Final Screening Assessment
Petroleum Sector Stream Approach

Fuel Oil No. 2
[Fuels]

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68476-30-2

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Synopsis

The Ministers of the Environment and of Health have conducted a screening assessment of the following fuel oil:

CAS RN	***Domestic Substances List* Name**
68476-30-2	Fuel Oil, No. 2

Fuel Oil No. 2 is primarily used as a fuel source for home heating. It was identified as a high priority for action during the categorization of the *Domestic Substances List*, as it was determined to present greatest potential for exposure of individuals in Canada and was considered to present a high hazard to human health. Fuel Oil No. 2 met the ecological categorization criteria for persistence or bioaccumulation and inherent toxicity to aquatic organisms. This substance was included in the Petroleum Sector Stream Approach (PSSA) because it is related to the petroleum sector and is considered to be of Unknown or Variable composition, Complex reaction products or Biological materials (UVCBs).

An analysis of Canadian Fuel Oil No. 2 spills data for the years 2000-2009 (as reported to the National Enforcement Management Information System and Intelligence System (NEMISIS) database) and of Ontario spills data for 2008-2012 was completed. NEMISIS data for Fuel Oil No. 2 is mainly based on spills reported by the Atlantic provinces; additional spill data from provinces other than Ontario were not available. A risk analysis was conducted using these data which indicates that there are on average approximately 12 spills per year during ship loading/unloading that are of sufficient size to be expected to be harmful to freshwater and marine organisms (fish, invertebrates, algae). In addition, Fuel Oil No. 2 is harmful to terrestrial organisms (invertebrates, plants) given the frequency and volume of spills to terrestrial habitats. Based on available information, there are an average of 200-300 spills per year to soil in the Atlantic provinces and 160-190 spills per year to soil in Ontario, of which at least half are expected to cause harm. The majority of these releases are associated with storage tanks for home heating fuel. The Atlantic provinces and Ontario represent approximately 60% of the use of Fuel Oil No. 2 in Canada.

Considering all available lines of evidence presented in this final Screening Assessment, there is risk of harm to organisms, but not to the broader integrity of the environment, from Fuel Oil No. 2. It is concluded that Fuel Oil No. 2 meets the criteria under paragraph 64(*a*) of the *Canadian Environmental Protection Act, 1999* (CEPA 1999) as it is entering or may enter 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. However, it is concluded that Fuel Oil No. 2 does not meet the criteria under paragraph 64(*b*) of CEPA 1999 as it is not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

A critical health effect for the initial categorization of Fuel Oil No. 2 was carcinogenicity, based primarily on classifications by international agencies. Skin painting studies in laboratory animals reported skin tumour development after chronic dermal exposure to Fuel Oil No. 2. Additionally, benzene, a component of Fuel Oil No. 2, 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 Fuel Oil No. 2 was determined to be inhalation, estimates of cancer potency for inhalation of benzene, a high-hazard component in Fuel Oil No. 2, were used to characterize risk to the general population from evaporative emissions of Fuel Oil No. 2.

Fuel Oil No. 2 exhibited positive genotoxicity results in both *in vivo* and *in vitro* assays. No reproductive or developmental health effects were observed in rats via the inhalation route of exposure and limited effects were noted at high doses via the dermal route of exposure.

The potential for general population exposure to Fuel Oil No. 2 was evaluated. Based on limited data, residences using Fuel Oil No. 2 as a fuel source did not have ambient levels of marker volatile organic compounds that were elevated relative to residences using other types of home heating. In the event of a residential fuel storage tank leak, exposure of the general population was not identified as a concern for human health because of the limited duration of potential exposure, the low acute toxicity of the fuel and existing leak mitigation measures. Additionally, inhalation exposure to individuals residing in the vicinity of a bulk storage facility was characterized. 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 Fuel Oil No. 2 does not meet the criteria under paragraph 64(*c*) of CEPA 1999 as it is 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.

Conclusion

It is concluded that Fuel Oil No. 2 (CAS RN 68476-30-2) meets one or more 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 of section 64 are met is based upon an assessment of potential risks to the environment and/or to human health associated withexposures 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 petroleum substances in the Chemicals Management Plan (CMP) is not relevant to, nor does it preclude, an assessment against the hazard criteria for WHMIS 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 undertaken in other sections of CEPA 1999 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. The fuel oil substance considered in this assessment occurs within the gas oil group.

This screening assessment addresses Fuel Oil No. 2 described under Chemical Abstracts Service Registry Number (CAS RN) 68476-30-2. This substance was identified as GPE during the categorization exercise and was considered to present a high hazard to human health. This substance met ecological categorization criteria for persistence or bioaccumulation and inherent toxicity to aquatic organisms.

Included in this screening assessment is the consideration of information on chemical properties, uses, exposure and effects. Data relevant to the screening assessment of this substance were identified in original literature, review and assessment documents, stakeholder research reports and from recent literature searches, up to June 2010 for the environmental section of the document and up to September 2011 for the health effects section of the document. Key studies

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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.

were critically evaluated; modelling results have been 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 release to the environment. To predict the overall environmental behaviour and properties of complex substances such as Fuel Oil No. 2, representative structures were selected from each chemical class contained within this substance. Conclusions regarding risk to the environment are 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. As well, other lines of evidence including fate, temporal/spatial presence in the environment and hazardous properties of the substances are 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 have assisted in the assessment.

Evaluation of risk to human health involves consideration of data relevant to estimation of exposure of the general population, as well as information on health effects. Health effects were assessed using pooled toxicological data from fuel oil and related substances, as well as for high-hazard components expected to be present in the fuel. Decisions for risk to human health are 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 context. The screening assessment does not present an exhaustive or critical review of all available data. Rather, it provides a summary of the critical information upon which the conclusion is based.

This screening assessment was prepared by officials 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 Dr. Bob Benson (United States Environmental Protection Agency [U.S. EPA]), Dr. Michael Jayjock (The LifeLine Group), 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

Fuel Oil No. 2 (CAS RN 68476-30-2) is a distillate fuel oil that is formed by vapourizing, condensing and blending petroleum components during a distillation process; it therefore has a boiling point range that excludes high-boiling components. There is significant variability in products sold as fuel oils. The hydrocarbon composition of Fuel Oil No. 2 can overlap with kerosene, Diesel Fuel No. 2 and Fuel Oil No. 1 on the light end (smaller hydrocarbons) and Fuel Oils No. 3 and 4 on the heavy end (larger hydrocarbons). Product volume information on light fuel oils provided by Statistics Canada includes Fuel Oil No. 3, as well as Fuel Oil No. 2 and other light fuel oils. Even within the product designation of Fuel Oil No. 2, compositions can vary with the refinery or upgrader streams from which it is blended (Air Force 1989). The composition of Fuel Oil No. 2 is similar to diesel fuel but since the use profiles of these two substances are very different and because diesel fuels must meet specific sulfur reduction targets (thus requiring further processing), they have been assessed separately under Stream 3.

Fuel Oil No. 2 contains C_{11}-C_{20} hydrocarbons and has an auto-ignition temperature in the range of 177–329°C (Coast Guard 1985). The 90% distillation point of 282–338°C suggests that only a small portion of Fuel Oil No. 2 is represented by the higher-boiling C_{20} fraction. Fuel Oil No. 2 typically has a composition of 75-80% aliphatic and 20–25% aromatic hydrocarbons (IARC 1981; NRC 1985). The aliphatic components consist of *n*-alkanes, branched (iso)alkanes and cycloalkanes. Fuel oils with a high aromatic content can have up to 38% aromatics, although this is not typical (NRC 1985). Fuel Oil No. 2 typically contains less than 5% polycyclic aromatic hydrocarbons (PAHs; Speight 2007) (Tables A2.1 and A2.2 in Appendix B).

This UVCB substance is a complex combination 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 its complex and variable composition, it could not practicably be formed by simply combining individual constituents.

3. Physical and Chemical Properties

The composition and physical-chemical properties of Fuel Oil No. 2 vary with the source of crude oil or bitumen and the refining steps involved (CONCAWE 1996). Physical-chemical properties of Fuel Oil No. 2 are presented in Table 3.1.

Table 3.1. Physical-chemical properties of Fuel Oil No. 2

Property	Value	Temperature (°C)	Reference
Boiling point (°C)	160 – 360	n/a	IARC 1989a
Relative density (g/mL)	0.81 – 0.94	15	Air Force 1989
Henry's Law constant ($Pa \cdot m^3/mol$)[a]	$5.98 – 7.5 \times 10^5$	20	Air Force 1989
Log K_{ow}	3.3 – 7.06		Air Force 1989
Vapour pressure (Pa)	280 – 3520	21	Air Force 1989
Water solubility (mg/L)	3 (freshwater) 3.2 (distilled water) 14 (saltwater)	20	Mackay et al. 1982; Frankenfeld 1973
Ratio of aromatics to aliphatics	25:75	n/a	IARC 1989a; NRC 1985

Abbreviations: K_{oc}, organic carbon-water partition coefficient; K_{ow}, octanol-water partition coefficient, n/a, not applicable

[a] Based on anthracene-dodecane range.

The average general composition of three Fuel Oil No. 2 samples was provided by the Alberta Research Council (Fuhr 2008; Table B.2 in Appendix B). From the major chemical classes identified, representative component substances were selected and are presented in Table B.3 (Appendix B). Experimental and modelled physical-chemical data for these structures are presented in Table B.3 (Appendix B).

While Table B.3 (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 Fuel Oil No. 2. 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 which are normally solid under environmental conditions, when part of a mixture may have lower melting points (and therefore be in a liquid state) and increased vapour pressure and water solubility (Banerjee 1984). This is not reflected in Table B.3.

Aliphatic components (*n*- and isoalkanes, cycloalkanes, dicycloalkanes and polycycloalkanes) make up about 75% of the total hydrocarbons found within Fuel Oil No. 2 (Table B.2 in Appendix B). These aliphatics are moderately volatile as indicated by the low to moderate vapour pressures (0.0006 – 163 Pa), generally high Henry's Law Constants (5700 – 2 600 000 $Pa \cdot m^3/mol$) and low water solubilities (0.0000002 – 0.9 mg/L) of the representative structures (Table

B.3 in Appendix B). The log K_{ow} range based on these representative structures is 4.2 – 10.2.

The aromatic components in Fuel Oil No. 2 make up roughly 26% of the total hydrocarbons (Table B.2 in Appendix B). The aromatic components generally have low vapour pressures (0.007 – 10.6 Pa), lower Henry's Law Constants (2.8 – 15 000 $Pa{\cdot}m^3/mol$) and low water solubilities (0.004 – 6.9 mg/L), based on the representative structures, indicating that aromatics are more likely to remain in the water compartment (Table B.3 in Appendix B). The log K_{ow} ranges of the representative aromatic structures are also typically lower than for aliphatic compounds (3.9 – 7.2).

4. Sources

Fuel Oil No. 2 is produced in refineries and upgraders in Canada by refining crude oil or bitumen, with most of the production in eastern Canada. Statistics Canada (2008a) provides information on the supply, movement and energy demand of "light fuel oil" (which includes all distillate fuel types for power burners, Fuel Oil No. 2, Fuel Oil No. 3, furnace fuel oil, gas oils and light industrial oils in Canada). In 2006, 8.3×10^9 litres of light fuel oil was produced in Canada with approximately half (50.4%) exported. Light fuel oil is also imported into Canada accounting for 1.1×10^8 litres (1.4%) (Statistics Canada 2008a; Table C.1 in Appendix C). In terms of total fuel oil production, 74% comes from Atlantic Canada, followed by Quebec with 14% and Ontario with 12% (Statistics Canada 2008a).

Table C.2 provides information on the production, movement and energy demand of "light fuel oil" in Canada from 2002-2008. There was an overall decrease in light fuel oil production and an increase in export from 2002-2008 (Table C.2 in Appendix C; Statistics Canada 2003-2011). Import of light fuel oil remained relatively unchanged.

5. Uses

Fuel Oil No. 2 is combusted to generate heat. This occurs in atomizing-type burners that spray the fuel into a combustion chamber and the aerosols burn while in suspension (CHEMINFO 2009). Fuel Oil No. 2 is primarily used as a fuel source for home heating, but also in medium capacity commercial/industrial burners.

Of the 4×10^9 L of light fuel oil (the majority of which is thought to be Fuel Oil No. 2) used domestically in 2006, the largest users were the residential (49% of total) and commercial (39%) sectors (Statistics Canada 2008a; Table C.3 in Appendix C). As of 2007, only approximately 7.3% of Canadian homes used Fuel Oil No. 2 as their main heating source, due to the increase in natural gas use (42% of

Canadian homes) (Statistics Canada 2008b). Currently, domestic heating oil sales are concentrated in Eastern Canada, with Atlantic Canada accounting for 34% of sales, followed by Quebec (30%) and Ontario (28%) (Statistics Canada 2008b).

As shown in Table C.2 (Appendix C), the final demand of light fuel oil in Canada decreased between 2002 and 2008 (Statistics Canada 2003-2011).

Fuel Oil No. 2 has been classified as a List 2 formulant by Health Canada's Pest Management Regulatory Agency (PMRA 2010) and its use is subject to the regulatory directive on formulants (PMRA 2006).

6. Releases to the Environment

Fuel Oil No. 2 may be released to the environment from activities associated with production, transportation, and storage, and commercial/industrial or consumer use.

Fuel Oil No. 2 originates from distillation columns as a residual fraction (bottom product) or a distillate in a refinery or upgrader. Thus, the potential locations for the controlled release of Fuel Oil No. 2 include relief valves or drain valves on the piping or equipment (e.g., vessels) in the vicinities surrounding this equipment. Under typical operating conditions, releases of Fuel Oil No. 2 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 of Fuel Oil No. 2 may occur at production facilities. Legislation targets releases of Fuel Oil No. 2 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 setup 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 under 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. Fuel Oil No. 2 evaporative emissions are not expected to be a significant source of exposure.

Fuel Oil No. 2 may be stored in bulk prior to transport to export wharves or to the marketplace. Potential exposure to evaporative releases from Fuel Oil No. 2 in bulk storage is considered in the human health portion of this assessment.

Fuel Oil No. 2 is transported from production facilities to a variety of locations, including bulk terminals, export wharves and customer storage tanks. In general, three operating procedures are involved in the process of transportation: loading, transit and unloading. Loading and unloading of Fuel Oil No. 2 is normally conducted at sites with limited access to the general public, such as bulk terminals and wharves.

The handling of Fuel Oil No. 2 at 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 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 because 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 2008). Cleaning facilities require processing of grey-water to meet local and provincial release standards.

6.1 Release Estimation

Fuel Oil No. 2 can be released to the environment during its production, formulation, transportation and use. Environment Canada’s National Enforcement Management Information System and Intelligence System (NEMISIS) database (Environment Canada 2011) was used to evaluate overall frequency and volume of releases of Fuel Oil No. 2. 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.

It should be noted that some provinces did not participate in, or report to, the NEMISIS database for every year (Table D.2 in Appendix D), thus gaps exist in the database. As well, there is no requirement for provinces to report spills to residential sites to the NEMISIS database and many do not; however, there is limited data available since the Atlantic region did report all spills including those of Fuel Oil No. 2 to residential sites.

The NEMISIS database was used to estimate release of Fuel Oil No. 2 to the environment. Spills due to aircraft crash, collision, earthquake/slide, ice/frost, road conditions, storm/flood, subsidence, or vandalism were not considered in the analysis. In addition, any high-volume spills that could not be confirmed through external sources as having occurred were excluded as they likely represent emergency spill simulations. The remaining spills data documented approximately 1 million litres of Fuel Oil No. 2 spilled in 6302 incidents between 2000 and 2009 (Environment Canada 2011). However, most of the incidents reported in the NEMISIS database had no estimated volumes 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 distribution of reported volumes released was representative of all releases. This estimation places the volume of spilled Fuel Oil No. 2 at approximately 2.2 million litres over ten years (Table D.1 in Appendix D).

Reported release volumes by year for each province and for the territories are shown in Table D.2 (Appendix D). The provinces with the greatest reported volumes of spills from 2000-2009 were Nova Scotia, Newfoundland and Labrador and New Brunswick which largely reflects the reporting of spills of Fuel Oil No. 2 to residential sites.

The NEMISIS database also separates spill data into the specific compartment affected (land, freshwater, marine), so the estimated average release quantity per spill to each compartment could be determined (Table D.3 in Appendix D). From 2000-2009, the majority of reported spills were to land (3661 incidents), followed by 369 releases to marine water and 282 releases to freshwater. There were 2023 spill reports that did not list the environmental medium of release. Thus, the total number of spills listed in Table D.3 (Appendix D) does not equate to the total shown in Table D.1 (Appendix D) because some spills affected more than one compartment, while other spills had no listed compartment affected in the NEMISIS database (Environment Canada 2011). Where reported, the majority of spills that affected an unknown medium had volumes of less than 100 L and frequently occurred in the Atlantic provinces near large population centers. Thus, spills to unknown media are likely spills to land. Overall, there has been a substantial decline in the number of spills reported per year (Table D.3 in Appendix D). Likewise, the annual volumes of reported spills have been declining. In 2000, approximately 150 000 L were reported spilled and in 2009, approximately 40 000 L were reported spilled (Environment Canada 2011).

Further analysis of the Environment Canada spills data shows that vegetation damage occurred yearly. Property damage was also common, yet it was shown to be declining (Environment Canada 2011). Some spills of Fuel Oil No. 2 also impacted other environmental resources, although they were not specified in the database and have declined considerably since 2004 (Environment Canada 2011). Most spills appear relatively small and occur in proximity to human habitation, although occasionally there are major spills. Although the total annual volume of spills is high, the statistics reflect a pattern of repeated, small quantities of Fuel Oil No. 2 released to the environment, with occasional large spills (Table D.1 in Appendix D); in most cases, the repeated small quantity releases appear to be from industrial handling and operations or associated with consumer use.

The estimated average release quantities (in kg and L, assuming a density of 0.885 kg/L) per spill event to freshwater, saltwater or soil from 2000-2009 are presented in Table 6.1. These values are used for determining the predicted environmental concentration (PEC) in the ecological exposure assessment. Maximum and median spill volumes per year are reported in Table D.1 (Appendix D).

Table 6.1. Estimated average annual release quantities per spill and per year of Fuel Oil No. 2 to various compartments based on historical spills data from 2000-2009 in Canada (Environment Canada 2011)[a]

Receiving compartment	Average number of spills per year	Average mass per spill (kg)	Average mass spilled per year (kg)	Average volume per spill[b] (L)	Average volume spilled per year (L)
Freshwater	28	705	19 740	795	22 290
Saltwater (Marine)	37	480	17 650	540	19 945
Land (Soil)	364	360	130 675	405	147 785

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

[b] Average release (litres) of Fuel Oil No. 2 to each compartment was determined by separating Fuel Oil No. 2 releases from 2000-2009 (Environment Canada 2011) into specific compartments (saltwater, freshwater, soil), determining the extrapolated total released within each compartment and then dividing this total by the total number of spills affecting that compartment.

The NEMISIS database also provides three columns of data (sources, causes and reasons) for many of the releases of Fuel Oil No. 2. The data in these columns were analyzed to determine how and why the majority of Fuel Oil No. 2 releases occur (Tables D.4a-c in Appendix D).

The majority of Fuel Oil No. 2 releases (93% of all spills and 92% of the total volume) are for the source categories “other”, storage (“other storage facilities” and “storage depot”), “tank truck” and “unknown” (Table D.4a in Appendix D). Of the 5276 spills from other, storage and unknown causes to all media, it is estimated (based on detailed analysis of 2008-2009 data) that approximately

54% (2842 spills) were associated with home fuel tanks on residential properties. Based on the same data, approximately 6% of all releases from tank trucks are also associated with home fuel tanks. A variety of other sources accounted for the remaining releases. Truck releases were greatest in Nova Scotia and New Brunswick, followed by Newfoundland and Labrador and Prince Edward Island. Releases to the marine environment occurred from barges, tankers, other water craft, bulk carriers and marine terminals.

The NEMISIS data were also analyzed for causes of leaks (Table D.4b in Appendix D); it was found that “above-ground tank” leaks accounted for 56% of the volume released, while pipe leaks accounted for 12% of the volume. Container leaks and “underground tank” leaks account for 10% of the volume released. There was a substantial decrease in the reported number of spills from underground tanks from 2000 to 2009; there were 20 to 30 spills yearly reported between 2000 and 2003 but zero to three spills yearly reported between 2005 and 2009 (Environment Canada 2011). Unknown causes accounted for 9% of the volume, overflows (presumably of tanks) accounted for 3%, valve fitting leaks accounted for 2% and the remaining releases were from a variety of causes (8%).

Analyzing the reasons data (Table D.4c in Appendix D) identified that unknown reasons were the major cause of releases, accounting for 29% of the volume. Material failure accounted for 26% of the volume, equipment failure accounted for 18%, corrosion accounted for 9%, other releases accounted for 5% and human error and negligence accounted for 7%. The remaining 6% was split between a variety of reasons.

In addition to the NEMISIS database, spill data provided by the province of Ontario on Fuel Oil No. 2 for 2008-2012 were also analyzed (Ontario 2013). Spills due to aircraft crash, collision/overturns, earthquake/slide, ice/frost, road conditions, storm/flood, subsidence, or vandalism, as well those to industrial sites were not considered in the analysis. There were a total of 1377 spills to all media from 2008 to 2012, with annual spill numbers ranging from approximately 225 to 335 spills/year. The average and median spill volumes were 344 and 75 L, respectively.

Fuel Oil No. 2 has been reported to be used as a component in a number of hydraulic fracturing fluids used in the United States in shale and other unconventional oil and gas formations (US House of Representatives 2011).

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 petroleum hydrocarbon components differently. For example, aromatics tend to be more water soluble than aliphatics, 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, while aliphatics will be the principal air contaminants (Potter and Simmons 1998). The trend in volatility by chemical class is: alkenes ≈ alkanes > than aromatics ≈ cycloalkanes. The most soluble and volatile components have the lowest molecular weight; thus, there is a general shift of having higher molecular weight components in residual materials. Following an initial loss due to volatilization and solubilization, the remaining degradative pathway is biodegradation, usually by bacteria.

Biodegradation is almost always operative when petroleum mixtures are released in the environment. It has been widely demonstrated that nearly all soils and sediments have populations of bacteria and other organisms that are 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, are degraded readily;
(2) isoalkanes;
(3) alkenes;
(4) benzene, toluene, ethylbenzene, xylenes (BTEX) (when present in concentrations which are not toxic to the microorganisms);
(5) monoaromatics;
(6) 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.

Fuel oils are considered to be inherently biodegradable based on their hydrocarbon components (CONCAWE 2001). For instance, *Rhodococcus erythropolis* were able to metabolize C_5–C_{16} hydrocarbons. Furthermore, 60% of a fuel oil in water was degraded after three months and total degradation was achieved after 9 months (De Carvalho and da Fonseca 2005).

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 Fuel Oil No. 2, the physical chemical properties of representative structures of Fuel Oil No. 2 (Table B.3 in Appendix B) were examined.

Based on the physical-chemical properties of representative structures of Fuel Oil No. 2, the majority of components are expected to partition to water and soil.

The C_{12}–C_{20} components have boiling points from 155 to 360°C. The individual components of Fuel Oil No. 2 are characterized by low to moderate water solubilities (1.7×10^{-6} to 6.9 mg/L), low vapour pressures (0.0006 to 163 Pa), low to high Henry’s Law constants (2.8 to 2×10^{7} Pa·m^3/mol), moderate to high log K_{ow} values (3.9 to 10.2) and moderate log K_{oc} values (3.3 to 8.8) (Table B.3 in Appendix B).

Based on the low vapour pressures (0.0006 to 163 Pa), the majority of Fuel Oil No. 2 components are not expected to partition to air (Table B.3 in Appendix B). The likelihood of a release of Fuel Oil No. 2 directly to air is expected to be minimal.

Petroleum hydrocarbons have limited solubility in water and can form fine dispersions and discrete particles in the water column (Gordon et al. 1973). Turbulence appears to have a pronounced and positive effect on the formation of particulate and sub-particulate oil. Once turbulence stops, much of the entrained oil returns to the surface film, unless the oil has a density similar to or greater than water. Gordon et al. (1973) found that concentrations of entrained oil doubled when the water temperature decreased from 19-21°C to 1-2°C.

With generally low solubility in water and a range of density from 0.81 – 0.94 g/mL (CONCAWE 1996), Fuel Oil No. 2 in water is initially expected to form a thin layer on the surface, where some components will evaporate (especially the isoalkanes, the dicycloalkanes and cycloalkane monoaromatics) and be photodegraded by reaction with ultraviolet light and hydroxyl radicals (CONCAWE 2001). Based on the water solubility of these components (1.7×10^{-6} to 6.9 mg/L), if a release occurs to water, aromatic components will dissolve partially in water. The aliphatic components are not expected to dissolve into water. Based on the moderate to high log K_{oc} values (3.3 to 8.8), Fuel Oil No. 2 is expected to sorb to suspended solids and sediments (Table B.3 in Appendix B).

Environment Canada (1976) studied the generation of a water soluble fraction (WSF) from Fuel Oil No. 2 and found that the concentration in the WSF increased to approximately 7 ppm in 4 days and did not exceed 8 ppm even after 7 days. This was in a closed container that prevented evaporation. Frankenfeld (1973) found up to 13 ppm total organics after 14 days in a closed system using sea water and roughly the same concentrations in fresh water. Gordon et al. (1973) found relatively little residue after 7 days using an open system, but this was likely due to evaporation of the volatile components. After exposure to air in a weathering simulator, Frankenfeld (1973) found that the solubility of the weathered Fuel Oil No. 2 increased, possibly due to photodegradation of components.

Based on the modelled log K_{oc} values of 3.3 to 8.8 for the representative structures (Table B.3 in Appendix B), Fuel Oil No. 2 is expected to sorb to soil and thus have low to moderate mobility in soil, although this depends largely on the concentration of organic matter in the soil and the volume of fuel oil released. Volatilization from moist soil surfaces is expected to be a relatively important fate process for those components with estimated Henry's Law constants of 20 000 – 1 700 000 Pa·m^3/mol (Table B.3 in Appendix B). However, other components of Fuel Oil No. 2 will not likely evaporate from moist soil based on low Henry's Law constants (less than 100 Pa·m^3/mol) (Table B.3 in Appendix B). The vapour pressures of the components indicate that some components will evaporate if they are not first sorbed to soil or dissolved in water.

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

Due to the complex nature of petroleum substances such as Fuel Oil No. 2, the persistence and bioaccumulation characteristics of this substance are assessed 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 E.1 (Appendix E).

Empirical and modelled half-lives in the atmosphere for many components of Fuel Oil No. 2 are less than 2 days (Environment Canada 2014). However, some components, such as the C_{13} cycloalkane diaromatics, can have half-lives greater than 2 days and thus may undergo long-range transport. In addition, some three-ring PAHs can undergo long-range transport to remote regions due to sorption to particulate matter (Environment Canada 2014).

With regards to the primary and ultimate biodegradation modelling, the C_{15}–C_{20} two-ring cycloalkanes, C_{18} polycycloalkanes, C_{12} one-ring aromatics, C_{12}–C_{20} cycloalkane monoaromatics, C_{12}–C_{20} two-ring aromatics, C_{12} cycloalkane diaromatics and C_{14} three-ring PAHs in Fuel Oil No. 2 have half lives in water or soil greater than 6 months or greater than a year in sediments. The C_{12} dicycloalkanes, C_{14} polycycloalkanes and C_{11} and C_{15} one-ring aromatics also have half-lives greater than a year in sediments (Table E.1, Appendix E).

8.2 Potential for Bioaccumulation

Bioaccumulation was determined 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} greater than approximately 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, 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 E.2 (Appendix E).

Overall, there is consistent empirical and predicted evidence to suggest that C_{13}-C_{15} isoalkanes, 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}–C_{20} cycloalkane monoaromatics, C_{12}-C_{13} diaromatics, C_{20} cycloalkane diaromatics and C_{14} and C_{20} three-ring PAHs have the potential for high bioaccumulation with BAF/BCF values greater than 5000 (Table E.2 in Appendix E). These components are associated with a slow rate of metabolism and are highly lipophilic. Exposures from water and the diet, when combined, suggest that the rate of uptake would exceed 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; however, one study (Harris et al. 2011) suggests that some alkyl-PAHs may biomagnify. While only Biota-Sediment Accumulation Factors (BSAFs) were found for some PAHs, it is possible that BSAFs will be more than 1 for invertebrates given that they do not have the same metabolic competency as fish.

9. Potential to Cause Ecological Harm

9.1 Ecological Effects Assessment

Data from Environment Canada's NEMISIS database that was evaluated for this assessment (2000-2009) recorded incidents of Fuel Oil No. 2 spills that affected migratory birds, resulted in fish kills, oiled birds, or caused other wildlife and vegetation damage (Environment Canada 2011).

9.1.1 Aquatic compartment (fish, invertebrates, algae)

Experimental aquatic toxicity data for Fuel Oil No. 2 are detailed in Table F.1 (Appendix F). Toxicity of a water soluble fraction (WSF) of Fuel Oil No. 2 was moderate with LC_{50} values ranging from 0.54 – 6.3 mg/L in various fish species including the pink salmon (*Oncorhynchus gorbuscha*), trout (*Salvenlinus malma*), inland silverside (*Menida beryllina*) and longnose killifish (*Fundulus similis*; Table F.1 in Appendix F). Invertebrates were slightly more sensitive to Fuel Oil No. 2 (WSF) compared to fish, with LC_{50} values ranging from 0.43 – 11.2 mg/L. However, with many of these studies there was a large loss of petroleum hydrocarbons observed over the test duration (Anderson et al. 1974; Rice et al. 1979; Rossi et al. 1976) likely resulting in an underestimation of the toxicity value. Other studies did not indicate if there was loss to air, though loss is expected based on the test conditions (static test with aeration; Tatem et al. 1978). In some studies, there was insufficient detail provided to determine if loss to air could be expected (Byrne 1989). A study by MacLean and Doe (1989), however, was conducted in such a way as to have little loss of the test substance and is considered reliable. MacLean and Doe (1989) used closed test systems with no headspace to determine the toxicity of various petroleum substances, including Fuel Oil No. 2, to brine shrimp (*Artemia* sp.) and *Daphnia magna*. Fortyeight hour median effective concentrations for immobilization following exposure to a WSF of Fuel Oil No. 2 were 8.35 and 1.9 mg/L for *Artemia* sp. and *D. magna*, respectively. Measured initial and final concentrations indicate little or no loss of Fuel Oil No. 2 over the test period.

Embryonic inland silversides (*Menidia beryllina*) exposed to 100% WSF of Fuel Oil No. 2 (9.3 mg/L total HC) first demonstrated reduced cardiac output followed by skeletal stunting and a slight reduction in the size of the craniofacial complex. These observed effects were generally followed by death of the embryos (Middaugh and Whiting 1995).

Embryos of gulf killifish (*Fundulus grandis*) were exposed continuously to 12.5, 25 and 50% dilutions of the WSF, corresponding to nominal aqueous petroleum hydrocarbon concentrations of 1.1, 2.2 and 4.4 ppm (Ernst et al. 1977). Embryos exposed to 12.5% WSF generally hatched earlier and most were normal (Ernst et al. 1977). This early hatching effect is known to happen in other species of fish exposed to petroleum hydrocarbons. Embryos treated with 25% WSF had significantly reduced hatching success (14%) and during development, took longer to develop to a given stage (Ernst et al. 1977). None of the embryos treated with 50% WSF hatched. Some of these embryos were severely deformed (Ernst et al. 1977).

The shrimp *Lucifer faxoni* was sensitive to Fuel Oil No. 2 when exposed to the WSF. At 1% WSF there was no effect on feeding rates, but at 10% WSF the feeding rate was cut approximately in half and lasted for several days. The effect was enhanced with fresh oil versus aged oil (Lee et al. 1978).

There is also evidence of phototoxicity when exposure of Fuel Oil No. 2 is combined with light. Scheier and Gominger (1976) showed that UV irradiation for 24 hours, 72 hours and 6 days of the WSF of Fuel Oil No. 2 increased toxicity by reducing the survival rate of five aquatic species. Length of irradiation of the fuel oil was positively correlated with toxicity. For *Palaemonetes pugio* (grass shrimp) exposed for 3 days to the non-UV-irradiated WSF, there was no effect. Shrimp exposed to water containing the WSF that had been previous exposed to 24 hours of UV irradiation, had a median Time to Lethality (TLm) of 3 hours.

Lee and Nicol (1980) studied the effects of the WSF of Fuel Oil No. 2 on the hatching and survival of two marine amphipods (*Parhyale hawaiensis* and *Amphithoe valida*). Exposure to 10% WSF resulted in 20% fewer *P. hawaiensis* eggs hatched in comparison to controls and at 40% WSF (approximately 8 ppm total petroleum hydrocarbons (TPH)) none of the eggs hatched. Of the eggs that were able to develop to juvenile form in WSF concentrations up to 40% (approximately 8 ppm TPH), deleterious effects were evident. Once the embryos hatched and were fully exposed to 30% or greater WSF, they died. Similarly, in the *A. valida* eggs exposed to 10% WSF, all of the eggs hatched but only 25% hatched at 20% WSF and none of the eggs hatched at 30% WSF.

Fuel Oil No. 2 was also found to have significant sub-lethal effects on the marine amphipod *Amphithoe valida* (Lee et al. 1981). Adults were exposed to the WSF (0 to 25%) for 6 days and then transferred to clean water for 7 days for recovery. Survival of amphipods was high (70% or greater) at 25% WSF (5 ppm). However, delayed toxicity and high mortality was observed for concentrations 15% or greater WSF during the recovery phase. Nest building activity was also severely impaired at 25% WSF. Recovery of nest building activity in clean water was either lacking or poor.

Long-term mesocosm tests with west coast marine ecosystems showed significant effects on the ecosystem. Specifically, the community structure and density of the benthic, meiobenthic and inbenthic invertebrate organisms, as well as the phytoplankton community can be altered (Stacey and Marcotte 1987; Grassle et al. 1981; Vargo et al. 1982; Bott and Rogenmuser 1978).

Stacey and Marcotte (1987) exposed harpacticoid copepods (9 species) to Fuel Oil No. 2 (190 µg/L) in free-standing mesocosms for 168 days, followed by 64 days of recovery. *Longipedia americana* and *Microarthridion littorale* were adversely affected by the oil additions shown by the statistically discernible difference in abundance between the experimental and control tanks for certain months of exposure. No acute or chronic LC_{50} tests were conducted on either species. During the 64-day period of recovery, the populations of *L. americana* and *M. littorale* did not recover. However, effects of chronic oil additions on the population dynamics of the regularly occurring species, *Ameiropsis brevicornis* and *Thompsonula hyaenae*, were not statistically significant.

Bott and Rogenmuser (1978) also studied the effects of water extracts of Fuel Oil No. 2 on algal communities under near-natural conditions for 5 weeks (average hydrocarbon concentration of 0.061 – 0.088 mg/L). There was an overall decrease in algal biomass (chlorophyll *a)* compared to the control. Species changes were also evident as there was blue-green algal dominance (*Schizothrix* and *Microcoleus*) and a decrease in the occurrence of diatoms. Thus, the community composition was affected and this may have implications in food webs were species preferences are important (Bott and Rogenmuser 1978).

Grassle et al. (1981) studied the effects of semi-continuous additions of oil-water dispersions of Fuel Oil No. 2 for 25 weeks on macrofauna and meiofauna. The chronic oil addition (overall mean of 190 ppb in the water column) resulted in a significant decline in the meiofauna. The microcrustacea (harpacticoids and ostracods) were the most sensitive groups. Unicellular meiofauna (Foraminifera and large ciliates) increased in the oil tanks, which Grassle et al. (1981) suggest is due to decreased predation and competition. One month after oil additions were stopped, oiled tanks still had significantly lower total meiofauna and nematodes, while harpacticoids were slightly higher. After 50 days of recovery, there were four times as many harpacticoids in the previously oiled tanks as in the controls.

Vargo et al. (1982) added oil-sea water dispersions of Fuel Oil No. 2 to microcosms twice weekly for 5.5 months in 1977 (averaging 190 µg/L) and 4 months in 1978 (averaging 93 µg/L). In both periods of oil addition, total phytoplankton abundance was elevated and species diversity was higher. Diatoms made up a greater proportion of total phytoplankton abundance than flagellates for the entire period of 1978 and during 4 months in 1977. Overall, the composition of the phytoplankton species in the oiled microcosms was similar to the source water. Vargo et al. (1982) also suggest that the elevated phytoplankton abundance in the oiled microcosms relative to the controls is due to reduced predation pressure and suggest altered herbivore feeding behaviour.

All four studies (Stacey and Marcotte 1987; Grassle et al. 1981; Vargo et al. 1982; Bott and Rogenmuser 1978) indicate adverse effects on some aquatic invertebrates. While Vargo et al. (1982) found effects at 93 µg/L, these were only relatively minor; changes in predation pressure and altered herbivore feeding behaviour. There are, however, significant effects with microcosm concentrations of 190 µg/L showing significant differences in populations of certain copepods and meiofauna compared to controls, although no acute or chronic LC_{50} tests were conducted. In both the oiled microcosms exposed to water column concentrations of total hydrocarbons averaging 93 and 190 µg/L, phytoplankton species composition in oiled tanks were similar to the source water (Vargo et al. 1982).

CONCAWE developed an aquatic toxicity model specific for petroleum hydrocarbon mixtures called PetroTox (2009). This model is based on 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 and compounds larger than C_{41} to be too hydrophobic and immobile to impart any significant aquatic toxicity. PetroTox (2009) generates estimates of toxicity with a median lethal loading concentration (LL_{50}) rather than a median lethal concentration (LC_{50}), i.e., it takes into account the poor solubility of petroleum substances in water. The LL_{50} value is the amount of petroleum substance needed to generate a water-accommodated fraction (WAF) that is toxic to 50% of the test organisms. It is not a direct measure of the concentration of the petroleum components in the water-accommodated fraction.

Results from PetroTox (2009) with a 10% headspace range from 0.19 to greater than 100 mg/L while a 50% headspace did not affect the overall toxicity with a range of 0.2 to greater than 1000 mg/L (Table 6.2 in Appendix F).

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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.3 in Appendix B.

The acute critical toxicity value (CTV) selected for Fuel Oil No. 2 toxicity to aquatic organisms is 1.9 mg/L; the 48 h EC_{50} for immobilization with *Daphnia magna,* which is the lowest aquatic toxicity value for both freshwater and marine water. Since there are few reliable toxicity values for Fuel Oil No. 2, this is used for both the freshwater and marine CTV.

9.1.2 Terrestrial Compartment

From studies on small mammals used to evaluate human health effects (Appendix H) selected endpoints (e.g., mortality) were also considered in order to bound terrestrial toxicity. Oral toxicity (LD_{50}) to rats was in the range 11 900 to 17 300 mg/kg-bw (CONCAWE 1996; API 2003a). Clinical signs observed in these studies included hypoactivity, ataxia, incontinence and hair loss. Gastric hemorrhage and/or irritation were commonly seen at necropsy in those animals that died.

Lin et al. (2002) studied the effects of Fuel Oil No. 2 on the above ground and below ground biomass in *Spartina alterniflora* (salt marsh grass). There was no significant difference in above ground biomass over three months at concentrations less than 57 000 mg/kg. Below ground biomass responded with an initial stimulation of growth at 7000 mg/kg, but with negative effects seen at concentrations above 14 g/kg.

The Canada-Wide Standards for Petroleum Hydrocarbons (CCME 2008) provide soil standards for petroleum substances based on toxicity to a variety of terrestrial organisms (invertebrates, plants). These standards are based on four fractions of total petroleum hydrocarbons (TPH): F1 (C_6–C_{10}), F2 (greater than C_{10} to C_{16}), F3 (greater than C_{16} to C_{34}) and F4 (greater than C_{34}) and assumes an 80:20 ratio of aliphatics to aromatics. Fractions 2 and 3 encompass the carbon range of Fuel Oil No. 2. The standards are also divided into four land-use classes (agricultural, residential, commercial, industrial) and two soil types (coarse grained and fine grained soils) for the determination of remedial standards. The most sensitive land-use and soil type is typically agricultural coarse-grained soils. The standards for F2 and F3 in agricultural coarse-grained soils are 150 and 300 mg/kg dry weight (dw) of soil, respectively (CCME 2008). As Fuel Oil No. 2 could fall into both of these categories, the lower value, 150 mg/kg dw of soil, is used for the terrestrial exposure CTV.

9.1.3 Avian Toxicity

Fuel Oil No. 2 can have the same effect on aquatic birds as many other petroleum substances, including loss of insulation and water repellency of feathers, water logging, hypothermia, ingestion of fuel by preening contaminated feathers, all potentially leading to death. Chronic ingestion of Fuel Oil No. 2 by mallard ducklings showed that, under realistic thermal and osmotic stress, ducks receiving 1% fuel oil exhibited mortality 20% greater than controls (Szaro et al. 1981; Holmes et al. 1979).

Nesting birds that come into contact with fuel oil may transfer oil from their feathers and feet to their eggs during incubation. Toxicity of Fuel Oil No. 2 to eggs has been shown. Hoffman and Albers (1994) determined that application of fuel oil to eggs had an LD_{50} of 3.2 µL per egg which can be attributed to the polycyclic aromatic compounds present in the fuel oil. Similarly, in tests with mallard duck eggs, the lowest-observed-effect-concentration (LOEC) was 1 µL/egg resulting in a 20% reduction in hatchability and 28% reduction in mallard duckling survival post-hatch (Szaro et al 1978; Albers 1977). Coon et al. (1979) tested the toxic response of Great Black-backed Gull (*Larus marinus*) eggs to Fuel Oil No. 2 and found that a 5 µL/egg treatment reduced hatchability by 28% from controls. The LD_{25} of Fuel Oil No. 2 to chicken (*Gallus gallus*) embryos was 8.5 µL/egg, while liver necrosis (ED_{25}) occurred at 13.1 µL/egg (Couillard and Leighton 1989). Mortality of common eider duck (*Somateria mollissima*), Louisiana heron (*Hydranassa tricolour*), laughing gull (*Larus atricilla*) and sandwich tern (*Sterna sandvicensis*) eggs were much higher than controls (from 20% to 81% mortality) at 20 µL/egg (Albers and Szaro 1978; White et al. 1979).

A study on duck eggs that were directly exposed to weathered Fuel Oil No. 2 determined that weathered fuel oil is less toxic than fresh fuel oil to duck eggs (Szaro et al. 1980).

9.2 Ecological Exposure Assessment

Release volumes for Fuel Oil No. 2 were determined from data on estimates of losses to sea on Canada’s east coast by Risk Management Research Institute (RMRI 2007) and Environment Canada’s NEMISIS database (Environment Canada 2011).

9.2.1 Aquatic Compartment

Release scenarios were developed for releases from ships to water during loading/unloading and transport. There were no other transportation methods or potential releases to water identified.

To determine the predicted environmental concentration (PEC) in water, the volume of water predicted to be in contact with spilled oil was provided by a report prepared by the Risk Management Research Institute (RMRI 2007). This work estimated the risk of oil spills in Hazard Zones around the southern coast of Newfoundland and Labrador based on the nature of the water (open or partially constricted), the type of vessels travelling through the zones and the quantities of oil transported. The estimated volume of water in contact with spilled oil was dependent on the volume of oil spilled during the event and the Hazard Zone of the spill.

For the ship loading and unloading scenarios, the volume of water in contact with oil is from Hazard Zone 1, as this region includes loading operations at Whiffen Head and Come By Chance refinery in Newfoundland and Labrador (RMRI 2007). For the ship transport scenarios, the estimated volume of water in contact with oil is 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 area of a slick created within Hazard Zones around Newfoundland was estimated for specific volume ranges of oil using ocean spill dispersion models and the volume of contacted water was then estimated by multiplying the area by 10 to represent the top 10 metres of water. This estimate assumes that all of the water is equally contacted by the petroleum substance spilled. This work was originally developed for crude oil, but it can be applied to Fuel Oil No. 2. The estimations of concentrations in water will, however, be conservative as Fuel Oil No. 2 is considerably less dense and has a higher proportion of volatile components than crude oil. Thus, it tends to disperse more rapidly into air and water than crude oil. To account for the lower density of Fuel Oil No. 2, the estimated volume of water expected to be in contact from a medium persistence oil was used rather than that for a highly persistent oil.

In the case of the transportation of Fuel Oil No. 2 by ship, on average an estimated 540 L (approximately 480 kg) of Fuel Oil No. 2 could be lost in one event to salt water (Table 6.1). At an average density of 0.89 kg/L, this is equivalent to 3.4 barrels of Fuel Oil No. 2 and is expected to be in contact with 5.3×10^{12} L of water (Table F.3 in Appendix F). The resulting concentration in water would be 0.00009 mg/L, which is considered the marine PEC for ship transport. In the case of loading and unloading of Fuel Oil No. 2 by ship, the estimated 540 L of Fuel Oil No. 2 is expected to come in contact with 40×10^9 L of water (Table F.3 in Appendix F). The resulting concentration in water would be 0.01 mg/L, which is considered the marine PEC for ship loading and unloading.

During the transportation of Fuel Oil No. 2 by ship in freshwater, on average an estimated 795 L (approximately 705 kg) of Fuel Oil No. 2 could be lost in one event to freshwater (Table 6.1). At an average density of 0.89 kg/L this is equivalent to 5 barrels of Fuel Oil No. 2 and is therefore expected to be in contact with 5.3×10^{12} L of water (Table F.3 in Appendix F). The resulting concentration in water would be 0.0001 mg/L, which is considered the freshwater PEC for ship transport. In the case of the loading and unloading of Fuel Oil No. 2 by ship, this volume of Fuel Oil No. 2 is expected to be in contact with 40×10^9 L of water (Table F.3 in Appendix F). The resulting concentration in water would be 0.02 mg/L, which is considered the freshwater PEC for ship loading/unloading.

9.2.2 Terrestrial Compartment

There were 3661 releases of Fuel Oil No. 2 (excluding spills due to aircraft crash, collision, earthquake/slide, ice/frost, road conditions, storm/flood, subsidence and vandalism) to land reported during the period 2000-2009 to the NEMISIS database (Table D.3 in Appendix D; Environment Canada 2011). The average spill volume from these releases was approximately 405 L with a median spill volume of 52 L.

The impact of Fuel Oil No. 2 releases to lands within the boundaries of industrial facilities was not considered in this assessment; it is expected that spills at these sites undergo immediate remediation that minimizes their entry into the environment. Therefore, all releases with the source identified as “industrial plant” or “refinery” (38 releases between 2000-2009) were assumed to occur at an industrial facility and were thus excluded. Releases to land from watercraft (i.e., “barge”, “other watercraft”; 4 spills) or “marine terminals” (1 spill) were assumed to occur on portlands/industrial sites and were also excluded. In addition, spills from motor transport (i.e., bulk carrier, tank truck, transport truck, other motor vehicle; 9 releases) for which “overturn” was given as a cause were also excluded, as these were considered to be motor vehicle accidents. Spills from motor transport identified as being caused by “overflow” (159 releases) may occur at an industrial fuel terminal or may occur during the filling of residential home fuel tanks. Due to the uncertainty in the location of such releases, these spills were included in the terrestrial exposure scenario.

Considering the above exclusions, there were 3609 reported releases of Fuel Oil No. 2 to land from 2000-2009 based on data from the NEMISIS database (Environment Canada 2011). Spills data from 2008-2009 were evaluated in detail to estimate the proportion of spills associated with residential home fuel tanks from 2000-2009. The number of spills associated with residential home fuel tanks is approximately 2842 (78%), of which approximately 22% occurred inside homes, 45% outside homes and 33% at an unknown location. Taking into consideration the spills reported without identification of spill location, it is estimated that between 625 and 1563 spills occurred indoors. When indoor releases are excluded, the approximate total number of releases of Fuel Oil No. 2 to land for 2000-2009 was 2050-2980, or approximately 200 to 300 releases per year.

An average and median release volume was determined by excluding volumes from releases with a source identified as “barge”, “marine terminal”, “other industrial plant”, “other watercraft” or “refinery”, or cause identified as “aircraft crash”, “collision”, or “overturn” (for motor transport only), or reason identified as “earthquake/slide”, “ice/frost”, “road conditions”, “storm/flood”, “subsidence” or “vandalism”. These were not considered relevant to the exposure scenario. All spill volumes from residential home fuel tank leaks, regardless of whether they occurred indoors or outdoors, were included, however. Based on this, the average release volume of Fuel Oil No. 2 remained approximately 405 L with a median volume of 52 L.

Spill data from the province of Ontario, using similar exclusion criteria, were also considered. There were 1007 reported releases of Fuel Oil No. 2 to land during the period 2008-2012 (Ontario 2013). Of these, 444 (44%) were due to residential home fuel tanks, of which 76 occurred inside homes, 254 occurred outside homes and 114 at an unknown location. Taking into consideration the spills reported without identification of spill location, it is estimated that between 76-190 spills occurred indoors. When indoor releases are excluded, the total number of releases of Fuel Oil No. 2 to land for 2008-2012 was approximately 820-930, or approximately 160 to 190 releases to land per year. The average spill volume to land was approximately 420 L and the median volume was approximately 130 L. Similar to what was done with the NEMISIS data, these volumes included indoor home fuel tank spills.

Due to the paucity of data available on the concentration of Fuel Oil No. 2 in receiving soils following an average spill of Fuel Oil No. 2, 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 fuel spills from truck transport to soil including volume spilled and total petroleum hydrocarbon (TPH) concentrations at the center of the spill.

In the first case study, Ganti and Frye (2008) reported a 379 L spill of diesel from a truck that was involved in a highway accident, spilling the diesel 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 dw In the second case study, Ganti and Frye (2008) reported a second truck involved in a highway accident spilling approximately 284 L onto the gravel road shoulder and adjacent embankment. The initial TPH concentration was 47 000 mg/kg dw at the center of the spill.

According to research by Brost and DeVaull (2000), fuel products in the density range of diesel fuel (such as Fuel Oil No. 2) will saturate soil in the range of 7700–34 000 mg/kg for soil types ranging from sand to coarse soil. Beyond this range they will form a Light Non-Aqueous Phase Liquid (LNAPL).

An average Fuel Oil No. 2 spill (2000 to 2009) to the terrestrial compartment is approximately 405 L. If the concentration in soil is a linear function of the volume spilled, then the average spill volume of 405 L would produce a concentration of approximately 68 200 mg/kg dw in the center of the spill, which, based on the information above, is greater than the concentration needed to form an LNAPL. When the median spill volume of 52 L is considered, a soil concentration of 8762 mg/kg dw is produced. For this assessment, the PEC for the terrestrial compartment is 8762 mg/kg dw.

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, a predicted no-effect concentration (PNEC) was determined. The PNEC is the critical toxicity value (CTV) selected for the organism of interest divided by an appropriate assessment factor. 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.

The PNEC for both the freshwater and marine transport and loading/unloading scenarios was determined based on the CTV of 1.9 mg/L which was the 48-hr EC_{50} for *Daphnia*. An assessment factor of 100 was applied to the CTV to account for laboratory to field exposure, species variability and acute to chronic extrapolation, giving a PNEC of 0.019 mg/L. For terrestrial scenarios, the Canada-wide standard for eco-soil contact for Fraction 2 in coarse-grained soil (150 mg/kg dw) (CCME 2008) is used as the PNEC. The resultant risk quotients for each exposure scenario are presented in Table 9.1.

Table 9.1. Risk quotients for Fuel Oil No. 2

Scenario	PEC	CTV	Assessment factor	PNEC	Risk quotient
Soil	8762 mg/kg dw	150 mg/kg	1	150 mg/kg dw	58
Freshwater Loading/ Unloading	0.02 mg/L	1.9 mg/L	100	0.019 mg/L	1.1
Freshwater Transport	0.0001 mg/L	1.9 mg/L	100	0.019 mg/L	0.005
Marine Loading/ Unloading	0.012 mg/L	1.9 mg/L	100	0.019 mg/L	0.6
Marine Transport	9×10^{-5} mg/L	1.9 mg/L	100	0.019 mg/L	0.005

To yield a risk quotient of 1, a marine spill during loading/unloading would need to be greater than 860 L given the scenario presented here. Sixteen percent of all marine spills with reported volumes in Canada from 2000 to 2009 were of that volume or greater. Given the number of unknown volume spills, there are approximately 6 spills per year to the marine environment during loading and unloading that could potentially cause adverse effects to marine organisms (fish, invertebrates, algae) based on the scenario considered (Table 9.2). The volume of Fuel Oil No. 2 required to yield a risk quotient of 1 with the marine transport scenario was 174 000 L which was greater than any recorded marine spill of Fuel Oil No. 2 in Canada from 2000 to 2009.

To generate a risk quotient of 1 in the freshwater scenario, a spill of 860 L would be required during loading and unloading. Twenty-three percent of all freshwater spills with reported volumes between 2000 and 2009 were greater than this threshold volume. Unknown volumes were estimated by extrapolation. It was estimated that there are approximately 6 spills yearly to the freshwater environment that could potentially cause adverse effects to freshwater organisms (fish, invertebrates, algae) (Table 9.2). The volume of Fuel Oil No. 2 required to yield a risk quotient of 1 during freshwater transport was 174 000 L which was greater than any recorded freshwater spill of Fuel Oil No. 2 in Canada from 2000 to 2009.

These spill volumes were calculated based on models developed by RMRI (2007) relating 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 a risk quotient 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 required to obtain a risk quotient of 1 and the percentage of reported spills above this threshold volume

Compartment affected	**Spill volume required to obtain RQ of 1 (threshold volume) (L)**	**Percentage of *reported* spills above the threshold volume**	**Approximate average number of spills per year above the threshold volume**
Freshwater Loading/Unloading	860	23%	6
Freshwater Transport	174 000	0%	0
MarineLoading/Unloading	860	16%	6
Marine Transport	174 000	0%	0

Risk quotients for soils were derived based on a PEC calculated using the median spill volume to soils from the 2000 to 2009 NEMISIS data (PEC = 52 L) (Environment Canada 2011). The resulting risk quotient is much greater than 1 (RQ = 58).

The minimum spill to terrestrial environments that would generate a risk quotient of 1 could not be determined given the information available. In the terrestrial environment, the reported number of spills on an annual basis across Canada in sufficiently large volumes demonstrates the likelihood of widespread adverse effects to terrestrial organisms. The exposure scenario for releases of Fuel Oil No. 2 to soil demonstrates that an expected median volume spill (based on NEMISIS data), and many at lower volumes, can cause harm to terrestrial organisms (invertebrates, plants). Between 2000 and 2009, there were approximately 2050–2980 spills of Fuel Oil No. 2 to soil (excluding indoor releases), or approximately 200-300 spills per year, based on the NEMISIS database. At least half of these spills (100-150 per year) were at sufficient quantities to cause harm to terrestrial organisms. Based solely on spill data from Ontario (Ontario 2013), there are approximately 160-190 spills per year to soil (excluding indoor releases) in Ontario of which at least half are expected to cause harm to terrestrial organisms.

Of the 2050-2980 releases to soil identified in NEMISIS for the years 2000 to 2009, approximately 1280-2220 (62-74%) were associated with residential home fuel tanks. An additional 676 were releases from tank trucks, transport trucks and other motor vehicles (excluding all overturns). Pipeline transport was not a significant source of Fuel Oil No. 2 release based on data from NEMISIS with only 8 total reported releases to land. In Ontario, 44% of all spills to soil from 2008 to 2012 (444 of 1007 releases to land) were associated with residential home fuel tanks.

The average frequency of spills of Fuel Oil No. 2 to soil is expected to be underestimated as the available data only accounts for spills from provinces representing approximately 60% of all sales of Fuel Oil No. 2. Spills to residential sites do not need to be reported to the NEMISIS database; however, the Atlantic region did include all residential spills when reporting to the database. Therefore, reports of Fuel Oil No. 2 spills associated with residential heating tanks, the largest contributor to the total releases of Fuel Oil No. 2 to land, are under represented nationally in NEMISIS and thus the estimated average annual number of spills is likely underestimated. For comparison, for the years 2008 to 2012, only 1.1% of Fuel Oil No. 2 spills in Ontario were reported in NEMISIS. Therefore, to supplement the NEMISIS data, Ontario spill data were considered for 2008 to 2012. Additionally, the amount of soil impacted from a spill is a function of the spill volume. As there is fairly limited dispersal of spilled Fuel Oil No. 2 in soil, there is a high likelihood of an ecological impact from a spill, but the extent of impact (i.e., area or volume of soil impacted) may be limited.

Fuel Oil No. 2 contains components that may persist in water, soil and/or sediment, thus increasing the duration of exposure to organisms.

Based on the combined evidence of empirical and modelled BAFs, Fuel Oil No. 2 also 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. In general, fish can efficiently metabolize aromatic compounds. There is some evidence that alkylation increases the 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 greater than 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, 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 of Fuel Oil No. 2 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).

The nature, extent and frequency of spills are key considerations in characterizing the ecological risks of this substance. Freshwater and marine organisms may be adversely affected by spills of Fuel Oil No. 2 during loading/unloading on average approximately 6 times per year each. Releases to terrestrial environments occur on average 200 to 300 times per year based on 2000-2009 data in the NEMISIS database, with at least 100-150 spills/year resulting in significant harm (RQ much greater than 1). Ontario spill data from 2008-2012 indicate that releases to terrestrial environments occur on average 160 to 190 times per year within that province alone, with at least 80-95 spills per year expected to result in significant harm.

Considering all available lines of evidence presented in this screening assessment, there is risk of harm to organisms, but not to the broader integrity of the environment from Fuel Oil No. 2. It is concluded that Fuel Oil No. 2 meets the criteria under paragraph 64(*a*) of CEPA 1999 as it is entering or may enter 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. However, it is concluded that Fuel Oil No. 2 does not meet the criteria under paragraph 64(*b*) of CEPA 1999 as it is not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

9.4 Uncertainties in Evaluation of Ecological Risk

The information reported to Environment Canada's NEMISIS database contains a degree of uncertainty particularly in relation to the reported quantities spilled, as well as the non-uniformity of spill data. Reporting requirements to NEMISIS are limited to spills 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. For the years 2008-2012, only 1.1% of all Ontario spills of Fuel Oil No. 2 were reported to NEMISIS, which indicates the degree that NEMISIS underreports spills nationally, especially to land. However, the Atlantic provinces did report all spills to NEMISIS during the 2000-2009 timeframe considered. These data and the 2008-2012 Ontario spill data were sufficient to determine that releases of Fuel Oil No. 2 were causing harm. The values presented in this report, however, are expected to underestimate the spills occurring nationally as the Atlantic provinces and Ontario only account for approximately 60% of all sales of Fuel Oil No. 2 and comprehensive spill data for the provinces and territories responsible for the remaining 40% of sales is lacking.

Forty-nine percent of the reported releases from the NEMISIS database did not report a quantity; therefore, unreported volumes are estimated. As part of this assessment, an assumption was made that the actual total volumes follow the same distribution and volumes as the reported volumes.

For the NEMISIS data, proportions based on 2008-2009 data on the number of spills associated with residential home heating tanks and the location of these spills were used to extrapolate to the entire database (2000-2009). There is uncertainty in these extrapolations. Additionally, assumptions were made with regard to the location of spills associated with residential home heating tanks. For many, the location (i.e., inside or outside of buildings) was unknown. To address this, the spills with unknown location were assumed to occur either entirely inside or entirely outside, thus giving a range of values of the number of releases.

All modelling of the substance's physical and chemical properties, persistence, bioaccumulation potential and toxicity characteristics is based on representative chemical structures. As Fuel Oil No. 2 is a UVCB, it cannot be represented by a single, discrete chemical structure. Therefore, for the purposes of modelling, a suite of 23 representative structures were identified to provide estimates for the entire range of components likely present. Given that a variety of different representative structures may be derived for the same petroleum UVCB, because of the lack of detailed information on their chemical make-up and the large number of individual components within the substance, it is recognized that structure-related uncertainties exist for this substance.

10. Potential to Cause Harm to Human Health

For the purpose of characterizing risk to human health, potential exposures from the use of Fuel Oil No. 2 in residential heating applications, and from the storage of the fuel at bulk storage facilities, are considered.

10.1 Exposure Assessment

The physical-chemical properties of Fuel Oil No. 2 (NCI 2006) enable it to be used as fuel in combustion devices such as burners, boilers, generators and engines. Residential applications use fuel oil to power furnaces and boiler systems. Residential fuel oil is contained within a fuel storage tank that is located either indoors or outdoors. There is the potential for fuel releases if the tank or associated parts become compromised (resulting in a fuel leak), or during tank filling (resulting in a fuel spill). Causes for leaks include metal corrosion, leaking pump, atomizer, or fuel oil filter, burst valves or fuel lines (from pressurization during the filling process when a vent pipe is blocked), improper tank location and improper installation and/or maintenance (Nova Scotia 2010). There are obligations that vary by province or territory for the reporting of a large volume leak or spill and to obtain information on proper clean-up procedures (TSSA 2007).

The assessment of the potential to cause ecological harm has focused on reported data of spills that occur during the process of transportation; these releases may occur to various receiving media. The general population is not expected to encounter Fuel Oil No. 2 during transport to final destinations (e.g., to residential homes).

There are minimum requirements and regulations for the safe installation and use of tanks and for fuel storage and handling (Appendix G). Tanks must be registered and inspected before filling by a licensed technician (Ontario 2000, 2008; Nova Scotia 2005). The fuel supplier is obligated to provide fuel only if the storage tank meets minimum standard requirements. There are also mandatory requirements for replacement of in-ground tanks older than approximately 25 years. Regulations that ensure indoor tanks are located above ground may result in earlier leak detection and thus help limit the volume released (Ontario 2000, Nova Scotia 2005). Additionally, some home insurance providers require replacement of older tanks, thus reducing the probability of a tank leak. Newer fuel oil tanks are made with durable materials including heavy gauge steel, fibreglass, or polyethylene surrounded by galvanized steel (ZCL 2010). Together, these measures reduce the magnitude and frequency of tank leaks.

In the event of a fuel tank leak within a home , exposure to fuel vapours and possibly skin contact with the fuel, could occur. However, if exposure to fuel oil occurs as a result of a tank leak, it is expected to be limited in duration and not recur. Given the unpredictable nature of residential fuel tank leaks, the low potential for exposure (due in part to the standard requirements, regulations and measures in place as mentioned above) and the expected limited duration of exposure, tank leaks are not considered to constitute a risk to human health and are not considered further.

It has been reported that fuel oil may sometimes be used in low quantities as a cleaning solvent for removing oil-based material from tools or from hands. This practice is not considered a normal use of the fuel and is unlikely given the viscosity, colour and unpleasant odour of the fuel (CONCAWE 1996); therefore, this use is not considered further.

Oral exposure to Fuel Oil No. 2 is not expected, as ingestion of the fuel is unlikely given the colour, odour and viscosity of the substance and because access to the substance is limited (CONCAWE 1996).

Under conditions of normal use of Fuel Oil No. 2 in residential heating applications, it is possible that individuals inside a residence may be exposed to evaporative emissions if the fuel storage tank is not air tight. Possible exposure to evaporative emissions is accounted for below by examining air monitoring data from homes with and without Fuel Oil No. 2 heating.

Fuel Oil No. 2 may be stored in bulk at refineries, upgraders or other storage sites (“bulk storage facilities”) prior to delivery to the marketplace. Thus, inhalation exposure to Fuel Oil No. 2 evaporative emissions may occur for the general population residing in the vicinity of bulk storage facilities. In order to derive levels of possible inhalation exposures for this scenario, in the absence of monitoring data for vapour releases from Fuel Oil No. 2, modelling the release and dispersion of benzene, a high-hazard component of fuel oil, was used.

Fuel Oil No. 2 Vapour Characterization

In the absence of sufficient exposure and health effects data on Fuel Oil No. 2 vapour, knowledge of the proportions, identities and health effects of the components comprising the vapours can help improve the characterization of risk of exposure to fuel oil for the general population. In conducting this assessment, the vapour components with the highest potential hazards to human health were considered.

Given that Fuel Oil No. 2 shares similar physical-chemical properties and carbon ranges with diesel fuels, vapour headspace analysis of the aromatic volatiles present in diesel fuel can be used for read-across to Fuel Oil No. 2 (Table 10.1).

Headspace analysis of both an arctic (winter) and summer diesel fuel determined the identity and relative percentage of each component present in the vapour of each sample (FLL 2008). Table 10.1 shows the percent composition of select vapour components.

Table 10.1. Select headspace components of diesel fuel (considered representative of the headspace of Fuel Oil No. 2)(FLL 2008)

Name	CAS RN	% Headspace composition in Arctic Diesel[1]	Concentration in Headspace in Arctic Diesel (mg/m^3)	% Headspace composition in Summer Diesel[1]	Concentration in Headspace in Summer Diesel (mg/m^3)
Benzene	71-43-2	0.92%	27	3.00%	70
Toluene	108-88-3	5.52%	162	5.95%	139
Ethyl benzene	100-41-4	2.73%	80	2.44%	57
***m*-Xylene**	108-38-3	5.28%	155	4.07%	95
***p*-Xylene**	106-42-3	1.91%	56	1.58%	37
***o*-xylene**	95-47-6	3.30%	97	2.27%	53

The headspace analysis indicates approximately 20% (w/w) of diesel fuel vapour (and, by read-across, Fuel Oil No. 2 vapour) is composed of benzene, toluene, ethylene and xylenes (BTEX). These substances occur at low concentrations in the liquid fuels; however, due to their volatility, they have higher relative concentrations in the headspace. Benzene was detected at 0.92% and 3% in the headspace of two fuel samples (Table 10.1). Benzene represents the component of highest concern because it was classified as a Group 1 carcinogen (*carcinogenic to humans*) by the International Agency for Research on Cancer (IARC) (1987, 2004, 2007), as well as a carcinogen by the Government of Canada (Canada 1993) and was added to the *List of Toxic Substances* in Schedule 1 of CEPA 1999. Based on its established potential as a carcinogen, benzene is considered to be the component representing the highest health concern for long-term inhalation exposures to fuel oil vapours.

10.1.1 Human Exposure Estimates (Inhalation)

The potential for inhalation exposure to the volatile fraction of Fuel Oil No. 2 inside a residence under conditions of normal use of the fuel, or in the vicinity of bulk storage facilities, were considered.

10.1.1.1 Inhalation exposure in residences heated with Fuel Oil No. 2

The following volatile components of Fuel Oil No. 2 have been identified as potential indicators of the presence of Fuel Oil No. 2: xylenes, *n*-nonane, *n*-decane, *n*-undecane, *n*-dodecane, ethylbenzene, isomers of trimethylbenzene and tetramethylbenzene, naphthalene, 1-methylnaphthalene and 2-methylnaphthalene (Kaplan et al. 1993; NYSDOH 2003).

A study was designed to assess the concentrations of volatile organic compounds and other pollutants in indoor and outdoor air for 54 Halifax residences. An analysis of the data indicated that 20 of the homes use Fuel Oil

No. 2 as a source for home heating and the other 34 homes use alternative sources for heating (Health Canada 2009, unpublished). By examining differences in air concentrations of Fuel Oil No. 2 marker components between homes with and without Fuel Oil No. 2 heating, the potential contribution of Fuel Oil No. 2 to increased levels of these volatile organic compounds hydrocarbons in indoor air can be evaluated. Indoor median and 75th percentile air concentrations of relevant components are presented in Table 10.2. Each sample point is the average result of a minimum of four days of measurements. Winter and summer sampling results for each home were used in determining the median values.

Table 10.2. Annual median and 75th percentile concentrations of select components in indoor ambient air in Halifax homes with and without Fuel Oil No. 2 heating.

VOC	Number of Samples	Fuel Oil No. 2 heating (yes/no)	Median (µg/m^3)	75th percentile (µg/m^3)
ethylbenzene	39	Yes	1.1	2.1
	61	No	1.1	3.0
m-*p*-xylene	39	Yes	2.8	7.6
	61	No	3.6	9.8
o-xylene	39	Yes	0.9	2.1
	61	No	0.9	2.9
n-nonane	39	Yes	0.8	1.6
	61	No	0.9	2.1
n-decane	39	Yes	1.9	4.0
	61	No	1.8	5.1
n-undecane	39	Yes	2.3	4.5
	61	No	3.0	5.8
n-dodecane	39	Yes	1.1	2.2
	61	No	1.4	2.4
1-2-4-trimethylbenzene	39	Yes	1.0	1.7
	61	No	1.6	4.5
1-2-3-trimethylbenzene	39	Yes	0.4	0.6
	61	No	0.6	1.2
1-3-5-trimethylbenzene	39	Yes	0.3	0.45
	61	No	0.5	1.3

Median and 75th percentile concentrations of every Fuel Oil No. 2 marker component were higher in non-Fuel Oil No. 2 heated homes, with the exception of *n*-decane (median concentration of 1.9 versus1.8 µg/m^3). There may be additional qualitative differences between homes with Fuel Oil No. 2 and those with alternative heating sources that could account for these observations. However, these results suggest that homes with Fuel Oil No. 2 do not have elevated VOC concentrations as compared to other homes.

A similar study conducted between 1997 and 2003 by the New York State Department of Health analyzed the concentrations of VOCs in the indoor air of 104 single family homes that heat with fuel oil (NYSDOH 2006). Residences were required to have no past oil spills, no hobbies or home businesses that regularly use products containing VOCs and no recent activities utilizing products that contain VOCs (e.g., painting, staining, etc.). The study was conducted during both heating and non-heating seasons and included air samples from basements and living rooms, as well as from outdoors in proximity to the study homes. Median and 75th percentile concentrations of Fuel Oil No. 2 marker components are presented in Table 10.3.

Table 10.3. Annual median and 75th percentile air concentrations of select components for homes heated with Fuel Oil No. 2 in New York state

VOC	Location	Number of Samples	Median[a] (µg/m^3)	75th percentile (µg/m^3)
ethylbenzene	indoor	58	1.0	2.8
	outdoor	107	<0.25	0.48
m-*p*-xylene	indoor	54	1.5	4.6
	outdoor	110	<0.25	0.48
o-xylene	indoor	71	1.1	3.1
	outdoor	120	<0.25	0.56
n-nonane	indoor	65	1.3	3.4
	outdoor	79	0.4	0.37
n-decane	indoor	40	2.7	6.6
	outdoor	174	<0.25	2.0
n-undecane	indoor	59	1.8	5.0
	outdoor	184	<0.25	0.67
n-dodecane	indoor	73	1.5	3.9
	outdoor	65	0.8	1.9
1-2-4-trimethylbenzene	indoor	49	1.9	4.3
	outdoor	109	<0.25	0.81
1-2-3-trimethylbenzene	indoor	164	0.4	1.1
	outdoor	165	<0.25	< 0.25
1-3-5-trimethylbenzene	indoor	100	0.6	1.1
	outdoor	143	<0.25	0.37

[a] Less than 0.25 indicates below the detection limit.

Comparison of the median data for Halifax and New York (Tables 10.2 and 10.3) shows similar concentrations for volatile organic compounds in Fuel Oil No. 2 heated homes, for example ethylbenzene (1.1 µg/m^3 versus 1.0 µg/m^3, respectively) and *o*-xylene (0.9 µg/m^3 and 1.1 µg/m^3, respectively).

Together these results, although limited, suggest that the residential use of Fuel Oil No. 2 does not contribute to elevated air concentrations of marker volatile organic compounds.

10.1.1.2 Inhalation exposure in the vicinity of a Fuel Oil No. 2 bulk storage facility

Refineries, upgraders and other petroleum facilities (e.g., terminals, bulk plants, etc.) typically have storage tanks on site for temporary storage of Fuel Oil No. 2 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 mentioned above), and their associated storage tanks, shows that residential homes can be in close proximity to the storage areas. Thus, the evaporative emissions from Fuel Oil No. 2 storage tanks at refineries and other facilities may be a source of exposure to fuel vapours for the general population in the vicinity of these 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) (ARC 2006; Chambers et al. 2008; U.S. EPA 2006). DIAL has been used in Europe for over twenty years to identify and quantify emissions from specific locations within refineries, thus enabling targeted reductions in emissions (ARC 2006; Chambers et al. 2008). Within a specific Canadian facility, Spectrasyne Environmental Surveying determined an emissions rate for benzene from gas oils/kerosene contained in fixed roof tanks to be 0.02 kg/hr-tank (Spectrasyne 2011).

The benzene emissions rate was used in SCREEN3 (1996) calculations to determine the benzene dispersion and thus concentration in air at various distances from the respective storage site. 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 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 one 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.

A scenario of benzene emissions from a facility with two fixed roof Fuel Oil No. 2 storage tanks in a 50 × 100 m^2 area was considered. Using SCREEN3 modelling (the input parameters used to model the releases are given in Table H.1 in Appendix H) with the benzene emissions rate of 0.02 kg/hr per tank and a release height of 10 m, the maximum concentration of benzene was determined to be at 130 m from the center 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 $μg/m^3$. 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 was calculated to be 0.91 $μg/m^3$. This concentration is taken in the context of the conservatism built into the scenario (SCREEN3 provides maximum values) and that the average ambient air concentration of benzene in Canada is 0.88 $μg/m^3$ (NAPS 2008).

The variation in benzene concentration with distance from the center of the bulk storage facility is provided in Table H.2 of Appendix H.

10.2 Health Effects Assessment

Given the limited number of identified studies evaluating the health effects of Fuel Oil No. 2 (CAS RN 68476-30-2), an adequate toxicological dataset of studies conducted with this CAS RN could not be obtained. Therefore, in order to characterize the health effects of Fuel Oil No. 2, similar PSSA gas oil substances, namely diesel fuels (CAS RNs 64742-80-9, 68334-30-5 and 68476-34-6), were considered. Because Fuel Oil No. 2 and diesel fuels have similar physical-chemical properties (CONCAWE 1996), their toxicological properties are likely similar. The health effects data were pooled and used to construct a profile considered representative of Fuel Oil No. 2.

Appendix I contains a summary of available health effects information for Fuel Oil No. 2 (and related gas oil substances) in laboratory animals, including the lowest-observed-adverse-effect levels/concentrations (LOAEL/Cs) and no-observed-adverse-effect levels/concentrations (NOAEL/Cs), as well as the corresponding health effects. A summary of key studies selected to represent the health effects of Fuel Oil No. 2 follows.

Fuel Oil No. 2 exhibits low acute toxicity in laboratory animals; oral LD_{50} values ranged from 11 900 to 17 300 mg/kg-bw in rats (CONCAWE 1996; API 2003a). The oral LD_{50} for Diesel Fuel No. 2 (sample API 79-6) was 7400 mg/kg-bw in rats (CONCAWE 1996; API 2003a). Other gas oils exhibited LC_{50} values ranging from

3350 to 7640 mg/m^3 in rats (CONCAWE 1996; API 2003b). A dermal LD$_{50}$ for Fuel Oil No. 2 was not established and was greater than 4100 mg/kg-bw in rabbits (CONCAWE 1996; API 2003a).

A single dermal exposure of laboratory animals to a high dose of Fuel Oil No. 2 typically resulted in moderate skin irritation (CONCAWE 1996; API 2003a, b). Rabbits dermally exposed with abrasion and occlusion to 2000 mg/kg-bw of CAS RN 64742-80-9 or to Diesel Fuel No. 2 for 24 hours did not exhibit test substance-specific systemic toxicity or gross organ pathology (CONCAWE 1996; API 2003b; Mayhew et al. 1985). In a dermal irritation study where New Zealand White rabbits were exposed via occlusion to 2 mL (~730 mg/kg-bw) of diesel fuel for 24 hours, no abnormal clinical signs were noted (Mayhew et al. 1985). Also, an acute dermal study designed to assess rabbit mortality after exposure to 4100 mg/kg-bw Diesel fuel No. 2 did not produce mortalities but did produce mild to moderate irritation, erythema and flaking of the skin at the application site (API 1980a; Beck et al. 1984).

One short-term repeated-dose dermal study was conducted for Fuel Oil No. 2. New Zealand White rabbits were exposed daily to 841, 2524 or 8414 mg/kg-bw test substance for two weeks. Dose-related skin deterioration was observed, with severe skin lesions occurring in the group receiving the highest dose (API 1980b).

In short-term and subchronic repeated-dose dermal studies conducted with diesel fuel or gas oil substances, moderate to severe skin irritation and inflammation were observed in laboratory animals at all doses tested. A LOAEL of 200 mg/kg-bw per day was established based on decreased body weight gain and mean corpuscular haemoglobin concentration, as well as dose-related dermal irritation, after exposure of male and female New Zealand white rabbits to Diesel fuel No. 2 for three weeks (IITRI 1984).

Studies assessing the health effects of exposure to Fuel Oil No. 2 vapour were not available. However, CAS RN 64742-80-9 was tested in a 4-week inhalation study of a single vapour concentration in Sprague-Dawley rats; a LOAEC of 23 mg/m^3 was established based on microscopic changes in the nasal tissue, including subacute inflammation of the respiratory mucosa (API 1986). An increased leukocyte count (~30%) was also noted, but no corresponding macroscopic changes were observed at necropsy. Additionally, a subchronic LOAEC of 250 mg/m^3 was identified in a study that exposed Sprague-Dawley rats to Diesel Fuel vapour for thirteen weeks. Decreased body weight and increased response time in a startle reflex assay were observed (but a corresponding histological change in the nervous system was not observed) (Lock et al. 1984).

Repeated-dose studies assessing oral exposure to Fuel Oil No. 2 were not available. However, an oral LOAEL of 500 mg/kg-bw was identified for Diesel

Fuel No. 2 (in a single dose level study). Sprague-Dawley rats were administered low or ultra-low sulphur diesel in corn oil by gavage 5 days per week for 4 weeks. Effects of low sulphur diesel included significant (p less than 0.05) increases in relative liver weights, liver enzymes (benzyloxyresorufin-*O*-dealkylase (BROD), 7-ethoxyresorufin-*O*-deethylase (EROD), pentoxyresorufin-*O*-dealkylase (PROD), glutathione-S-transferase (GST), UDP-glucuronosyl-transferase (UDPGT), palmitoyl-CoA oxidase (PCO)), serum free fatty acids, urinary albumin and urinary ascorbic acid, significantly (p less than 0.05) decreased liver triglycerides and kidney tubular outer cortex cytoplasmic inclusions and cytoplasmic shedding into the lumen (Poon et al. 2007). Effects of ultra-low sulphur diesel included significant (p less than 0.05) increases in liver GST, BROD, EROD, PROD, acyl-CoA oxidase, in serum calcium and inorganic phosphate and in urinary ascorbic acid, albumin and N-acetylglucosaminidase activity and significant (p less than 0.05) decreases in serum lactate dehydrogenase and free fatty acids. Mild histopathological changes in the liver, hepatomegaly, increased kidney weights and changes in kidney histopathology were also observed (Poon et al. 2009). Biochemical changes were also noted in a short-term study of male Sprague-Dawley rats administered 1013 mg/kg-bw commercial Diesel Fuel No. 2 by gavage. Increases in the hepatic enzymes EROD, 7-ethoxycoumarin-*O*-deethylase (ECOD), GST and aryl hydrocarbon hydroxylase were observed (Khan et al. 2001).

Fuel Oil No. 2 has been classified by the European Commission as a Category 3 carcinogen (R40: *limited evidence of a carcinogenic effect*) (European Commission 1994; ESIS c1995-2012). The European Commission also adopted the United Nations' Globally Harmonized System of Classification and Labelling of Chemicals which classified Fuel Oil No. 2 as a Category 2 carcinogen (H351: *suspected of causing cancer*) (European Commission 2008a). IARC has determined the overall classification for distillate (light) fuel oils to be Group 3 carcinogens (*not classifiable as to their carcinogenicity to humans because of an absence of data*) and that there is *limited evidence* for the carcinogenicity in experimental animals of Fuel Oil No. 2 (IARC 1989a).

The carcinogenicity of Fuel Oil No. 2 has been investigated in multiple skin painting studies in mice. An increase in the number of mice with skin tumours (papillomas and carcinomas) occurred after chronic dermal exposure to doses that ranged from 287 to 1148 mg/kg-bw (Witschi et al. 1987; Gerhart et al. 1988; Biles et al. 1988). One dermal study investigated the tumour initiating and promoting activity of Fuel Oil No. 2 in male mice (Gerhart et al. 1988). Tumour initiation was concluded to be not statistically significantly increased following exposure to 559 or 1117 mg/kg-bw for 5 days. However, statistically significant skin tumour promotion was observed following application of 1117 mg/kg-bw, 2 times per week for 25 weeks.

Diesel fuels have also been assessed in chronic skin painting studies and shown similar trends. Male mice dermally exposed to CAS RN 68476-34-6 (diesel fuel sample LF-7765 RI) at a dose of 1095 mg/kg-bw, 2 times per week for life had statistically significant skin tumour formation (squamous cell carcinomas and fibrosarcomas) (IITRI 1985). In another study assessing the same CAS RN (petroleum diesel), an increase in skin tumour formation (although not statistically significant) was observed after male and female mice were exposed to 833 mg/kg-bw, 3 times per week for 54 weeks (Clark et al. 1988). One dermal study also investigated the initiation/promotion ability of CAS RN 68334-30-5 (sample DGMK No. 22) in male mice (DGMK 1993). No skin tumour initiation was seen following exposure to 1111 mg/kg-bw for 5 days. Only 1 of 30 mice developed skin tumours (and no tumours developed in the negative control group) using promotion methodology that included application of CAS RN 68334-30-5 (1111 mg/kg-bw), 2 times per week for 24 weeks.

Although limited, these results indicate that Fuel Oil No. 2 and the diesel fuels can exhibit localized carcinogenicity when chronically applied to the skin of mice.

The genotoxicity of Fuel Oil No. 2 has been assessed in *in vivo* and *in vitro* genotoxicity assays. *In vivo* studies gave positive results for chromosomal aberrations in rats following oral exposure (Conaway et al. 1984; API 1979a). A negative result was observed in a micronuclei induction study following oral exposure of mice (McKee et al. 1994). *In vitro* genotoxicity studies were largely positive including in the Ames and modified Ames assays and sister chromatid exchange and mouse lymphoma assays (McKee et al. 1994; Conaway et al. 1984; API 1979a; Ellenton and Hallett 1981; DGMK 1991). One Ames assay reported negative results (DGMK 1991). Overall the genotoxicity database indicates that Fuel Oil No. 2 exhibits genotoxic potential.

Limited data were available to assess the potential for reproductive and developmental health effects of Fuel Oil No. 2. Two studies showed no adverse effects in rats after inhalation exposure to 2945 and 3081 mg/m^3 test substance aerosols (Beliles and Mecler 1983; Schreiner 1984). Diesel fuels have also been investigated for their potential to cause developmental and reproductive toxicity and have similarly tested negative in rats via inhalation (from 250 to 3777 mg/mg^3) (API 1979b; Beliles and Mecler 1983; Schreiner 1984; Lock et al. 1984). These substances were also negative at 4050 mg/kg-bw per day for dermal exposure (UBTL 1986). Developmental health effects have been observed for a gas oil substance (CAS RN 64741-59-9) at 1000 mg/kg-bw per day. The substance was applied dermally to female rats on days 0 to 6 and 6 to 15 of gestation. Increased incidence of foetal resorptions and decreased foetal body weight were seen for these dosing regimens, respectively (Feuston et al. 1994; Mobil 1988). All other studies, with test substances administered dermally or via inhalation, had negative results.

A limited number of diesel fuel empirical studies, case reports and epidemiology studies were identified for read-across to assess potential health effects of Fuel Oil No. 2 in humans exposed via inhalation and dermal routes. In a single exposure inhalation study in healthy human volunteers, eye, nose and throat irritation were negligible after exposure to diesel oil aerosols at 332 mg/m^3 for 10 minutes and no other effects were noted (Dautrebande and Capps 1950). A case report of a much longer inhalation exposure involved a truck driver exposed for 10 days to high concentrations of diesel fuel vapour in his cab (due to a cracked fuel injector) (Reidenberg et al.1964). This individual developed reversible acute renal failure secondary to acute tubular necrosis. Another case report describes substantial and prolonged dermal exposure to ‘diesel oil’, where it was used over several weeks as an arm and hand cleaner. In this case, development of epigastric and loin pains, nausea, anorexia, degeneration of kidney tubular epithelium and reversible renal failure were observed (Crisp et al. 1979). The irritant properties of diesel fuels have been assessed in studies of short-term dermal exposures of human volunteers. No visible skin effects were seen after 15 minute dermal exposure to 1.5 mL of six diesel fuel samples over an area of 3.1 cm^2; however, a slight increase in blood flow to the area was noted in some cases (Wahlberg 1995). Another dermal study in human volunteers observed increased skin irritancy with cumulative exposure time, when diesel fuel samples were applied from 15 minutes to 48 hours. Irritation was first noted after 4 hours of exposure and occlusion of the application site and the application of ‘newer’ (i.e., lower sulphur and aromatic content) blends of diesel fuels (samples MK I and MK II) produced greater irritancy (Fischer and Bjarnason 1996). Adverse systemic or other effects were not noted in these human studies of short term dermal exposures. With respect to occupational exposures to diesel fuels, a case-control study of male cancer patients revealed a combined adjusted odds ratio of 1.9 (90% confidence interval = 1.2-3.0) for prostate cancer in men with non-substantial or substantial exposures to diesel fuel. However, there is no evidence of a positive dose-response relationship in this study and the results are confounded by exposures to other petroleum substances and unknown routes of exposure (Siemiatycki et al. 1987). Due to limited data and confounding variables, the evidence gathered from these human studies is inadequate for determining the presence of systemic effects from short-term exposure to diesel fuel; however, the absence of adverse effects in the inhalation and dermal exposure studies in humans, together with a lack of overt toxicity in animal studies, suggests diesel fuels (and, by analogy, Fuel Oil No. 2) have low acute toxicity.

Fuel Oil No. 2 contains the high-hazard component benzene at approximately less than 0.02% (w/w); however, due to its high volatility, benzene may represent up to approximately 3% of the Fuel Oil No. 2 vapour phase (Table 5). Benzene has been assessed by Health Canada under CEPA, 1999 (Canada 1993), was determined to be a carcinogen and was added to the *List of Toxic Substances* in Schedule 1 of CEPA 1999. International organizations have drawn similar conclusions; IARC classifies benzene as Group 1 (*carcinogenic to humans*) (IARC 1987, 2004, 2007). The Government of Canada has previously developed estimates of carcinogenic potency associated with inhalation exposure to benzene. A 5% tumourigenic concentration (TC_{05}) for benzene was calculated to be 14.7×10^3 µg/m^3 (Canada 1993) from the epidemiological investigation of Rinsky et al. (1987), based on acute myelogenous leukaemia in Pliofilm workers. 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], WHO [2000]) are similar to the TC_{05} used below in this screening assessment 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

Fuel Oil No. 2 was identified as a high priority for action during categorization of the DSL because it was determined to present the greatest potential for exposure of individuals in Canada and was considered to present a high hazard to human health. A critical effect for the initial categorization of Fuel Oil No. 2 was carcinogenicity, based on classifications by international agencies and skin painting studies in laboratory animals demonstrating the development of skin tumours following chronic dermal exposure. Fuel Oil No. 2 is classified as a Category 3 carcinogen by the European Commission (European Commission 1994; ESIS c1995-2012), a Category 2 carcinogen using the adopted Globally Harmonized System (European Commission 2008a) and a Group 3 carcinogen by IARC (IARC 1989a).

Based on limited data, residences using Fuel Oil No. 2 as a heating source, under normal use conditions, do not have elevated indoor air levels of marker volatile organic compounds relative to residences using other types of home heating. Therefore, based on these data, exposures from the use of Fuel Oil No. 2 for residential heating are considered to be negligible and risk to the general population is considered to be low.

In the event of a residential fuel storage tank leak, exposure of the general population was not identified as a concern for human health because of the limited duration of potential exposure, the low acute toxicity of the fuel and existing leak mitigation measures. There is potential for inhalation exposure to Fuel Oil No. 2 volatiles in the vicinity of bulk storage facilities. To characterize the risk from potential exposures to these evaporative emissions, the annual upperbound estimated concentration of the high-hazard component of Fuel Oil No. 2 vapour, benzene (0.91 µg/m^3), was compared with its carcinogenic potency ($TC_{05} = 14.7 \times 10^3$ µg/m^3), previously developed by the Government of Canada (Canada 1993). The resulting margin of exposure at 300 m from a bulk storage facility with two storage tanks containing Fuel Oil No. 2 is approximately 16 000.

This margin is considered adequate to address uncertainties related to health effects and exposure.

10.4 Uncertainties in Evaluation of Human Health Risk

A standard chemical composition for Fuel Oil No. 2 does not exist because it is a UVCB and, by definition, its specific composition is variable and not well-defined. Fuel Oil No. 2 varies in part based on the source of crude oil or bitumen from which it is derived. This variability in chemical composition adds uncertainty to the overall characterization of risk in that the actual levels of exposure of the mixture, and the propensity for causing health effects, may vary from batch to batch.

There is some uncertainty in the determination of the level of exposure of individuals in homes with fuel oil heating due to limited air monitoring data for the volatile fraction of Fuel Oil No. 2.

For the bulk storage scenario, there is some conservatism and uncertainty in the characterization of risk from long-term inhalation exposure due to the assumption that exposures are continuous. Additionally, if the storage tank density is greater than used in this assessment, then the exposures would have been underestimated.

It is difficult to obtain a representative toxicological dataset because Fuel Oil No. 2 obtained under the same CAS RN can vary in the number, identity and proportion of component compounds, depending on the refinery operating conditions, source of feedstocks and types of processing units. Furthermore, there is a general lack of data characterizing the health effects of Fuel Oil No. 2. For these reasons, all available health effects data on Fuel Oil No. 2, as well as additional similar PSSA gas oil substances, namely the diesel fuel substances, were pooled to develop a comprehensive health effects profile.

Uncertainty also exists due to the fact that certain details characterizing the laboratory animals (i.e., sex, strain and body weight) were not always reported in the studies and these data gaps were filled using standard laboratory data where appropriate. Thus, the assumed animal population characteristics may not be entirely representative of the actual individual physical characteristics of the laboratory animals used in the respective studies.

There was also a lack of information regarding the physical-chemical properties of certain CAS RNs used to generate the pooled health effects profile. The densities of specific CAS RNs were not provided in some studies; thus, these properties were obtained from alternate sources.

There is uncertainty in the exposure estimates and in the health effects database as they pertain to the use of a single high-hazard component to characterize risk.

A varying and wide range of chemical components, with individual physical-chemical properties that may change due to mixture effects, are present in Fuel Oil No. 2. Characterizing risk based on a single high-hazard component may be protective of potential risks from other components, but inherently cannot account for mixture effects (i.e., the influence of concurrent exposure to multiple components on the pharmacokinetic and pharmacodynamic properties of a single component).

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

11. Conclusion

Based on the available information presented in this screening assessment on the frequency and magnitude of spills, Fuel Oil No. 2 may cause harm to organisms in areas adjacent to sources of release; however, these releases do not compromise the broader integrity of the environment. It is therefore concluded that Fuel Oil No. 2 (CAS RN 68476-30-2) meets the criteria under paragraph 64(*a*) of CEPA 1999 as it is entering or may enter 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. However, it is concluded that Fuel Oil No. 2 (CAS RN 68476-30-2) does not meet the criteria under paragraph 64(*b*) of CEPA 1999 as it is not entering the environment in a quantity or concentration or under conditions that constitute or may constitute a danger to the environment on which life depends.

Margins of exposure between upper-bounding estimates of exposure to benzene, a high-hazard component of Fuel Oil No. 2 vapour, and estimates of cancer potency are considered adequate to address uncertainties related to health effects and exposure for long-term exposure to evaporative emissions of Fuel Oil No. 2 in the vicinity of storage facilities, or from residential heating. It is therefore concluded that Fuel Oil No. 2 (CAS RN 68476-30-2) does not meet the criteria under paragraph 64(*c*) of CEPA 1999 as it is 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 Fuel Oil No. 2 (CAS RN 68476-30-2) meets one or more 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–C_5	Propane
Low boiling point naphthas	Complex combinations of hydrocarbons primarily from C_4–C_{12}	Gasoline
Gas oils	Complex combinations of hydrocarbons primarily from C_9–C_{25}	Diesel fuel
Heavy fuel oils	Complex combinations of heavy hydrocarbons primarily from C_{11}–C_{50}	Fuel Oil No. 6
Base oils	Complex combinations of hydrocarbons primarily from C_{15}–C_{50}	Lubricating oils
Aromatic extracts	Complex combinations of primarily aromatic hydrocarbons from C_{15}–C_{50}	Feedstock for benzene production
Waxes, slack waxes and petrolatum	Complex combinations of primarily aliphatic hydrocarbons from C_{12}–C_{85}	Petrolatum
Asphalt	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 and chemical data tables for Fuel Oil No. 2

Table B.1. Substance identity of Fuel Oil No. 2

CAS RN and DSL Name	68476-30-2 Fuel Oil, No. 2	NCI 2006
Chemical group	Petroleum – Gas Oils	-
Major components	Aromatic and aliphatic hydrocarbons	CONCAWE 1996
Carbon range	C_{11}–C_{20}[a]	Coast Guard 1985
Approximate ratio of aromatics to non-aromatics	25:75	IAR 198I; NRC 1985
Three- to seven-ring polycyclic aromatic hydrocarbons (PAHs) (weight %)	Less than 5%	Speight 2007

[a] Fuel Oils under the same CAS RN can vary in carbon number, identity and proportion of components, depending on the source of crude oil, bitumen, or natural gas and its subsequent processing.

Table B.2. Compositional information based on an average of three samples of Canadian Fuel Oil No. 2 (Fuhr 2008)

Category	Weight %
n-Alkanes and isoalkanes	35.3
Monocycloalkanes	18.6
Dicycloalkanes	11.9
Polycycloalkanes	7.2
Monoaromatics	12.1
Cycloalkane monoaromatics	9.3
Diaromatics	3.4
Cycloalkane diaromatics	1.1
Polyaromatics	0.1
Other[a]	1.0

[a] Includes component groups not found to be significant in the studied Fuel Oil No. 2 sample (*n*-alkenes, isoalkenes and alkyl, aromatic sulfurs).

Table B.3. Physical and chemical properties for representative structures of Fuel Oil No. 2 (experimental and modelled values, EPISuite 2008)[a]

***n*-Alkanes**

Name and CAS RN	**Boiling Point (°C)**	**Melting Point (°C)**	**Vapour pressure (Pa)[b]**	**Henry's Law Constant (Pa·m^3/mol)**
C_{12} *n*-dodecane **(**112-40-3**)**	216.3 (exp.)	9.6 (exp.)	18.0 (exp.)	8.3×10^5 (exp.)
C_{15} pentadecane (629-62-9)	270.6 (exp.)	9.9 (exp.)	0.5 (exp.)	1.3×10^6 (exp.)
C_{20} eicosane (112-95-8)	343 (exp.)	36.8 (exp.)	6×10^{-4} (exp.)	2.2×10^7

Isoalkanes

Name and CAS RN	**Boiling Point (°C)**	**Melting Point (°C)**	**Vapour pressure (Pa)[b]**	**Henry's Law Constant (Pa·m^3/mol)**
C_{15} 2-methyltetra-decane (1560-95-8)	250.2	1.5	5.8	4.6×10^6
C_{20} 3-methyl nonadecane (6418-45-7)	326.3	39.5	0.09	2.6×10^7

One-ring cycloalkanes

Chemical Class, Name and CAS RN	**Boiling Point (°C)**	**Melting Point (°C)**	**Vapour pressure (Pa)[b]**	**Henry's Law Constant (Pa·m^3/mol)**
C_{12} n-hexylcyclohexane (4292-75-5)	224 (exp.)	43 (exp.)	15.2 (exp.)	1.9×10^5
C_{15} nonyl cyclohexane (2883-02-5)	282 (exp.)	10 (exp.)	0.3 (exp.)	5.3×10^5
C_{20} tetradecylcyclohexane (1795-18-2)	360 (exp.)	24 (exp.)	0.02	3.0×10^6

Two-ring cycloalkanes

Chemical Class, Name and CAS RN	**Boiling Point (°C)**	**Melting Point (°C)**	**Vapour pressure (Pa)[b]**	**Henry's Law Constant (Pa·m^3/mol)**

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)[b]	Henry's Law Constant (Pa·m^3/mol)
C_{12} dicyclohexyl (92-51-3)	238 (exp.)	4 (exp.)	14.4 (exp.)	$2.6×10^4$
C_{15} pentamethyl decalin (91-17-8)	187.3 (exp.)	30.3 (exp.)	163 (exp.)	$4.8 ×10^4$ (exp.)
C_{20} 2,4-dimethyl octyl-2-decalin	323.9	41.0	0.1	$7.2×10^5$

Polycycloalkanes

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)[b]	Henry's Law Constant (Pa·m^3/mol)
C_{14} hydro-phenanthrene	255	20.8	4.5	$8.6 ×10^3$
C_{18} hydro-chrysene	353 (exp.)	115 (exp.)	0.004	$5.7 ×10^3$

One-ring aromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)[b]	Henry's Law Constant (Pa·m^3/mol)
C_{12} 1,2,3-triethylbenzene (42205-08-3)	229.6	11.9	10.6	$2.5×10^3$
C_{15} *n*-nonyl benzene (1081-77-2)	280.5 (exp.)	24 (exp.)	0.8 (exp.)	$1.0×10^4$

Cycloalkane monoaromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)[b]	Henry's Law Constant (Pa·m^3/mol)
C_{12} ethyl tetralin (32367-54-7)	235 (expt.)	-42.8 (expt.)	8.0	$2.4 ×10^2$
C_{15} methyl-octahydro-phenanthrene	267.1	27.9	2.3	$1.5×10^4$
C_{20} ethyl-dodecahydro-	338.4	81.9	0.02	$1.4×10^4$

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)^{b}	Henry's Law Constant (Pa·m^{3}/mol)
chyrsene				

Two-ring aromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)^{b}	Henry's Law Constant (Pa·m^{3}/mol)
C_{12} 1,1'-biphenyl (92-52-4)	256.1 (exp.)	69 (exp.)	1.2 (exp.)	31.2 (exp.)
C_{15} 4-isopropyl biphenyl (7116-95-2)	309	43.7	0.1	98.7

Cycloalkane diaromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)^{b}	Henry's Law Constant (Pa·m^{3}/mol)
C_{12} acenaphthene (83-32-9)	279 (exp.)	93.4 (exp.)	0.3 (exp.)	18.6 (exp.)
C_{15} ethylfluorene (65319-49-5)	337.6	94.7	7.3×10^{-3}	5.6

Three-ring aromatics

Chemical Class, Name and CAS RN	Boiling Point (°C)	Melting Point (°C)	Vapour pressure (Pa)^{b}	Henry's Law Constant (Pa·m^{3}/mol)
C_{15} 2-methylphenanthrene (2531-84-2)	155-160 (exp.)	57-59 (exp.)	8.9×10^{-3}	2.8

Table B.3 cont. Physical and chemical properties for representative structures of Fuel Oil No. 2

n-Alkanes

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)^{c}
C_{12} *n*-dodecane (112-40-3)	6.1 (exp.)	5.3	3.7×10^{-3} (exp.)
C_{15} pentadecane	7.7	6.7	7.6×10^{-5} (exp.)

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)^c
(629-62-9)			
C_{20} eicosane (112-95-8)	10.2	8.8	0.02 (exp.)

Isoalkanes

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)^c
C_{15} 2-methyltetra-decane (1560-95-8)	7.6	6.6	3.3×10^{-3}
C_{20} 3-methyl nonadecane (6418-45-7)	10.1	8.8	1.1×10^{-5}

One-ring cycloalkanes

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)^c
C_{12} n-hexylcyclohexane (4292-75-5)	6.1	5.3	0.1
C_{15} nonyl cyclohexane (2883-02-5)	7.5	6.5	4.9×10^{-3}
C_{20} tetradecylcyclohexane (1795-18-2)	10	8.7	1.7×10^{-6}

Two-ring cycloalkanes

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)^c
C_{12} dicyclohexyl (92-51-3)	5.9	5.1	0.2
C_{15} pentamethyl decalin (91-17-8)	4.2	3.7 (exp.)	0.9 (exp.)
C_{20} 2,4-dimethyl octyl-2-decalin	8.9	7.7	1.2×10^{-4}

Polycycloalkanes

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)[c]
C_{14} hydro-phenanthrene	5.2	4.5	0.5
C_{18} hydro-chrysene	6.2	5.4	0.01

One-ring aromatics

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)[c]
C_{12} 1,2,3-triethylbenzene (42205-08-3)	5.1	4.4	2.9
C_{15} *n*-nonyl benzene (1081-77-2)	7.1 (exp.)	6.2	0.03

Cycloalkane monoaromatics

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)[c]
C_{12} ethyl tetralin (32367-54-7)	4.9	4.2	5.3
C_{15} methyl-octahydro-phenanthrene	5.6	4.9	0.2
C_{20} ethyl-dodecahydro-chyrsene	7.2	6.2	3.9×10^{-3}

Two-ring aromatics

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)[c]
C_{12} 1,1’-biphenyl (92-52-4)	4.0 (exp.)	3.3 (exp.)	6.9 (exp.)
C_{15} 4-isopropyl biphenyl (7116-95-2)	5.5 (exp.)	4.8	0.9

Cycloalkane diaromatics

Name and CAS RN	Log K_{ow}	Log K_{oc}	Aqueous solubility (mg/L at 25°C)[c]
C_{12}	3.9	3.6	3.9 (exp.)

acenaphthene (83-32-9)	(exp.)	(exp.)	
C_{15} ethylfluorene (65319-49-5)	5.1	4.4	0.2

Three-ring aromatics

Name and CAS RN	**Log K_{ow}**	**Log K_{oc}**	**Aqueous solubility (mg/L at 25°C)[c]**
C_{15} 2-methylphenanthrene (2531-84-2)	5.2 (exp.) and 4.9 (exp.)	4.2	0.3 (exp.)

[a] All values are modelled unless denoted with an (expt.) for experimental data. Models used were: MPBPWIN (Version 1.43) for melting point, boiling point and vapour pressure, HenryWin (Version 3.20) for Henry's Law constants, KOWWIN (Version 1.6G) for log K_{ow}, KOCWIN (Version2.0) for log K_{oc}, WSKOW (Version 1.41) for water solubility.

[b] This is the maximum vapour pressure of the representative substance; the actual vapour pressure as a component of a mixture will be lower 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). The lightest C_{15} representative substances were chosen to estimate a range of vapour pressures from the minimum to maximum values.

[c] 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 solubilities of the mole fractions of each individual component (Banerjee 1984).

Appendix C: Supply, demand and release estimation of Fuel Oil No. 2 during transportation

Table C.1. Supply and demand characteristics for light fuel oil in Canada, 2006[a] (Statistics Canada 2008b)

Supply and demand characteristics	**Volume (m^3 × 1000)**
Production	8291.7
Exports	4178.4
Imports	113.7
Stock variation	44.4
Inter-product transfers	-254.1
Other adjustments	185.9
Final demand in Canada	4114.4
Residential	2002.9
Commercial and other institutional	1612.6
Total industrial	242.1
Manufacturing	120.3
All other manufacturing	104.5
Mining and oil and gas extraction	56.2
Construction	53.5
Forestry and logging and support activities for forestry	12.1
Pulp and paper manufacturing	10.2
Aluminum and non-ferrous metal Manufacturing	5.6
Public administration	153.8
Agriculture	76.1
Producer consumption	16.4
Power generation by utilities	10.5
Transportation	0.0

[a] Includes all distillate fuel types for power burners, Fuel Oil No. 2, Fuel Oil No. 3, furnace fuel oil, gas oils and light industrial oils.

Table C.2. Production, movement and energy demand of light fuel oil in Canada in thousands of cubic metres from 2002 to 2008 (Statistics Canada 2003-2011)[a]

Year	**Refinery Production**	**Imports**	**Exports**	**Energy Use (Final Demand)**
2002	8866.0	34.9	4115.6	4988.7
2004	8954.6	152	4356.1	5132.1

Year	Refinery Production	Imports	Exports	Energy Use (Final Demand)
2006	8291.7	113.7	4178.4	4114.4
2008	8643.2	105.8	4598.9	3728.5

[a] Includes all distillate fuel types for power burners, Fuel Oil No. 2, Fuel Oil No. 3, furnace fuel oil, gas oils and light industrial oils.

Table C.3. Energy use of light fuel oils in Canada, 2006 (Statistics Canada 2008a)[a]

User	Millions of litres	Share
Residential	2002.9	49%
Commercial and Other Institutional	1612.6	39%
Industrial and Manufacturing	242.1	6%
Public Administration	153.8	4%
Agriculture	76.1	2%
Total	4087.5	100%

[a] Includes all distillate fuel types for power burners, Fuel Oil No. 2, Fuel Oil No. 3, furnace fuel oil, gas oils and light industrial oils.

Appendix D: Releases of Fuel Oil No. 2

Table D.1. Reported and extrapolated release volumes and spill numbers of Fuel Oil No. 2 in Canada from 2000-2009 (Environment Canada 2011)[a]

Year	Average spill volume (litres)	Maximum single spill volume (litres)	Median spill volume (litres)	Number spills reported	% of spills with unknown volume	Total known volume spilled (litres)	Extrapolated total volume spilled[b] (litres)
2009	767	10 000	227	96	45.8	39 866	93 191
2008	367	8000	68	207	43.5	42 984	96 310
2007	229	2500	50	203	48.3	24 031	77 356
2006	173	1135	21	297	53.5	23 843	77 169
2005	241	6500	20	446	55.8	47 409	130 919
2004	467	13 000	76	518	55.2	108 297	204 216
2003	197	6500	19	874	57.0	73 954	240 975
2002	468	89 000	12	1037	52.1	232 682	413 788
2001	304	17 000	30	1667	52.5	241 133	534 593
2000	350	40 244	19	957	55.2	150 150	327 232
-	-	-	-	-	Total volume spilled	984 347	2 195 749

[a] Does not include releases due to aircraft crash and collision as a cause of release and earthquake/slide, ice/frost, road conditions, storm/flood, subsidence and vandalism as a reason.

[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 D.2. Approximate volume (L) of spills in Canada from 2000-2009 (Environment Canada 2011)[a]

Province	2000	2001	2002	2003	2004
Alberta	NA[b]	NA	NA	NA	NA
British Columbia	11 920	10 140	5259	17 966	12 463
Manitoba	NA	NA	NA	NA	NA
Ontario	11 910	NA	750	7295	16 843
Quebec	NA	23 000	1119	1638	24 663
New Brunswick	19 494	35 182	29 862	11 670	13 973
Nova Scotia	45 712	67 778	130 188	21 383	16 134
Prince Edward Island	3521	13 674	2843	2996	4507
Newfoundland and Labrador	15 074	83 457	61 661	11 008	19 704
Nunavut	NA	NA	NA	NA	NA

Northwest Territories	40 244	NA	NA	NA	NA
Yukon Territory	2274	7000	NA	NA	NA
Annual Total[c]	150 149	240 231	231 682	73 956	108 287

Table D.2 cont. Approximate volume (L) of spills in Canada from 2000-2009 (Environment Canada 2011)

Province	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
Alberta	NA	NA	NA	NA	NA	NA
British Columbia	2681	NA	NA	2473	1895	64 796
Manitoba	454	80	NA	NA	NA	534
Ontario	40	863	450	1254	20 927	60 332
Quebec	2959	2342	NA	9600	1469	66 790
New Brunswick	11 099	6996	4063	8664	2320	143 321
Nova Scotia	21 422	6346	11 906	5934	2699	329 501
Prince Edward Island	1258	1058	511	3035	3350	36 753
Newfoundland and Labrador	7496	6158	7099	10 605	4581	226 843
Nunavut	NA	NA	NA	170	NA	170
Northwest Territories	NA	NA	NA	NA	900	41 144
Yukon Territory	NA	NA	NA	1136	NA	10 410
Annual Total[b]	47 409	23 843	24 029	42 871	38 141	

[a] Does not include releases due to aircraft crash and collision as a cause of release and earthquake/slide, ice/frost, road conditions, storm/flood, subsidence and vandalism as a reason.

[b] NA – not applicable with no reported spills.

[c] Some spills in the NEMISIS database did not specify which province they were spilled in and therefore were not included in this table.

Table D.3. Number of Fuel Oil No. 2 spills affecting air, land, freshwater and saltwater in Canada (2000-2009) (Environment Canada 2011)

-	**Air**	**Land**	**Freshwater**	**Salt water**	**Unknown**	**Total**
2000	11	635	12	37	269	964
2001	34	1154	20	55	427	1690
2002	27	413	44	73	494	1051
2003	15	331	50	108	395	899
2004	8	248	39	59	179	533
2005	10	286	36	6	114	452
2006	4	213	32	18	46	313
2007	3	158	8	3	41	213
2008	2	167	18	5	28	220
2009	0	56	23	5	30	114

-	Air	Land	Freshwater	Salt water	Unknown	Total
Total	114	3661	282	369	2023	6449

Table D.4a. Sources of Fuel Oil No. 2 spill in Canada from 2000-2009 (Environment Canada 2011)[a]

Source	Total number of releases	Total volume of releases (litres)	Proportion of volume	Average release (litres)
Other	4006	595 651	0.61	326
Other Storage Facilities	645	193 249	0.20	680
Tank Truck	610	54 442	0.06	114
Storage Depot	27	30 061	0.03	1253
Refinery	20	25 324	0.03	1948
Unknown	598	24 203	0.02	210
Other Motor Vehicle	104	10 595	0.01	154
Other Industrial Plant	44	9479	0.01	351
Transport Truck	10	6345	0.01	793
Pipeline	12	6013	0.01	752
Electrical Equipment	34	5975	0.01	373
Barge	7	5040	0.01	2520
Marine Tanker	6	5008	0.01	1002
Other Watercraft	87	4878	0.00	212
Production Field	8	3117	0.00	779
Service Station	24	2484	0.00	166
Municipal Sewer	42	1267	0.00	127
Bulk Carrier	4	1155	0.00	578
Marine Terminal	8	54	0.00	27
Aircraft	1	5	0.00	5
Municipal Sewage Treatment Plant	2	2	0.00	2
Train	1	1	0.00	1
Chemical Plant	1	0	0.00	0
Migration	1	0	0.00	0
Total	**6302**	**984 347**	**1.00**	**335**

[a] Does not include releases due to aircraft crash and collision as a cause of release and earthquake/slide, ice/frost, road conditions, storm/flood, subsidence and vandalism as a reason.

Table D.4b. Causes of Fuel Oil No. 2 spill in Canada from 2000-2009 (Environment Canada 2011)[a]

Cause	Total number of releases	Total volume of releases	Proportion of volume	Average release (litres)

		(litres)		
Above-gGround Tank Leak	3572	550 620	0.56	339
Pipe Leak	359	117 327	0.12	578
Unknown	837	85 753	0.09	427
Container Leak	161	61 675	0.06	734
Other	353	54 288	0.06	271
Underground Tank Leak	128	38 563	0.04	1134
Overflow	489	25 261	0.03	70
Valve, Fitting Leak	186	19 629	0.02	161
Discharge	163	19 492	0.02	232
Overturn	18	7905	0.01	988
Sinking	16	3392	0.00	678
Process Upset	9	433	0.00	87
Bilge Pumping	4	8	0.00	4
Grounding	6	1	0.00	1
Dyke Failure	1	0	0.00	0
Total	**6302**	**984 347**	**1.00**	**335**

[a] Does not include releases due to aircraft crash and collision as a cause of release and earthquake/slide, ice/frost, road conditions, storm/flood, subsidence and vandalism as a reason.

Table D.4c. Reasons for Fuel Oil No. 2 spill in Canada from 2000-2009 (Environment Canada 2011)[a]

Reason	**Total number of releases**	**Total volume of releases (litres)**	**Proportion of volume**	**Average release (litres)**
Unknown	1901	285 694	0.29	440
Material Failure	1433	257 312	0.26	411
Equipment Failure	774	178 646	0.18	387
Corrosion	676	93 051	0.09	311
Other	478	53 868	0.05	217
Human Error	687	44 036	0.04	90
Negligence	90	27 183	0.03	715
Fire, Explosion	21	22 306	0.02	3718
Gasket, Joint	85	8081	0.01	207
Intent	107	6642	0.01	133
Damage by Equipment	28	6050	0.01	403
Weld, Seam Failure	20	1465	0.00	147
Overstress	1	14	0.00	14
Migration	1	0	0.00	0
Total	**6302**	**984 347**	**1.00**	**335**

[a] Does not include releases due to aircraft crash and collision as a cause of release and earthquake/slide, ice/frost, road conditions, storm/flood, subsidence and vandalism as a reason.

Appendix E: Persistence and bioaccumulation

Table E.1. An analysis of persistence data for petroleum hydrocarbons representative of Fuel Oil No. 2 based on Environment Canada (2013)

# of carbons	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{18}	C_{20}
***n*-alkane**	n/a	-	n/a	n/a	-	-	-
***i*-alkane**	n/a	-	-	n/a	-	n/a	-
Mono-cycloalkane	n/a	-	n/a	n/a	-	n/a	-
dicycloalkane	n/a	Sd	n/a	n/a	S,W, Sd	n/a	S,W, Sd
Poly-cycloalkane	n/a	n/a	n/a	S	n/a	S,W, Sd	n/a
monoaromatic	Sd	S,W, Sd	n/a	n/a	Sd	n/a	-
cycloalkane monoaromatic	n/a	S,W, Sd	n/a	n/a	S,W, Sd	n/a	S,W, Sd
diaromatic	n/a	S,W, Sd	n/a	n/a	S,W, Sd	n/a	S,W, Sd
cycloalkane diaromatic	n/a	S,W, Sd	A	n/a	-	n/a	-
3-ring polyaromatic	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-lives in soil of 6 months or greater
W – Predicted half-lives in water of 6 months or greater
Sd – Predicted half-life in sediment of one year or greater
n/a Indicates that no such carbon numbers exist within the group or the structure was not modelled
- Indicates that these structures are considered to not persist for long periods in air, soil, water or sediment.

Table E.2. An analysis of experimental and modelled bioaccumulation data for petroleum hydrocarbons representative of Fuel Oil No. 2 based on Environment Canada (2013)

# of carbons	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{18}	C_{20}
***n*-alkane**	n/a	-	-	-	-	-	-
***i*-alkane**	n/a	-	B	n/a	B	n/a	n/a
monocycloalkane	n/a	B	n/a	n/a	B	n/a	n/a
dicycloalkane	n/a	B	-	n/a	B	n/a	n/a
polycycloalkane	n/a	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	n/a	B	n/a	B
diaromatic	-	B	B	-	-	n/a	n/a
cycloalkane	n/a	-	-	-	-	n/a	B

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

B – Predicted highly bioaccumulative with a BCF/BAF greater than 5000

n/a Indicates that no such carbon numbers exist within the group or the structure was not considered

- Indicates that these structures are not considered highly bioaccumulative

Appendix F: Toxicity of Fuel Oil No. 2

Table F.1. Aquatic toxicity of Fuel Oil No. 2

Fish

Test Organism	Common Name	Length of test	Endpoint	Comment	Value (mg/L)	Reference
Onchorhynchus gorbuscha	Pink salmon	96-hr	LC_{50}	WSF[a]	0.5	Rice et al. 1979
Salvelinus malma	Dolly varden trout	96-hr	LC_{50}	WSF	0.7	Rice et al. 1979
Myoxocephalus polyacanthocephalus	Great sculpin	96-hr	LC_{50}	WSF	2.4	Rice et al. 1979
Cyprinodon variegatus	Sheepshead minnow	96-hr	LC_{50}	Dispersion	93	Anderson et al. 1974
Cyprinodon variegatus	Sheepshead minnow	96-hr	LC_{50}	WSF	6.3	Anderson et al. 1974
Menidia beryllina	Inland silverside	48-hr	LC_{50}	Dispersion	125	Anderson et al. 1974
Menidia beryllina	Inland silverside	96-hr	LC_{50}	WSF	3.9	Anderson et al. 1974
Menidia beryllina	Inland silverside	96-hr	LOEC	WSF	9.3	Middaugh and Whiting 1995
Fundulus similis	Longnose killifish	96-hr	LC_{50}	Dispersion	33	Anderson et al. 1974
Fundulus similis	Longnose killifish	96-hr	LC_{50}	WSF	3.9	Anderson et al. 1974
Jordanella floridae	American flagfish	24-hr	LC_{50}	WSF (Static)	More than100% WSF	Hedtke and Puglisi 1982
Jordanella floridae	American flagfish	96-hr	LC_{50}	WSF (Static)	More than100% WSF	Hedtke and Puglisi 1982
Pimephales promelas	Fathead minnow	24-hr	LC_{50}	WSF (Static)	More than100% WSF	Hedtke and Puglisi 1982
Pimephales promelas	Fathead minnow	96-hr	LC_{50}	WSF (Static)	More than100% WSF	Hedtke and Puglisi 1982

Invertebrates

Test Organism	**Common Name**	**Length of test**	**Endpoint**	**Comment**	**Value (mg/L)**	**Reference**
Mysidopsis almyra	Mysid shrimp	48-hr	LC_{50}	Oil in water Dispersion	1.3	Anderson et al. 1974
Mysidopsis almyra	Mysid shrimp	48-hr	LC_{50}	WSF	0.9	Anderson et al. 1974
Artemia sp.	Brine shrimp	48-hr	EC_{50} (immobilization)	WSF	8.35 (5.45-11.2)^{b}	MacLean and Doe 1989
Artemia sp	Brine shrimp	48-hr	LC_{50}	WSF	11.16 (8.41-13.9)	MacLean and Doe 1989
Daphnia magna	Water flea	48-hr	EC_{50} (immobilization)	WSF	1.9 (1.63-2.24)	MacLean and Doe 1989
Daphnia magna	Water flea	48-hr	LC_{50}	WSF	2.18 (0.09-3.47)	MacLean and Doe 1989
Palaeomonetes pugio	Grass shrimp larvae	96-hr	LC_{50}	WSF	1.2	Tatem et al. 1978
Palaeomonetes pugio	Grass shrimp larvae	96-hr	LC_{50}	Dispersion	1.7	Tatem et al. 1978
Palaeomonetes pugio	Grass shrimp larvae	96 hr	LL_{50}	Dispersion	3.0	Anderson et al. 1974
Palaeomonetes pugio	Grass shrimp larvae	96 hr	LC_{50}	WSF	3.5	Anderson et al. 1974
Penaeus aztecus (post larvae)	Brown shrimp	96-hr	LL_{50}	Dispersion	9.4	Anderson et al. 1974
Penaeus aztecus (post larvae)	Brown shrimp	96-hr	LC_{50}	WSF	4.9	Anderson et al. 1974
Eualus suckleyi	Eualid shrimp	96-hr	LC_{50}	WSF	0.6	Rice et al. 1979
Crangon alaskensis	Alaska Bay shrimp	96-hr	LC_{50}	WSF	0.43	Rice et al. 1979
Paralithodes camtschatica	King crab	96-hr	TLm	WSF	0.8	Rice et al. 1979
Skeletonema costatum	Marine diatom	96-hr	LC_{50}	WSF	1-2	Mahoney and Haskin 1980
Isochrysis galbana	Marine microalga	96-hr	LC_{50}	WSF	2-3	Mahoney and Haskin

Test Organism	Common Name	Length of test	Endpoint	Comment	Value (mg/L)	Reference
	e					1980
Monochrysis lutheri	Marine microalgae	96-hr	LC_{50}	WSF	4-5	Mahoney and Haskin 1980
Nannochloris oculata	Marine microalgae	72-hr	LC_{50}	WSF	3-4	Mahoney and Haskin 1980
Neanthes arenaceodentata	Marine polychaete	96-hr	LC_{50}	WSF	6.1	Rossi et al. 1976
Capitella capitata	Worm	96-hr	LC_{50}	WSF	2	Rossi et al. 1976
Crassostrea virginica	Eastern oyster	96-hr	LC_{50}	WSF	1.9	Sigler and Leibovitz 1982
Mercenaria mercenaria	Quahog clam	48-hr	LC_{50}	WSF	0.6 (0.48 – 0.69)	Byrne 1989

Other

Test Organism	Common Name	Length of test	Endpoint	Comment	Value (mg/L)	Reference
Rana sylvatica	Wood frog	24-hr	LC_{50}	WSF (Static)	More than100% WSF	Hedtke and Puglisi 1982
Rana sylvatica	Wood frog	96-hr	LC_{50}	WSF (Static)	413 (342-561)	Hedtke and Puglisi 1982

[a] Water-soluble fraction.
[b] Bracketed values refer to the 95% confidence interval.

Table F.2. Modelled data for toxicity to aquatic organisms from PetroTox (2009)[a]

Organism	Acute LL_{50}[b] (mg/L) 10% headspace	Acute LL_{50}[b] (mg/L) 50% headspace
Daphnia magna	4.9	6.1
Oncorhynchus mykiss	0.9	1.1
Pseudokirchneriella subcapitatum[c]	1.4	1.5
Rhepoxynius abronius	0.19	0.2

Palaemonetes pugio	0.6	0.8
Menidia beryllina	More than 1000	More than 1000
Neanthes arenaceodentata	264.0	294.5

[a] All results are from PetroTox (2009) Version 3.04 using the low resolution procedure.

[b] Median lethal loading concentration (LL_{50}) was used in place of median lethal concentration (LC_{50}) due to the insolubility of petroleum substances in water.

[c] Default particulate organic carbon (POC) concentration for algae: 2.0 mg/L.

Table F.3. Estimated volume of water in contact with medium persistence oil (x10^6 m^3) for loading/unloading and transport processes of crude oil 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
More than 200 000	33 000	62 000

Appendix G: Codes and standards pertaining to residential storage tanks for Fuel Oil No. 2

Codes

National Fire Code of Canada 2010
National Building Code of Canada 2010

These codes are available for purchase from the National Research Council Canada in Ottawa. Available from: http://www.nrc-cnrc.gc.ca/eng/publications/codes_centre/2010_national_fire_code.html and http://www.nrc-nrc.gc.ca/eng/publications/codes_centre/2010_national_building_code.html

Standards

Underwriters' Laboratory of Canada Publications:

National Standard of Canada. CAN/ULC-S602, Above Ground Steel Tanks for the Storage of Combustible Liquids Intended to Be Used as Heating and/or Generator Fuels. Available from: http://www.orderline.com/detail.asp?group=448

Underwriters' Laboratories of Canada. ULC/ORD C80.1, Aboveground Non-Metallic Tanks For Fuel Oil. Available from: http://www.ul.com/canada/documents/certificationbulletin2012/Certification_Bulletin_2012-01(ENG)_ULC-ORD-C80.1.pdf

Canadian Standards Association (CSA):

Canadian Standards Association, Installation Code for Oil Burning Equipment (CSA B-139) Available from: http://www.csa.ca/products/energy/Default.asp?articleID=4414&language=english.

Appendix H: Exposure characterization

Table H.1. Variable inputs to SCREEN3

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.

Table H.2. Ambient concentrations of benzene in the vicinity of a Fuel Oil No. 2 bulk storage facility (benzene emission rate 0.02 kg/hr per tank) at receptor height of 1.74 m

Distance (m)	**Maximum 1-hour conc. (μg/m^3)**	**Maximum annual conc. (μg/m^3)**
1	3.08	0.62
20	4.58	0.92
30	5.41	1.08
40	6.13	1.23
50	6.76	1.35
60	7.18	1.44
70	7.97	1.59
80	8.59	1.72
90	8.72	1.74
100	8.46	1.69
110	8.92	1.78
120	9.25	1.85
130	9.37	1.87
140	9.32	1.86
150	9.14	1.83
200	7.48	1.50

Distance (m)	**Maximum 1-hour conc. (μg/m^3)**	**Maximum annual conc. (μg/m^3)**
250	5.82	1.16
300	4.57	0.91
350	3.66	0.73
400	3.00	0.60
450	2.50	0.50
500	2.13	0.43
600	1.60	0.32
700	1.26	0.25
800	1.02	0.20
900	0.85	0.17
1000	0.73	0.15
1100	0.63	0.13
1200	0.55	0.11
1300	0.49	0.10
1400	0.44	0.09
1500	0.40	0.08

Appendix I: Summary of health effects information for Fuel Oil No. 2 (CAS RN 68476-30-2)

Endpoints	CAS RN[a]	Effect levels[b]/Results
Acute health effects	64741-59-9	**Lowest inhalation LC$_{50}$** (rat) = 3350 mg/m^3 (3.35 mg/L)[c] for sample API 83-07 (males) (API 2003b).
	64741-59-9 64742-80-9	Other inhalation LC$_{50}$s (rat) = 4600–7640 mg/m^3 (4.6 – 7.64 mg/L)[c] for two CAS RNs tested (male and female) (CONCAWE 1996; API 2003b).
	68476-30-2 (3 samples)	Oral LD$_{50}$s (rat) = 11 900, 15 600, 17 300 mg/kg-bw (14.5, 19, 21.2 mL/kg)[d,e] for samples API 78-3, 78-2, 78-4, respectively (male and female) (CONCAWE 1996; API 2003a).
	68476-34-6	**Lowest oral LD$_{50}$** (rat) = 7400 mg/kg-bw for sample API 79-6 (CONCAWE 1996; API 2003a).
	68476-30-2 (3 samples)	**Lowest dermal LD$_{50}$** (rabbit) = >4100 mg/kg-bw (>5 mL/kg)[d,e] for samples API 78-2, 78-3 and 78-4 (male and female) (CONCAWE 1996; API 2003a).
	64742-80-9	**Dermal study** (rabbit): 24-hour occluded exposure to 2000 mg/kg-bw of API sample 81-09 or 81-10 resulted in local skin effects (erythema, edema, desquamation, fissures) but no mortalities and no systemic toxicity was observed during a 14-day follow-up (CONCAWE 1996; API 2003b).
	68476-34-6	Male and female New Zealand White rabbits (5 per sex) were dermally exposed with abrasion and occlusion to 2000 mg/kg-bw diesel fuel for 24 hours and then observed for 14 days. Erythema, edema, desquamation and fissures at the test site and some foamy, loose stools were noted. At necropsy, fluid was found in the stomach and intestine, mucous in the colon and red focal areas in the lungs. One rabbit did not survive the observation period but the death was considered by the researchers as unrelated to the test substance (Mayhew et al. 1985).
		Diesel fuel (0.5 mL per application site; total exposure dose 764 mg/kg-bw) was moderately irritating (primary irritation score of 4) to the skin of New Zealand White rabbits after 24 hour occluded exposure. The density of diesel fuel was given as 839.9 mg/mL and average rabbit weight of 2.2 kg. The study was conducted according to GLP (Mayhew et al. 1985).
		Male and female New Zealand White rabbits (4 per sex) were dermally exposed with occlusion to 5 mL/kg (4100 mg/kg-bw) of a marketplace sample of diesel fuel (sample API 79-6) for 24 hours and then observed for 14 days. The application site (shaved dorsal skin) was abraded in four rabbits (2 per sex). At the application site, mild-to-moderate irritation, erythema and flaking of the skin was noted, but signs of systemic effects or

Endpoints	**CAS RN**[a]	**Effect levels**[b]**/Results**
		gross organ pathology were not observed. At necropsy, congested kidneys were noted in four rabbits; two rabbits had tracheal haemorrhaging and one had a congested liver, but the researchers noted that these effects were unrelated to the test substance (API 1980a; Beck et al. 1984).
Short-term and subchronic repeated-exposure health effects	**68476-30-2** 68476-34-6 64741-82-8 64742-80-9	**Dermal Study (short-term)**: 841, 2524 or 8414 mg/kg-bw per day (1, 3 or 10 mL/kg per day)[d] was applied to New Zealand white rabbits (4 animals per sex per dose) using a gauze patch on shaved skin, 5 days per week for 2 weeks. Progressive deterioration of application site skin was observed at all doses. At the two highest doses anorexia and mortality (25% and 87.5%, respectively) were observed, but these effects were considered to be secondary to the skin lesions (API 1980b). **Dermal LOAEL (short-term) = 200 mg/kg-bw per day** was identified based on haematological changes including decreased MCHC, as well as decreased body weight gain, in New Zealand white rabbits. Rabbits (10 per sex per dose) were fitted with collars and dermally exposed to diesel fuel sample LF-7765 RI at 200, 670 or 2000 mg/kg-bw per day, 5 days per week for 3 weeks. Application site skin was shorn and unoccluded. Another effect at greater than or equal to200 mg/kg-bw was dose-related dermal irritation. At 670 and 2000 mg/kg-bw, decreased body weight gain, depressed MCHC and alkaline phosphatase levels and elevated glucose and WBC levels were observed. At 2000 mg/kg-bw, decreased serum albumin, RBCs, hematocrit and haemoglobin and increased glutamate–oxaloacetate transaminase (SGOT) and mature neutrophils were observed, as well as statistically significant changes in relative brain, liver, kidney, adrenal and heart weights. Three rabbits (2 female, 1 male) died in the highest dose group (IITRI 1984). **Dermal LOAEL (subchronic)** = **30 mg/kg-bw per day** was identified based on increased lymphocytes in female rats and decreased thymus weight (10% reduction) in male rats. Sprague-Dawley rats (10 animals per sex per dose) were exposed 5 days per week for 13 weeks to 30, 125, 500 or 2000 mg/kg-bw per day test substance via application to the shaved skin. At doses greater than or equal to 125 mg/kg-bw per day, changes in megakaryocytes, increased lymphocytes and decreased body weight in male rats were observed. Additional effects were observed at doses greater than or equal to 500 mg/kg-bw per day, including severe skin irritation and decreased body weight in females. Exposure to the highest dose resulted in increased leukocytes (white blood cells) and segmented neutrophils, as well as a reduction in erythropoietic cells and megakaryocytes. Basophilia in the renal tubular cortex was also observed in male rats (Mobil 1991). **Inhalation LOAEC (short-term)** = **23 mg/m^3** was identified based on microscopic changes in nasal tissue and subacute inflammation of the respiratory mucosa. Sprague-Dawley rats (20 per sex) were exposed to API 81-09 (mean concentration 23 mg/m^3) and API 81-10 (mean concentration 24 mg/m^3) 6

Endpoints	CAS RN[a]	Effect levels[b]/Results
	68334-30-5	hours per day, 5 days per week for four weeks. An approximate 30% increase in leukocytes was noted (for sample API 81-10), but no macroscopic changes were observed at necropsy; this effect was suggested by the authors to be stress-related. Test substance was atomized into an atomization chamber, aerosols were then diluted with chamber air to achieve the desired concentration (API 1986).
	68476-34-6	**Inhalation LOAEC (subchronic) = 250 mg/m^3** was identified based on decreased body weight and increased response time in an acoustic startle reflex assay. Sprague-Dawley rats (24 per sex per concentration) were exposed to diesel fuel at 250, 750 or 1500 mg/m^3, 4 hours per day, 2 days per week for 13 weeks. Decreased body weight and increased response time, as measured in the startle reflex assay, were observed following exposure to concentrations greater than or equal to 250 mg/m^3. However, corresponding histological changes in the nervous system were not identified. Following exposure to the highest concentration, increased relative weight of right lung lobe (no histopathological changes or effects on pulmonary function noted) and decreased blood cholesterol level (in females; not considered treatment-related) were observed. Test substance was flash vaporized using a Vycor heater attached to the end of a stainless steel tube. The aerosols were subsequently carried into the exposure chamber and diluted with chamber air to achieve the desired concentrations (Lock et al. 1984).
		Oral LOAEL (short-term) = **500 mg/kg-bw** was identified (in a single dose level study) based on liver and kidney effects in seven male Sprague-Dawley rats administered low sulfur diesel in corn oil by gavage 5 days per week for 4 weeks. Effects included significant (p less than 0.05) increases in relative liver weights, liver enzymes (benzyloxyresorufin-O-dealkylase (BROD), 7-ethoxyresorufin-O-deethylase (EROD), pentoxyresorufin-O-dealkylase (PROD), glutathione-S-transferase (GST), UDP-glucuronosy-transferase (UDPGT), palmitoyl-CoA oxidase (PCO)), serum free fatty acids, urinary albumin and urinary ascorbic acid, significantly (pLess than0.05) decreased liver triglycerides and kidney tubular outer cortex cytoplasmic inclusions and cytoplasmic shedding into the lumen (Poon et al. 2007).
		Oral LOAEL (short-term) = **500 mg/kg-bw** was identified for ultra-low sulphur diesel in a similar study as above. Effects in the male rats included significant (p less than 0.05) increases in liver GST, BROD, EROD, PROD, acyl-CoA oxidase, in serum calcium and inorganic phosphate, urinary ascorbic acid, albumin and N-acetylglucosaminidase activity and significant (p less than 0.05) decreases in serum lactate dehydrogenase and free fatty acids. Mild histopathological changes in the liver, hepatomegaly, increased kidney weights and changes in kidney histopathology were also noted (Poon et al. 2009).
		Other oral study (short-term): 1013 mg/kg-bw was identified as an effect level based on biochemical changes in six male

Endpoints	**CAS RN**[a]	**Effect levels**[b]**/Results**
		Sprague-Dawley rats administered 1.25 mL/kg (1013 mg/kg-bw)[d] of commercial diesel fuel No. 2, via gavage, on days 1, 3, 5 and 8 of the study. Effects included an increase in the liver somatic index, increased activity of hepatic enzymes (EROD, 7-ethoxycoumarin-*O*-deethylase (ECOD), GST and aryl hydrocarbon hydroxylase) and increased activity of renal enzymes (ECOD) (Khan et al. 2001).
Carcinogenicity	**68476-30-2**	**Chronic skin painting studies** Doses of 559 mg/kg-bw [f,g,h] of 6 different formulations were applied to the clipped dorsal skin of male C3H/HeJ mice (40-50 animals per group), 3 times per week for life. A significant increase in skin tumour incidence (papillomas and carcinomas) was observed: 6/50, 6/40, 11/50, 5/50, 9/50 and 10/50 exposed mice developed tumours after 124, 113, 114, 127, 116 and 114 weeks, respectively. Exposure to the negative control (white mineral oil) resulted in 0 mice developing tumours and exposure to the positive control (1, 3.3, 20 and 25% CCCO) resulted in 9/50, 50/50, 39/50 and 39/40 mice developing skin tumours after 106, 35, 65 and 30 weeks, respectively (Biles et al. 1988). Doses of 287, 574 or 1148 mg/kg-bw [f,g,h,i] (50 µl at 25, 50 or 100% dilution) were applied to the shaved dorsal skin of C3H/Bd$_f$ mice (25 animals per sex per dose), 3 times per week for life or until a tumour persisted for 2 weeks. An increase in skin tumour incidence (papillomas and carcinomas) occured. 15/150 exposed mice developed tumours (considering all doses and both sexes) after approximately 80 weeks. Exposure to the negative control (acetone) resulted in 0 mice developing tumours and exposure to the positive control (B[*a*]P) resulted in 299/300 mice developing skin tumours for all doses in both sexes after 14-19 weeks (Witschi et al. 1987). A dose of 1117 mg/kg-bw [f,g,h] (50 µl) was applied to the clipped dorsal lumbar skin of male C3H/HeN mice (50 animals per group), 2 times per week for life. A significant increase in skin tumour incidence was observed. 9/43 exposed mice developed tumours after approximately 89 weeks. Exposure to the negative control (sham-handled) resulted in 0 mice developing tumours. It was noted that 2 of 9 mice that developed tumours at the application site also developed tumours on unexposed areas of the skin (Gerhart et al. 1988). **Initiation Study** Groups of male CD-1 mice (30 animals per dose) were exposed to 559 or 1117 mg/kg-bw (25 or 50 µl neat)[f,g,h] to the clipped dorsal lumbar skin for 5 consecutive days. After a two-week rest period, 5µg of the promoter PMA was applied 2 times per week for 25 weeks. Observed insignificant increase in skin tumour incidence. **Promotion Study** Groups of male CD-1 mice (30 animals per group) were exposed to a single 50 µg application of the initiator DMBA to the clipped dorsal lumbar skin. After a two-week rest period, 1117 mg/kg-bw (50µl neat)[f,g,h] was applied 2 times per week for

Endpoints	**CAS RN**[a]	**Effect levels**[b]**/Results**
	64742-80-9	25 weeks. Observed significant increase in skin tumour incidence. 12/30 exposed mice developed tumours after 22.4 weeks. Exposure to the negative control (sham-handled) resulted in 0 mice developing tumours and exposure to the positive control (DMBA/PMA) resulted in 28/29 mice developing skin tumours after 10.5 weeks (Gerhart et al. 1988). **Chronic skin painting study** Male C3H/HeJ mice (50 per group) were exposed to 50 µL (1116 mg/kg-bw)[f,g,p] of undiluted test substance, twice per week for life. Test substance was applied to the shaved interscapular skin. A significant increase in skin tumours was observed, with 63% of exposed mice developing squamous cell papillomas, carcinomas or fibrosarcomas with a mean latency of onset of 73 weeks. Sham-handled animals did not develop tumours. Four positive control groups (exposed to 0.01 or 0.05% B[*a*]P over 24 months or for life) resulted in 53-100% tumour incidences and 47-87 week latencies (Broddle et al. 1996). **Initiation study** Male C3H/HeJ mice (30 per group) were exposed to 50 µL (1116 mg/kg-bw)[f,g,p] of undiluted test substance, once per day for 5 consecutive days. After a two week rest period, 50 µL of PMA was applied twice per week for 25 weeks. Both substances were applied to the shaved intrascapular skin. A non-statistically significant increase in skin tumours was observed (6/30 exposed mice developed tumours after 18 weeks). Three of 30 mice developed tumours in the negative control group (exposed to acetone then PMA) after 16 weeks. The positive control group (exposed to DMBA then PMA) had 30/30 mice with skin tumours after 9 weeks (Skisak et al. 1994). **Promotion study** Male C3H/HeJ mice (30 per group) were exposed once to 50 µL of DMBA. After a two week rest period, 50 µL (1116 mg/kg-bw)[f,g,p] of undiluted test substance was applied twice per week for 25 weeks. Both substances were applied to the shaved intrascapular skin. A significant increase in skin tumours (16/30 exposed mice developed tumours after 13 weeks) occurred. Sham-handled mice did not develop tumours. The positive control group (exposed to DMBA then PMA) had 30/30 mice with skin tumours after 9 weeks (Skisak et al. 1994).
	68476-34-6	**Chronic skin painting studies** Male C3H mice (50 per group) were exposed to 50 µL (1095 mg/kg-bw)[f,g,j] undiluted diesel fuel sample LF-7765 RI, twice per week for life. The test substance was applied to the shorn dorsal skin. A significant increase in skin tumours was observed (9 of 46 exposed mice developed squamous cell carcinomas or fibrosarcomas with a mean latency of 94 weeks). No sham-exposed mice developed tumours (IITRI 1985). A dose of 833 mg/kg-bw [f,k] (25 mg) of petroleum diesel was applied to the dorsal thoracic skin of C3H/HeN mice (25 animals per sex per dose), 3 times per week for 54 weeks. A non-

Endpoints	CAS RN[a]	Effect levels[b]/Results
	68334-30-5	statistically significant increase in skin tumour incidence was observed (squamous cell carcinomas and fibrosarcomas). Two (of 27) exposed mice developed tumours after 64 weeks. Exposure to the negative control (mineral oil or sham handled) resulted in 1/46 and 0 mice developing skin tumours after 77 weeks, respectively. Exposure to the positive control (B[*a*]P) resulted in 47/48 and 49/49 mice developing skin tumours after 31 and 28 weeks, respectively (Clark et al. 1988). **Initiation Study** Groups of male CD-1 mice (30 animals per group) were exposed to 50 µl (1111 mg/kg-bw)[f,g,h] DGMK No. 22 via shorn dorsal skin for 5 consecutive days. After two-weeks, 5µg of the tumour promoter TPA was applied 2 times per week for 25 weeks. No increase in skin tumour incidence occurred. **Promotion Study** Groups of male CD-1 mice (30 animals per group) were exposed to 50 µg of the tumour initiator DBMA via the shorn dorsal skin. After a two-weeks, 50 µl (1111 mg/kg-bw)[f,g,h] DGMK No. 22 was applied two times per week for 25 weeks. One (of 30) exposed mice developed skin tumours (squamous cell papilloma). Exposure to the negative control (DMBA/acetone) resulted in no mice with skin tumours. Exposure to the positive control (DMBA/TPA) resulted in 30/30 mice developing skin tumours (DGMK 1993).
Developmental and Reproductive health effects	**68476-30-2**	**Inhalation Studies** No teratogenic effects were observed after pregnant rats were exposed via inhalation to test substance at 626 or 3081 mg/m^3 (85 or 410 ppm)[l,m] for 6 hours per day from gestational days 6 to 15 (Schreiner 1984). A concentration of 2945 mg/m^3 (400ppm)[l,m] did not result in developmental effects when pregnant rats were exposed via inhalation from gestational days 6 to 15 (Beliles and Mecler 1983).
	68334-30-5	**Inhalation NOAEC** = **3777 mg/m^3** was identified for lack of developmental toxicity. Pregnant rats were exposed to 401.5 ppm (3777 mg/m^3)[l,n] of diesel fuel from gestational days 6 to 15. The hours of exposure per day was not given. Developmental effects were not observed (Beliles and Mecler 1983).
	68476-34-6	**Dermal NOAEC** = **4050 mg/kg-bw per day** was identified for lack of reproductive toxicity. Doses of 405, 1620 or 4050 mg/kg-bw per day (0.5, 2 or 5 mL/kg per day)[d,j] of Diesel Fuel No. 2 were applied to the shaved dorsal skin of Sprague-Dawley rats (10 animals per sex per dose), 5 days per week for 4 weeks. No effects on testes or ovaries were observed (UBTL 1986).
	64741-59-9	**Dermal LOAEL = 1000 mg/kg-bw per day** was identified for reproductive toxicity based on an increased incidence of resorptions following dermal application of 25, 50, 125, 250 or 500 mg/kg-bw per day to pregnant Sprague-Dawley rats from gestational days 0 to 19 and 1000 mg/kg-bw per day from

Endpoints	CAS RN^a	Effect levels^b/Results
		gestational days 6 to 15 (Feuston et al. 1994). **Dermal LOAEL = 1000 mg/kg-bw per day** for developmental toxicity based on decreased foetal body weight following dermal application of 25, 50, 125, 250 or 500 mg/kg-bw per day to the shorn dorsal skin of pregnant Sprague-Dawley rats from gestational days 0-19 and 1000 mg/kg-bw per day from gestational days 0-6 and 6-15. No developmental malformations or reproductive effects were noted (Mobil 1988).
Genotoxicity – *in vivo*	**68476-30-2**	**Chromosomal Aberrations** Groups of Sprague-Dawley rats were orally administered 125, 417 or 1250 mg/kg-bw per day for 5 days. Increases in cells with chromatid breaks and aberrant cells in the bone marrow were observed (Conaway et al. 1984; API 1979a). **Micronuclei Induction** Groups of CD-1 mice (15 per sex per dose) were exposed via oral gavage to a single exposure of 1000, 2500 or 5000 mg/kg-bw. No increase in frequency of micronuclei induction in bone marrow was observed (McKee et al. 1994).
	68334-30-5	**Chromosomal Aberrations** Sprague-Dawley rats were administered diesel fuel by intraperitoneal (i.p.) injection at doses of 2.0 or 6.0 mL/kg-bw (1644 and 4933 mg/kg-bw)^{d,h} for a single dose or daily for 5 days. With both regimens there was an increased frequency of chromosomal aberrations in the bone marrow (Conaway et al. 1984).
	68476-34-6	**Chromosomal Aberrations** Male rats (5 per dose) were administered sample No. 2-DA by i.p. injection at doses of 0.6, 2.0 or 6.0 mL/kg-bw (486, 1620 or 4860 mg/kg-bw)^{d,j} for a single dose (groups were sacrificed at 6, 24 and 48 hours post injection) or daily for 5 days (animals were sacrificed 6 hours after the last dose). Bone marrow analysis revealed clastogenicity at the two highest doses (API 1978). **Dominant Lethal Mutations** Male CD-1 mice (12 per concentration) were exposed to sample No. 2-DA by inhalation at concentrations of 777 or 3108 mg/m^3 (100 or 400 ppm)^{l,o}, 6 hours per day, 5 days per week for 8 weeks. There was no effect on the frequency of dominant lethal mutations (API 1980c).
	64742-80-9	**Chromosomal aberration** Exposure to samples API 81-09 and API 81-10 did not result in an increase in chromosomal aberrations in bone marrow cells (species, dose and route of administration not specified) (API 1984a).
	64741-59-9	**Sister Chromatid Exchange** Mice were exposed by intraperitoneal injection to 340, 1700 or 3400 mg/kg-bw (API 1989). Positive results were observed.
Genotoxicity – *in vitro*	**68476-30-2**	**Mouse Lymphoma Assay** L5178Y TK$^{+/-}$ cells were exposed to 1.2 µg/mL test substance. A

Endpoints	**CAS RN[a]**	**Effect levels[b]/Results**
	68334-30-5	mutation frequency 17.1 times higher than controls was observed (without metabolic activation) (Conaway et al. 1984). L5178Y $TK^{+/-}$ cells were exposed to test substance, with and without S9 metabolic activation. An increased frequency of forward mutations were observed at 12.5 µg/mL (with activation) and at 800 µg/mL (without activation) (API 1979a). **Sister Chromatid Exchange** Chinese hamster ovary cells were exposed to fractions of Fuel Oil No. 2. Positive results were observed with metabolic activation (Ellenton and Hallett 1981). **Mutagenicity** *S. typhimurium* TA98 was exposed to DMSO extracts of test substance (up to 60 µl/plate) as well as cyclohexane extracts (up to 50 µl/plate), with S9 metabolic activation, in a modified Ames assay (Aroclor 1254-induced hamster S9 at a level 8 times higher than standard). A reversion frequency 2 times greater than the vehicle control, as well as a concentration-response trend, was noted for the DMSO extracts. Mutagenic index was 3.9 revertants/µl. A concentration-response trend for reversion frequency was also observed for the cyclohexane extracts. Mutagenic index was Less than 2 (McKee et al. 1994). *S. typhimurium* TA98 and TA100 were exposed to test substance at 0.26 – 42 mg/plate, with and without S9 metabolic activation, in the Ames assay. Positive results were obtained (Conaway et al. 1984). *S. typhimurium* TA100 was exposed to fractions of Fuel Oil No. 2, with S9 metabolic activation, in the Ames assay. A concentration-related trend for reversion frequency was noted. Mutagenicity not observed for some fractions or in other *S. typhimurium* strains (Ellenton and Hallett 1981). *S. typhimurium* TA1535, TA1537, TA1538, TA98 and TA100 were exposed, with and without S9 metabolic activation, in the Ames assay. A 2-fold increase in reversion frequency occured at 4 test substance concentrations (no concentration-response noted) (API 1971). Unspecified bacterial strains were exposed to six samples, with S9 metabolic activation, in the Ames assay. Positive results were obtained (DGMK 1991). Unspecified bacterial strains were exposed to one sample, with S9 metabolic activation, in the Ames assay. Negative results were obtained (DGMK 1991). **Mutagenicity** DMSO extracts of diesel fuel (DGMK samples 22, 23 and 24) were tested using a modified Ames assay in S. typhimurium TA98 from 5-60 µL/60µL, with and without S9 metabolic activation. The samples were considered mutagenic with MIs of

Endpoints	**CAS RN^a**	**Effect levels^b/Results**
		1.7, 3.9 and 2.0 reported (Blackburn et al. 1984, 1986; DGMK 1991).
Human Studies	Acute Inhalation study	Healthy human volunteers were exposed to 166 and 332 mg/m^3 aerosolized diesel oil for 10 minutes. Essentially no irritation of the eyes, nose or throat occurred. No other effects were noted as related to these exposures, but endpoints other than irritation were not specifically assessed (Dautrebande and Capps 1950).
	Inhalation Case Report: diesel fuel	A driver of a truck was exposed to diesel fuel vapour in his cab over a period of 10 days. He developed thrombocytopenic purpura and reversible acute renal failure secondary to acute tubular necrosis (Reidenberg 1964).
	Acute dermal study	A study designed to assess the irritant properties of diesel fuel dye additives did not report any adverse effects or visible skin reactions in human volunteers exposed for 15 minutes to 1.5 mL (on 3.1 cm^2) of 3 samples of dyed or 3 samples of undyed diesel fuels. A slight increase in blood flow to the area was noted in some cases (Wahlberg 1995).
	Acute dermal study	Increased skin irritancy was noted with increased exposure time in human volunteers that were dermally exposed to diesel fuel samples for 15 minutes to 48 hours (irritation was first noted at 4 hours). Additionally, occlusion and 'newer' (i.e., lower sulphur and aromatic content) blends of diesel fuel (samples MK I and MK II) produced greater reactions (Fischer and Bjarnason1996).
	Dermal Case Report: diesel oil	Diesel oil used over several weeks as an arm and hand cleaner resulted in epigastric and loin pains, nausea, anorexia and degeneration of kidney tubular epithelium and renal failure. The patient subsequently made a good recovery. There was no history of exposure to any other nephrotoxin (Crisp et al. 1979).
	Case-Control study: diesel fuel	A case-control study of men with various cancers revealed an adjusted odds ratio of 1.9 (90% confidence interval = 1.2-3.0) for prostate cancer with exposure to diesel fuel. There was no evidence for a positive dose-response relationship (Siemiatycki et al. 1987).
Sensitization	68476-34-6	Market-place diesel fuel was not sensitizing in guinea pigs using the Buehler (closed patch test) method. The skin of male albino guinea pigs was exposed 10 times over 3 weeks to 0.5 mL test substance (each exposure was for 6 hours with occlusion). After a challenge with test substance, the scores for erythema and edema were not greater than scores recorded during the induction phase. A positive control group exposed to 0.05% chlorodinitrobenzene exhibited sensitization. Study was conducted according to GLP (API 1980a).
	64742-80-9	Substance API 81-09 was not sensitizing in guinea pigs using the Buehler (closed patch test) method. Ten male Hartley guinea pigs were exposed during the induction phase to either one dose per week of 0.4 mL of a 25% solution of test substance in paraffin oil, or to three doses per week of 0.5 mL of undiluted test substance for 3 weeks. Subsequently, animals were challenged with either 0.4 mL of a 10% solution, or 0.5 mL of neat test substance and scores were taken at 24 and 48 hours. Five of ten animals showed slight erythema in the former study, but these reactions were similar to what was seen in two of ten naïve-exposed animals (animals exposed only during the

Endpoints	CAS RN[a]	Effect levels[b]/Results
		challenge phase), indicating that the erythema was not a result of sensitization. In the latter study, scores were lower in the challenge phase than in the induction phase, indicating a lack of sensitization. Substance API 81-10 was similarly not sensitizing. Positive control groups consisting of animals exposed to dilute solutions of 2,4-dintirochlorobenzene exhibited sensitization. Studies were conducted according to GLP (API 1984b, c).

[a] Studies investigating Fuel Oil No. 2 indicate the CAS RN in bold.

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

[c] 1 m^3 = 1000 L

[d] The following formula was used for conversion of provided values into mg/kg-bw: *x* mL/kg-bw x ρ.

[e] Converted value obtained from identical reference listed in CONCAWE 1996.

[f] Body weight (bw) not provided, thus laboratory standards from Salem and Katz, Inhalation Toxicology, 2006 were used.

[g] The following formula was used for conversion of provided values into mg/kg bw: (% of dilution x *x* mL x ρ) / bw.

[h] Density not provided, thus a density from API 2003b was used.

[i] A volume/volume dilution was assumed.

[j] Density not provided, thus a density from Khan et al. 2001 was used.

[k] The following formula was used for conversion of provided values into mg/kg bw: *x* mg / bw.

[l] The following formula was used for conversion of provided values into mg/m^3: (*x* ppm x MM) / 24.45.

[m] Molecular weight (MW) of Fuel Oil No. 2 assumed to be 180 g/mol (U.S. EPA 2013)

[n] Molecular weight (MW) of Diesel Fuel reported to be 230 g/mol (U.S. EPA 2013).

[o] Molecular weight (MW) of Diesel Fuel No. 2 reported to be 190 g/mol:
(OHS 2003)

[p] Density obtained from European Commission c2000b.