C_{12} one- and two-ring cycloalkanes might be present in the assessed aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5), as it is the only component that fits within the boiling point range of these substances. The aviation turbine fuel (CAS RN 64741-86-2) may contain all of the components.

9. Potential to Cause Ecological Harm

9.1 Ecological Effects Assessment

Environment Canada's NEMISIS database from 2001 and 2009 has recorded several aviation fuel spills to soil, freshwater and saltwater that affected migratory birds or caused other environmental damage (Environment Canada 2011). The frequency of reported incidents is low, with an average of approximately 9 incidents per year (ranging between 1 and 26 per year).

9.1.1 Aquatic compartment (fish, invertebrates, alga, phytoplankton)

Experimental aquatic toxicity data on various aviation turbine and aviation gasoline fuels are detailed in Tables E-5a and b (Appendix E).

For the water-soluble fractions (WSF) of aviation gasoline fuel, the freshwater 48-hour median lethal concentrations (LC_{50}) ranged from 15 to 28 mg/L for *Daphnia magna* (Harris 1994; Table E-1a in Appendix E). The design of this study is acceptable; however, the analytical method used (purge and trap with gas chromatography) did not measure total petroleum hydrocarbons but rather only the very volatile components (e.g., monoaromatics). Therefore, this toxicity value is considered to be conservative. As no saltwater toxicity data were available for aviation gasoline fuels, a read-across approach was used and compared against gasoline.

Empirical aquatic toxicity values for gasoline are presented in Table E-2a (Appendix E). Gasoline exhibits a moderate toxicity to aquatic organisms, with a large range of toxic concentrations. Aquatic 24-hour LC_{50} values for various types of gasoline ranged from 18 to 47 mg/L; 48-hour LC_{50} values ranged from 5 to 51 mg/L; and 96-hour LC_{50} values ranged from 0.1 to 182 mg/L. In saltwater, 96-hour LC_{50} values for gasoline ranged from 0.1 to 171 mg/L. The tropical mysid *Metamsidopsis insularis* was very sensitive, with a 96-hour LC_{50} of 0.1 mg/L; however, nominal concentrations were used and the results are not considered acceptable. The mysid shrimp *Mysidopsis bahia* is especially sensitive, with a 96-hour LC_{50} of 1.8 mg/L using the API PS-6 standard gasoline. A lower value of 0.3 was obtained with a “synthetic gasoline”. However, as no data on the composition of this fuel were available, the toxicity value was not used. The copepod *Tiriopus californicus* exhibited a low 24-hour LC_{85} value of 1 mg/L, but the test was not conducted in a robust, scientifically acceptable manner (CONCAWE 1992).

Aquatic toxicity (LC_{50}) values ranged from 5.5 to 26 mg/L for various aviation turbine fuels (Table E-1b in Appendix E). The lowest value of 5.5 mg/L was a 96-hour LC_{50} using a water-soluble fraction of JP-8 with *Pimephales promelas* (fathead minnow) (Fisher et al. 1985). This study, however, had significant loss of test substance over the test duration (70–80% loss over 48 hours), and therefore the results were not considered acceptable. Harris (1994) reported a 48-hour LC_{50} of 6 mg/L for *Daphnia magna* using a water-soluble fraction of Jet A. As noted previously, toxicity values from this study are considered conservative due to the analytical method used.

There were no experimental data found on aviation turbine fuels in saltwater; therefore, a read-across approach was used with diesel fuel. Empirical aquatic toxicity values for diesel fuel are presented in Table E-2b (Appendix E). The values varied greatly for aquatic species such as rainbow trout and *Daphnia magna*, demonstrating the inherent variability of diesel fuel compositions and its effects on toxicity. Most experimental acute toxicity values are above 1 mg/L. The lowest 48-hour LC_{50} for salmonids was 2.4 mg/L (CONCAWE 1996). *Daphnia magna* had a 24-hour LC_{50} of 1.8 mg/L (Khan et al. 2007).

The tropical mysid *Metamysidopsis insularis* was shown to be very sensitive to diesel fuel, with a 96-hour LC_{50} value of 0.22 mg/L (Mohammed 2005); this species has been shown to be as sensitive as temperate mysids to toxicants (Garcia et al. 2008). However, Mohammed (2005) used nominal concentrations, and therefore this study was not considered acceptable. Franklin and Lloyd (1982) tested a diesel fuel with brown or common shrimp (*Crangon crangon*) and determined a 96-hour LC_{50} of 22 mg/L. They also tested a "gas oil" and determined a 96-hour LC_{50} of 12 mg/L.

The steady state cell density of marine phytoplankton decreased with increasing concentrations of diesel fuel, with different sensitivities between species (Hing et al. 2011). The diatom *Phaeodactylum tricornutum* showed a 20% decrease in cell density in 24 hours following a 3 mg/L exposure with a 24-hour no-observed-effect concentration (NOEC) of 2.5 mg/L. The microalga *Isochrysis galbana* was more tolerant to diesel fuel, with a 24-hour lowest-observed-effect concentration (LOEC) of 26 mg/L (14% decrease in cell density), and a NOEC of 25 mg/L. Finally, the green algae *Chlorella salina* was relatively insensitive to diesel fuel contamination, with a 24-hour LOEC of 170 mg/L (27% decrease in cell density), and a NOEC of 160 mg/L (Hing et al. 2011). All populations of phytoplankton returned to a steady state within 5 days of exposure.

CONCAWE developed an aquatic toxicity model specifically for petroleum hydrocarbon mixtures, called PETROTOX (2009). This model assumes chemical action via narcosis, and therefore accounts for additive effects according to the toxic unit approach. It can model petroleum hydrocarbon toxicity for C_4–C_{41} compounds dissolved in the water fraction.[3] Substances smaller than C_4 are considered too volatile to impart any significant toxicity, while those larger than C_{41} are considered to be too hydrophobic and immobile to impart any significant acute aquatic toxicity. PETROTOX (2009) generates estimates of toxicity with a median lethal loading (LL_{50}) concentration rather than an LC_{50}, due to the insolubility of petroleum products in water. The LL_{50} value is the amount of petroleum product (in mg/L) needed to generate a water-accommodated fraction (WAF) that is lethally toxic to 50% of the test organisms. It is not a measure of the concentration of the petroleum components in the WAF.

A range of modelled aquatic toxicity values were obtained using PETROTOX (2009), and results are shown in Table E-3 (Appendix E). For the two aviation gasoline fuels, the modelled LL_{50}s ranged from 0.4 to 19.1 mg/L (Table E-3 in Appendix E). The modelled data for *Daphnia magna* are lower than the empirical data for these fuels (Table E-1a in Appendix E). The range of values is also lower than the empirical toxicity tests for various types of gasoline (Table E-2a in Appendix E). For the aviation turbine fuel, the modelled LL_{50}s ranged from 0.07

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[3] PETROTOX uses its own library of petroleum hydrocarbons and their associated physical-chemical properties. These properties may differ from those given for the same representative structures in Table B-1 in Appendix B.

to 45 mg/L. Again, the modelled toxicity is lower than what was observed in empirical tests with diesel fuel; however, the model covers the range of values determined in empirical tests. PETROTOX (2009) does predict toxicities in the range to be expected from bioassay tests.

The freshwater critical toxicity value (CTV) used for aviation gasoline fuel was the lowest available experimental value for aviation gasoline, which was the 48-hour LC_{50} of 15 mg/L for *Daphnia magna.* While marine toxicity values were reported by CONCAWE (1992) for gasoline, the studies were not available and could not be evaluated for their reliability or acceptability. Therefore, the modelled LL_{50} of 0.4 mg/L for *Rhepoxynius abronius* (Table E-3 in Appendix E) was used as the marine CTV for aviation gasoline fuel.

The freshwater CTV for aviation turbine fuel was the lowest experimental value, which was the 96-hour LC_{50} of 6 mg/L for a water-soluble fraction of Jet A with *Daphnia magna* (Harris 1994). For marine scenarios, the CTV was the 24-hour NOEC of 2.5 mg/L to the marine diatom *Phaeodactylum tricornutum* (Hing et al. 2011); this study was considered acceptable.

9.1.2 Terrestrial compartment

Overall, aviation fuels have low acute oral (median lethal dose [LD_{50}] > 5000 mg/kg-bw) and inhalation toxicity (LC_{50} > 5000 mg/m^3) for exposure to mammals (API 1980a, 1985a as cited in API 2003a; API 1986a as cited in CONCAWE 1992 and API 2008; ATDAEI 1990 as cited in RTECS 2009). Kerosene and Jet-A did not elicit developmental toxicity in inhalation studies conducted in rats (API 1979a, 1979b as cited in API 2003a; IARC 1989a); however, in a study conducted with JP-8 in mice, a lowest-observed-adverse-effect concentration (LOAEC) of 1000 mg/m^3 was established for maternal, reproductive and developmental toxicity (Harris et al. 2007a).

9.1.2.1 Aviation gasoline fuels

For the aviation gasoline fuels assessed in this report (CAS RNs 64741-87-3 and 68527-27-5), automotive gasoline is a reasonable read-across based on similarities in carbon and boiling point range.

The terrestrial toxicity of gasoline is primarily expected to affect soil invertebrates and plants due to the likelihood of gasoline present in soil to remain in soil. ESG International (2000) investigated the effects of additive-free gasoline in soil on earthworms and springtails in both open- and closed-air systems, and on four plant species in closed-air systems. Due to the highly volatile nature of gasoline, preparation of the soil led to initial exposure concentrations between 8 and 30% of the nominal concentrations, and thus all concentrations of gasoline in soil within this study reflect the original (nominal) concentration initially added and not the measured concentration.

Gasoline appears to be moderately toxic to earthworms (*Eisenia fetida*) in native sandy-loam soil with a 7-day LC_{50} of 630 mg/kg dry weight (d.w.) nominal in closed systems, and 710 mg/kg d.w. nominal when exposed to air. The 14-day LC_{50} was lower, with a toxicity of 400 mg/kg in closed systems. There were no apparent effects on adult earthworm survival or the number of juveniles produced in chronic earthworm tests until the exposure reached or exceeded 1000 mg/kg in both artificial and native soils.

Plants, including alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), corn (*Zea mays*) and red fescue (*Festuca rubra*), exhibited mild acute effects when exposed to gasoline, although inhibition of growth often occurred at lower concentrations in native soils relative to artificial soil. Root length was compared with dry mass or shoot length (ESG International 2000). Corn was the most sensitive species, with a root-length 7-day IC_{20} (20% inhibitory concentration) of 1000 mg/kg d.w. nominal when exposed to soil open to air. Under open conditions, 7-day IC_{20} toxicity values ranged from 2310 to 4430 mg/kg d.w. nominal in barley for inhibition of both root and shoot growth, respectively

9.1.2.2 Aviation turbine fuel

For the aviation turbine fuel assessed in this report (CAS RN 64741-86-2), diesel fuel is a reasonable read-across based on a similar carbon range and boiling point range.

In sandy soils, earthworm (*Eisenia fetida*) mortality only occurred at diesel fuel concentrations greater than 10 000 mg/kg, which was also the concentration at which sub-lethal weight loss was recorded (Shin et al. 2005).

Nephrotoxic effects of diesel fuel have been documented in several animal and human studies (Riedenberg et al. 1964; Hartung and Hunt 1966; Barrientos et al. 1977; Crisp et al. 1979; Dede and Kagbo 2001: EHC Monographs 1996). Some species of birds (mallard ducks in particular) are generally resistant to the toxic effects of petrochemical ingestion, and large amounts of petrochemicals are needed in order to cause direct mortality (Stubblefield et al. 1995; Hartung 1995; Coon and Dieter 1981; Fleming et al. 1982).

To determine the effect of aviation kerosene (similar to aviation turbine fuel) on the hatching success of mallard eggs (*Anas platyrhynchos)*, Albers and Gay (1982) applied either 1, 5 or 20 µL of unweathered or weathered aviation kerosene to the surface of eggs and observed the resulting hatching success. They found no statistically significant difference between egg hatching success in the control group and the groups treated with unweathered or weathered aviation kerosene. Likewise, hatching success was not found to be dose-dependent (Albers and Gay 1982).

Hoffman and Albers (1984) applied aviation kerosene externally to mallard eggs during the first week of development. The LD_{50} was determined to be greater than 50 µL/egg. After 18 days, there was no evidence of reduced growth, abnormal survivors or malformations in survivors (Hoffman and Albers 1984).

9.1.3 Critical toxicity value (CTV) selection

The *Canada-Wide Standards for Petroleum Hydrocarbons in Soil* (CCME 2008) were used as a data source for the quantification of effects of aviation fuels on terrestrial ecosystems. This system is based on four fractions of total petroleum hydrocarbons (TPH): F1 (C_6–C_{10}), F2 (> C_{10}–C_{16}), F3 (> C_{16}–C_{34}), F4 (> C_{34}), and assumes an 80:20 ratio of aliphatics to aromatics. This system uses four land-use classes (agricultural, residential, commercial and industrial) and two soil types (coarse grained and fine grained) for the determination of remedial standards. The most sensitive land-use and soil type is typically agricultural coarse-grained soils.

Fractions 1 and 2 (F1 and F2) are most like the aviation gasoline fuels assessed in this report. Table E-4 (Appendix E) shows that for F1 and F2, the standard for soil contact by non-human organisms is 150–210 mg/kg d.w. (CCME 2008). As aviation gasoline fuel could fall into both of these categories, the lower value, 150 mg/kg d.w. of soil, is used as the terrestrial exposure CTV for aviation gasoline fuel.

Fractions 1, 2 and 3 (F1, F2 and F3) are most like the aviation turbine fuel. Table E-4 (Appendix E) shows that for F1, F2 and F3, the standard for soil contact by non-human organisms is 150–300 mg/kg d.w. (CCME 2008). As aviation turbine fuel could fall into all three categories, the lower value, 150 mg/kg d.w. of soil, is used as the terrestrial exposure CTV for aviation turbine fuel.

9.2 Ecological Exposure Assessment

To develop the exposure scenarios, estimations of releases of aviation fuel were made using data from Transport Canada estimations of petrochemical losses to the sea on Canada’s east coast (RMRI 2007), and from Environment Canada’s NEMISIS database (Environment Canada 2011). Release scenarios were developed for loading/transport/unloading operations via ship and transport across terrestrial environments (including truck, train and pipeline transport).

9.2.1 Aquatic compartment

To determine the predicted environmental concentration (PEC), the volume of water predicted to be in contact with spilled oil was provided by a study conducted by the Risk Management Research Institute (RMRI 2007). The area of a slick created within hazard zones around Newfoundland was estimated for specific volume ranges of oil using ocean spill dispersion models, and then the volume of contacted water was estimated by multiplying the area by 10 to represent the top 10 m of water.

For the ship loading scenario, the volume of water in contact with the petroleum product from Hazard Zone 1 was used (RMRI 2007), as this region included loading operations at Whiffen Head and Come By Chance oil refinery. For the ship transport scenarios, the estimated volume of water in contact with aviation fuel was the volume of water averaged over hazard zones 2 to 5 (the average volume of water for summer and winter for Hazard Zone 2 was used in this calculation), as this area is a major ship transportation corridor. The RMRI report was originally prepared based on spills of crude oil, but it can be applied to aviation fuels. The estimations of concentrations in water will be conservative with aviation fuels, as they are considerably less dense and have a higher proportion of volatile components than crude oil. Thus, they tend to disperse more rapidly into air and water than does crude oil.

As aviation gasoline fuels are not transported by ship, this scenario is developed for aviation turbine fuel only, The average aviation turbine fuel spill (2000–2009) in marine waters was approximately 1700 L in a single spill. This is equivalent to 10.7 barrels, and is therefore expected to be in contact with 40×10^9 L of water during loading and unloading (Table E-5 in Appendix E). Aviation turbine fuel has an average density of 0.81 kg/L (CONCAWE 1995), and therefore an average spill is approximately 910 kg, with a resulting concentration of aviation turbine fuel in water of 0.023 mg/L (9.10×10^8 mg / 40×10^9 L), which is considered the PEC for ship loading/unloading in marine waters.

In the case of marine transport of aviation turbine fuels by ship, an average spill of 910 kg of aviation turbine fuel is expected to be in contact with 5.3×10^{12} L of water (Table E-5 in Appendix E). The resulting concentration in water would be 0.00017 mg/L (9.10×10^8 mg / 5.3×10^{12} L), which is considered to be the PEC for ship transport in marine waters.

The potential exposure for freshwater scenarios was calculated using the same approach as the marine exposure, but took into consideration unloading a ship at a dock in the Great Lakes.

The average aviation turbine fuel spill (2000–2009) into freshwater was approximately 5850 L (~4740 kg). This is equivalent to 36.8 barrels, and is therefore expected to be in contact with 40×10^9 L of water during loading and unloading (Table E-5 in Appendix E). Based on the average density of aviation turbine fuel, the resulting PEC for aviation fuel in freshwater loading and unloading would be 0.12 mg/L (4.74×10^9 mg / 40×10^9 L).

In the case of freshwater transport, an average spill of 4740 kg is expected to be in contact with 5.3×10^{12} L of water (Table E-5 in Appendix E). The resulting concentration in water would be 0.00089 mg/L (4.74×10^{9} mg / 5.3×10^{12} L), which is considered to be the PEC for freshwater ship transport.

9.2.2 Terrestrial compartment

There were approximately 450 releases of aviation fuel (aviation gasoline fuels and aviation turbine fuel—excluding spills due to aircraft crash, collisions, ice/frost, road conditions, subsidence and vandalism) to land from 2000 to 2009 based on data from the Environment Canada NEMISIS database (Environment Canada 2011). The average spill volume from these releases was approximately 2320 L. Aviation fuels are a specialty petroleum product with use limited mainly to airports; thus, spills of these fuels to land mainly occur at large-scale petroleum handling facilities (including storage facilities), at airports, or during fuel transport.

Spills to soil within the boundaries of industrial facilities (e.g, refineries, bulk storage terminals) or commercial airports are not considered within this assessment, as it is expected that spills at these sites undergo immediate remediation that minimizes their entry into the environment. Therefore, all releases clearly identified as occurring at airports were excluded from the terrestrial exposure scenario. It is additionally assumed that all releases with the source identified in the Environment Canada NEMISIS database as “industrial plant” or “refinery” occurred at an industrial facility and are thus excluded. Releases to land from marine tankers are assumed to occur on portlands/industrial sites and are also excluded. Due to the specialty use of these aviation fuels, a number of other releases to land were assumed to occur at airports and were excluded. These included the following:

- releases with the source identified as “aircraft”;
- releases with the source identified as “service station”, the assumption being that all aviation fuel service stations will be located at an airport; and
- all releases with the source identified as “storage depot”, “other storage facility”, “other”, or “unknown” and that occurred in a city with an airport were assumed to have occurred at the local airport.

In addition, for any spill to a mode of motor-transport for which “overflow” was given as the cause, it was assumed that this overflow occurred at an industrial fuel terminal or airport during loading. As well, spills from motor-transport for which “overturn” was given as a cause were also excluded, as these were considered to be motor vehicle accidents.

When these exclusions are considered, there were approximately 84 releases of aviation fuel to land from 2000–2009 based on data from the Environment Canada NEMISIS database (Environment Canada 2011). It is acknowledged, however, that the majority of the releases involving motor transport likely occur during the loading, transport and unloading of aviation fuel at the airport. The number of such releases is unknown. If it is assumed that all releases associated with motor-transport that occur in a city with an airport occurred on airport property, the total number of releases of aviation fuel to land from 2000 to 2009 becomes 39. Therefore, the range of releases of aviation fuel to land between 2000 and 2009 is in the range of approximately 40 to 80; the actual number of releases is expected to be closer to the lower estimate.

An average release volume was determined for the approximately 40 to 80 spills. Releases that were only excluded in the above determination of total spill numbers due to their occurrence in a city with an airport or the spill location being clearly identified as occurring at an airport were included in the volume estimate. The magnitude of such releases is not dependent on their location and, therefore, inclusion of these volumes provides a better estimate of the average spill volume.[4] Based on this, the average release volume of aviation fuels to soil is approximately 4940 L.

Due to the paucity of data available on the concentration of aviation fuel in receiving soil following an average spill of aviation fuel, the terrestrial scenario involves a read-across from data on diesel fuel to estimate the level of contamination following a spill. Ganti and Frye (2008) provide data on the volume of diesel fuel spills from truck transport to soil, including volume spilled and TPH concentrations at the center of the spill.

In the first case study, Ganti and Frye (2008) reported a 379-L spill of diesel fuel from a truck that was involved in a highway accident, spilling the diesel fuel at the bottom of an embankment over approximately 30 m. At the center of the spill, approximately 2 inches below the soil surface, the TPH was at a concentration of 65 000 mg/kg. In the second case study, Ganti and Frye (2008) reported a second truck involved in a highway accident spilling approximately 284 L onto a gravel road and the adjacent embankment. The initial TPH concentration was 47 000 mg/kg at the center of the spill.

According to research by Brost and DeVaull (2000), fuel products in the density range of diesel fuel will saturate soil in the range of 7700–34 000 mg/kg, depending on the type of soil. Beyond this range, they will form a light non-aqueous phase liquid (LNAPL).

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[4] An average release volume was determined by excluding volumes from releases with a source identified as “aircraft”, “marine tanker”, “service station”, “other industrial plant” or “refinery”; or cause identified as “aircraft crash”, “collision” or “overturn”; or reason identified as “ice/frost”, “road conditions”, “subsidence” or “vandalism”. All releases with “overflow” as the cause and a motor-transport vehicle as the source were also excluded. These were considered not relevant to the exposure scenario. All other releases to land, regardless of whether they occurred at an airport or in the ambient environment, were included in the calculation, as they are relevant to the release scenario and the magnitude of the release is not dependent on the location of the spill.

An average aviation fuel spill to the terrestrial compartment is approximately 4940 L. Based on the above information, that volume of aviation fuel will form an LNAPL in soil. If the concentration in soil is a linear function of the volume spilled, 4940 L would produce a concentration of approximately 832 000 mg/kg in the center of the spill. However, it is likely that a higher-volume spill would spread over a greater soil volume due to the formation of an LNAPL. For this assessment, the PEC for the terrestrial compartment will be 34 000 mg/kg based on the upper concentration above which formation of a LNAPL is expected (Brost and DeVaull 2000).

9.3 Characterization of Ecological Risk

The approach taken in this ecological screening assessment was to examine available scientific information and develop conclusions based on a weight-of-evidence approach as required under section 76.1 of CEPA 1999. For each endpoint organism, an estimate of the potential to cause adverse effects and predicted no-effect concentration (PNEC) was determined. The PNEC is the CTV selected for the organism of interest divided by an appropriate assessment factor. Also, a PEC was determined for each aquatic exposure scenario. A risk quotient (RQ = PEC/PNEC) was calculated for each endpoint organism and is an important line of evidence in evaluating the potential risk to the environment.

For the aviation gasoline fuels, the only relevent release scenario identified was to land. For terrestrial scenarios, the Canada-wide standard (CWS) for eco-soil contact for Fraction 2 in coarse-grained soil, 150 mg/kg d.w. (CCME 2008), was used as the PNEC. The resultant RQ (PEC/PNEC) for releases to land is 227

For the aviation turbine fuel, the PNEC for freshwater scenarios was determined based on the CTV, which was the 96-hour LC_{50} of 5.5 mg/L JP-8 fuel for *Pimpephales promelas* (Table E-1b in Appendix E). An assessment factor of 10 was applied to the CTV to account for laboratory to field extrapolations and inter- and intra-species variability, resulting in a freshwater PNEC of 0.55 mg/L. For the marine scenarios, the PNEC was determined based on the 24-hour NOEC of 2.5 mg/L diesel fuel for the marine diatom *Phaeodactylum tricornutum* (Table E-3 in Appendix E). As this value was already a NOEC, no assessment factor was used, and therefore the PNEC was 2.5 mg/L. For terrestrial scenarios, the CWS for eco-soil contact for Fraction 2 in coarse-grained soil, 150 mg/kg d.w., was used as the PNEC. The resultant RQs (PEC/PNEC) for each exposure scenario are presented in Table 9-1.

Table 9-1. Risk quotients (RQs) calculated for aviation turbine fuel (CAS RN 64741-86-2)

Medium	Organism	PEC	CTV	Assessment factor	PNEC	RQ
Marine (loading/	*Phaeo-dactylum*	0.023 mg/L	2.5 mg/L	1	2.5 mg/L	0.01

unloading)	*tricornutum*					
Marine (transport)	*Phaeo-dactylum tricornutum*	0.00017 mg/L	2.5 mg/L	1	2.5 mg/L	< 0.0001
Fresh-water (loading/ unloading)	*Daphnia magna*	0.12 mg/L	6 mg/L	10	0.6 mg/L	0.2
Fresh-water (transport)	*Daphnia magna*	0.00089 mg/L	6 mg/L	10	0.6 mg/L	1.5×10^{-3}
Terrestrial	n/a	34 000 mg/kg	150 mg/kg	1	150 mg/kg[a]	227

[a] CCME Canada-wide standard for petroleum hydrocarbon Fraction 2 in coarse-grained agricultural soils.
n/a: not applicable

Based on calculations during the exposure assessment and the RQ analyses of the potential effects of estimated average releases of aviation fuel, neither freshwater nor marine exposure scenarios for aviation gasoline and aviation turbine fuels show a potential for ecological harm. However, the RQs of 227 for aviation gasoline fuels and aviation turbine fuel indicate that releases to soil may cause harm to terrestrial organisms.

For all aquatic spill scenarios, the spill volume required to obtain an RQ equal to 1 was determined (Table 9-2). The frequency of spills above that threshold was determined from the Environment Canada NEMISIS database (Environment Canada 2011). These spill volumes were calculated based on models developed by RMRI (2007) that relate the volume spilled and concentration of petroleum substance in the water. These models take into consideration dispersion of the petroleum substance spilled, and therefore the calculated spill volume relating to an RQ of 1 is not for the acute, initial exposure to the spilled material. It is recognized that local, acute effects may occur during the initial phase of a spill before significant dispersion occurs.

Table 9-2. Spill volumes of aviation turbine fuel required to create harmful conditions to aquatic organisms and the proportion of reported spills above this threshold volume

Compartment affected	Spill volume required to obtain RQ of 1 (threshold volume) (L)[a]	Proportion of reported spills above the threshold volume (%)[b]	Proportion of reported spills above the threshold volume (%)[b]
Marine	465 000	0	0

(loading/unloading)			
Marine (transport)	114 000 000	0	0
Freshwater (loading/unloading)	41 000	3	< 1
Freshwater (transport)	9 600 000	0	0

[a] The volume required to generate an RQ of 1 is based on the relationship between volume spilled and volume of water contacted as given in RMRI (2007).
[b] Over a ten-year reporting period (2000–2009) to the NEMISIS database.

For both the marine and freshwater scenarios for the transport of aviation turbine fuel, none of the reported spills from 2000 to 2009 in the NEMISIS database was greater than the threshold volume required to obtain an RQ of 1 (Table 9-2). For the freshwater scenario of ship loading and unloading of aviation turbine fuel substances, less than one reported spill is expected to exceed the threshold volume per year (3% of reported spills). For the marine scenario of ship loading and unloading, no releases reported to the NEMISIS database exceeded an RQ of 1 (Table 9-2).

While there is uncertainty, the overall weight of evidence suggests that there is a low risk of harm to aquatic organisms (fish, invertebrates, algae, phytoplankton) from releases of aviation gasoline and turbine fuels given the frequency and volume of spills of these substances to marine and freshwater aquatic habitats.

RQs for soils were derived using a PEC based on a concentration at which an LNAPL forms. RQs at environmental concentrations above those required for LNAPL formation have less meaning, as the soil is saturated and there is no longer a linear relationship between risk and environmental concentration. However, RQs greater than 1 occur at environmental concentrations below those resulting in an LNAPL.

Approximately 40 to 80 aviation fuel spills to the terrestrial environment were reported to have occurred between 2000 and 2009 (Environment Canada 2011), or approximately 4 to 8 spills to soil per year. This range reflects the lack of data on the specific location of spills from motor-transport (i.e., bulk carriers, tank trucks, transport trucks, other motor vehicles); it is expected that many of these releases occurred at airports and that the actual yearly number of spills is closer to the lower end of this range. Data provided in the Environment Canada Spills database indicate that there is no systemic cause for these releases to soil.

Based on the available information, the aviation turbine fuel (CAS RN 64741-86-2) and aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) contain components that may persist in air sufficiently long to be transported a distance from the source of release. They also contain components that may persist in soil, water and/or sediment for long periods of time, thus increasing the duration of exposure to organisms.

Based on the combined evidence of empirical data and modelled BAFs, the aviation turbine fuel assessed in this report contains components that are highly bioaccumulative. Studies suggest that most components will not likely biomagnify in food webs; however, there is some indication that alkylated PAHs might (Harris et al. 2011). The aviation gasoline fuels assessed in this report are expected to contain a low proportion of components that are highly bioaccumulative.

In general, fish can efficiently metabolize aromatic compounds. There is some evidence that alkylation increases bioaccumulation of naphthalene (Neff et al. 1976; Lampi et al. 2010), but it is not known if this can be generalized to larger PAHs or if any potential increase in bioaccumulation due to alkylation will be sufficient to exceed a BAF/BCF of 5000.

Some lower trophic level organisms (i.e., invertebrates) appear to lack the capacity to efficiently metabolize aromatic compounds, resulting in high bioaccumulation potential for some aromatic components as compared to fish. This is the case for the C_{14} three-ring PAH, which was bioconcentrated to a high level (BCF > 5000) by invertebrates but not by fish. There is potential for such bioaccumulative components to reach toxic levels in organisms if exposure is continuous and of sufficient magnitude, though this is unlikely in the water column following a spill scenario due to relatively rapid dispersal. However, some components of aviation turbine fuel, such as C_{14} three-ring PAHs, can persist in sediments for long periods of time, which can increase the exposure duration of benthic invertebrates to this component. The proportion in aviation turbine fuel of such bioaccumulative substances with long degradation half-lives is likely low.

Bioaccumulation of aromatic compounds might be lower in natural environments than what is observed in the laboratory. PAHs may sorb to organic material suspended in the water column (dissolved humic material), which decreases their overall bioavailability primarily due to an increase in size. This has been observed with fish (Weinstein and Oris 1999) and *Daphnia* (McCarthy et al. 1985).

A key consideration in characterizing the ecological risks of these substances is the nature, extent and frequency of spills. Spills during handling of aviation gasoline fuels and aviation turbine fuel have the potential to cause harm to aquatic life in the confined waters around loading/unloading wharves; however, based on the low frequency (less than one per year), and resulting low exposure to the environment from spills, there is a low risk of harm to the environment. Spills of aviation gasoline fuels and aviation turbine fuel to soil may cause adverse effects to terrestrial organisms (invertebrates, plants), with approximately 4 to 8 spills occurring per year of which the average spill volume is expected to cause harm. However, the actual number of spills is likely closer to the lower range, and not all of the releases will be of a sufficient volume to cause harm. In addition, no systemic cause for the releases was identified.

Considering all available lines of evidence presented in this screening assessment, there is a low risk of harm to organisms and the broader integrity of the environment from these substances. It is concluded that the aviation turbine fuel (CAS RN 64741-86-2) and aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet the criteria under paragraphs 64(*a*) or (*b*) of CEPA 1999, as they are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity, or that constitute or may constitute a danger to the environment on which life depends.

9.4 Uncertainties in Evaluation of Ecological Risk

This analysis addresses uncertainty associated with each component of the current assessment, including but not limited to representative structures selection and quantification, exposure estimation, effects estimation, and risk characterization.

All modelling of the substances’ physical and chemical properties and persistence, bioaccumulation and toxicity characteristics is based on chemical structures. As aviation fuels are UVCBs, they cannot be represented by a single, discrete chemical structure; additionally, the specific chemical compositions of aviation fuels are not well defined. Aviation fuel streams under the same CAS RNs can vary significantly in the number, identity and proportion of constituent components, depending on operating conditions, feedstocks and processing units. Therefore, for the purposes of modelling, a suite of representative structures that would provide average estimates for the entire range of components likely present was identified. Specifically, these structures were used to assess the fate and hazard properties of aviation fuels. Given that more than one representative structure may be used for the same carbon range and type of component, it is recognized that structure-related uncertainties exist for this substance. The physical-chemical properties of 24 representative structures were used to estimate the overall behaviour of aviation fuels, in order to represent the expected range in physical-chemical characteristics. Given the large number of potential permutations of the type and percentages of the structures in aviation fuels, there is uncertainty in the results associated with modelling. However, the limited number of hydrocarbons theoretically present in aviation fuels (based on the required boiling point ranges for aviation fuels, which limits the carbon ranges of the components) also reduces the uncertainty in this approach.

Given the uncertainties associated with the model-estimated values, the reliance on such methods generates uncertainties in the prediction of partitioning to different environmental compartments, and of persistence and bioaccumulation.

The BAF model calculations were derived from a large database of measured BAF values from the Great Lakes for chemicals that are poorly metabolized (e.g., PCBs). With metabolic biotransformation, the BAF model predictions are in general agreement with measured BAFs in fish. The model may not adequately capture biotransformation at the first trophic level for chemicals that are readily biotransformed in invertebrates and plankton. Many petroleum hydrocarbons are readily metabolized—somewhat by invertebrates, and at much higher levels in fish. Model predictions at log K_{ow} values > 8 were not used, due to limitations of the model (Arnot and Gobas 2003; Arnot et al. 2008).

There is uncertainty in the use of historical spills information from the NEMISIS database (Environment Canada 2011), as spill reports did not distinguish between aviation gasoline and aviation turbine fuels. However, this uncertainty was addressed by proportionally adjusting the spills based on the known refinery production proportions of these two substances from Statistics Canada (2009). Reporting requirements to NEMISIS are limited to releases involving or affecting a federal agency or department, a federal government facility or undertaking, or Aboriginal land; or releases that contravene CEPA 1999 or the *Fisheries Act*; releases that affect fish, migratory birds or species at risk or that impact an interprovincial or international boundary; and releases from marine vessels. Therefore, NEMISIS likely under-reports spills nationally, especially spills to land. However, given that spills of aviation fuels to land will largely occur on federal land (airports), this uncertainty is lessened.

A number of assumptions were made with regard to the location of the spills and, thereby, their environmental significance. There is uncertainty associated with these assumptions. To address the assumptions with regard to the location of spills during transport by motor vehicles, a range is provided for the number of releases from this source with the acknowledgement that the true number lies between the two extremes.

10. Potential to Cause Harm to Human Health

10.1 Exposure Assessment

The general population of Canada (other than private pilots, considered below) does not have direct access to aviation fuels, and therefore oral and dermal exposures are not expected (Tharby 2010; CONCAWE 1999).

The general population of Canada may be exposed to the volatile fraction of aviation fuels due to evaporative emissions released during fuel handling and during storage at airports and bulk storage facilities. Due to limited information on evaporation associated with these complex mixtures as a whole, it was considered appropriate to characterize the release of specific components. Benzene was selected from the list of components that confer a broad range of potential toxicities, as it is a high-hazard component representing the potential effects on human health of exposure to aviation fuels. It has been cited as likely the most hazardous component of aviation fuels (Egeghy et al. 2003).

Private pilots may potentially be intermittently exposed to aviation gasoline fuels during the refuelling of small piston-engine aeroplanes (Tharby 2010). Given the extensive nature of training required to become a licensed pilot (e.g., pilots are educated on proper techniques for refuelling and grounding of the aircraft, they conduct visual checks of fuel quantity and contamination, and they understand the importance of using the proper grade of fuel and fuel logs, etc. [Transport Canada 2010]), as well as the intermittent nature of the exposure, this scenario is not considered further in this assessment.

In contrast to the relatively uniform use of aviation gasoline fuels at small airports and private airfields across Canada, the use of aviation turbine fuel is concentrated at eight major Canadian airports, accounting for 85% of its use in Canada (Tharby 2010). At a major Canadian airport, annual plane refuelling can require up to approximately 2 billion litres of fuel. Given the potential for evaporative emissions from stored fuels, and the venting of fuel vapours from aircraft wing tips during refuelling, the potential exists for exposure to these releases in the vicinity of such airports (Tharby 2010). Inhalation exposure of the general population to aviation turbine fuel evaporative emissions may therefore occur at major Canadian airports.

Inhalation exposures to individuals in the vicinity of small airports and private airfields are considered to be lower than, and thus conservatively accounted for in, the exposure scenarios for aviation turbine fuel storage and handling at major Canadian airports (considered below).

Estimates of inhalation exposures to evaporative emissions of aviation fuel are derived for scenarios of short-term exposure of the general population at major airports, and of long-term exposure of those that reside in the vicinity of major airports or bulk fuel storage facilities.

10.1.1 Human exposure estimates (inhalation)

10.1.1.1 Short-term exposure at Canadian airports

The general population may be exposed to evaporative emissions of aviation fuel, including the high-hazard component of aviation fuel, benzene, at airports in Canada. For the short-term exposure scenario, an individual was considered to spend four hours at a major Canadian airport, located 300 m from the source of evaporative emissions.

Recent air monitoring data at Canadian airports were not available for determining possible short-term exposure concentrations of airborne pollutants. There are also limited air monitoring data for major international airports. At

Hamburg and Frankfurt airports in Germany, Tesseraux (2004) reported the mean annual air concentrations of benzene to be 1 and 2.8 µg/m^3, respectively. Additionally, an occupational air monitoring study of United States Air Force workers at a busy military airport reported a median short-term benzene exposure concentration of 3.1 µg/m^3 for those not handling or working in direct proximity to jet fuels (Egeghy et al. 2003; Pleil et al. 2000). These monitoring data can include contributions from background ambient air pollution, exhaust from planes and automobiles, uncombusted fuel and evaporative emissions from ground support vehicles and local vehicular traffic, and heating (with the latter fuelled by either gasoline or diesel fuel). Thus, it is not possible to determine the level of exposure to aviation fuel evaporative emissions from these studies, nor is it possible to determine the proportion contributed by aviation fuel evaporation to these air concentrations of benzene. Therefore, modelling of aviation fuel evaporative emissions was used to estimate possible exposure concentrations.

The magnitude of evaporative emissions pertaining to the presence and dispensing of Jet A-1 (aviation turbine fuel) at a major Canadian airport has previously been estimated to be 90–180 kg per day (Tharby 2010; Woodrow 2003). These releases include displaced vapours from aircraft fuel tanks during refuelling, vapours from storage tanks as fresh fuel is reintroduced, and evaporative emissions from mobile refuelling vehicles. This emission range was used in SCREEN3 (1996; discussed below) calculations to characterize the dispersion and thus concentration in air at various distances from the respective release site (input variables are given in Table F-1 in Appendix F).

SCREEN3 is a screening-level Gaussian air dispersion model based on the Industrial Source Complex (ISC) model (for assessing pollutant concentrations from various sources in an industry complex). The key influencing variable for air dispersion in the SCREEN3 model is wind. The maximum calculated exposure concentration is selected based on a built-in meteorological data matrix of different combinations of meteorological conditions, including wind speed, turbulence and humidity. This model directly predicts concentrations resulting from point, area and volume source releases. SCREEN3 gives the maximum concentrations of a substance at chosen receptor heights and at various distances from a release source in the direction downwind from the prevalent wind 1 hour after a given release event. During a 24-hour period, for point emission sources, the maximum 1-hour exposure (as assessed by the ISC Version 3) is multiplied by a factor of 0.4 to account for variable wind direction. This gives an estimate of the air concentration over a 24-hour exposure (U.S. EPA 1992). Similarly, for exposure events happening over the span of a year, it can be expected that the direction of the prevalent winds will be more variable and uncorrelated to the wind direction for a single event; thus, the maximum amortized exposure concentration for one year is determined by multiplying the maximum 1-hour exposure by a factor of 0.08. Such scaling factors are not used for non-point-source emissions. However, to prevent overestimation of the exposures originating from area sources, a scaling factor of 0.2 was used to obtain the yearly amortized concentration from the value of the maximum 1-hour exposure concentration determined by SCREEN3.

SCREEN3 dispersion modelling of estimated total volatiles (90 and 180 kg per day) from aviation turbine fuel storage and handling at a major Canadian airport was used to estimate the maximum 24-hour emissions concentration to which an individual might be exposed (Table F-2 in Appendix F). At 300 m from the release source, the total volatiles in air were estimated to be 14.8 µg/m^3. This concentration was taken to represent a conservative estimate of short-term inhalation exposure to aviation fuel.

To estimate human exposure to benzene as a result of exposure to the volatile fraction of aviation fuel as above, the proportion of benzene in the volatile fraction is required. No data specific to aviation fuels were identified to indicate the concentration of benzene in aviation fuel vapour. There are, however, data on the headspace (i.e., vapour) composition of diesel fuel samples. Analysis of two samples of diesel fuel (a summer and winter blend) indicated the percentage of benzene in the vapour phase to be 0.92% and 3.00%, respectively (FLL 2008). The concentration of benzene found in the headspace of diesel fuel provides an approximation of the level that might be found for aviation fuel, because diesel fuel hydrocarbons (predominantly C_{10}–C_{25}) essentially overlap those of aviation turbine fuel (which can be considered similar to kerosene, a narrow cut of the gas oil group—predominantly C_9–C_{16}) (CONCAWE 2007). Also, the percentage of benzene in the liquid phase of both diesel fuel and JP-8 is typically below 0.02% (Egeghy et al. 2003; IARC 1989b; Tharby 2010). It has also been shown that benzene, due to its high volatility and lower combustibility than alkanes, is found in the vapour phase in an amount disproportionately higher than its concentration in the liquid phase of jet fuels (Egeghy 2003). Therefore, 0.92–3.00% was taken to represent the proportion of aviation fuel vapours that could be composed of benzene.

As a proportion of the maximum 24-hour, upper-bound aviation fuel volatiles concentration of 14.8 µg/m^3 at 300 m, the benzene concentration is therefore estimated to be 0.14–0.44 µg/m^3. This benzene concentration (as attributed to evaporative emissions of aviation fuel at a major Canadian airport) is below the average ambient air concentration of benzene in Canada (0.88 µg/m^3) (NAPS 2008).

Other air dispersion models such as the U.S. EPA AERMOD and the accompanying screening model AERSCREEN are available. These models require topological and meteorological data from the site for which the dispersion calculation will be performed. Given the nature of the present screening assessment and the use of SCREEN3 in the U.S. EPA Exposure and Fate Assessment Screening Tool, Version 2.0 (EFAST), SCREEN3 was selected for the assessment of aviation fuel inhalation exposure.

10.1.1.2 Long-term exposure in the vicinity of Canadian airports

Evaporative emissions that result from the storage and handling of aviation fuels at airports may disperse outside the airport boundaries, potentially resulting in exposure of the general population residing in the vicinity. SCREEN3 air dispersion modelling was therefore used to estimate the levels of exposure to the volatile fraction of aviation fuel at various distances from the release source. Emission rates were estimated from the total fugitive release estimates of 90–180 kg per day for Jet A-1 at a large Canadian airport (Tharby 2010; Woodrow 2003). The results for 3000 m from a release source (representative of a distance within which the general population may reside in the vicinity of an airport), gives an annual average concentration range for the volatile fraction of 4.7–9.4 µg/m^3 (Table F-2 in Appendix F). Given a benzene proportion of 0.92–3%, the average annual exposure at 3000 m to aviation-fuel derived benzene would therefore be 0.04-0.14 µg/m^3 (for the minimum volatile emissions of 90 kg) and 0.09-0.28-µg/m^3 (for the maximum volatile emissions of 180 kg). These levels are below the reported average ambient air concentration of benzene in Canada (0.88 µg/m^3) (NAPS 2008).

10.1.1.3 Long-term exposure in the vicinity of aviation fuel storage tanks

Refineries and other petroleum facilities (e.g., terminals, bulk plants) typically have storage tanks on site for temporary storage of aviation fuels and other finished products prior to distribution. The stationary nature of these tanks and the constant production and turnover of finished products results in evaporative emissions, because storage tanks have an associated standing (breathing) loss, as well as displacement of vapours during substance loading (U.S. EPA 2006). The emissions level can vary based on tank size and design, tank maintenance, properties of the stored substance, whether the tank is being filled, stable or emptied, as well as wind speed (Chambers et al. 2008). Aerial map analysis of refineries and other facility types (as noted above), and their associated bulk storage facilities (i.e., large numbers of storage tanks), shows that residential homes can be in close proximity to the storage areas. Thus, the evaporative emissions from aviation fuel storage tanks at refineries may be a source of exposure to fuel vapours for the general population in the vicinity of bulk storage facilities.

Bulk storage facilities have previously been identified as a source of emissions in Canada by the Alberta Research Council, and these emissions have been quantified by Differential Absorption Light Detection and Ranging (DIAL) (Chambers and Strosher 2006; Chambers et al. 2008; U.S. EPA 2006, 2010). DIAL has been used in Europe for over 20 years to identify and quantify emissions from specific locations within refineries, thus enabling targeted reductions in emissions (Chambers and Strosher 2006; Chambers et al. 2008). Within a specific Canadian facility, Spectrasyne Environmental Surveying determined an emissions rate for benzene from fixed roof tanks containing gas oils/kerosene to be 0.02 kg/hr per tank (Spectrasyne 2011).

A scenario of benzene emissions from a facility with two fixed-roof aviation fuel storage tanks in a 50 × 100 m^2 area was thus considered. Using SCREEN3 dispersion modelling with the benzene emissions rate of 0.02 kg/hr per tank and a release height of 10 m (input variables are given in Table F-3 in Appendix F), the maximum concentration of benzene was determined to be at 130 m from the centre of the facility. At this distance, the average annual ambient air concentration of benzene at a receptor height of 1.74 m was determined to be 1.9 $\mu g/m^3$. At 300 m from the centre of the facility, the distance where residences have been observed, the benzene concentration resulting from emissions from the two storage tanks is 0.91 $\mu g/m^3$. This level is considered in the context of the conservatism built into the scenario and the average ambient benzene air concentration of 0.88 $\mu g/m^3$ in Canada.

10.2 Health Effects Assessment

The health effects database was limited with respect to the aviation fuel CAS RNs considered in this screening assessment. A few studies conducted with one aviation gasoline fuel (CAS RN 64741-87-3) were identified, but data on the other two CAS RNs (68527-27-5 and 64741-86-2) were not identified. Therefore, kerosene (straight-run and hydrodesulfurized) and related jet fuels (e.g., JP-5, JP-8, Jet-A, Jet-A1) were selected for characterization of health effects considered representative of the aviation fuels. Kerosene is similar to aviation turbine fuel (CAS RN 64741-86-2) from both a process and physical-chemical perspective, but is refined to less stringent requirements and is not subject to the same additives as final aviation fuels. JP-5, JP-8 and Jet-A are military and commercial grades of aviation turbine fuel, and are therefore also relevant for consideration in the health effects assessment of aviation fuels. A screening-level hazard characterization prepared by the U.S. EPA (2011) included JP fuels and Jet A/A-1 among the supporting substances in its kerosene / jet fuel category.

Appendix G contains an overview of health effects information on aviation fuels and related substances. Key studies outlining potential health effects of exposure to aviation fuels are described below.

CAS RN 64741-87-3 and kerosene have low acute toxicity in laboratory animals via the oral (LD_{50} > 5000 mg/kg body weight [kg-bw]), dermal (LD_{50} > 2000 mg/kg-bw) and inhalation (LC_{50} > 5000 mg/m^3) routes of exposure. They are not skin sensitizers, but can produce eye and skin irritation (mild and mild-to-severe, respectively) (API 1980a, 1985a, 1986a; ATDAEI 1990). A one-hour nose-only exposure of female C57Bl/6 mice to 1000 mg/m^3 JP-8 caused immediate immunosuppression, a significant loss of viable immune cells and significantly reduced immune organ weights (Harris et al. 2002). Additional one-hour exposures resulted in greater immunosuppression (Harris et al. 1997, 2007b).

Skin irritation was the only effect reported after dermal exposure of male and female Sprague-Dawley (SD) rats to 678 mg/kg-bw per day of aviation gasoline fuel (CAS RN 64741-87-3) 5 days per week for 4 weeks (UBTL 1994). Increased spleen weights and decreased red blood cells were observed in rabbits dermally exposed to 200 mg/kg-bw (a lowest-observed-adverse-effect level [LOAEL]) kerosene 3 times per week for 4 weeks (API 1985a). Immunosuppression (as indicated by impaired induction of contact hypersensitivity and suppression of the delayed-type hypersensitivity response) in female mice was seen after dermal exposure to 1140 mg/kg-bw of JP-8 once per day for 5 days (Ullrich 1999). In female SD rats, immunosuppression was not observed after dermal exposure to Jet-A at 495 mg/kg-bw per day for 4 weeks (Mann et al. 2008).

Generalized sloughing of the bronchiolar epithelium and various cellular changes in alveolar type II epithelial cells, including increased number and size of surfactant-producing lamellar bodies, was observed in male C57Bl/6 mice that were nose-only exposed to JP-8 vapours and aerosols at 45 mg/m^3 (a LOAEC) for 1 hour per day for 7 days (Herrin et al. 2006). In another study, groups of male B6.A.D. mice were exposed to 0, 7, 12, 26, 48 and 118 mg/m^3 JP-8 for 1 hour per day for 7 days (Robledo et al. 2000). The vapour/aerosol combination in this study would have resulted in actual exposures of 0, 57, 97, 211, 390 and 960 mg/m^3 (as specified in Herrin et al. 2006). Thus, exposure to 390 mg/m^3 resulted in increased alveolar permeability, increased total protein in the bronchoalveolar lavage fluid, and concentration-dependent morphological lung and alveolar injury. Although these effects occurred in the absence of impaired respiratory function, they were considered by the authors as adverse because they exhibited concentration-dependency and are predictive of longer-term respiratory damage. In another study of mice exposed to JP-8, significant concentration-dependent decreases in thymic cell viability and splenic immune cell proliferation have been noted at 810 mg/m^3, the lowest concentration tested (the 100 mg/m^3 exposure group was actually exposed to 810 mg/m^3 combined vapour/aerosols) (Harris et al. 1997). Mice exposed to 1000 mg/m^3 for one 1 per day for 7 days exhibited reduced immune response to influenza viral infection, decreased immune cell viability, decreased immune cell proliferative response to mitogens, and a loss of T cells from the lymph nodes (Harris et al. 2008). Exposure of rats to 1000 mg/m^3 JP-8 for 6 hours per day, 5 days per week for 6 weeks, had significant effects on neurobehavioural capacity (Rossi et al. 2001).

A LOAEC of 58 mg/m^3 was identified based on decreased blood glucose in Wistar rats exposed to kerosene vapours for 6 hours per day, 6 days per week for 14 weeks (Starek and Vojtisek 1986). In another study, male rats exposed to JP-5 vapours/aerosols at 150 mg/m^3 for 90 days exhibited nephrotoxicity. This adverse effect, however, is thought to be linked to the unique and specific male rat protein, α-2-microglobulin, and therefore is not considered relevant to humans. Inhalation exposure to JP-5 at 750 mg/m^3 resulted in decreased growth rate in male rats, and statistically significant increases in blood urea nitrogen and serum creatinine levels in both sexes (Bruner 1984; Gaworski et al. 1984; MacNaughton and Uddin 1984). Another inhalation study showed bone marrow histological changes (10% reduction in fat cells), as well as low-level cell proliferation in male rats exposed to 250 mg/m^3 JP-5 (Hanas et al. 2010).

No adverse effects were reported in rats administered 3000 mg/kg JP-8 by gavage daily for 90 days (Mattie et al. 1995). In a subchronic dermal study, dose-dependent skin irritation and increased spleen weights in high-dose females were reported after male and female SD rats were exposed to 165, 330 or 495 mg/kg-bw hydrodesulfurized kerosene daily for 13 weeks (U.S. EPA 2011).

No developmental or reproductive studies were identified for the aviation fuels. Kerosene and Jet-A did not exhibit reproductive or developmental effects in rats at high concentrations (no-observed-adverse-effect concentrations [NOAECs] of 2780 and 2945 mg/m^3) via the inhalation route of exposure (API 1979a, 1979b; IARC 1989a). Conversely, developmental effects were observed in C57Bl/6 mice exposed to a maternally toxic concentration of JP-8. Mouse dams were exposed, nose-only, to 1000 mg/m^3 JP-8 aerosols, in a single-concentration study, 1 time per day from gestational days 7 or 15 to birth. Adverse effects occurred in dams and pups of both groups, and included statistically significant immunosuppression as measured at 6 to 8 weeks postpartum. Other statistically significant effects included decreased spleen weights and splenic cells (pups), decreased thymus weights and precursor T cells (dams and pups), and decreased litter sizes. Male pup birth and survival rates were also decreased (Harris et al. 2007a).

One chronic dermal study assessing non-cancer endpoints was identified for the aviation fuels. No significant health effects were seen in male mice exposed to 970 mg/kg-bw of aviation gasoline fuel (CAS RN 64741-87-3) twice weekly for life; however, mild to moderate desquamation with slight irritation and scabbing was noted at the application site (API 1989a). In a similar study of male and female mice dermally exposed to JP-5, a LOAEL of 250 mg/kg-bw was identified based on a marked increase in dermal ulceration, inflammation and epithelial hyperplasia at the application site (NTP 1986). Skin ulceration and irritation were also seen at the application site in mice after chronic dermal exposure to 1170 mg/kg-bw kerosene twice weekly for up to 24 months (API 1986c). These mice also exhibited increased absolute and relative liver, lung and kidney weights. In mice dermally exposed to 1070 mg/kg-bw JP-5 or JP-8 3 times per week for 60 weeks, renal lesions, nephron atrophy and degeneration, and papillary necrosis were observed (Easley et al. 1982).

The International Agency for Research on Cancer (IARC) classified “jet fuel” (CAS RN not assigned) as a group 3 carcinogen (“not classifiable as to its carcinogenicity to humans" – inadequate data in humans and inadequate or limited data in animals) (IARC 1989a). In deriving this classification, IARC in part considered health effects data on kerosene (CAS RN 8008-20-6). The aviation fuels (CAS RNs 64741-86-2, 64741-87-3 and 68527-27-5) were classified as EU category 2 carcinogens ("may cause cancer") by the European Commission (European Commission 2004; ESIS c1995-2012). The risk phrases R65 for classification and labelling ("harmful: may cause lung damage if swallowed") and R46 ("may cause heritable genetic damage") were also assigned by the European Commission to CAS RNs 64741-87-3 and 68527-27-5.

Carcinogenicity studies that assessed the aviation fuels were found only for aviation gasoline fuel (CAS RN 64741-87-3). An insignificant number of skin tumours in male mice were observed after dermal application of 970 mg/kg-bw aviation gasoline fuel twice weekly for life (Skisak et al. 1994). Three of 50 mice developed skin tumours in the test substance group (2 squamous cell papillomas and 1 squamous cell carcinoma) with mean latency to tumour formation of 113 weeks. In the vehicle (toluene) control group, 3 mice developed squamous cell carcinoma and 1 developed fibrosarcoma. In another lifetime skin painting study with aviation gasoline fuel, 4 of 50 mice developed benign skin tumours, with a mean latency of development of 112 weeks (API 1986b, 1986d). Another skin painting study exposed male mice to 970 mg/kg-bw twice weekly for 139 weeks, resulting in benign and malignant tumour incidences comparable to that seen in the negative and solvent control groups (API 1989a). Aviation gasoline fuel was negative in tumour initiation and tumour promotion studies (Skisak et al. 1994).

Carcinogenicity studies were available for the related aviation fuel substances. Two studies of dermal application of Jet-A to mice three times per week resulted in skin tumour incidences of 26% and 44%, and mean latency to tumour formation of 79 weeks when exposed for 105 weeks (Clark et al. 1988; Freeman et al 1993). Straight-run kerosene was tested in 3 skin painting assays in mice, for durations ranging from 80 weeks to life. Increased induction of skin tumours in the test groups compared to control groups was reported in all studies, and tumour incidences ranged from 4 of 27 to 20 of 50. Mean latency to tumour development ranged from 62 to 76 weeks (Blackburn et al. 1986; CONCAWE 1991; API 1986c). JP-5 applied daily to mice at 250 or 500 mg/kg-bw for 103 weeks resulted in malignant lymphomas in females with incidences of 19 of 49 and 5 of 47, respectively. However, these incidence levels were within the rate of historical untreated controls and therefore not considered substance-related (NTP 1986).

Evaluation of the genotoxic potential of aviation fuels was conducted through *in vivo* and *in vitro* assays. Aviation gasoline fuel (CAS RN 64741-87-3) produced negative results in genotoxicity assays. In an *in vivo* chromosomal aberration assay, male and female SD rats were exposed via inhalation to up to 5443 mg/m^3 for 6 hours per day for 5 days; an induction of chromosomal aberrations in the bone marrow was not observed (API 1986e). An *in vitro* mouse lymphoma assay was also negative with and without metabolic activation of the test substance (API 1985c).

Genotoxicity assays of kerosene and jet fuels were also identified. Jet-A was positive for chromosomal aberration in rats and had mixed results (one positive, one negative) for micronuclei induction in mice (API 1979c; Conaway et al. 1984; Vijayalaxmi et al. 2004, 2006). It was also positive *in vitro* in the mouse lymphoma assay after S9 activation (Conaway et al. 1984). Kerosene gave mixed results *in vivo* for sister chromatid exchange (API 1988), but was negative in rat bone marrow cytogenetic assays (API 1977, 1979c, 1984, 1985c). Kerosene produced mixed results *in vitro* in the modified Ames assay and mouse lymphoma assay (API 1977, 1979c, 1985d; Blackburn et al. 1986; CONCAWE 1991). JP-8 had mixed results *in vivo* for micronuclei induction; studies reported positive results in peripheral blood of mice and negative results in bone marrow and peripheral blood of mice (Vijayalaxmi et al. 2004, 2006). Positive results were reported *in vitro* for JP-8 and JP-8+100 for induction of DNA strand breaks and lesions (Grant et al. 2001; Jackman et al. 2002). JP-5 was negative in the Ames and mouse lymphoma assays with and without activation, while DNA damage was reported in blood cells (NTP 1986; Jackman et al. 2002).

There are several occupational epidemiological studies of exposure to jet fuel. A cross-sectional study of 63 female United States Air Force employees found that those with high breath concentrations of JP-8 aliphatic hydrocarbons (mean = 280 parts per billion [ppb] for hexane to undecane) exhibited significantly ($p = 0.007$) reduced urinary luteinizing hormone, indicating an association between jet fuel exposure and possible adverse reproductive effects. Additionally, a trend of decreased urinary luteinizing hormone ($p = 0.1$) and decreased urinary midluteal pregnanediol 3-glucuronide (Pd3G) ($p = 0.08$) was noted in the group with the highest breath concentrations of BTEX (mean = 74 ppb) (Reutman et al. 2002). In a case-control study of 3726 men with cancer, the excess risk (odds ratio) of kidney cancer among workers with substantial occupational exposure to aviation gasoline or jet fuel was 3.9 and 3.4 (90% confidence intervals = 1.7–8.8 and 1.5-7.6), respectively (Siemiatycki et al. 1987). However, from this study it is difficult to determine causal relationships, as workers were often occupationally exposed to other substances, and absolute exposure levels were not reported. Recently, occupational inhalation exposures to JP-8 at less than 50 mg/m^3 has been linked to adverse immune system effects, including an immediate increase in neutrophils and eosinophils, and decreased total leukocytes in the peripheral blood (Harris 2011). Other studies indicate that exposure to jet fuel may negatively affect neurological function, including associated learning, sensorimotor speed and higher-level brainstem functions (Knave et al. 1978, 1979; Odkvist et al. 1987; Ritchie et al. 2001a).

Aviation fuels contain the high-hazard component benzene at < 0.02% (weight per weight [w/w]); however, due to its high volatility, benzene may represent up to 3% of aviation fuel vapour (as determined from a headspace analysis on diesel fuel samples). Benzene has been assessed by Health Canada (Canada 1993); it was determined to be a carcinogen and was therefore added to the List of Toxic Substances in Schedule 1 of CEPA 1999. Similarly, IARC classifies benzene as a Group 1 carcinogen (carcinogenic to humans) (IARC 1987, 2004, 2007). The Government of Canada has previously published estimates of benzene carcinogenic potency associated with inhalation exposure. A 5% tumourigenic concentration (TC_{05}) for benzene was calculated to be 14.7×10^3 $\mu g/m^3$ (Canada 1993) based on epidemiological data of acute myelogenous leukaemia in Pliofilm workers (Rinsky et al. 1987). The TC_{05} value is the air concentration of a substance associated with a 5% increase in incidence or mortality due to tumours (Health Canada 1996). Reference values for benzene from other international agencies (U.S. EPA 2000; W.H.O. 2000) are similar to the TC_{05} used below for the characterization of risk to human health.

With respect to the short-term inhalation effects of benzene, Health Canada identified a critical effect level of 32 mg/m^3, based on immunological effects in mice after exposure for 6 hours per day for 6 days (Rozen et al. 1984). The Priority Substances List Assessment Report for benzene summarizes the Rinsky et al. (1987) and Rozen et al. (1984) studies (Canada 1993).

10.3 Characterization of Risk to Human Health

Aviation fuels were identified as high priorities for action during categorization of the DSL, as they were determined to present the greatest potential or intermediate potential for exposure of individuals in Canada, and were considered to present a high hazard to human health. A critical effect for the initial categorization of aviation fuels was carcinogenicity, based on classifications by international agencies. Aviation fuels were classified as category 2 carcinogens (“may cause cancer”) by the European Commission (European Commission 2004; ESIS c1995-2012).

Exposure to aviation fuel vapours may occur in the vicinity of airports and fuel storage facilities. Characterizing the risk associated with short-term inhalation exposure at airports involved the consideration of health effects data for the volatile fraction of aviation fuels and the high-hazard component, benzene. Long-term inhalation exposures in the vicinity of airports and bulk storage facilities involved the consideration of health effects data for benzene.

10.3.1 Short-term exposure at Canadian airports

A scenario of an individual present for four hours at a major airport, 300 m from the source of aviation fuel evaporative emissions, was considered. There were no recent Canadian monitoring data available on which to base the characterization of risk of such potential exposures. Modelling the dispersion and air concentration of estimated aviation turbine fuel evaporative emissions from a major Canadian airport resulted in a maximum 24-hour, upper-bounding value for total volatiles of 14.8 µg/m^3 at 300 m from the release source. Comparing this estimate with the short-term non-cancer effect level of 45 mg/m^3 in mice (as based on generalized sloughing of bronchiolar epithelium following an exposure regimen to jet fuel of 1 hour per day for 7 days) (Herrin et al. 2006) results in a margin of exposure (MOE) of approximately 3000. Comparing the respective benzene concentrations of 0.14–0.44 µg/m^3 at 300 m (considering benzene represents 0.92–3% of the estimated total volatiles), with the short-term non-cancer effect level for benzene of 32 mg/m^3 (as based on immunological effects in male mice following an exposure regimen of 6 hours per day for 6 days) (Rozen et al. 1984), results in margins of exposure of approximately 73 000–228 000. The above MOEs are considered adequate to address uncertainties related to health effects and exposure.

10.3.2 Long-term exposure in the vicinity of airports or bulk storage facilities

10.3.2.1 Airports

Air dispersion modelling of minimum and maximum volatiles released daily (90 and 180 kg, respectively) from the storage and handling of Jet A-1 at a large Canadian airport indicates that, at 3000 m from the point of release, the average annual air concentration of these volatiles would be 4.7 and 9.4 µg/m^3, respectively. Exposure to benzene as a proportion (0.92–3%) of the total volatiles would be 0.04–0.14 µg/m^3 (for the minimum release estimate) and 0.09-0.28 µg/m^3 (for the maximum release estimate).

To characterize the risk from potential long-term exposures to these evaporative emissions, the maximum annual upper-bound estimated concentration of benzene (0.28 µg/m^3), was compared with its carcinogenic potency (14.7×10^3 µg/m^3). The resulting margin of exposure at 3000 m from an airport is approximately 52 500. This margin is considered adequate to address uncertainties related to health effects and exposure.

10.3.2.2 Bulk Storage Facilities

There is potential for inhalation exposure to aviation fuel evaporative emissions in the vicinity of bulk storage facilities. To characterize the risk from potential long-term exposure to these emissions, the annual upper-bound estimated concentration of benzene (0.91 µg/m^3) was compared with its carcinogenic potency (14.7×10^3 µg/m^3). The resulting margin of exposure at 300 m from a bulk storage facility with two storage tanks containing aviation fuel is approximately 16 000. This margin is considered adequate to address uncertainties related to health effects and exposure.

10.4 Uncertainties in Evaluation of Risk to Human Health

Uncertainty exists in the estimates of total daily volatiles from Jet A-1 at a major Canadian airport, in the modelling of these dispersions, and in the proportion of benzene present in the volatile fraction of aviation fuels; therefore, there is uncertainty in the derived short-term and long-term margins of exposure. Monitoring data on the amount and composition of vapours released from wing-tip venting of aircraft fuel tanks during various stages of idling and refuelling would aid in estimating exposures in the vicinity of aircraft boarding areas.

There are inherent variables that influence the magnitude of exposures to the volatile fraction of aviation fuels stored at bulk storage facilities, some of which include the size, number and state of repair of the tanks, fuel turnover, and the presence, magnitude and duration of the prevailing winds; these variables are not identical across storage sites, and differences in these variables are not accounted for in the exposure estimation.

For the scenarios of living in the vicinity of bulk storage facilities or airports, there is uncertainty in the characterization of risk of long-term exposure due to the assumption that inhalation exposure occurs continuously. Additionally, the presence of more storage tanks or an increase in fuel throughput in a defined area would increase the estimates of exposure.

As aviation fuels are UVCBs, their specific compositions are broadly defined, and different samples labelled with the same CAS RN can vary in the number, identity and proportion of components, depending on the feedstocks, operating conditions and processing units used to form the final fuel. Thus, it is difficult to obtain a representative toxicological dataset given that health effects may vary from batch to batch and between CAS RNs. For these reasons, all available health effects data on the aviation fuels and related substances were taken into consideration.

Another contributor to uncertainty is that certain details of the laboratory animals (e.g., body weight) or test substance (e.g., density) were not always reported in the health effects studies, and were thus obtained from standard data. These parameters may not be entirely representative of the physical features of the actual test animals or substances used in the studies.

There is uncertainty in the exposure estimates and in the health effects database, as they pertain to the use of benzene as a single high-hazard component to characterize general population risk. A varying and wide range of chemical components, with individual physical-chemical properties that may change due to mixture effects, are present in the UVCB aviation fuels. Characterizing risk based on a single high-hazard component may be protective of potential risks from other components, but cannot account for the effects of mixtures of substances with differing hazards and potencies (i.e., the influence of concurrent exposure to multiple components on the pharmacokinetic and pharmacodynamic properties of a single component).

Determining the health effects of individual fuel additives was outside the scope of this assessment.

11. Conclusion

Considering all available lines of evidence presented in this screening assessment, there is low risk of harm to organisms or the broader integrity of the environment from these substances. It is concluded that the aviation turbine fuel (CAS RN 64741-86-2) and the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet the criteria under paragraphs 64(*a*) or (*b*) of CEPA 1999, as they are not entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity, or that constitute or may constitute a danger to the environment on which life depends.

For potential non-cancer effects from short-term inhalation exposures, margins of exposure between upper-bounding estimates of exposure to aviation fuel evaporative emissions, and the critical effect levels identified in laboratory animals, are considered adequate to address uncertainties related to health effects and exposure. For cancer from long-term inhalation exposures, margins of exposure between upper-bounding estimates of exposure to benzene (a high-hazard component of aviation fuels) and estimates of cancer potency are considered adequate to address uncertainties related to health effects and exposure. Accordingly, it is concluded that the aviation turbine fuel (CAS RN 64741-86-2) and the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet the criteria under paragraph 64(*c*) of CEPA 1999 as they are not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.

It is therefore concluded that the aviation turbine fuel (CAS RN 64741-86-2) and the aviation gasoline fuels (CAS RNs 64741-87-3 and 68527-27-5) do not meet any of the criteria set out in section 64 of CEPA 1999.

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Appendix A: Petroleum Substance Grouping

Table A-1. Description of the nine groups of petroleum substances

Group[a]	**Description**	**Example**
Crude oils	Complex combinations of aliphatic and aromatic hydrocarbons and small amounts of inorganic compounds, naturally occurring under the Earth's surface or under the sea floor	Crude oil
Petroleum and refinery gases	Complex combinations of light hydrocarbons, primarily from C_1 to C_5	Propane
Low boiling point naphthas	Complex combinations of hydrocarbons, primarily from C_4 to C_{12}	Gasoline
Gas oils	Complex combinations of hydrocarbons, primarily from C_9 to C_{25}	Diesel fuel
Heavy fuel oils	Complex combinations of heavy hydrocarbons, primarily from C_{11} to C_{50}	Fuel Oil No. 6
Base oils	Complex combinations of hydrocarbons, primarily from C_{15} to C_{50}	Lubricating oils
Aromatic extracts	Complex combinations of primarily aromatic hydrocarbons from C_{15} to C_{50}	Feedstock for benzene production
Waxes, slack waxes and petrolatum	Complex combinations of primarily aliphatic hydrocarbons from C_{12} to C_{85}	Petrolatum
Bitumen or vacuum residues	Complex combinations of heavy hydrocarbons having carbon numbers greater than C_{25}	Asphalt

[a] These groups were based on classifications developed by CONCAWE and a contractor's report presented to the Canadian Petroleum Products Institute (CPPI) (Simpson 2005).

Appendix B: Physical-chemical Properties of Representative Structures for Aviation Fuels

Table B-1. Physical-chemical properties of representative substances for aviation fuels (EPI Suite 2008)[a]

Alkanes

Chemical class, name and CAS RN	Aviation fuel represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)	Henry's Law constant (Pa·m^3/mol)
C_9 *n*-nonane (111-84-2)	64741-87-3 68527-27-5 64741-86-2	150.8 (expt.)	-53.5 (expt.)	593 (expt.)	3.5×10^5 (expt.)
C_{12} *n*-dodecane (112-40-3)	64741-87-3 64741-86-2	216.3 (expt.)	-9.6 (expt.)	18.0 (expt.)	8.3×10^5 (expt.)
C_{15} *n*-pentadecane (629-62-9)	64741-86-2	271 (expt.)	9.9 (expt.)	0.5 (expt.)	1.3×10^6 (expt.)

Isoalkanes

Chemical class, name and CAS RN	Aviation fuel represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)	Henry's Law constant (Pa·m^3/mol)
C_6 2-methyl pentane (43133-95-5)	64741-87-3	60.2 (expt.)	-153.7 (expt.)	2.8×10^4 (expt.)	1.7×10^5 (expt.)
C_9 2,2-dimethyl heptane (1071-26-7)	64741-87-3 68527-27-5 64741-86-2	133 (expt.)	-113 (expt.)	1.4×10^3	5.8×10^5
C_{12} 2,3-dimethyl decane (17312-44-6)	64741-87-3 68527-27-5 64741-86-2	181.4	-43.0	165	2×10^6
C_{15} 2-methyl tetradecane	64741-86-2	250	1.5	5.8	4.6×10^6

(1560-95-8)					

One-ring cycloalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Boiling point (°C)**	**Melting point (°C)**	**Vapour pressure (Pa)**	**Henry's Law constant (Pa·m^3/mol)**
C_9 1,2,3-trimethyl-cyclohexane (1678-97-3)	64741-87-3 68527-27-5 64741-86-2	151.2 (expt.)	-85.7 (expt.)	649	9.6×10^4
C_{12} *n*-hexylcyclohexane (4292-75-5)	64741-87-3 68527-27-5 64741-86-2	224 (expt.)	-43 (expt.)	15.2 (expt.)	2×10^5
C_{15} nonylcyclohexane (2883-02-5)	64741-86-2	282 (expt.)	-10 (expt.)	0.3 (expt.)	5.3×10^5

Two-ring cycloalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Boiling point (°C)**	**Melting point (°C)**	**Vapour pressure (Pa)**	**Henry's Law constant (Pa·m^3/mol)**
C_9 *cis*-bicyclononane (4551-51-3)	64741-87-3 68527-27-5 64741-86-2	167 (expt.)	-53 (expt.)	320	9210
C_{15} 2-isopentadecylin	64741-86-2	244	23	2.4	4.8×10^4 (expt.)
C_{20} 2,4-dimethyloctyl-2-decalin	64741-86-2	324	41	0.1	7.2×10^5

Polycycloalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Boiling point (°C)**	**Melting point (°C)**	**Vapour pressure (Pa)**	**Henry's Law constant (Pa·m^3/mol)**
C_{14} hydro-phenanthrene	64741-86-2	255	21	4.5	8590

One-ring aromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Boiling point (°C)**	**Melting point (°C)**	**Vapour pressure (Pa)**	**Henry's Law constant (Pa·m^3/mol)**
C_6 benzene (71-43-2)	64741-87-3 68527-27-5	80 (expt.)	5.5 (expt.)	1.3×10^4 (expt.)	562 (expt.)
C_9 1-methyl-2-ethylbenzene (611-14-3)	64741-87-3 68527-27-5 64741-86-2	165.2 (expt.)	-80.8 (expt.)	348 (expt.)	560 (expt.)
C_{15} *n*-nonyl benzene (1081-77-2)	64741-86-2	281 (expt.)	-24 (expt.)	0.8 (expt.)	1.0×10^4

Cycloalkane monoaromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Boiling point (°C)**	**Melting point (°C)**	**Vapour pressure (Pa)**	**Henry's Law constant (Pa·m^3/mol)**
C_{10} tetralin (119-64-2)	64741-87-3 68527-27-5 64741-86-2	102-104 (expt.)	-35.7 (expt.)	49.1 (expt.)	138 (expt.)
C_{15} methyloctahydro-phenanthrene	64741-87-3 64741-86-2	267.1	27.9	2.3	1.5×10^4

Two-ring aromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Boiling point (°C)**	**Melting point (°C)**	**Vapour pressure (Pa)**	**Henry's Law constant (Pa·m^3/mol)**
C_{10} naphthalene (91-20-3)	64741-87-3 68527-27-5 64741-86-2	217.9 (expt.)	80.2 (expt.)	13.1 (expt.)	45 (expt.)
C_{15} 4-isopropyl biphenyl (7116-95-2)	64741-86-2	309	43.7	0.1	98.7

Cycloalkane diaromatics

Chemical class, name and CAS RN	Aviation fuel represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)	Henry's Law constant (Pa·m^3/mol)
C_{12} acenaphthene (83-32-9)	64741-86-2	279 (expt.)	93.4 (expt.)	0.3 (expt.)	18.6 (expt.)
C_{15} ethylfluorene (65319-49-5)	64741-86-2	337.6	94.6	0.007	5.6

Three-ring aromatics

Chemical class, name and CAS RN	Aviation fuel represented	Boiling point (°C)	Melting point (°C)	Vapour pressure (Pa)	Henry's Law Constant (Pa·m^3/mol)
C_{15} 2-methyl phenanthrene (2531-84-2)	64741-86-2	155–160 (expt.)	57–59 (expt.)	0.009	2.8

Table B-1 cont. Physical-chemical properties of representative substances for aviation fuels (EPI Suite 2008)[a]

Alkanes

Chemical class, name and CAS RN	Aviation fuel represented	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L)[b]
C_9 *n*-nonane (111-84-2)	64741-87-3 68527-27-5 64741-86-2	5.65 (expt.)	4.9	0.22 (expt.)
C_{12} *n*-dodecane (112-40-3)	64741-87-3 64741-86-2	6.1 (expt.)	5.3	0.004 (expt.)
C_{15} *n*-pentadecane (629-62-9)	64741-86-2	7.7	6.7	8×10^{-5} (expt.)

Isoalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_6 2-methyl pentane (43133-95-5)	64741-87-3	3.2	2.7	13 (expt.)
C_9 2,2-dimethyl heptane (1071-26-7)	64741-87-3 68527-27-5 64741-86-2	4.7	4.0	2.9
C_{12} 2,3-dimethyl decane (17312-44-6)	64741-87-3 68527-27-5 64741-86-2	6.1	5.3	0.1
C_{15} 2-methyl tetradecane (1560-95-8)	64741-86-2	7.6	6.6	0.003

One-ring cycloalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_9 1,2,3-trimethyl-cyclohexane (1678-97-3)	64741-87-3 68527-27-5 64741-86-2	4.4	3.8	5.1
C_{12} *n*-hexylcyclohexane (4292-75-5)	64741-87-3 68527-27-5 64741-86-2	6.1	5.3	0.1
C_{15} nonylcyclohexane (2883-02-5)	64741-86-2	7.5	6.5	0.005

Two-ring cycloalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_9 *cis*-	64741-87-3 68527-27-5	3.7	3.2	25.1

bicyclononane (4551-51-3)	64741-86-2			
C_{15} 2-isopentadecylin	64741-86-2	4.2	3.7 (expt.)	0.9 (expt.)
C_{20} 2,4-dimethyloctyl-2-decalin	64741-86-2	8.9	7.7	1.2×10^{-4}

Polycycloalkanes

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_{14} hydro-phenanthrene	64741-86-2	5.2	4.5	0.5

One-ring aromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_6 benzene (71-43-2)	64741-87-3 68527-27-5	2.1 (expt.)	1.8 (expt.)	2.1 (expt.)
C_9 1-methyl-2-ethylbenzene (611-14-3)	64741-87-3 68527-27-5 64741-86-2	3.5 (expt.)	3.1	3.5 (expt.)
C_{15} *n*-nonyl benzene (1081-77-2)	64741-86-2	7.1 (expt.)	6.2	7.1 (expt.)

Cycloalkane monoaromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous Ssolubility (mg/L)[b]**
C_{10} tetralin (119-64-2)	64741-87-3 68527-27-5 64741-86-2	3.5 (expt.)	3.0	47 (expt.)
C_{15} methyloctahydro-	64741-87-3 64741-86-2	5.6	4.9	0.2

phenanthrene				

Two-ring aromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_{10} Naphthalene (91-20-3)	64741-87-3 68527-27-5 64741-86-2	3.3 (expt.)	3.0 (expt.)	31.0 (expt.)
C_{15} 4-isopropyl biphenyl (7116-95-2)	64741-86-2	5.5 (expt.)	4.8	0.9

Cycloalkane diaromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_{12} acenaphthene (83-32-9)	64741-86-2	3.9 (expt.)	3.6 (expt.)	3.9 (expt.)
C_{15} ethylfluorene (65319-49-5)	64741-86-2	5.1	4.4	0.2

Three-ring aromatics

Chemical class, name and CAS RN	**Aviation fuel represented**	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L)[b]**
C_{15} 2-methyl phenanthrene (2531-84-2)	64741-86-2	5.2 (expt.) and 4.9 (expt.)	4.2	0.3 (expt.)

Abbreviations: K_{oc}, organic carbon-water partition coefficient; K_{ow}, octanol-water partition coefficient; expt., experimental data.

[a] All values are modelled unless denoted with an (expt.) for experimental data. Models used were HENRYWIN (2011) for Henrys Law constants, KOWWIN (2010) for log K_{ow}, KOCWIN (2010) for log K_{oc}, WSKOWWIN (2010) for water solubility.

[b] Maximum water solubility was estimated for each representative substance based on its individual physical-chemical properties. The actual water solubility of a component in a mixture will decrease, as the total water solubility of an ideal mixture is proportional to the sum of the water solubility of the mole fractions of each individual component (Banerjee 1984).

Appendix C: Production and Transportation Information

Table C-1. Canadian production, import and export of aviation gasoline and aviation turbine fuels in 2011, in millions of litres (Statistics Canada 2012)

Product	**Refinery production**	**Net production[a]**	**Imports**	**Exports**
Aviation gasoline[b]	49.9	49.5	0.0	8.4
Aviation turbo fuel – kerosene type[c]	4056.8	3868.8	2217.9	307.9
Total	4106.7	3918.3	2217.9	316.3

[a] Net production following inter-product transfers.
[b] All gasoline type fuels for piston-type aircraft engines.
[c] All kerosene type fuels for turbo-jet or straight-type jet aircraft engines.

Table C-2. Disposition of aviation gasoline and aviation turbine fuels in Canada, 2008, millions of litres (Statistics Canada 2009)

Volume (millions of litres)

Distributions	**Aviation gasoline**	**Aviation turbine fuel[a]**
Canadian airlines	34.3	5042.9
Foreign airlines	0.0	638.0
Public administration	1.7	200.2
Commercial / other institutional	53.5	849.6

[a] Includes aviation turbo fuel – naphtha and kerosene types.

Table C-3. National aviation fuel (aviation gasoline and aviation turbine fuels) spills information, 2000–2009, from Environment Canada's NEMISIS database (Environment Canada 2011)[a]

Year	**Average spill volume (litres)**	**Maximum single spill volume (litres)**	**Median spill volume (litres)**	**Number of spills reported**	**% of spills with unknown volume**	**Total known volume spilled (litres)**	**Extrapolated total volume spilled[b] (litres)**
2009	576	3 388	278	28	10.7	14 404	20 573
2008	704	18 000	20	76	2.6	52 121	56 234
2007	6 873	200 000	38	80	5	522 385	530 610
2006	1 151	22 000	50	83	3.7	90 939	97 108

Year	Average spill volume (litres)	Maxi-mum single spill volume (litres)	Median spill volume (litres)	Number of spills reported	% of spills with unknown volume	Total known volume spilled (litres)	Extrapo-lated total volume spilled[b] (litres)
2005	3 555	179 280	68	108	5.6	362 566	374 903
2004	597	16 957	50	97	9.3	52 498	71 004
2003	1 117	26 768	100	99	11.1	98 319	120 938
2002	1 063	18 000	133	64	9.4	61 662	74 000
2001	2 274	150 000	100	120	7.5	252 408	270 914
2000	977	26 145	60	70	12.9	59 566	78 073
Total volume spilled						1 566 868	1 694 355

[a] Does not include releases due to aircraft crash, collision, ice/frost, road conditions, subsidence or vandalism.

[b] The extrapolated total volume was calculated using a proportional estimate of known spills to determine the frequency and volume of unknown spill volumes, assuming that the distribution of reported volumes released was representative of all releases.

Table C-4. Approximate volume (L) of aviation fuel (aviation gasoline and aviation turbine fuels) releases per Canadian province, 2000–2009 (Environment Canada 2011)[a]

Province	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
British Columbia	9 953	27 000	21 244	12 962	2 908	5 500
Alberta	26 145	NA	NA	3 058	41	138 662
Saskatchewan	NA	NA	NA	NA	NA	NA
Manitoba	NA	NA	NA	NA	NA	NA
Ontario	10 816	12 500	NA	NA	NA	1000
Quebec	5 797	14 042	12 259	6 030	1 462	197 780
New Brunswick	3 391	30	5 200	9 004	355	985
Nova Scotia	836	11 217	5 227	12 001	8 153	14 934
Prince Edward Island	NA	15	NA	NA	NA	NA
Newfoundland and Labrador	2 628	185 630	17 732	55 264	39 579	3 555
Nunavut	NA	NA	NA	NA	NA	100
Northwest Territories	NA	NA	NA	NA	NA	50
Yukon	NA	461	NA	NA	NA	NA
Yearly totals	59 566	252 408	61 662	98 319	52 498	362 566

[a] Does not include spills due to aircraft crash, collision, ice/frost, road conditions, subsidence or vandalism.

NA – not applicable, with no reported release volumes.

Table C-4 cont. Approximate volume (L) of aviation fuel (aviation gasoline and aviation turbine fuels) releases per Canadian province, 2000–2009 (Environment Canada 2011)[a]

Province	2006	2007	2008	2009	Total
British Columbia	NA	400	NA	NA	79 967
Alberta	5 165	20	NA	9 288	182 379
Saskatchewan	NA	NA	NA	500	500
Manitoba	NA	6 650	4 000	505	11 155
Ontario	23 030	200 000	90	4	247 440
Quebec	12 413	127 204	8 378	1 367	386 733
New Brunswick	175	NA	6 359	1	25 501
Nova Scotia	5 883	2 076	13 571	1 616	75 512
Prince Edward Island	NA	NA	NA	NA	15
Newfoundland and Labrador	17 656	35 401	19 269	1 073	377 787
Nunavut	26 617	150 583	NA	50	177 350
Northwest Territories	NA	36	NA	NA	86
Yukon	NA	15	454	NA	931
Yearly totals	90 939	522 285	52 121	14 404	1 566 868[b]

[a] Does not include releases due to aircraft crash, collision, ice/frost, road conditions, subsidence, or vandalism.
[b] Releases that did not indicate province were not included in this total.
NA – not applicable, with no reported release volumes.

Table C-5. Number of aviation fuel spills affecting air, land, freshwater and saltwater, 2000–2009 (Environment Canada 2011)[a]

Year	Air	Land	Freshwater	Saltwater
2000	8	45	4	2
2001	12	64	3	9
2002	4	46	4	3
2003	16	56	4	9
2004	13	45	2	13
2005	21	55	8	7
2006	13	48	3	8
2007	7	38	1	9
2008	4	38	3	1
2009	5	12	2	5
Total[b]	103	447	34	66
Average	11	48	3	7
% of total[c]	15.8%	68.8%	5.2%	10.2%

[a] Does not include releases due to aircraft crash, collision, ice/frost, road conditions, subsidence or vandalism.
[b] Releases that affected multiple media were not differentiated from releases that affected a single medium. Releases that listed the medium affected as groundwater only (3), unknown (21), or that did not list a medium (216) are not included.
[c] Percent of total releases to air, land, freshwater and saltwater (650 releases).

Table C-6a. Sources of aviation fuel spills in Canada, 2000–2009 (Environment Canada 2011)[a]

Source	Total number of releases	Total volume of releases (litres)	Proportion of volume	Average release (litres)
Other storage facilities	46	507 475	0.32	11 534
Aircraft	472	406 807	0.26	906
Train	3	286 480	0.18	95 493
Other	77	173 420	0.11	2 477
Tank truck	85	67 618	0.04	856
Storage depot	13	42 310	0.03	4 701
Pipeline	10	31 382	0.02	3 487
Other industrial plant	7	12 454	0.01	1 779
Other watercraft	6	12 185	0.01	2 437
Other motor vehicle	39	7 266	0.00	196
Refinery	2	6 374	0.00	3 187
Unknown	31	3 924	0.00	178
Migration	7	3 560	0.00	593
Barge	5	2 045	0.00	511
Bulk carrier	6	1 750	0.00	350
Service station	5	800	0.00	800
Production field	1	410	0.00	410
Transport truck	4	330	0.00	83
Marine tanker	5	267	0.00	67
Electrical equipment	1	11	0.00	11
Municipal sewer	0	0	0.00	0
Municipal sewage treatment plant	0	0	0.00	0
Chemical plant	0	0	0.00	0
Marine terminal	0	0	0.00	0
-	-	-	-	-
Total	**825**	**1 566 868**	**1.00**	**2056**

[a] Does not include releases due to aircraft crash and collision, ice/frost, road conditions, subsidence and vandalism.

Table C-6b. Causes of aviation fuel spills in Canada, 2000–2009 (Environment Canada 2011)[a]

Cause	Total number of releases	Total volume of releases (litres)	Proportion of volume	Average release (litres)
Discharge	122	359 915	0.23	3 130
Derailment	2	286 080	0.18	143 040
Above-ground tank leak	40	208 925	0.13	6 145
Other	103	199 025	0.13	2 140
Container leak	34	176 354	0.11	5 511
Overflow	216	157 427	0.10	764
Unknown	88	60 804	0.04	833
Pipe leak	73	56 012	0.04	849
Overturn	8	21 500	0.01	4 300
Process upset	58	20 960	0.01	361
Valve, fitting leak	69	19 501	0.01	287
Sinking	2	190	0.00	190
Well blowout	7	147	0.00	21
Cooling system leak	1	25	0.00	25
Bilge pumping	1	2	0.00	2
Grounding	1	0	0.00	0
Dyke failure	0	0	0.00	0
Underground tank leak	0	0	0.00	0
Total	**825**	**1 566 868**	**1.00**	**2056**

[a] Does not include releases due to aircraft crash and collision, ice/frost, road conditions, subsidence and vandalism.

Table C-6c. Reasons for aviation fuel spills in Canada, 2000–2009 (Environment Canada 2011)[a]

Reason	Total number of releases	Total volume of releases (litres)	Proportion of volume	Average release (litres)
Unknown	120	440 075	0.28	4 445
Equipment failure	150	282 292	0.18	2 002
Human error	162	251 562	0.16	1 688
Material failure	187	184 449	0.12	1 019
Other	100	166 321	0.11	1 769
Damage by	10	112 838	0.07	12 538

equipment				
Intentional	53	98 520	0.06	1 932
Negligence	20	15 606	0.01	867
Corrosion	2	7 700	0.00	7 700
Migration	7	5 489	0.00	915
Overstress	5	1 791	0.00	358
Gasket, joint	8	221	0.00	32
Fire, explosion	1	3	0.00	3
Power failure	0	0	0.00	0
Weld, seam failure	0	0	0.00	0
Total	**825**	**1 566 868**	**1.00**	**2056**

[a] Does not include releases due to aircraft crash and collision, ice/frost, road conditions, subsidence and vandalism.

Appendix D: Persistence and Bioaccumulation

Table D-1. Experimental aerobic half-lives of hydrocarbons from a formulated gasoline in water (Prince et al. 2007b)

Aromatics

Chemical	Median half-life (days)	Mean half-life (days)
Benzene	3.2	4.6
1-methylethylbenzene	3.2	5.2
2-ethyl-1,3-dimethylbenzene	3.2	4.9

Two –ring aromatics

Chemical	Median half-life (days)	Mean half-life (days)
Naphthalene	3.2	4.4

***n*-Alkanes**

Chemical	Median half-life (days)	Mean half-life (days)
Butane	15.0	31.8
Hexane	6.5	10.2
Nonane	3.2	4.4
Dodecane	2.8	3.8

Isoalkanes

Chemical	Median half-life (days)	Mean half-life (days)
2-methylpropane (isobutane)	17.1	41.7
2-methylpentane	10.4	16.7
3-methylpentane	10.1	21.3
2-methylheptane	4.8	6.0
4-methylnonane	3.2	4.8

Cycloalkanes

Chemical	Median half-life (days)	Mean half-life (days)
1,1,3-trimethylcyclohexane	8.5	14.2

Alkenes

Chemical	Median half-life (days)	Mean half-life (days)
cis-3-hexene	6.5	8.4

Cycloalkenes

Chemical	Median half-life (days)	Mean half-life (days)
Cyclopentene	8.1	11.5
4-methylcyclopentene	8.1	12.5

Table D-2. Experimental biodegradation values for diesel fuel components in water (Penet et al. 2004)

Diesel fuel type	Culture type	Degradation endpoints/ units	Degradation value (%)	Mineralization value (%)
Straight run	Soil, Sludge	Biodegradation, % (28 days)	91 ± 1 45 ± 15	70 ± 4, 66 ± 13
Hydrocracking	Soil, Sludge	Biodegradation, % (28 days)	93 ± 3 61 ± 6	67 ±4, 50 ± 11
Supplemented hydrocracking	Soil, Sludge	Biodegradation, % (28 days)	90 ± 2 82 ± 4	85 ± 12, 58 ± 6
Light cycle	Soil, Sludge	Biodegradation, % (28 days)	88 ± 1 75 ± 7	70 ± 5, 53 ± 6
Fischer-Tropsch	Soil, Sludge	Biodegradation, % (28 days)	95 ± 4 79 ± 4	55 ± 8, 66 ± 4
Commercial	Soil, Sludge	Biodegradation, % (28 days)	93 ± 2 61	54 ± 4, 54

Table D-3. An analysis of persistence data for petroleum hydrocarbons representative of aviation fuels based on Environment Canada (2014)

Number of carbons	C_4	C_5	C_6	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{18}	C_{20}
***n*-alkane**	A	A	A	n/a	-	-	n/a	-	n/a	n/a	-	-	-
***i*-alkane**	A	A	A	-	-	-	n/a	-	-	n/a	-	n/a	-
***n*-alkene**	-	Sd	n/a	n/a	-	n/a	n/a	-	n/a	n/a	n/a	n/a	n/a
Monocycloalkane	n/a	n/a	-	-	-	-	n/a	-	n/a	n/a	-	n/a	-
Dicyclo-	n/	n/	n/	n/	Sd	n/	n/	Sd	n/a	n/a	S,	n/a	S,

alkane	a	a	a	a		a	a				W, Sd		W, Sd
Poly-cyclo-alkane	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Sd	n/a	S, W, Sd	n/a
Mono-aromatic	n/a	n/a	A	A	Sd		Sd	S, W, Sd	n/a	n/a	Sd	n/a	-
Cyclo-alkane mono-aromatic	n/a	n/a	n/a	n/a	S, W, Sd	S, W, Sd	n/a	S, W, Sd	n/a	n/a	S, W, Sd	n/a	S, W, Sd
di-aromatic	n/a	n/a	n/a	n/a	n/a	S, W, Sd	n/a	S, W, Sd	n/a	n/a	S, W, Sd	n/a	S, W, Sd
cyclo-alkane di-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	S, W, Sd	A	n/a	-	n/a	-
3-ring poly-aromatic	n/a	n/a	n/a	n/a	n/a	n/a	n/a	A	n/a	A,S, W, Sd	-	n/a	-

A – Predicted half-life in air of 2 days or greater
S – Predicted half-life in soil of 6 months or greater
W – Predicted half-life in water of 6 months or greater
Sd – Predicted half-life in sediment of one year or greater
- Indicates that these structures are not considered to persist for long periods of time in air, soil, water, or sediment**.**
n/a – not-applicable. Indicates that no such carbon number exists within the group or it was not modelled

Table D-4. An analysis of experimental and modelled bioaccumulation data for petroleum hydrocarbons representative of aviation fuels based on Environment Canada (2014)

# of carbons	**C_{12}**	**C_{13}**	**C_{14}**	**C_{15}**	**C_{18}**	**C_{20}**
***n*-alkane**	-	-	-	-	-	-
***i*-alkane**	-	B	n/a	B	n/a	n/a
alkene	B	n/a	n/a	n/a	n/a	n/a
monocycloalkane	B	n/a	n/a	B	n/a	n/a
dicycloalkane	B	-	n/a	B	n/a	n/a
polycycloalkane	n/a	n/a	B	n/a	-	n/a
monoaromatic	-	n/a	n/a	B	n/a	n/a
cycloalkane monoaromatic	-	n/a	n/a	B	-	B
diaromatic	B	B	-	-	n/a	n/a
cycloalkane	-	-	-	-	n/a	B

diaromatic						
3-Ring polyaromatic	-	n/a	B	-	n/a	B

B – Predicted highly bioaccumulative with a BCF/BAF greater than 5000
n/a – not-applicable. Indicates that no such carbon number exists within the group or it was not modelled
- Indicates that these structures are not considered highly bioaccumulative

Appendix E: Ecological Effects

Table E-1a. Acute empirical aquatic toxicity values of various aviation gasoline fuels

Organism	Common name	Test	Dose (mg/L)	Comment	Reference
Daphnia magna	Water flea	48-hr LC_{50}	28	AvGas 110 WSF [a]	Harris 1994
Daphnia magna	Water flea	48-hr LC_{50}	15	AvGas 80 WSF	Harris 1994

[a] Water-soluble fraction

Table E-1b. Acute empirical aquatic toxicity values of various aviation turbine fuels

Organism	Common name	Test	Dose (mg/L)	Comment	Reference
Daphnia magna	Water flea	48-hr LC_{50}	6	Jet A WSF	Harris 1994
Daphnia magna	Water flea	48-hr LC_{50}	26	Jet B WSF	Harris 1994
Pimpephales promelas	Fathead minnow	96-hr LC_{50}	18	Jet Fuel JP-4 WSF	Fisher et al. 1983
Pimpephales promelas	Fathead minnow	96-hr LC_{50}	18.7	Jet Fuel JP-4 WSF	Fisher et al. 1985
Pimpephales promelas	Fathead minnow	96-hr LC_{50}	18.8	Jet Fuel JP-4 WSF	Fisher et al. 1985
Pimpephales promelas	Fathead minnow	96-hr LC_{50}	5.5	Jet Fuel JP-8 WSF	Fisher et al. 1985
Oncorhynchus mykiss	Rainbow trout	128-day NOEC (mortality)	> 1.4	Jet Fuel JP-8 WSF	Klein and Jenkins 1983
Notemigonus chysolencas	Golden shiner	96-hr LC_{50}	8	Jet Fuel JP-8 WSF	Klein and Jenkins 1983
Jordanella floridae	Flagfish	128-day NOEC	> 1.5	Jet Fuel JP-8 WSF	Klein and Jenkins 1983

Table E-2a. Experimental aquatic toxicity values for gasoline

Fish: *Cyprinodon variegates* (sheepshead minnow)

Gasoline type	**Test**	**Toxicity value (mg/L)**	**Reference**
API PS-6	96-hr LC_{50}	8.3	CONCAWE 1992
Synthetic gasoline	96-hr LC_{50}	5.3	CONCAWE 1992

Fish: *Lepomis macrochirus* (bluegill sunfish)

Gasoline type	**Test**	**Toxicity value (mg/L)**	**Reference**
API PS-6	96-hr LC_{50}	6.3	CONCAWE 1992
Synthetic gasoline	96-hr LC_{50}	6.4	CONCAWE 1992

Fish: *Oncorhynchus mykiss* (rainbow trout)

Gasoline type	**Test**	**Toxicity value (mg/L)**	**Reference**
API PS-6	96-hr LC_{50}	2.7	CONCAWE 1992
Synthetic gasoline	96-hr LC_{50}	5.1	CONCAWE 1992
Unleaded / low-lead gasoline	48-hr LC_{50}	5.4–6.8	CONCAWE 1992
Unleaded / low-lead gasoline	96-hr LC_{50}	125–182	CONCAWE 1992
Unleaded / low-lead gasoline	168-hr LC_{50}	96–182	CONCAWE 1992
Unleaded / low-lead gasoline	96-hr LL_{50}	10–18	CONCAWE 1992
Unleaded / low-lead gasoline	96-hr NOEL	4.5–10	CONCAWE 1992

Fish: *Oncorhynchus mykiss* (Rainbow trout larvae)

Gasoline type	**Test**	**Toxicity value (mg/L)**	**Reference**
Unleaded / low-lead gasoline	48-hr LC_{50}	7	Lockhart et al. 1987
Unleaded / low-lead gasoline	48-hr LC_{50}	5	Lockhart et al. 1987

Fish: *Alburnus alburnus* (common bleak)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Unleaded / low lead gasoline	24-hr LC_{50}	47	CONCAWE 1992

Fish: *Alosa sapidissima* (American shad)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Gasoline (unspecified)	24-hr TLM	90–91	CONCAWE 1992
Gasoline (unspecified)	48-hr TLM	91	CONCAWE 1992

Freshwater invertebrates: *Daphnia magna* (water flea)

Gasoline type	Test	Toxicity value (mg/L)	Reference
API PS-6	48-hr EC_{50} (immobility)	3	CONCAWE 1992
Synthetic gasoline	48-hr EC_{50} (immobility)	1.2	CONCAWE 1992
Unleaded / low-lead gasoline	24-hr EC_{50} (immobility)	260	CONCAWE 1992
Unleaded / low-lead gasoline	24-hr EC_{50} (immobility)	345	CONCAWE 1992
Unleaded / low-lead gasoline	48-hr EC_{50} (immobility)	6.3	MacLean and Doe 1989
Unleaded / low-lead gasoline	48-hr EC_{50} (immobility)	4.9	MacLean and Doe 1989
Unleaded / low-lead gasoline	48-hr LC_{50}	6.8	Lockhart et al. 1987
Unleaded / low-lead gasoline	48-hr LC_{50}	5.4	Lockhart et al. 1987
Unleaded / low-lead gasoline	48-hr LC_{50}	50	MacLean and Doe 1989
Unleaded / low-lead gasoline	48-hr LC_{50}	18	MacLean and Doe 1989
Unleaded / low-lead gasoline	48-hr EC_{50} (immobility)	4.5–13	CONCAWE 1992
Unleaded / low-lead gasoline	48-hr NOEL (immobility)	4.5	CONCAWE 1992

Marine invertebrates: *Artemia sp.* (brine shrimp)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Unleaded / low-lead gasoline	48-hr EC_{50}	25.1	CONCAWE 1992
Unleaded / low-lead gasoline	48-hr LC_{50}	51	MacLean and Doe 1989

Marine invertebrates: *Mysidopsis bahia* (mysid shrimp)

Gasoline type	Test	Toxicity value (mg/L)	Reference
API PS-6	96-hr LC_{50}	1.8	CONCAWE 1992
Synthetic gasoline	96-hr LC_{50}	0.3	CONCAWE 1992

Marine invertebrates: *Metamysidopsis insularis* (mysid shrimp)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Unleaded gasoline	96-hr LC_{50}	0.1	Mohammed 2005

Marine invertebrates: *Strongylocentrotus droebachiensis* eggs (green sea urchin)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Gasoline (unspecified)	Cytolysis	> 38	CONCAWE 1992

Marine invertebrates: *Strongylocentrotus pallidus* eggs (pale sea urchin)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Gasoline (unspecified)	Irregular cleavage	28	CONCAWE 1992

Marine invertebrates: *Nitocra spinipes* (copepod)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Unleaded / low-lead gasoline	96-hr LC_{50}	171	CONCAWE 1992

Marine invertebrates: *Crangon crangon* (common shrimp)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Gasoline (unspecified)	96-hr LC_{50}	15	CONCAWE 1992

Marine invertebrates: *Tigriopus californicus* (copepod)

Gasoline type	Test	Toxicity value (mg/L)	Reference
Gasoline (unspecified)	24-hr 85% mortality	1	CONCAWE 1992

Marine invertebrates: *Tretraselmis chuii* (microalga)

Gasoline type	Test	Toxicity value (mg/L)	Reference
14 gasoline formations	96-hr IC_{50}	4.93–96.52	Paixão et al. 2007

Marine invertebrates: *Crassostrea rhizophorae* (oyster embryos)

Gasoline type	Test	Toxicity value (mg/L)	Reference
14 gasoline formulations	24-hr EC_{50}	8.25–41.37	Paixão et al. 2007

Table E-2b. Experimental aquatic toxicity values for diesel fuel

Algae: *Raphidocelis subcapitata* (green alga)

Test	Toxicity value (mg/L)	Reference
72-hr EL_{50}	2.6–25	CONCAWE 1996

Algae: *Phaeodactylum tricornutum* (marine diatom)

Test	Toxicity value (mg/L)	Reference
24-hr, 20% reduction in growth	3	Hing et al. 2011
24-hr NOEC	2.5	Hing et al. 2011

Algae: *Isochrysis galbana* (microalga)

Test	Toxicity value (mg/L)	Reference
24-hr LOEC (14%	26	Hing et al. 2011

reduction in growth)		

Algae: *Chlorella salina* (green alga)

Test	Toxicity value (mg/L)	Reference
24-hr LOEC	170	Hing et al. 2011

Algae: *Diatomus forbesi* (diatom)

Test	Toxicity value (mg/L)	Reference
96-hr LC_{50}	86.0	Lockhart et al. 1987

Invertebrates: *Artemia sp.* (brine shrimp)

Test	Toxicity value (mg/L)	Reference
48-hr LL_{50}	22	CONCAWE 1996
48-hr EC_{50}	36	Maclean and Doe 1989
48-hr LC_{50}	39	Maclean and Doe 1989

Invertebrates: *Crangon crangon* (brown shrimp)

Test	Toxicity value (mg/L)	Reference
96-hr LC_{50} (diesel fuel)	21	Franklin and Lloyd 1982
96-hr LC_{50} (diesel fuel)	12	Franklin and Lloyd 1982

Invertebrates: *Mysidopsis bahia* (mysid shrimp)

Test	Toxicity value (mg/L)	Reference
96-hr LL_{50}	8400	Neff et al. 2000

Invertebrates: *Metamysidopsis insularis* (tropical mysid)

Test	Toxicity value (mg/L)	Reference
96-hr LC_{50} UV light	0.17	Mohammed 2005
96-hr LC_{50} fluorescent light	0.22	Mohammed 2005

Invertebrates: *Penaeus vannamei* (whiteleg shrimp)

Test	Toxicity value (mg/L)	Reference
96-hr LL_{50}	8680	Neff et al. 2000

Invertebrates: *Arbacia punctulata* larvae (sea urchin)

Test	Toxicity value (mg/L)	Reference
96-hr LL_{50}	> 28 000	Neff et al. 2000

Invertebrates: *Daphnia magna* (water flea)

Test	Toxicity value (mg/L)	Reference
48-hr EC_{50} (immob)	0.29	Maclean and Doe 1989
48-hr EC_{50} (immob)	4.07	Maclean and Doe 1989
48-hr EL_{50} (repro.)	4.1	CONCAWE 1996
48-hr EC_{50} (repro.)	10	Environment Canada 2010
22-hr EC_{50} (repro.)	11.1	Wernersson 2003
22-hr EC_{50} (repro.)	17.6	Wernersson 2003
22-hr EC_{50} (repro.)	24.9	Wernersson 2003
24-hr LC_{50}	1.78	Khan et al. 2007
48-hr LC_{50}	18	Environment Canada 2010

Invertebrates: *Trigriopus californicus* (harpacticoid copepod))

Test	Toxicity value (mg/L)	Reference
48-hr LL_{50}	87.5	CONCAWE 1996

Invertebrates: Mytilus edulis (blue mussel)

Test	Toxicity value (mg/L)	Reference
30-day EC_{50} spawning	0.8	Strømgren et al. 1991[a]
10-day EC_{50} larval growth	0.03	Strømgren et al. 1991[a]
30-day LC_{50} adult	5.0	Strømgren et al. 1991[a]
10-day LC_{50} larvae	0.04	Strømgren et al. 1991[a]

Invertebrates: *Abra alba* (white furrow shell)

Test	Toxicity value (mg/L)	Reference
96-hr EC_{50}	44.0	Strømgren et al. 1993

fecal pellet production		

Fish: *Oncohrynchus mykiss* (rainbow trout)

Test	Toxicity value (mg/L)	Reference
48-hr LL_{50}	2.4	CONCAWE 1996
96-hr LC_{50}	100	Poirier et al. 1986
14-day EC_{50}	44.8	Mos et al. 2008[b]

Fish: *Oreochromis niloticus* (Nile tilapia)

Test	Toxicity value (mg/L)	Reference
96-hr LC_{50}	8.08	Dede and Kaglo 2001

Fish: *Micropogonius undulatus* (Atlantic croaker)

Test	Toxicity value (mg/L)	Reference
8-week sexual maturity	70% of WAF	Thomas and Budiantara 1995

Fish: *Amphirion clarkia* (yellowtail clownfish)

Test	Toxicity value (mg/L)	Reference
96-hr LL_{50}	> 28 000	Neff et al. 2000

Fish: *Menidia beryllina* (inland silverside)

Test	Toxicity value (mg/L)	Reference
96-hr LL_{50}	15 120	Neff et al. 2000

Fish: *Salmo sp.* (salmon species)

Test	Toxicity value (mg/L)	Reference
48-hr LC_{50}	2.52	Lockhart et al. 1987

Fish: *Alosa sapidissima (*American shad)

Test	Toxicity value (mg/L)	Reference
48-hr TLM	167	Lockhart et al. 1987

[a] Study based on microencapsulated diesel fuel ingested by bivalves.

[b] Low-sulphur diesel fuel.

LL_{50}: lethal loading 50, the amount of oil added to the test container that caused 50% toxicity.

TLM: median tolerance limit, the concentration of product necessary for 50% of the test organisms to die.

WSF: water-soluble fraction, the mass of product that dissolves into water at which 50% of the test organisms die. It is not acceptable to use a dilution of the WSF.

Table E-3. Modelled acute aquatic toxicity data for aviation fuels (PETROTOX 2009)[a,b]

Test organism	**Common name**	**CAS RN 64741-87-3 LL_{50}[c] (mg/L)** 10% HS[d] Ar:Al[e] = 26:52	**CAS RN 68527-27-5 LL_{50}[c] (mg/L)** 10% HS[d] Ar:Al[e] = 26:52	**CAS RN 64741-86-2 LL_{50}[c] (mg/L)** 10% HS[d] Ar:Al[e] = 52:48
Daphnia magna	Water flea	1.9	3.2	0.9
Oncorhynchus mykiss	Rainbow trout	0.9	1.8	0.3
Pseudokirchneriella capricornutum	Green algae	1.2	1.7[f]	0.5
Rhepoxynius abronius	Marine amphipod	0.4 [f]	0.9[f]	0.07
Palaemonetes pugio	Grass shrimp	0.8 [f]	1.6[f]	0.2
Menidia beryllina	Inland silverside	19.1	12	45
Neanthes arenaceodentata	Marine worm	5.4	5.1[f]	3.5

[a] PETROTOX was run in the low-resolution mode that requires only an aromatic to aliphatic ratio and a boiling point range for each hydrocarbon block.

[b] For modelling, PETROTOX uses physical-chemical properties for components found within the model database that may not be the same as those found in Table B-1.

[c] LL_{50} refers to lethal loading, the amount of product necessary to be added in order to kill 50% of test organisms.

[d] HS = Headspace.

[e] Ar:Al, aromatic: aliphatic ratio.

[f] No free product present at this loading.

Table E-4. Canada-wide standards for petroleum hydrocarbon fractions 1-4 in coarse-grained agricultural soils (CCME 2008)

Exposure pathways	**F1[a] (C_6–C_{10})**	**F2 (> C_{10}–C_{16})**	**F3 (> C_{16}–C_{34})**	**F4 (> C_{34})**
Protection of groundwater for aquatic life	970	380	N/A[b]	N/A
Protection of groundwater for livestock watering	5300	14 000	N/A	N/A
Nutrient cycling	NC[c]	NC	NC	NC
Eco soil contact	210	150	300	2800
Eco soil ingestion	NC	NC	NC	NC

[a] F: fraction.

[b] N/A: not available.

[c] NC: not calculated.

Table E-5. Estimated volume of water in contact with medium-persistence oil (m^3 x 10^6) for loading/unloading and transport processes via ship for various spill sizes (RMRI 2007)

Spill size (barrels)	Loading/unloading	Transport
1–49	40	5300
50–999	60	5500
1000–9999	150	8100
10 000–99 999	500	14 000
100 000–199 999	3500	37 000
> 200 000	33 000	62 000

Appendix **F**: Exposure Estimate Modelling Data and Results

Table F-1. Variable inputs to SCREEN3 for 90 and 180 kg/day total volatiles from aviation turbine fuel at a major Canadian airport

Variables	Input variables
Source type	Area
Process area	4890×2335 m^2[a]
Vapour release from refuelling operations	2.91×10^{-7} and 5.81×10^{-7} g/s·m^2
Effective area of refuelling	0.2 · (4890×3665 m^2)[b]
Receptor height	1.74 m[c]
Source release height	3 m[d]
Adjustment factor for yearly concentration	0.2[e]
Adjustment factor for daily concentration	0.4[e]
Urban/rural option	Urban
Meteorology	1 (Full meteorology)[f]
Minimum and maximum distance to use	1–10 0000 m

[a] Aerial photo analysis and professional judgement.
[b] Professional judgement, fraction of airport which acts as an emission source.
[c] Curry et al. 1993.
[d] Emissions were specified at 3 m, accounting for the common discharging points from storage tanks and vapour release from aircraft fuel tanks.
[e] U.S. EPA (1992) and professional judgement.
[f] Default value in SCREEN3.

Table F-2. Concentration (of volatiles derived from aviation fuel at a large Canadian airport based on 90 kg/day emissions.

	Concentration (µg/m^3)	Concentration (µg/m^3)	Concentration (µg/m^3)
Distance (m)	**Maximum 1 hr**	**Maximum 24 hr**	**Annual average**
1	18.0	7.2	3.6

	Concentration ($\mu g/m^3$)	**Concentration ($\mu g/m^3$)**	**Concentration ($\mu g/m^3$)**
100	18.2	7.3	3.6
200	18.4	7.4	3.7
300	18.6	7.4	3.7
400	18.8	7.5	3.8
500	19.0	7.6	3.8
600	19.2	7.7	3.8
700	19.4	7.7	3.9
800	19.6	7.8	3.9
900	19.7	7.9	3.9
1000	19.9	8.0	4.0
1100	20.1	8.0	4.0
1200	20.2	8.1	4.0
1300	20.4	8.2	4.1
1400	20.6	8.2	4.1
1500	20.8	8.3	4.2
1600	20.9	8.4	4.2
1700	21.1	8.4	4.2
1800	21.5	8.6	4.3
1900	21.7	8.7	4.3
2000	21.9	8.7	4.4
2100	22.0	8.8	4.4
2200	22.2	8.9	4.4
2300	22.3	8.9	4.5
2400	22.5	9.0	4.5
2500	22.6	9.1	4.5
2600	22.8	9.1	4.6
2700	23.0	9.2	4.6
2800	23.1	9.2	4.6
2900	23.3	9.3	4.7
3000	23.4	9.4	4.7

Assumptions made in the modelling:

- All evaporative emissions of aviation turbine fuel from the airport are assumed to be attributed to the fugitive emissions from refuelling of aircraft and storage tankers at the airport and from mobile refuelling sources.
- All releases occur for Jet A-1 handling at a large Canadian airport only.
- 90% of fuel is loaded through hydrant systems with no fugitive releases.
- Vapour release heights occur at 3 m (wing height of a passenger jet).
- Considering the fact that the release sources are actually multiple point sources spatially distributed over the airport area, the effective processing area used for calculation of emission rate is assumed to be 20% of the total airport area. Concentrations for the 180 kg/day emission rates at each distance are twice these values.

Table F-3. Variable inputs to SCREEN3 for bulk storage facility emissions

Variables	**Input variables**
Source type	Area
Effective emission area[a]	50×100 m^2

Emission rate of benzene (kg/hr)	2×0.02
Receptor height[b]	1.74 m (average adult height)
Source release height[a]	10 m
Adjustment factor[c]	0.4 (variable wind direction during 24-hr period) 0.2 average wind direction during 1-year period)
Urban-rural option	Urban
Meteorology[d]	1 (full meteorology)
Minimum and maximum distance	0–3000 m

[a] Professional judgement.
[b] Curry et al. (1993).
[c] U.S. EPA (1992).
[d] Default value in SCREEN3.

Appendix G: Summary of Health Effects Information for Aviation Fuels

Kerosene and related jet fuels were considered in the health effects profile for aviation fuels.

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
Acute health effects	64741-87-3	LC_{50} (inhalation; rat) >5000 mg/m^3 for a 4-hour exposure (ATDAEI 1990; CONCAWE 1992).
Acute health effects	8008-20-6 (straight-run kerosene)	LC_{50} (inhalation; rat) >5000 mg/m^3. No deaths occurred when rats were exposed for 4 hours to test substance vapours (Vernot et al. 1990).
Acute health effects	64742-80-1 (hydrodesulfurized kerosene)	LC_{50} (inhalation; rat) >5200 mg/L (5.2 mg/L). Rats exposed to sample 81-07 (hydrodesulfurized kerosene) for 4 hours (API 1983).
Acute health effects	JP-8	LOAEC (inhalation; mouse) = 50 mg/m^3. Male mice (C57BL/6 and B6.A.D.; 12/strain/concentration group) were nose-only exposed to 0, 5, 12, 28, 50 and 113 mg/m^3 JP-8 aerosols/vapours (generated using a nebulizer) for 1 hour. At 24–30 hours post-exposure, measurements of respiratory function, permeability and cellular injury were taken. Significantly increased respiratory permeability, concentration-dependent alveolar macrophage hyperplasia and infiltration, and significant mild to moderate microscopic and ultrastructural injury to the terminal bronchioles were noted at 50 mg/m^3. The authors hypothesize that these are reversible effects (Robledo and Whitten 1998). Female C57Bl/6 mice were nose-only exposed to 1000 mg/m^3 JP-8 aerosols for 1 hour. An immediate loss of immune function, accompanied by significant loss of viable immune cells and significant

Endpoint	**CAS RN / substance / study type**	**Effect levels^a/results**
		decreases in immune organ weights, were observed (Harris et al. 2002).
Acute health effects	64741-87-3	LD_{50} (dermal; rabbit) >2000 mg/kg-bw (API 1986a; ATDAEI 1990).
Acute health effects	8008-20-6 (straight-run kerosene)	LD_{50} (dermal; rabbit) >2000 mg/kg-bw. Undiluted test substance API 83-09 was applied occluded to abraded (1 rabbit/sex) and intact (1 rabbit/sex) skin for 24 hours. No deaths occurred, but hypoactivity and diarrhea were noted. Dermal irritation ranged from slight to marked (API 1985b).
Acute health effects	Jet-A	LD_{50} (dermal; species not stated) >4000 mg/kg-bw (API 1980a).
Acute health effects	64741-87-3	LD_{50} (oral; rat) >5000 mg/kg-bw. Effects noted included GI tract hyper-motility and diarrhea (API 1986a; ATDAEI 1990).
Acute health effects	Straight-run kerosene	LD_{50} (oral; rat) >5000 mg/kg-bw. Sample API 83-09 was administered to 5 male and 5 female SD rats as a single dose of 5 g/kg-bw via oral gavage. No deaths occurred, but hypoactivity, ataxia, prostration, lacrymation and hair loss were noted (API 1985b).
Acute health effects	Jet-A	LD_{50} (oral; rat) >20 000 mg/kg-bw (API 1980a).
Acute health effects	JP-5	LD_{50} (oral; rat) >60 mL/kg-bw (45 g/kg-bw)^b. Male SD rats administered 24 mlLkg-bw (18 g/kg-bw) exhibited moderately impaired renal and hepatic function in addition to fatty changes, and 1 mL/kg-bw (0.75 g/kg-bw) caused slight behavioural disturbances (Parker et al. 1981).
Short-term repeated-exposure health effects	64741-87-3	NOEL (dermal; rat) = 678 mg/kg-bw. 0, 50, 250 or 1000 µL/kg (0, 34, 170 or 678 mg/kg-bw) of undiluted test substance was applied to the clipped back skin of male and female SD rats (10/sex/group) and occluded for 6 hours/day, 5 days/week, for 4 weeks. Histologically confirmed, dose-dependent, slight to moderate skin irritation occurred. No

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		changes in body or organ weights, hematology or clinical chemistry parameters were observed (UBTL 1994).
Short-term repeated-exposure health effects	8008-20-6 (straight-run kerosene)	LOAEL (dermal; rabbit) = 200 mg/kg-bw/day based on significantly increased absolute and relative spleen weights in females, decreased hemoglobin and hematocrit and significantly decreased red blood cells in males, and thinness, lethargy, wheezing and nasal and anal discharge in both sexes. Undiluted test substance API 83-09 was applied to the shorn dorsal skin at 200, 1000 and 2000 mg/kg-bw, 3 times/week, for 28 days. In the higher-dose groups, both sexes had increased relative heart weights, and one male and one female died in the highest-dose group. Also noted at the highest dose were proliferative inflammatory changes in the skin at the application site, as well as bone marrow granulopoiesis in animals of both sexes. Increases in adrenal weights and testicular tubular hypoplasia in high-dose males were considered to be due to stress and changes to the skin or body weight, respectively (API 1985a).
Short-term repeated-exposure health effects	Jet-A	A 28-day unoccluded dermal study was conducted in female SD rats (10/dose). Groups were exposed to 0, 165, 330 or 495 mg/kg-bw/day of Jet A in mineral oil (positive control groups received cyclophosphamide and anti-asialo GM1). No immunotoxicity was identified in the test substance groups that included screening for spleen and thymus weights, IgM antibody-forming cell response to T-dependent antigen, splenic lymphocyte subpopulations and cell proliferative response to anti-CD3 antibody, natural killer cell activity and immune response to sheep red blood cells (Mann et al. 2008).

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		A 14-day dermal study was conducted using rabbits. Test substance was applied 5 times/week at 6400 mg/kg-bw/day. Depression, weight loss and severe skin damage at the application site was noted. Considered secondary to the skin damage was liver necrosis and kidney and bladder hyperplasia (API 1985a, 1985c).
Short-term repeated-exposure health effects	JP-8	LOAEL (dermal; mouse) = 1140 mg/kg-bw[e,h]. Female C3H/HeNCr mice (3–5/group) were exposed via the dorsal skin to 50 µL (40 mg) JP-8 once/day for 1–5 days (a parallel study also exposed groups to 25, 100, 200 and 300 µL for 5 days). Dose-dependent suppression of the immune system, as indicated by the impaired induction of contact hypersensitivity ($p < 0.05$ at 4 and 5 days of exposure) and suppression of delayed-type hypersensitivity ($p < 0.05$) (examined at day 5) to a bacterial antigen was observed (Ullrich 1999).
Short-term repeated-exposure health effects	JP-8	LOAEC (inhalation; mouse) = 45 mg/m^3. Male C57BL/6 mice (12/exposure level; 6/control group) were nose-only exposed to JP-8 aerosols (5–15% of total) and vapours (85-95% of total) at an average concentration of 45, 267 and 406 mg/m^3 for 1 hour/day for 7 days (daily exposures were within 10% of the listed averages). At all concentrations, generalized sloughing of the bronchiolar epithelium was seen, and various cellular changes were observed in alveolar type II epithelial cells, including increased number and size of surfactant-producing lamellar bodies; however, at the lower concentrations, lung function was not affected. At the highest concentration, a statistically significant 20% decrease in inspiratory dynamic lung compliance was observed (Herrin et al 2006).

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		Groups of male B6.A.D. mice (12/concentration level) were nose-only exposed to JP-8 aerosols (5–15% of total) and vapours (85–95% of total) (generated with a nebulizer) at average concentrations of 0, 7, 12, 26, 48 and 118 mg/m^3 for 1 hour/day for 7 days. Mice exposed to 48 mg/m^3 exhibited increased respiratory permeability (as measured by the pulmonary clearance of intratracheally instilled ^{99m}Tc-labelled diethylenetriaminepentaacetic acid), increased total protein in the bronchoalveolar lavage fluid and concentration-dependent morphological lung and alveolar injury (Robledo et al. 2000). Male and female mice (C57BL/6 and B6.A.D.; 3–21/group) were nose-only exposed to 0, 100, 250, 500, 1000 and 2500 mg/m^3 JP-8 vapours/aerosols (generated using a nebulizer) for 1 hour/day for 7 days. A concentration-dependent, significant loss of total viable cells from the thymus was seen for the group(s) exposed to 100 mg/m^3. A statistically significant ($p < 0.05$) suppressive effect on splenic immune cell proliferation was also seen at this concentration. A statistically significant, concentration-dependent decrease in spleen and thymus weights was noted at the three highest concentrations. The authors reported that male and female mice were equally affected by exposure to JP-8, but they did not provide gender- or strain-specific data (Harris et al. 1997). Female C57B1/6 mice were exposed by nose-only inhalation to 0 or 1000 mg/m^3 aerosolized JP-8 for 1 hour/day for 7

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		days. A significant change in thymus cell subpopulations was reported in the exposed mice, as was a suppression of splenic cell immune function (Harris et al. 2000). C57Bl/6 mice exhibited significant immunosuppression after exposure to 1000 mg/m^3 JP-8 for 1 hour/day for 1 (Harris et al. 2002) to 7 days (Harris et al. 2008), and during gestation (Harris et al. 2007a). JP-8 exposure was shown to reduce the immune response to influenza viral infection, including decreased immune cell viability, and resulted in a greater than four-fold decrease in immune cell proliferative responses to mitogens and a loss of T cells from the lymph nodes (Harris et al. 2008). Immunotoxicity of JP-8 has been implicated as a mechanism for increasing the incidence and metastatsis of lung tumours, and decreased survival, in a melanoma B16 mouse tumour model (Harris et al. 2007b). Increase in cytokine levels and decrease in immune function in female C57BL/6 mice due to inhalation of 1000 mg/m^3 aerosolized JP-8 for 1 hour/day for 7 days (significant increase in IL-10, increase in PGE2 levels). A partial recovery of immune function returned after a Cox-2 inhibitor was administered. The increased PGE_2 levels were considered by the authors to not be the sole cause of loss of immune function due to JP-8 exposure (Harris et al. 2007c). There was a significant increase in inspiratory and expiratory lung resistance compared to controls in male C57BL/6

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		mice exposed via nose-only inhalation to vapour/aerosol at 0 and 53 mg/m^3 JP-8 daily for 1 hour for 7 days. In addition, cell injury was noted in the Clara cells of the terminal bronchioles, and changes to type II epithelial cells were reported (Wong et al. 2008). There was a significant difference compared with controls in the inflammatory response of young (3.5 month old) and adult (12 month old) male C57BL/6 mice from inhalation of 1000 mg/m^3 aerosolized JP-8 daily for 1 hour for 7 days. Broncho alveolar lavage fluid (BALF) cell differential, tumour necrosis factor-α (TNF-α), 8-isoPGF$_2$ levels were different between young and adult mice, where increased lung compliance, respiratory permeability, MIP-2 levels, as well as decreased PGE$_2$ levels were reported similarities (Wang et al. 2001). There was a significant increase in pulmonary vascular permeability, BALF SP levels in female C57BL/6 mice exposed via inhalation to 1023 mg/m^3 aerosolized JP-8 for 1 hour for 7 days, compared to controls. Dilation of respiratory bronchioles and alveoli were also observed (Wong et al. 2004). Male Long-Evans Rats were exposed via inhalation (nose-only) to 0, 500, 1000 or 2000 mg/m^3 aerosolized JP-8 for 4 hours/day for 5 days. Following exposure, groups were exposed to 1 hour of noise, or to no noise. No ototoxicity was noted in rats exposed to JP-8 without subsequent noise (Fechter et al. 2010). Male Long-Evans rats were exposed through inhalation (nose-only) to 1000

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		mg/m^3 aerosolized JP-8 for 4 hours/day for 1 or 5 days. In addition, noise or no noise followed JP-8 treatment. No ototoxicity was noted after a single JP-8 exposure. Repeated exposure was reported to have an effect on outer hair cell function (decrease in distortion product otoacoustic emissions [DPOAE] amplitude); however, some recovery was noted 4 weeks after exposure. A significant decrease in liver glutathione levels was reported immediately after, and 1 hour following, exposure (Fechter et al. 2007). Male F344 rats were exposed via inhalation (nose-only) to control or the mean aerosolized JP-8 level of 1236.8 mg/m^3 for 1 hour/day, 5 days/week for 28 days. Exposed mice were reported to have significant differences in spontaneous activity and central nervous system (CNS) excitability compared to controls, as well as more locomotive behaviour and faster swim speeds when conducting the functional observational battery (FOB) (Baldwin et al. 2001). Male SD rats were exposed via whole-body inhalation to 0, 500 or 1000 mg/m^3 JP-8 vapour for 6 hours/day, 5 days/week for 6 weeks. At the low concentration, treated rats exceeded control animals when learning and performing complex tasks. At the high-concentration level, deficits in learning and performance at moderate or difficult tasks were reported. Treated rats were also noted to have significantly higher neurotransmitter levels compared to control animals (Ritchie et al. 2001b). SD rats were exposed to 1100 mg/m^3 test

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		substance vapours for 30 days. Significant polydipsia was noted in the exposed group relative to the control group (Bogo et al 1984).
Short-term repeated-exposure health effects	JP-5 / JP-8	SD rats were exposed to 0 or 1000 mg/m^3 JP-8 vapour or 1200 mg/m^3 JP-5 vapour for 6 hours/day, 5 days/week for 6 weeks. Significant changes in neurobehavioural capacity were noted, including significant changes to neurotransmitter levels, and testing results (appetitive reinforcer approach sensitization [ARAS], forelimb grip strength) from the Neurobehavioural Toxicity Assessment Battery (NTAB) (Rossi et al. 2001).
Subchronic repeated-exposure health effects	Kerosene	LOAEC (inhalation; rat) = 58 mg/m^3 was identified based on decreased blood glucose in Wistar rats exposed to kerosene vapours for 6 hours/day, 6 days/week for 14 weeks. At a higher exposure level (231 mg/m^3), increased blood lactate and pyruvate levels, and decreased metabolism of phenacetin, was noted (Starek and Vojtisek 1986).
Subchronic repeated-exposure health effects	JP-5	Markedly increased hyaline droplets in kidney proximal tubular cells and dilated corticomedullary tubules (that were plugged with necrotic debris) were seen in almost all male Fischer 344 rats exposed to 150 or 750 mg/m^3 petroleum and shale-derived JP-5 vapours (generated by heating the fuels to 50-57^{o}C) for 24 hours/day for 90 days. Other effects noted included decreased growth rate of male rats, and statistically significant increases in blood urea nitrogen (BUN) and serum creatinine levels in high-concentration male and female rats. Animals were followed for 19 months post-exposure; exposure-related effects included concentration-dependent medullary intratubular mineralization,

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		concentration-related focal hyperplasia of the renal pelvis, and increased severity of progressive renal nephropathy (tubule degeneration). The kidney effects may be mediated through a male rat-specific protein, α-2-microglobulin, and therefore the relevance of these effects to humans is questionable (Bruner 1984; Gaworski et al. 1984; MacNaughton and Uddin 1984).
Subchronic repeated-exposure health effects	JP-8	Male SD rats were whole-body exposed to heated JP-8 vapours at 0, 250, 500 and 1000 mg/m^3 for 6 hours/day for 91 days. At the lowest concentration, concentration-dependent effects included mild damage to kidney proximal convoluted tubules, a 10% reduction in bone marrow fat cells/globules, and a low level of cell proliferation in the bone marrow. At the two highest concentrations, these effects were enhanced, and histological changes to the liver, bone marrow and heart damage, as well as enlargement of lung capillaries were noted (Hanas et al. 2010). Male and female Fischer 344 rats (7–15/sex/group) and C57BL/6 mice (100/sex/group) were exposed continuously to 0, 500 or 1000 mg/m^3 JP-8 vapour for 90 days. In mice, no effects were observed apart from necrotizing dermatitis due to fighting, which caused increased mortality, especially in males. In male rats, a significant decrease in body weight, increased absolute and relative kidney weight and increased basophilic foci in livers were noted at both concentration levels. In addition, renal effects consistent with chronic progressive nephrosis due to α-2-microglobulin were observed in male

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		rats. This is a mechanism that may not be relevant to humans. LOAEC: 500 mg/m^3 as identified by U.S. EPA (2011) for decreased body weight and increased absolute and relative kidney weight in male rats (Mattie et al. 1991).
Subchronic repeated-exposure health effects	JP-8	NOAEL (oral; rat) = 3000 mg/kg-bw/day. Rats were administered test substance daily via oral gavage for 90 days. No deaths or histopathological changes were observed (Mattie et al. 1995).
Subchronic repeated-exposure health effects	Hydrodesulfurized kerosene (64742-80-1)	Dose-dependent skin irritation was seen in male and female SD rats (12/sex/dose) dermally exposed to test substance at 165, 330 or 495 mg/kg-bw/day, 5 days/week for 13 weeks. At the highest dose, females had increased absolute and relative spleen weights (U.S. EPA 2011).
Reproductive and developmental health effects	JP-8	Maternal and developmental effects, including immunotoxicity and decreased birth rate and survival of pups, were observed at 1000 mg/m^3 in a JP-8 inhalation study in mice. Pregnant C57Bl/6 mice were nose-only exposed to aerosols of JP-8 at 1000 mg/m^3 for 1 hour/day, from gestational days (GD) 7 to birth or from GD 15 to birth. Maternal effects were noted in both groups, and included decreased thymus weights and viable immune cells, and depressed immune function, as measured at 6–8 weeks post-exposure. Developmental effects included decreased births and viability of male offspring. All newborn pups exhibited decreased immune organ weights, decreased viable immune cell numbers and reduced immune function, with male pups being affected to a greater extent (Harris et al. 2007a).
Reproductive and	Kerosene	NOAEC (inhalation; rat) = 400 ppm (2780 mg/m^3).[c] Groups of 20 SD rat

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
developmental health effects		dams were exposed to 100 or 400 ppm (695 and 2780 mg/m^3) test substance vapour for 6 hours/day on gestation days 6–15. No reproductive or developmental toxicities were noted (API 1979a).
Reproductive and developmental health effects	Jet-A	NOAEC (inhalation; rat) = 400 ppm (2945 mg/m^3).[d] Charles River CD rat dams were exposed to 100 and 400 ppm (736 and 2945 mg/m^3) Jet-A for 6 hours/day on days 6-15 of gestation. No embryotoxic, fetotoxic or teratogenic effects were observed (Beliles and Mecler 1982). NOAEC (inhalation; rat) = 400 ppm (2945 mg/m^3).[d] Groups of 20 SD rat dams were exposed to 100 or 400 ppm (736 and 2945 mg/m^3) of test substance vapour for 6 hours/day on gestation days 6–15. There was a slight increase in fetuses with retarded bone ossification in the high-concentration group, but these effects were not considered by the authors to be adverse. No other effects were noted (API 1979b). In a different study (dominant lethal assay), exposure of male mice to Jet-A vapours at 100 or 400 ppm (736 and 2945 mg/m^3)[d] for 6 hours/day, 5 days/week for 8 weeks did not affect female reproductive parameters after mating, such as fertility index, number of implants and proportion of dead implantations (API 1980b).
Chronic health effects (non-carcinogenicity studies)	64741-87-3	NOEL (dermal; mouse) = 970 mg/kg-bw. Male C3H mice (group of 47) were exposed to 50 µL (970 mg/kg-bw) [e,f,g] of undiluted test substance (sample API 81-08) twice/week for life. Body weights and clinical signs were normal. At the application site, mild to moderate desquamation with slight irritation and

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		scabbing was noted (API 1989a).
Chronic health effects (non-carcinogenicity studies)	JP-5 navy fuel* / Kerosene	LOAEL (dermal; mouse): 250 mg/kg-bw/day. Male and female B6C3F1 mice (50/group) were exposed to JP-5 navy fuel* at 0, 250 or 500 mg/kg-bw/day in 0.1 mL acetone for 5 days/week for 103 weeks (90 weeks for high-dose females). A marked increase in the incidence of dermal ulceration, inflammation and epithelial hyperplasia were observed. High-dose males and females exhibited multiple organ amyloidosis, and high-dose females had approximately 50% decreased survival to 90 weeks relative to low-dose females at 105 weeks (17/50 vs. 33/50, respectively) (NTP 1986). *also referred to as CAS RN 8008-20-6 (kerosene) in the study
Chronic health effects (non-carcinogenicity studies)	Straight-run kerosene (8008-20-6)	50 µL (1170 mg/kg-bw)[e,i,j] of undiluted test substance (straight-run kerosene; sample API 83-09) was applied twice weekly to mice for periods ranging from 3–24 months. Some animals showed skin ulceration and one squamous cell carcinoma was found at 12 months. Also, chronic skin irritation, and increases in absolute and relative kidney, liver and lung weights, were reported (API 1986c).
Chronic health effects (non-carcinogenicity studies)	JP-5 and JP-8	LOAEL (dermal; mouse) = 50 µL (1070 mg/kg-bw)[b,e]. $C3H_f/Bd_f$ mice developed renal lesions after exposure to test substances applied to clipped back skin thrice weekly for 60 weeks. Nephron atrophy and degeneration, and papillary necrosis, were also observed (Easley et al. 1982).
Carcinogenicity	64741-87-3	Skin painting studies: Undiluted test substance (API 81-08; 50 µL [970 mg/kg-bw])[e,f,g] was applied to the shaved intrascapular skin of male C3H/HeJ mice (group of 50) twice/week for life. A non statistically significant

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		increase in the incidence of squamous cell papillomas (4%) and carcinomas (2%) was noted (3/50 mice in the test substance group developed tumours). The toluene-only-exposed group had 4 mice with tumours with a squamous cell carcinoma incidence of 6% and fibrosarcoma incidence of 2%, and all mice (49/49) in the positive control group (0.05% w/v benzo[*a*]pyrene in toluene) developed tumours. Mean latency to tumour formation was 113 weeks in the test group, 111 weeks in the toluene-exposed group and 49 weeks in the positive control group (Skisak et al. 1994). Undiluted test substance (API 81-08; 50 µL [970 mg/kg-bw]) [e,f,g] was applied over at least 1 cm^2 to the clipped intrascapular region of the backs of male C3H/HeJ mice (50/group) twice per week for life. After 31 months, 4 mice in the test group each had a benign tumour, while the negative control mice had no tumours, and 33 mice in the positive control group had tumours (14 benign and 19 malignant). Mean latency to tumour formation was 112 weeks for the test group and 84.5 weeks for the positive control group (API 1986b, 1986d). C3H male mice (a group of 47) were exposed twice weekly for 139 weeks to 50 µL (970 mg/kg-bw) [e,f,g] test substance API 81-08. Benign skin tumours developed in 4% of test group mice (0% incidence in both the negative and solvent control groups). Malignant skin tumours developed in 2% of test group mice (0% and 8% for the control groups as above, respectively). Regarding benign and malignant tumours at other

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		sites, 2% of mice in the test substance group had benign tumours (0% and 2% for control groups, respectively) and 4% had malignant tumours (2% and 0% for control groups, respectively). Using a Chi square test, it was determined that the test substance did not cause a statistically significant increase in tumours above that seen in the negative and solvent control groups (API 1989a). Initiation study: Male CD-1 mice (30/group) were exposed to 50 µL (970 mg/kg-bw/day)[e,f,g] of undiluted test substance for 5 consecutive days. After a 2-week rest period, 50 µL of the tumour promoter phorbol-12-myristate-13-acetate (PMA) was administered twice/week for 25 weeks. Both substances were applied to shaved dorsal intrascapular skin. There was no increased incidence of tumour formation in the test group (3/29 mice in the test group developed tumours (squamous cell papillomas) compared with 3/30 mice in the negative control group and 30/30 in the positive control group). Mean latency to tumour formation was 20 weeks (Skisak et al. 1994). Promotion study: Male CD-1 mice (30/group) were exposed once to 50 µL of tumour initiator 7,12-dimethylbenzanthracene (DMBA). After 2 weeks, 50 µL (970 mg/kg-bw per day)[e,f,g] of undiluted test substance was applied twice/week for 25 weeks. Both DMBA and test substance were applied to shaved dorsal intrascapular skin. No tumours formed in the test and negative control groups, whereas 30/30 mice in

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		the positive control group developed tumours (Skisak et al. 1994).
Carcinogenicity	Straight-run kerosene (8008-20-6)	Skin painting studies: Male C3H/HeJ mice (50/group) were exposed to 50 mg test substance (1430 mg/kg-bw)[e,h] twice weekly for 80 weeks or until a papilloma larger than 1 mm^3 appeared. Test substance was applied to the shaved interscapular region. In 2 test substance groups, 9 of 30 and 4 of 27 mice developed tumours with average latency periods of 70 and 62 weeks, respectively. The negative control groups consisted of shaved-only (four groups) or toluene-treated (7 groups) and, combined, 0 and 3 mice developed tumours within these groups, respectively (Blackburn et al. 1986). Male C3H/HeJ mice (50/group) were exposed to 100% test substance (1170 mg-kg/bw)[e,i,j] MD-3 twice/week, or 50% (580 mg-kg/bw) 4 times/week, or 28.5% (330 mg-kg/bw) 7 times/week (in 50 µL) for 104 weeks. A negative control group received 35 µL mineral oil 7 times/week. Substances were applied to the shorn dorsal skin. Skin tumours did not form in the groups receiving 0%, 28.5% or 50% test substance. However, 12 of 50 mice developed skin tumours (squamous cell carcinomas, papillomas, fibrosarcomas) in the group exposed to 100% test substance. Dermal irritation was highest in this group and was suspected of playing a role in tumour development (CONCAWE 1991). Exposure of 50 mice twice weekly for life (> 2 years) to 50 µL test substance (1170 mg-kg/bw)[e,i,j] API 83-09 resulted in 1 benign and 19 malignant skin tumours.

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		Mean latency to tumour development was 76 weeks (API 1989b).
Carcinogenicity	JP-5	Skin painting study: Male and female B6C3F1 mice (50/group) were exposed to JP-5 navy fuel at 0, 250 or 500 mg/kg-bw per day in 0.1 mL acetone for 5 days/week for 103 weeks (90 weeks for high-dose females). Skin neoplasms at the application site did not occur, but inguinal carcinomas were observed in 1 high-dose male and female, and in 1 low-dose male. Additionally, the incidence of malignant lymphomas was increased in low-dose females (control: 7/48; low dose: 19/49; high dose: 5/47). High-dose females exhibited approximately 50% decreased survival to 90 weeks relative to low-dose females at 105 weeks (17/50 vs. 33/50, respectively), as well as severe skin ulcerations that necessitated sacrifice of the remaining 17 high-dose females 15 weeks earlier than the other groups. The significantly decreased survival rate and early sacrifice likely precluded the determination of the actual number of high-dose females with malignant lymphomas. However, the high number seen in the low-dose group (19/49) was within range for historical untreated control mice from the same laboratory (NTP 1986).
Carcinogenicity	Jet-A	Skin painting study: Male and female C3H/HeN mice (25/sex/group) were exposed to 25 mg test substance (710 mg/kg-bw)[e,h], 3 times/week for 105 weeks. Skin tumours (squamous cell carcinomas and fibrosarcomas) formed in 11 of 43 mice after exposure to petroleum-derived Jet-A, with a mean latency to tumour

Endpoint	CAS RN / substance / study type	Effect levels^a/results
		development of 79 weeks (Clark et al. 1988). In another study, the role of dermal irritation in skin tumourigenicity was investigated. One group of mice received test substance thrice weekly, whereas another group received test substance intermittently, and only when signs of dermal irritation were diminished. In the former group, 44% of the mice had skin tumours whereas in the latter only 2% had tumours. The authors concluded that chronic skin irritation may play a role in skin tumourigenicity of this substance (Freeman et al. 1993).
Genotoxicity: *in vivo*	64741-87-3	Chromosomal aberration: Male and female SD rats (10/sex/group) were whole-body exposed to 0, 65, 300 or 2050 ppm (173, 796 or 5442 mg/m^3) of test substance (API 81-08) 6 hours/day for 5 days. A positive control group received an intraperitoneal injection of 0.8 mg/kg triethylenemelamine. Tibia bone marrow was harvested 6 hours after the final exposure of the test and negative control groups. No induction of chromosomal aberrations occurred in the test or negative control groups, and no systemic toxicity was observed (API 1986e).
Genotoxicity: *in vivo*	Straight-run kerosene	Chromosomal aberration: Bone marrow cytogenetic tests in SD rats were negative with four samples of kerosene (API 1977, 1979c, 1984, 1985c). One study administered test substance API 83-09 via intraperitoneal injection at 300, 1000 and 3000 mg/kg-bw. Sister chromatid exchange (SCE):

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		A positive result was seen in male mice and a negative result in female mice in a sister chromatid exchange assay (API 1988).
Genotoxicity: *in vivo*	Hydrodesulfurized kerosene	Chromosomal aberration: Hydrodesulfurized kerosene in corn oil was applied intraperitoneally to B6C3F1 mice (5/sex/dose) at levels of 0, 400, 2000 or 4000 mg/kg-bw (U.S. EPA 2011). Significant increases in chromosomal aberrations were induced in male mice at all doses. No structural/chromosomal aberrations were observed after intraperitoneal administration of 0, 0.3, 1 or 3 g/kg hydrodesulfurized kerosene to male and female SD rats (15/sex/dose) (U.S. EPA 2011; API 1984).
Genotoxicity: *in vivo*	JP-8	Micronuclei induction: There was a significant difference in micronuclei incidence in peripheral blood of female mice 72 hours after dermal exposure to JP-8 (240 mg/mouse or 300 µL) compared to negative controls (Vijayalaxmi et al. 2004). Female C3H/H3NCR mice were dermally exposed to 50, 100 or 300 µL of undiluted JP-8 for 3 consecutive days. Application weekly for 3 weeks or a single exposure did not increase micronuclei incidence in bone marrow and peripheral blood (Vijayalaxmi et al. 2006).
Genotoxicity: *in vivo*	Jet-A	Chromosomal aberration: Test substance induced chromosomal aberrations in the bone marrow of male and female SD rats exposed via inhalation for 20 days to 100 ppm (736

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		mg/m^3)^d or 5 days to 400 ppm (2945 mg/m^3)^d (API 1979c; Conaway et al. 1984). Nasal irritation, sneezing and respiratory distress were noted in the animals. Mutagenicity: Test substance was negative in a dominant lethal assay after administration to male CD-1 mice at 100 and 400 ppm via inhalation for 6 hours/day, 5 days/week for 8 weeks (API 1973, 1980b). Micronuclei induction: There was a significant difference for micronuclei incidence in peripheral blood of female mice 72 hours after dermal exposure to Jet-A (240 mg/mouse or 300 µL) compared to negative controls (Vijayalaxmi et al. 2004). Female mice were dermally exposed to 50, 100 or 300 µL of undiluted Jet-A for 3 consecutive days. Application weekly for 3 weeks or a single exposure did not increase micronuclei incidence in bone marrow and peripheral blood (Vijayalaxmi et al. 2006).
Genotoxicity: *in vitro*	64741-87-3	Mutagenicity: L5178Y TK$^{+/-}$ mouse lymphoma cells were exposed to test substance (API 81-08) for 4 hours at concentrations of 0.005-0.08 µL/mL without S9 activation and 0.00004-0.8 µL/mL with Aroclor-induced rat liver S9 activation. Five trials were performed to verify the absence of genotoxicity due to a fluctuating range of toxicity and sporadic increases in mutant frequencies (API 1985c).

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
Genotoxicity: *in vitro*	Straight-run kerosene	Mutagenicity: Test substance gave negative and positive results at 50 μL/plate in *Salmonella typhimurium* TA98 using the modified Ames assay, with activation by Aroclor-induced rat liver S9. In other trials, mutagenicity indices of 0 and 2.9 were assigned, and no 3–7 ring PAHs were measured in the sample (API 1977, 1978, 1979; Blackburn et al. 1986; CONCAWE 1991). Mouse lymphoma: In a mouse lymphoma assay conducted according to good laboratory practices, kerosene was positive without metabolic activation and equivocal with activation (API 1985d as cited in API 2003a). In another study, kerosene produced negative results (API 1977).
Genotoxicity: *in vitro*	Hydrodesulfurized kerosene	Mouse lymphoma: No increase in mutation frequency with or without activation in mouse lymphoma L5178Y cells. Cells were exposed to 0, 6.25, 12.5, 25 and 37.5 nL/mL hydrodesulfurized kerosene (API sample 81-07) in ethanol for 4 hours with or without metabolic activation (U.S. EPA 2011; API 1984). Sister chromatid exchange: No increased incidence of sister chromatid exchange in Chinese hamster ovary cells with and without activation. Cells were exposed to 0.007–0.05 µL/mL hydrodesulfurized kerosene (sample API 81-07) in acetone (U.S. EPA 2011; API 1988).
Genotoxicity: *in*	JP-8	DNA damage:

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
vitro		Increase in strand breaks and DNA lesions with increasing concentration of JP-8 (3-20 µg/mL) in rat hepatoma (H4IIE) cells compared to ethanol controls, where the cell strain is noted to be metabolically active (Grant et al. 2001). There was a significant difference for 1:300 to 1:75 JP-8 dilutions compared to control for mean tail moment and mean percent DNA when JP-8 (dilutions from 1:500 to 1:75) was added to peripheral lymphocytes and monocytes from whole peripheral blood of human volunteers (Jackman et al. 2002).
Genotoxicity: *in vitro*	JP-8+100	DNA damage: Significant difference for 1:500 to 1:75 JP-8+100 dilutions compared to control for mean tail moment and mean percent DNA when JP-8+100 (dilutions from 1:500 to 1:75) was added to peripheral lymphocytes and monocytes from whole peripheral blood of human volunteers (Jackman et al. 2002).
Genotoxicity: *in vitro*	JP-5	Mutagenicity: Test substance was not mutagenic in the Ames assay at 0.1–10 mg per plate with or without Aroclor 1254-induced rat or hamster liver S9. *Salmonella typhimurium* strains TA97, TA98, TA100 and TA1535 were used (NTP 1986). Test substance was negative in the mouse lymphoma assay at 10 mg/plate, with and without activation. L5178 TK$^{+/-}$ cells were used (NTP 1986). DNA damage:

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		There was a significant difference for 1:300 to 1:75 JP-5 dilutions compared to control for mean tail moment and mean percent DNA when JP-5 (dilutions from 1:500 to 1:75) was added to peripheral lymphocytes and monocytes from whole peripheral blood of human volunteers (Jackman et al. 2002).
Genotoxicity: *in vitro*	Jet-A	Mutagenicity: Test substance was positive for mutagenicity in a mouse lymphoma assay with activation by mouse or rat liver S9. L5178 $TK^{+/-}$ cells were used (Conaway et al. 1984). Substance was negative without activation.
Human studies	Case-control study	A study examining 20 different cancer sites among 3726 affected men was conducted to determine potential excess risk of a particular cancer due to occupational exposure to petroleum-derived liquids. Men with substantial exposure to aviation gasoline or jet fuel (kerosene-type and wide-cut) had an excess risk for kidney cancer (adjusted odds ratios [OR] = 3.9 and 3.4; 90% confidence intervals [CIs] = 1.7–8.8 and 1.5–7.6, respectively). Controls were composed of men with non-kidney cancers (Siemiatycki et al. 1987).
Human studies	Cross-sectional study	A study of 63 female United States Air Force employees found that individuals with high breath concentrations of JP-8 aliphatic hydrocarbons (mean = 280 ppb for hexane to undecane) exhibited significantly ($p = 0.007$) reduced urinary luteinizing hormone. Additionally, a trend to decreased urinary luteinizing hormone ($p = 0.1$) and decreased urinary midluteal pregnanediol 3-glucuronide (Pd3G) ($p = 0.08$) was noted in the group with high breath concentrations of BTEX (mean = 74 ppb) (Reutman et al. 2002).

Endpoint	**CAS RN / substance / study type**	**Effect levels[a]/results**
Human studies	Cross-sectional study	A higher prevalence of psychiatric symptoms, poorer performance in some psychological tests and reduced sensorimotor speed were reported among 30 workers exposed to jet fuel vapour (average 300 mg/m^3, mean employment: 17 years) compared to a group of 30 or 60 unexposed controls (Knave et al. 1978, 1979).
Human studies	Cohort study	A cohort of 2182 men in the Swedish armed forces exposed to aviation kerosene, jet fuel, isopropyl nitrate (a starter fuel) and aviation gasoline (for piston engines) was followed for 9–10 years. Exposure levels in some workplaces exceeded 350 mg/m^3. There was significantly lower mortality for air force personnel (due to low cardiovascular deaths) compared to national rates, and 25 malignant neoplasms compared to 29 expected (Selden and Ahlborg 1987).
Human studies	Case study	During a flight, two military pilots were exposed to JP-5 vapours in the cockpit. The pilots experienced nausea, fatigue, burning eyes, impaired hand-eye coordination, euphoria and memory defects (Porter 1990).
Human studies	Cross-sectional study	U.S. military personnel were evaluated for medical and neurobehavioural effects from JP-8 exposures after at least 4 months in “high-exposure” occupations (fuel tank maintenance and cleaning) and were compared to non-exposed controls. Significantly impaired associated hearing was found among exposed workers (Ritchie et al. 2001a).
Human studies	Cross-sectional study	Eight jet mechanics chronically exposed (mean = 25 years) to jet fuel were examined for effects on audiological and vestibulo-oculomotor function. The findings suggest that chronic exposure to jet fuel may result in subtle deficits in the

Endpoint	CAS RN / substance / study type	Effect levels[a]/results
		higher-level inhibition (cerebellar, cortical, etc.) of brainstem functions (Odkvist et al. 1987).
Human studies	Cross-sectional study	A blinded, occupational JP-8 inhalation exposure study was conducted on National Guard personnel. Exposures at less than 50 mg/m^3 resulted in immune system effects, including increased plasma prostaglandin E_2 levels, immediately increased neutrophils and eosinophils, and decreased total leukocytes in the peripheral blood (Harris 2011).

[a] LD_{50}, median lethal dose; LC_{50}, median lethal concentration; LOAEL, lowest-observed-adverse-effect level; LOAEC, lowest-observed-adverse-effect concentration; NOAEL, no-observed-adverse-effect level; NOAEC, no-observed-adverse-effect concentration.

[b] Density, ρ = 0.747 g/mL (BP 2000) was used for conversion of volume into g/kg-bw: (x mL/kg-bw × ρ).

[c] Molecular weight of 170 g/mol was used for conversion of ppm into mg/m^3: (ppm × MW / 24.45).

[d] Molecular weight of 180 g/mol was used for conversion of ppm into mg/m^3: (ppm × MW / 24.45).

[e] Body weight (bw) not provided; 35 grams used for C3H mice (laboratory standards from Salem and Katz (2006) were used).

[f] Density ρ = 0.678 g/mL was reported in API 2003b.

[g] The formula (x mL/kg-bw × ρ) was used for conversion of values into mg/kg-bw.

[h] The formula (x mg / bw) was used for conversion of values into mg/kg-bw.

[i] Density ρ = 0.817 g/mL was used.

[j] The formula (% fractional dilution × x mL × ρ / bw) was used for conversion of volume into mg/kg-bw.