AREVA

Kiggavik Project

Environmental Impact Statement

Tier 3 Technical Appendix 10A

Transportation Risk Assessment

December 2011

KIGGAVIK PROJECT
TRANSPORTATION RISK ASSESSMENT

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December 2011

Printed on Recycled Paper Containing Post-Consumer Fibre

EXECUTIVE SUMMARY

This report is the compilation of the assessment of the risk of the transportation of yellowcake and other reagents related to the proposed Kiggavik Project. The Kiggavik Project is a uranium mine development prospect situated approximately 80 kilometres west of Baker Lake, Nunavut, Canada. The report addresses the risks of transporting hazardous goods and yellowcake through various transportation modes (i.e. via truck, barge and aircraft) to workers, the public, and the environment. Risks were considered during routine operations and if an accident were to occur.

The yellowcake will be transported from the Kiggavik site to Points North (or another destination with ground link to the south) and then transported to refineries via land route by truck. An airstrip will be constructed at the Kiggavik site (the Pointer Lake airstrip). Truck transportation will be limited to transport from the Kiggavik site to the Pointer Lake airstrip (assumed to be 10 km maximum with no water crossing).

The air transport accident scenario assessed involved an airplane crash and release of yellowcake.

Assessment of routine operations involved the assessment of the radiation dose to the following receptors:

- Forklift operator
- Truck driver
- Aircraft pilot
- Driver of heavy duty forklift
- Member of the public

For accident assessment, various transportation accidents statistics for various modes of transportation were used to calculate the frequencies of accident scenarios.

The following species were considered for the assessment of accidents:

- Aquatic Receptors:
    - Aquatic Plants
    - Benthic Invertebrates
    - Forage Fish
    - Predatory Fish

- Terrestrial Receptors:
  - Sandpiper
  - Tundra Swan
  - Merganser
  - Caribou

- Human Receptor:
  - Toddler
  - Child
  - adult

The assessment of consequences was based on the calculations of the chemical concentrations in various environmental media, exposure pathways modelling for various receptors, selection of appropriate benchmark and risk characterization via comparison of the calculated values with the their corresponding benchmarks.

Assessment of Routine Operation

Potential consequences of routine operation were discussed in this report. Such impacts are limited to external radiation dose to human receptors in close proximity to yellowcake containers. In the absence of an accidental release, none of the ecological species will be exposed to yellowcake during transportation. Routine transport of fuel and reagents has minimal exposure of humans and ecological receptors.

Various receptors and exposure scenarios were defined for this analysis. Receptors included a forklift operator loading drums of yellowcake into a sea-container, a truck driver transporting a sea-container, a pilot transporting a sea-container, driver of a heavy duty forklift in the storage area, and a member of the public living near the storage area.

The following Table shows the effective annual dose for human receptors during routine operations. The maximum annual dose was for the forklift operator (4.1 mSv).

Receptor Description	Total Dose (mSv/y)
Forklift operator	4.1
Truck driver	1.1
Pilot (343 trips)	0.051
Driver of heavy duty forklift	3.9
Member of the public	0.02

The CNSC (2000) radiation dose limit for a member of the public is 1 mSv per year (over natural background levels). The guideline for a nuclear energy worker (NEW) is 100 mSv for five years (i.e., an average of 20 mSv/year). The radiation doses estimated for routine operations in this section are below 1 mSv/y for all members of the public.

The forklift operators and truck driver at Kiggavik will be NEWs; they will not receive radiation doses higher than accepted (i.e. 20 mSv/y) from these operations.

Assessment of the accidents

The assessment of risk of transportation of yellowcake, fuel, and reagents involved the assessment of probability of accidents scenarios and the assessment of the impacts of the bounding scenarios that would serve to illustrate the most severe potential consequences. The bounding scenarios are selected based on the following aspects.

- Frequency of the occurrence
- Quantity of hazardous substances involved
- Duration and potential spatial extent of releases to the environment
- Magnitude of the effect on the environment

Yellowcake Release

The combined frequency of crash and rollover along the haul route between the Kiggavik Site and the airstrip was 4.7×10^{-5}. No significant adverse environmental effects are expected as there is no water crossing along the route and any release to ground can be contained and cleaned effectively.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, an accident between the Kiggavik site and airstrip is highly unlikely, with minor consequences. The risk is negligible and no residual environmental effects are expected.

The in-flight crash frequency into a large lake was 1.1×10^{-4} per year for Kiggavik- Points North (year round).

This report present the results of the aquatic and terrestrial radiological assessments under the different RBE assumptions (10 and 40) for the large lake and land release scenarios involving aircraft accidents resulting in a yellowcake spill. The results indicated that the Screening Index (SI) values were exceeded in all scenarios for all aquatic species with respect to the lower reference dose at both RBE values (10 and 40). With respect to the higher reference dose, the SI values were not exceeded for predatory and forage fish species at both RBE values (10 and 40), but were exceeded in all cases for aquatic plants (leaves and roots) and benthic invertebrates. These results indicated that a spill of yellowcake into a large lake could potentially affect the populations of aquatic plants, benthic invertebrates and fish species. For fish species, only the more conservative lower reference dose was exceeded.

In addition to being exposed to water, benthic invertebrates reside in sediment, which represents another pathway of exposure to uranium. Uranium concentrations in large lake sediments resulting from a spill of yellowcake would not be high enough with respect to the SEL benchmark for adverse effects to be expected on benthic invertebrates. However, with respect to the LEL benchmark, benthic invertebrates may potentially be at risk in large lake sediments following an accident. While the LEL value is a reliable predictor of uranium sediment concentrations (<LEL value) that will not adversely affect benthic invertebrates, the SEL value is not considered reliable in predicting concentrations at which potential effects will be expected (>SEL value). At concentrations occurring between the LEL and SEL values (as is this case for most of the assessed scenarios), benthic invertebrates may potentially be adversely affected.

The report also provides the SI values for terrestrial species, which include waterfowl (sandpiper, merganser and tundra swan) and caribou, for large lake scenario, water, and caribou and arctic ground squirrel ingesting soil following a release into the land. The results indicated that the terrestrial species potentially at most risk would be the waterfowl, which have an aquatic based diet. The SI values for all three waterfowl were exceeded for the lower reference dose at both RBE values (10 and 40) following an accident into a large lake. However, at the higher reference dose the SI value at an RBE value of 10 was not exceeded for the merganser, which, unlike the sandpiper and tundra swan, does not consume benthic invertebrates. The SI values in all cases were below 1 for the caribou ingesting contaminated water (Caribou 1) and for the caribou (Caribou 2) and arctic ground squirrel ingesting contaminated soil.

With respect to waterfowl that have an aquatic based diet, the spill scenario would not result in potential risks of adverse effects to merganser while the tundra swan and especially the sandpiper may be at risk. The sandpiper would potentially be at risk when considering both the NOAEL and ENEV TRVs, as well as the tundra swan but with respect to the ENEV only.

With respect to human receptor, the Predicted uranium concentrations in a large lake following a yellowcake spill would exceed the Canadian Drinking Water Quality Guideline (Health Canada 2008) for uranium (0.02 mg/L) under both scenarios.

The doses to a toddler and child would be twice as high as that to an adult under the spill scenario. In all cases, however, the dose estimates were well below (<1 mSv/yr) the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1000 μSv/yr for members of the public as well as the Health Canada dose constraint limit of 300 μSv/yr. In case of adverse water quality following an accident, drinking water advisory will be in place to prevent the exposure of human receptors to contaminated water during the response to the spill.

It should be noted that, the frequencies of the accidents resulting in higher SI values are very low. And the effects are transient in nature and contained within local areas at the vicinity of the spill for most cases. It is expected that the environment fully recovers from such spills after the appropriate response and cleanup following each accident scenarios.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, the air transport crash scenario is unlikely, and may have major consequences. The risk was rated as low. In the long-term and following a response to spill, no residual environmental effect is expected.

A crash into a small lake may have larger consequences requiring significant cleanup effort. However, the likelihood of such accident is highly unlikely.

Spill of fuel and Reagents

The frequencies of spill near water (due to roll-over or crash) can be up to 3×10^{-4} per year for diesel fuel, and 2×10^{-4} per year for sulphur on the longest routes. The frequencies are more than an order of magnitude lower (with a maximum of 2×10^{-5} per year) for other materials as the quantities transported are much lower. For small quantities of oil spill from vessels, the frequency of spill is 71 per billion barrels of oil transported.

The frequency of release of fuel (from tanker or fuel bunker) during marine transport was estimated at 0.027 per year.

The frequencies of fire and explosion for various routes can be up to 1.6×10^{-6} per year for diesel fuel, and 2.1×10^{-6} per year for ammonium nitrate on the longest routes. The frequencies are more than an order of magnitude lower for other materials as the quantities transported are much lower.

A spill of fuel to water may result in a change in surface water quality. Following a fuel spill, steps will be taken to reduce and mitigate the local impact of the spill by containing the plume with fuel containment booms and collecting the fuel from the surface of the water. Lake water sampling will also be conducted to monitor the movement of the spilled fuel and its potential to cause an adverse effect on the environment. After clean-up, all collected fuel will be stored, or disposed of safely in accordance with applicable regulations.

With respect to the fish exposure, during the daytime the fish population density is very low compared with the population at the depths greater than 2 m because of the exposure to high energy environment at the surface. During the night, the fish population move to the higher depths. This will allow a timely clean up of the residual oil from the surface of water while the fish exposure is minimal.

Following a spill, the fuel may be washed to the shoreline where the benthic exposure is possible. The wave action makes the nearshore zone at Baker Lake Dock or Chesterfield Inlet unfavourable for benthic communities. For the areas with higher densities of benthic invertebrates, the population of such communities, as well as rooted aquatic plants, are expected to recover after the cleanup is completed.

As opposed to the crude oil, diesel fuel does not leave viscous or high density residues on the shore lines that could physically coat the ecological receptors body. In addition, the spill is expected to be relatively small temporally and spatially, and no lasting residual effect is expected from this accident scenario, however, as a result of this fuel spill, there may be environmental effects experienced on the aquatic environment.

Therefore, long-term exposure of the aquatic species is not expected from this scenario.

As for the human receptors, if the spill cannot be contained locally, the plume of spilled fuel may move toward the intake of a drinking water system. Protection of the drinking water system against a potential fuel spill will involve a multiple-barrier approach that includes:

- Preventive measures to reduce the likelihood of a fuel spill from occurring;
- Mitigative measures to contain the spilled fuel; and
- Notification to the operators of nearby drinking water supply plants for appropriate action.

Advanced notification procedures will be in place to inform applicable drinking water supply plant operators of any spill where there is potential for the contamination of the drinking water supply. The notification will ensure that the operator has adequate time to take precautions and appropriate actions before the plume of spilled fuel reaches the intake of the drinking water supply plant system. The limited nature of the spill that would result from this scenario would add an additional level of protection against contamination concerns.

Adverse effects resulting from a fuel spill on the quality of a community’s drinking water are very unlikely and any effects would be mitigated prior to reaching the water supply of those in the community. There are no residual effects anticipated as a result of this scenario.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, the fuel (or other reagents) spill into the surface water during marine transport is likely during the lifetime of the project. However, the consequences will be moderate. The risk was rated as moderate in short-term. In long-term, and following a response to the spill, the consequences are minor and the risk is rated as low; no residual environmental effect is expected.

Fire and Explosion

The frequencies of fire and explosion for various routes can be up to 1.6 x 10^{-6} per year for diesel fuel, and 2.1 x 10^{-6} per year for ammonium nitrate on the longest routes. The frequencies are more than an order of magnitude lower for other materials as the quantities transported are much lower.

In case some oil reached the surface water during a fire, the effects will be bounded by the fuel spill scenario discussed in the previous section. If a fuel truck is involved in a fire, it is anticipated that during a fire, atmospheric release will originate from the diesel fuel and tires of the truck.

In case of a fire following a fuel transportation accident scenario, all efforts would be made to extinguish the fire as rapidly as possible in order to prevent releases to the atmospheric environment. Considering all mitigating activities, it is expected that full cleanup of the surrounding environment will be possible following this accident scenario.

The burning of fuel oil is largely accepted to result in short-term effects at close vicinity of the fire provided that measures are put in place to stop the fire as rapidly as possible in order to minimize the extent of the smoke plume. As a result of the rapid response and the ensuing mitigation measures that will be put in place, it is not expected that there will be residual effects from this scenario.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, the fire and explosion accidents are highly likely during the lifetime of the project. The environmental consequences were judged to be minor to moderate. The risk was rated as low and no residual environmental effect is expected.

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1.0 INTRODUCTION

1.1 PROJECT DESCRIPTION

The proposed Kiggavik Project is a uranium mine development prospect situated approximately 80 kilometres west of Baker Lake, Nunavut, Canada (see Figure 1-1). The Project includes a uranium mill with a nominal production capacity of approximately 4,000 tonnes U per year and a feed grade of 0.4% U. The mill would be located at the Kiggavik site, and will produce uranium concentrate (yellowcake), which will be transported to refineries for further processing.

There are three main geographical areas incorporated in the Kiggavik Project; these are the Kiggavik site, the Sissons site and the Baker Lake dock site. The main base of operations will be the Kiggavik site, which will include open pit mining, power generation, ore processing, warehousing, administration and personnel accommodation. The proposed activities at Sissons include open pit mining, underground mining, and the ancillary activities required to support these mining operations. The dock site at Baker Lake will serve as a transfer and storage facility for materials and supplies en route to Kiggavik.

The remote location of the project and the climatic conditions impose strong seasonal constraints on transportation. The Kiggavik site can be reached either by air, or by waterways and roads from Baker Lake. An airstrip would be constructed in the vicinity of the Kiggavik site.

Reagents, fuel and supplies would be barged to a storage facility near Baker Lake and then transported to Kiggavik via truck on a 90 – 100 km access road. An airstrip would be constructed on site for the transport of both employees and materials. The airstrip would also be used to transport drums of uranium concentrate by air.

Previous studies on the Kiggavik Project referred to in this report include the following:

- The Kiggavik Project Prefeasibility Study; Section 14: Logistics and Transportation (November 2007);
- Screening Level Environmental Effects Assessment for the Proposed Kiggavik Project (July 2008); and,
- The Kiggavik Project Logistics Summary.
- Kiggavik Project Environmental effects Assessment, Project Description (2011)

1.2 DESCRIPTION OF STUDY AREA

The study area is located in the “Barrenlands”, well north of the tree line in the continuous permafrost zone. For the most part, the area has a gently rolling topography with a few low escarpments associated mainly with east-west trending faults. In general, the surficial deposits in the study area comprise mainly granular glacial till overlying Precambrian intrusive igneous and metamorphic bedrock that are typically quartzite, schist or granite. The glacial till is typically well-graded silty sand with some gravel, cobbles and occasional boulders.

This region is considered to have an arid arctic climate where snow fall rarely exceeds 1 m and annual rainfall is not significant. Arctic winter conditions prevail from October through May, with temperatures ranging from +5°C to -60°C. Light to moderate snowfall is accompanied by variable winds of up to 90 km/h. Summer temperatures usually range from -5°C to +25°C.

The mine deposits are located within the Anigaq River watershed, which drains into the western end of Baker Lake. Baker Lake is one of the larger fresh water bodies in the study area, extending approximately 80 km in length and 25 km in width. A community is established along the northwest shore of the lake between the airport and the Agnico Eagle Dock, at approximately 80 km east of the Kiggavik site. Baker Lake is fed by several rivers, the largest ones being the Thelon River and the Kazan River, both of which have been designated Heritage Rivers. The Thelon River enters the lake just west of the Baker Lake community while the Kazan River enters the lake from the south. Baker Lake drains to the east through the Chesterfield Narrows into Chesterfield Inlet, which subsequently drains into Hudson Bay. The Chesterfield Inlet is a salt-water tidal corridor, 200 km long that joins Hudson Bay with Baker Lake. The section of the passage near Baker Lake is referred to as the Chesterfield Narrows.

The Water Survey of Canada (WSC) has operated a number of hydrometric monitoring stations within the region. Unit area runoff has been estimated for three WSC stations near the Project over the period of record. Despite a wide range of drainage areas, mean annual unit-area runoff ranged from 0.0061 $m^3/s/km^2$ to 0.0063 $m^3/s/km^2$ for the Thelon River, the Anigaq River, and Qinguq Creek, which are closest to the Kiggavik site. Mean unit area runoff was estimated to be 0.0058 $m^3/s/km^2$ for the six WSC stations within 100 km of the Project.

Baker Lake (or Qamanittuaq) is the Kivalliq community closest to the proposed Project, and is located near the geographical centre of Canada. The only inland community in Nunavut, in 2006 Baker Lake had a population of 1,728, which had grown since 2001 by 14.7%.

There have been an increasing number of mineral exploration companies operating out of Baker Lake over the last few years, including the Meadowbank gold mine project, located 70 km north of Baker Lake. Mine commissioning and first gold production from the Portage open pit began in early 2010. Such events appear to have generated significant changes in the Baker Lake hamlet, particularly in employment and business activity.

1.3 STUDY PURPOSE AND SCOPE

The objective of the study was to conduct a transportation risk assessment for the Kiggavik Project. The report addresses the risks of transporting hazardous goods and yellowcake via truck, barge and aircraft to workers, the public, and the environment. Risks were considered during routine operations and if an accident were to occur.

1.4 REPORT STRUCTURE

This study covers the impact of transportation during both normal operations and in case of an accident.

The assessment for normal operation focused on radiological impact on workers and people in close proximity to yellowcake. Such impacts were assessed using the Microshield program (Grove Engineering 2008).

The assessment for accidents included estimation of risk, taking into account both the probability of an accident and the potential consequences thereof. Accident probabilities were defined based on the Project characteristics and available statistics on accident frequencies. Consequences were defined for credible accident scenarios for exposure of non-human and human biota to spilled materials.

The report focuses on yellowcake as the main material of concern, but also deals with other materials transported to the site (fuel and reagents).

The report is structured based on this general methodology. The Kiggavik Project and its transportation components are characterized in Sections 1 and 2. Accident scenarios are defined in Section 3, with their frequencies assessed in Section 4. Sections 5 cover exposure and receptors characteristics and 6 and consequence assessment for both normal and accident conditions. Summary and conclusion of the report are provided in Section 7.

1.5 RISK MATRIX FOR ACCIDENT SCENARIO

ssessment of the likelihood of the event occurring is based on the criteria shown in Table 1.1. Assessment of the potential consequences of the event occurring is based on the criteria shown in Table 1.2. Key categories used for consequence assessment include health and safety, radiation exposure, and environment. Assigning risk rating is based on Table 1.3.

Table 1.1 Criteria for Assessing Likelihood

	Likelihood	**Comments**	**Probability of Event occurring within 40 yrs**
Almost Certain	> 1 in 10 Years	It is likely that the event has occurred at the site if the facility is more then a few years old	Greater then 98.5%
Likely	1 in 10 to 1 in 100 years	Might happen in a career	Between 98.5% and 44%
Unlikely	1 in 100 to 1 in 1000 years	Conceivable – has never happened in this facility but has probably occurred in a similar plant somewhere else	Between 44% and 4%
Highly Unlikely	< 1 in 1000 years	Essentially Impossible	Less then 4%

Table 1.2 Criteria for Assessing Consequences

Category	**Consequence Rating**			
	1	2	3	4
Health & Safety Risk	Minor: Nuisance and irritation, ill health leading to temporary discomfort, first aid treatment, minor cuts and bruises, eye irritation from dust, area exceeds internal administrative level.	Moderate: Some loss of hearing, dermatitis, asthma, upper limb disorder, minor disability, medical aid required, lacerations, burns, concussions, serious sprains, minor fractures, area exceeds a Threshold Limit Value	Major: Deafness, ill-health leading to major disability, medical aid required, lost limb injury, amputation, major muscle strain, major fracture, poisoning, multiple injuries, area routinely exceeds a Threshold Limit Value	Catastrophic: Life-shortening diseases, acute fatal diseases, ill health leading to permanent disability, fatality, area exceeds a Threshold Limit Value and causes harm to individual.
Radiation Exposure Risk	Minor: Area or dose exposure exceeds an internal administrative level.	Moderate: Area or dose exposure exceeds regulatory action levels.	Major: Area or dose exposure exceeds regulatory action levels.	Catastrophic: Dose exposure exceeds regulatory emergency dose

Category	**Consequence Rating**			
	1	2	3	4
Environmental Risk	Minor: Incident, spill or occurrence reportable to regulators, measurable impacts to the environment is localized, exceeds admin. level	Moderate: Incident, spill or occurrence reportable to regulators, measurable impact to the environment causes harm but limited to site, exceeds regulatory action level requiring an official investigation	Major: Incident, spill or occurrence causes extensive harm beyond property, impacts have short term or reversible effects, exceeds regulatory limits	Catastrophic: Life shortening incident, spill or occurrence causes ecosystem to be impaired, either long term or irreversible effect to the environment, public inquiry

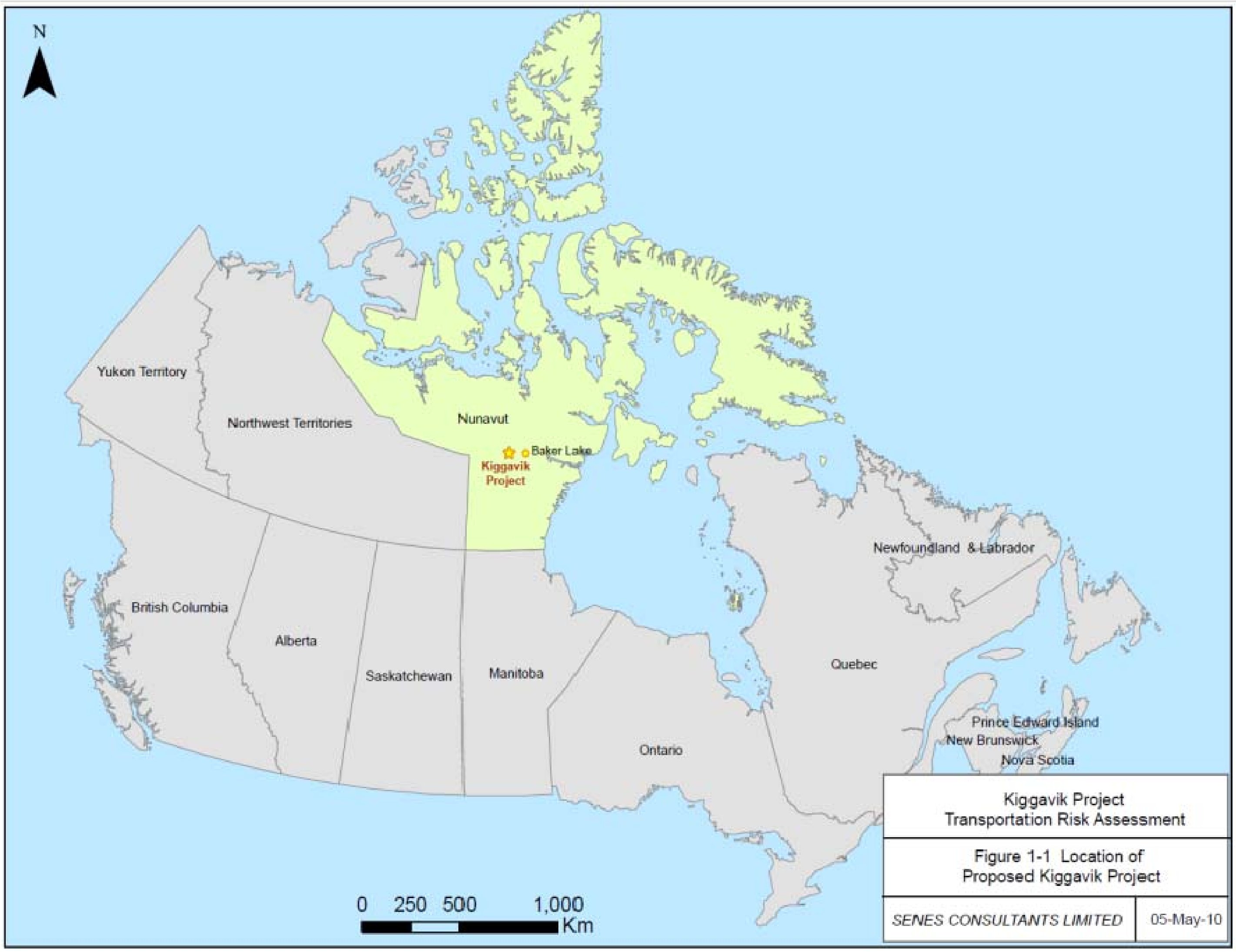
Table 1.3 Risk Rating Matrix

Likelihood		**Consequence**			
		1	**2**	**3**	**4**
		Minor	**Moderate**	**Major**	**Catastrophic**
4	Almost certain: > 1 in 10 yrs	2	3	4	4
3	Likely: 1 in 10 to 1 in 100 yrs	2	3	3	4
2	Unlikely: 1 in 100 to 1 in 1000 yrs	1	2	2	3
1	Highly unlikely: < 1 in 1000 yrs	1	1	2	2

Where:

- 4– High Risk
- 3– Moderate Risk
- 2 – Low Risk
- 1 – Negligible Risk

Figure 1-1 Location of Proposed Kiggavik Project



2.0 TRANSPORTATION CHARACTERISTICS

The logistics and transportation strategy adopted for the Kiggavik Project is similar to the strategies of many mining projects in northern Canada. Broadly, the strategy includes air transportation, and a combination of open water marine transportation, in conjunction with an all weather road and/or winter road access to the Project site.

The majority of the goods required for the Project will be shipped via marine transportation during the open water season to a dock facility along the north shore of Baker Lake Transportation will then be by winter and/or all-season road to the Kiggavik site. An airstrip will also be constructed at the Kiggavik site for the transportation of yellowcake and the delivery of perishable goods, emergency supplies and personnel. This is a similar transportation strategy as that employed at other northern mine projects and is consistent with input received from the public (Volume 3).

2.1 TRANSPORTATION ARRANGEMENTS

2.1.1 Yellowcake Transport

The yellowcake will be transported from the Kiggavik site to Points North (or another destinations with ground link to the south) and then transport to refineries via land route by truck. An airstrip will be constructed at the Kiggavik site (the Pointer Lake airstrip). Truck transportation will be limited to transport from the Kiggavik site to the Pointer Lake airstrip (assumed to be 10 km maximum with no water crossing).

2.1.2 Transport of Fuel, Reagents and Supplies

The primary routing for fuel, reagents and supplies can be broken into three components: from the point of origin to the port of Churchill (and/or lighter point near Chesterfield Inlet), from Churchill/Chesterfield to Baker Lake, and from Baker Lake to Kiggavik. Dry cargo may be loaded on ocean-going barges in southern ports and delivered direct to Baker Lake. This study assesses the risks for transport from Churchill/Chesterfield forwards.

The road options being considered for transport from Baker Lake to the Kiggavik site are:

- All-weather north road; and/or
- Winter road

Fuel, reagents and supplies will be stored at Baker Lake until they can be trucked to the Kiggavik site. This will depend on the type of road available and haulage seasons. In the case of the all-weather roads, haulage could be spread throughout the year, or half of the containers could be transported during summer months, whereas the other half would be stored until winter. In the case of the winter road, all cargo has to be stored from the open-water season in the summer until the winter road season.

2.2 MATERIALS AND CONTAINERS

2.2.1 Yellowcake

Yellowcake (uranium concentrate) will be produced at an on-site mill at Kiggavik through processing of the ore. The yellowcake production will amount to 4,000 tonnes of uranium per year as a low-moisture final product. Yellowcake would be discharged from the product surge bin to the packaging system, which fills steel drums. Each sealed drum containing approximately 400 kg of yellowcake would then be stored in a designated area prior to shipping off site.

Based on a 4,000-tonne uranium per year operation, approximately 4800 tonnes of yellowcake will be produced each year at Kiggavik. The yellowcake will be packaged in steel 55-gallon drums and sealed, with each drum holding approximately 400 kg of yellowcake.

According to the IAEA regulations for the safe transport of radioactive material (IAEA 1996) and the Canadian Packaging and Transport of Nuclear Substances Regulations (2000) , uranium concentrate is considered Low Specific Activity material (LSA-I) and is to be packaged in Industrial Package Type 1 (IP-1). The main requirements for such a package are that it shall be designed so that it can be transported easily and safely, can be properly secured in or on the conveyance during transport, have robust lifting attachments, nuts, bolts and other securing devices, and can withstand ambient temperature and pressure during air transport. The package is not required to be water-tight.

This package design has passed the free drop test from 1.2 meters, during which the drums sustained structural compression, but maintained their sealed integrity and did not allow any of the contents to be released. This package has also passed the Stacking Test with a weight of 5 times the mass of the actual package for a period of 24 hours. The packages are watertight as long as the lid is in place properly. The water spray test will have no effect on this package. There will be no loss or dispersal of the radioactive contents, and no loss of shielding integrity of the package if subjected to the water spray test (Greif 2004).

The site will produce approximately 12,000 drums of yellowcake annually, which will be loaded into sea-containers. Limitations apply to the transportation of radioactive goods, and it has been estimated that a maximum of 35 drums may be loaded into a container to maintain a

Transportation Index (TI) of less than 6. It is therefore expected that 343 sea-containers will be shipped to the south annually.

2.2.2 Fuel, Reagents and Supplies

The annual estimated quantities of supplies for the Project are summarized in Table 2.1. The total annual diesel fuel requirement will be approximately 55,000 tonnes (peak) while the dry goods and reagents total approximately 91,000 tonnes (peak). The largest tonnages will be for diesel fuel, cement (for underground mine backfill), lime and sulphur (mill reagents). Lime and sulphur requirements are expected to be reduced as a result of on-going tests and optimization studies.

A number of the site supplies listed are hazardous goods; these will be shipped in accordance with international, federal, and territorial regulations. Fuel will be shipped in bulk. Hazardous goods will be transported either in product-specific ISO containers or, in the case of smaller volumes, as palletized sealed drums placed in standard sea containers. Additional details are provided in the Hazardous Materials Management Plan (Appendix 2U).

Non-hazardous material will be shipped in standard sea-containers, or standard drums. Such materials are not included in this risk assessment.

Table 2.1 Estimated Annual Quantities of Reagents and Supplies

Supplies	Maximum Annual Shipping			TEUs
	Value	Units	Packaging	
Blasting materials	9,000	tonnes	tote bags	500
Cement	8,200	tonnes	tote bags	456
Flocculant "A"	93	tonnes	tote bags	5
Flocculant "B"	2	tonnes	drums	0
Lime CaO	47,200	tonnes	tote bags	2,622
SAG Mill Grinding Balls (3" & 4")	278	tonnes	bulk	15
Ball Mill Grinding Balls (2")	370	tonnes	bulk	21
Sulphur	26,700	tonnes	tote bags	1,483
Barium chloride	194	tonnes	tote bags	11
Ferric sulphate	130	tonnes	tote bags	7
NaOH	1,348	tonnes	drums	75
Na2(SO4)	553	tonnes	tote bags	31
H2O2 (50%) - U	1,502	tonnes	ISO containers	83
Resins Ambersep 920U - U	137	tonnes	tote bags	8
Product drums - U	11,100	drums	drums	617
Diesel Fuel	55,400	tonnes		

TEU = Twenty-foot container equivalent unit

3.0 ACCIDENT SCENARIOS

3.1 TRANSPORTATION OF YELLOWCAKE VIA AIR

Several accident scenarios may be defined for yellowcake transport via air. Credible scenarios are described below.

- Scenario 1: Aircraft crash during takeoff or landing (on land or water)
- Scenario 2: Aircraft crash during cruising (on land or water)

A release of yellowcake to land away from a water body will be easily contained in a localized area. Following initial containment, it will be possible to excavate impacted material and reduce radiological contamination to background levels. However, an aircraft crash on land may need more time to be attended and remediated due to the time required for locating the crash site and arrival of the emergency crew to the site. AREVA has an ERAP in place to facilitate the response to transportation accidents.

If the aircraft crashed into the water, the container may breach, and lids may open resulting in the release of the content of drums into the water. Therefore, potential consequences need to be assessed for this scenario.

3.2 TRANSPORTATION OF FUEL, REAGENTS AND SUPPLIES

About 55,400 tonnes of diesel fuel need to be transported to the Kiggavik site annually. Other petroleum-based supplies include kerosene, gasoline, lubricants, hydraulic fluids, solvents and oil with a total quantity of less than 380 tonnes per year.

Other reagents and supplies transported to Kiggavik include amines (625 tonnes), isodecanol (31 tonnes) and hydrogen peroxide (1500 tonnes) in liquid form, lime (47,200 tonnes), sodium hydroxide (1,348 tonnes), sodium sulphate (553 tonnes), sulphur (about 26,700 tonnes) and ammonium nitrate (9000 tonnes) in solid form, all transported in ISO containers.

Credible accident scenarios for these operations are described below.

3.2.1 Transport via Truck

Three credible accident scenarios were identified for transport of fuel, reagents and supplies via truck, as follows:

- Scenario 1: Collision of two vehicles (head-on collision)

- Scenario 2: Roll over into a ditch or down an embankment
- Scenario 3: Roll over directly into a significant water body (considered the most extreme environmental accident)

Accidents during handling of containers on land can result in spill and soil contamination in the area. If a fuel tanker or reagent truck becomes involved in an accident near water bodies, the content of a tanker (about 50 m^3) may be released into the water, thus contaminating the water body.

An accident involving a tanker on a frozen lake results in a spill on the ice surface. A tanker breaking through the ice and sinking may result in chemical release and contamination of the lake. A scenario was defined for this accident as follows:

- Scenario 4: Ice breakage and sinking of a tanker into a significant water body

Petroleum products, other flammable liquids, and ammonium nitrate may catch fire during an accident. Therefore, a credible accident scenario was identified as follows:

- Scenario 5: Fire in a container of fuel, hydrogen peroxide or ammonium nitrate

3.2.2 Marine Transport

For transport of materials, the following hazards (involving potential release of material) were identified:

- During fuel discharge from tanker to Churchill tank farm:
    - Mechanical breakdown of unloading pumps on tanker
    - Tanker has discharge hose/connection failure
    - Tank farm over flows tank
    - Tanker parts mooring lines at Churchill
- During materials loading at Churchill and transport to Baker Lake:
    - Tug or barge grounds in Chesterfield Inlet or Narrows
    - Tug or barge involved in collision with conflicting traffic
    - Tug or barge collides with dock at Baker Lake
    - Tug is damaged by serious fire/mechanical failure
    - Tow lines get fouled
- During materials unloading to Baker Lake storage tanks:
    - Mechanical breakdown of unloading pumps on barge
    - Barge has discharge hose/connection failure
    - Tank farm over flows tank

  - Damage to barge due to ranging

As a result of each of these hazards, fuel or other chemicals may be released into water in the port or along the shipping route.

For transport of reagents and supplies, the following hazards scenarios were identified:

- Containers get damaged or washed overboard in bad weather
- Tug or barge grounds in the port
- Tug or barge collides with conflicting marine traffic
- Tug or barge sinks
- Container drops during loading/unloading

However, marine accidents during transport of reagents are less likely and of lower consequences compared to a fuel spill from the ship carrying the material. Frequencies will be lower as the materials' containers are more robust and secure than the fuel bunker. Consequences are lower as the quantity of oil used as fuel in a ship is higher than the quantity of each of these materials (about 26000 L or 22 tonnes of fuel for a 5000 tonnes barge travelling from Churchill to Baker Lake versus one or a few TEU's of materials). Therefore, an oil spill from the ship fuel bunker was considered a bounding for most of the scenarios that could be envisaged.

The accident scenarios for transportation of fuel and reagents were defined as follows:

- Scenario 1: Spill of the entire content of a tanker in water (30,000 tonnes in Churchill or Chesterfield Inlet, and 5,000 tonnes in Chesterfield Narrows or Baker Lake)
- Scenario 2: Spill of ship fuel (22 tonnes) in Churchill, Chesterfield Inlet or Narrows, or Baker Lake

4.0 FREQUENCY ASSESSMENT

4.1 OVERVIEW OF FREQUENCY ANALYSIS

In this section, accident statistics are presented and used to derive estimates of frequency of events that could result in spills to the environment, or fire and/or explosion.

As materials are transported in drums and containers, in addition to a transportation accident, there are a number of subsequent events that must occur for a release to take place. The frequency and severity of damage to a container in an accident is a function of the severity of the accident, the form and amount of force applied to the container and the ability of the container to withstand these forces. The frequency of a release can then be described symbolically as the product of conditional probabilities:

Frequency of release = frequency of accident x conditional probability of damage to the containment

The analysis summarized in this section brackets the range of probable accidents from high probability-low impact events to low probability-high impact events. A spill to a significant water body, with the potential transport downstream of spilled material, represents the worst-case accident scenario from an environmental perspective.

To impart conservatism into the analysis, all calculations are based on the assumption that any accident with sufficient energy to breach the inner container will result in the total release of container contents. The conservative nature of this assumption is discussed in a subsequent section.

4.2 ACCIDENT STATISTICS

4.2.1 Transportation via Trucks

4.2.1.1 General

Accident statistics reported for the United States and Canada were reviewed for selecting appropriate statistics to use in the current assessment. Accident statistics for northern conditions, specifically for roads in Nunavut and the Northwest Territories were reviewed where available.

4.2.1.1.1 U.S. Statistics

The U.S. DOT (2007) statistical data for hazardous material transportation in 2007 showed that the frequency of accidents involving hazardous material transport on all roads and rural roads were 0.136 and 0.051 accidents per million ton-miles, respectively (0.077 and 0.029 accidents per million tonne-kilometres).

The U.S. DOT statistics indicate that the frequencies of rollovers and truck crashes during transportation of hazardous materials were 6.7×10^{-4} and 8.1×10^{-4} accidents per million ton-miles, respectively (3.8×10^{-4} to 4.6×10^{-4} accidents per million tonne-kilometres). The U.S. DOT reported that in 2007 only 8 out of 17,000 hazardous material transportation accidents involved radioactive material.

4.2.1.1.2 Saskatchewan Statistics

From a review of accident statistics for semi-trailers in northern Saskatchewan (SENES 1999), it was found that the reportable accident frequency equalled 0.66 accidents per million vehicle kilometres travelled. Over the same period, the rollover rate equalled 0.066 rollovers per million vehicle kilometres travelled as compared to a provincial rate of 0.11 rollovers per million vehicle kilometres travelled. These statistics are inclusive of all goods hauled and not specific to the transport of hazardous materials. To allow comparison of these statistics to those reported by the U.S. DOT, the accident rates were divided by an assumed payload of 25 tonnes. The equivalent accident and rollover rates in northern Saskatchewan were calculated to equal 0.026 and 0.0026 accidents per million tonne-kilometres.

Statistics published by Saskatchewan Government Insurance[1] indicate that during 2007 there have been 23 traffic accidents involving dangerous goods of which only one involved radioactive materials.

4.2.1.1.3 Nunavut Statistics

According to our National Collision Database (NCDB), for the five years from 2003 to 2007 there were only three collisions on winter roads in Nunavut that involved trucks. All three collisions were classified as property damage only (PDO), single vehicle collisions: one truck hit a building, one hit a sign post and one hit a utility pole. There were 31 PDO, and eight fatal/injury-producing collisions involving trucks on all roads in Nunavut during this time period. Twelve of the accidents were single vehicle and nineteen were two-vehicle collisions. Of the twelve trucks involved in single vehicle collisions, all ran off the road. Ten hit objects off the road such as utility poles. Of these, seven occurred on roads covered with fresh snow or

[1] http://www.sgi.sk.ca/about/publications/collisionstats/index.html

ice/packed snow. Two trucks rolled over. Of the nineteen two-vehicle collisions, six involved a truck hitting a parked vehicle. Half of these occurred on roads covered with fresh snow. The remaining accidents involved trucks hitting a pedestrian, a snowmobile, or other vehicles in different configurations (Transport Canada 2010a). Traffic volume for trucks on ice roads and all roads in Nunavut are not available. The Statistics Canada (2003, 2004, 2005, 2006 and 2007) report on Canadian Vehicle Survey, however, provides the estimated vehicle-kilometre travelled by all vehicles above 4.5 tonnes on Nunavut roads as 19.2 million between the years 2003 and 2007. Therefore, the truck accident rate on all roads in Nunavut can be estimated as 31/19.2 or 1.6 accidents per million vehicle kilometres, which for an average truck weight of 15 tonnes will be 0.1 accidents per million tonnes kilometres.

4.2.1.1.4 The Northwest Territories Statistics

The Northwest Territories highway network consists of 2200 kilometres of all-weather roads and 1400 kilometres of winter roads (excluding winter roads constructed by mining companies to facilitate mine supply). Based on the 2008 highway traffic report (NWT DOT 2009a), the estimated vehicle kilometres traveled on all NWT highways was about 142 million. During 2008, 740 accidents leading to property damage were reported on these roads (NWT DOT 2009b). This statistics do not exclude materials related to mining operations. Specific statistics related to the mining operations were not available. Therefore, all vehicles in the NWT had an accident rate of 5.2 accidents per million vehicle kilometres. Of the 740 property damage accidents on record, 42 involved unit trucks (>4500 kg) and road tractors. Assuming a truck capacity of 15 tonnes, the truck accident rate on all roads is estimated at 0.09 accidents per million tonnes kilometres.

The estimated vehicle kilometres traveled on winter roads by all vehicles in the NWT was about 7.7 million in 2008 (NWT DOT 2010a). Ten accidents leading to property damage were reported on these roads (NWT DOT 2009b), resulting in an accident rate of 1.3 accidents per million vehicle kilometres. Similar statistics for trucks over 4500 kg show that two accidents (NWT DOT 2010a) occurred over 1.7 million vehicle kilometres (assuming that the ratio of trucks/all vehicles is the same for 'all roads' and 'winter roads'). Assuming a truck capacity of 15 tonnes, the truck accident rate on winter roads is estimated at 0.08 accidents per million tonnes kilometres.

Where environmental conditions were a major contributing factor (about 5% of all accidents), 93% were related to ‘animal on roadway’, and the rest to weather and road conditions. Of the 740 accidents, 10 occurred on ice roads and the remaining on other types of roads (asphalt, concrete, gravel, dirt, etc.). Accidents were also classified based on road conditions. Of the 740 accidents, 104 occurred on roads with snow, 336 on icy roads, 213 on dry roads, and the rest on roads with other conditions (wet, slush, loose sand, muddy, etc.).

In 2006, 5994 trucks carrying dangerous goods in NWT reported to weight scales. During the same year, 19 road transport spills were reported to the spill line, most of which involved fuel spill (NWT DOT 2006). Based on this information, the spill rate for dangerous goods from tucks on all roads can be estimated at 0.0032 spills per truck.

4.2.1.1.5 Selected Statistics

A comparison of statistics provided above is shown in Table 4.1. Application of each of these numbers has its merits and disadvantages for the current study. The U.S. DOT data have been developed specifically from a large database on the transport of hazardous materials. In addition, there is a differentiation between the types of accidents, which allows for a more detailed consequence assessment. The Saskatchewan data are less specific. The Nunavut data are limited, while the data from NWT are more comprehensive and can be used as representative of environmental and driving conditions in Nunavut.

The head-on collision of two vehicles represents the highest energy accident likely to be experienced by a container in a collision situation. In this study, it was assumed that the statistics for truck crashes can be used as a surrogate for head-on collisions. This is a conservative assumption, as only a portion of the crashes are head-on collisions. A rollover of one vehicle represents the most likely scenario for puncturing of the container.

In the current study, an accident rate of 0.09 accidents per million tonnes kilometres were used for all truck accidents on all roads and winter roads. These numbers correspond to roll-over and crash rates of 4.4 $x10^{-4}$ and 5.3 $x10^{-4}$ accidents per million tonnes kilometres (prorated to the U.S data). The frequency of accidents analysed is a linear function of the accidents rates selected (accidents per million tonnes kilometres).

Table 4.1 Comparison of Truck Accident Rates (accidents per million tonnes-km) in Different Jurisdictions

Jurisdiction	All Roads	Winter Roads
U.S.	0.077	-
Saskatchewan	0.026	-
Nunavut	0.11	-
NWT	0.09	0.08

4.2.1.2 Accidents at or near Water Bodies

The statistics presented above do not address specific issues related to an accident occurring at stream or river crossings or adjacent to nearby lakes. Factors that may affect accidents at bridge crossings include:

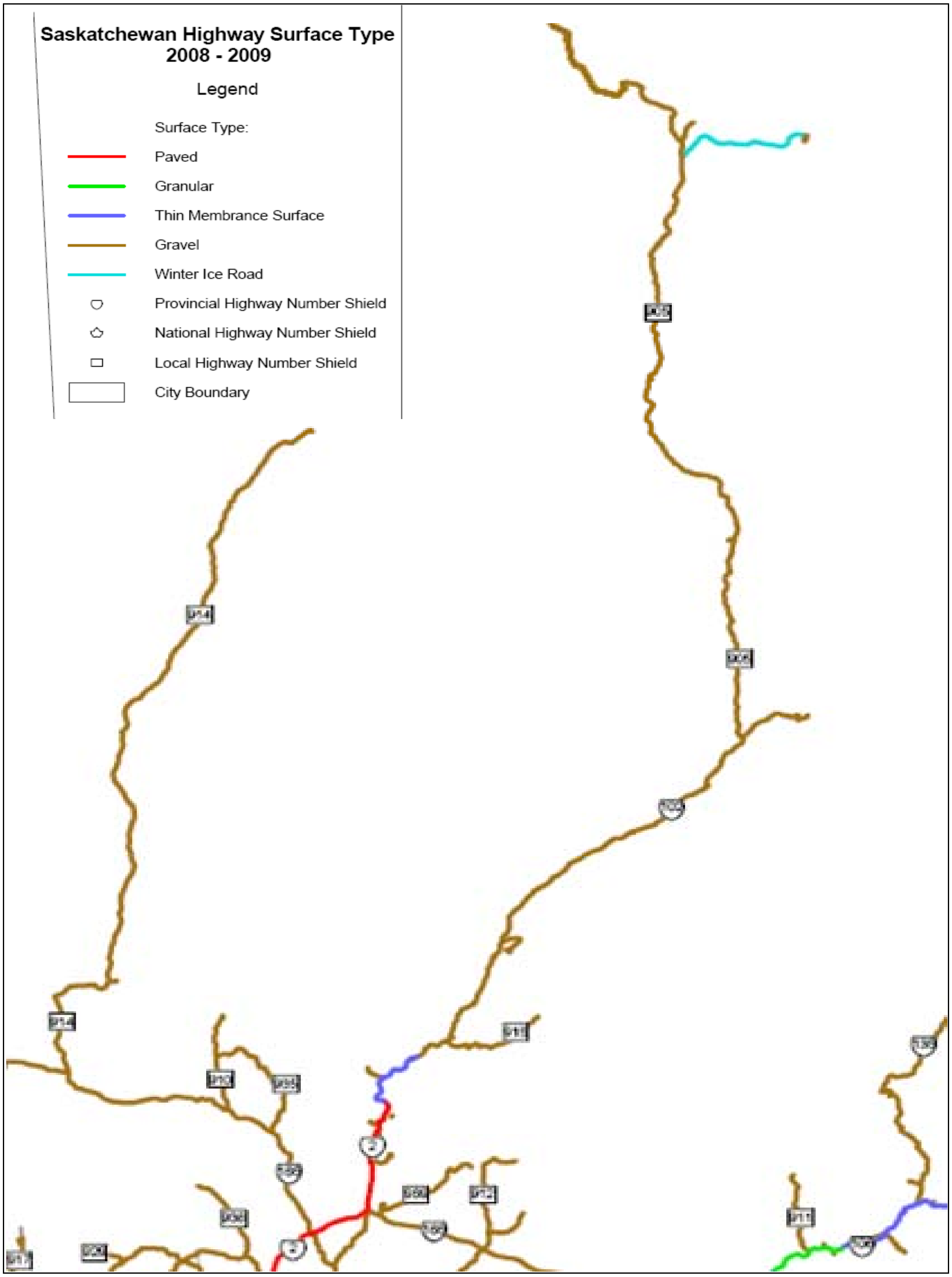
- Low visibility in foggy conditions increases the risk of an accident at bridge crossings as they are normally narrower than other parts of the road. Bridges do not have shoulders and typically the clearance of trucks from the side of the bridge is low.
- Accidents on bridges normally involve a fall with higher frequency of damage compared with accidents that occur along other parts of the road.
- Presence of structural materials such as steel structures, rebar and other reinforcement steels can puncture containers during an accident.

Thus, additional safety measures are warranted at bridge crossings to reduce the frequency of accident events occurring. Such measures include signs, reduced speed limits, and appropriate guard rails.

4.2.1.3 Vehicle- Wildlife Collisions

Another factor that influences accident statistics is vehicle-wildlife collisions. Accident statistics reported by Saskatchewan Government Insurance (SGI 2003) indicate that the Annual Average Daily Traffic (AADT) volumes for highways #905 and #102 were approximately 45 and 600 vehicles per day, respectively. In the same period there was reported to be 9 and 18 vehicle-wildlife collisions respectively on highways #905 and #102 from 1988 to 2002. The number of collisions in year 2002 was 2 and 0 collisions for highways #905 and #102, respectively. Using the same statistics, e.g., with a maximum of 22 trips per day on the all weather north road, the number of vehicle-wildlife collisions is expected to be less than 2 per year on the access road. While at higher speeds, vehicle-wildlife collisions could potentially cause significant property damage to smaller vehicles (e.g., cars and pickup trucks), these types of collisions are not expected to cause a rollover and consequently spill from a heavy low-speed truck carrying yellowcake. In addition, the access road will not be used when large migrations of caribou come through. Therefore, vehicle-wildlife collisions were not considered as a factor affecting the frequency of spill.

Figure 4-1
Northern Saskatchewan highways



4.2.1.4 Weather Conditions

Weather is also a determinant of truck crashes. Specific types of short term weather conditions (e.g., heavy snow, freezing rain and strong wind) affect truck crash conditions, and driver decision-making ability. Climate change can have longer term impacts on safety, infrastructure and vehicles due to larger, more frequent or more intense storms, precipitation and winds, and extreme temperatures, among other factors.

Heavy snow causes loss of traction, loss of visibility, and other driver control problems. Surface temperatures on bridges and ramps cool more rapidly than the surrounding roadbeds, producing hazardous local icing conditions and resultant property damage. Freezing rain, black ice and light frozen precipitation glaze roads as temperatures fall over a short period. Winter conditions also place additional stress on truck components. Strong winds and cross winds can disrupt truck operations. High profile trucks are susceptible to potential vehicle instability, loss of control and blow-overs from crosswinds in exposed areas such as bridges. Expected peak wind gusts may also play a role in determining the maximum wind speed in which a heavy truck can safely drive. The potential impact of such extreme weather conditions on accident frequency on roads was explicitly included by using accident statistics from the northern locations.

The long term impacts of climate change in northern regions may include higher winter temperature and shorter snow season, elevated storm surges and more flood episodes. Higher winter temperature will limit the duration of travel on ice roads. Problems posed by high waters from floods are sometimes a significant concern for trucks. Wet brakes may weaken or apply unevenly. Floods can also make roads and bridges impassable or produce complete washouts that require closures and rerouting.

The NWT Department of Transportation (2007) has conducted a research project to better understand climate change impacts on the land transportation network in the NWT, including permafrost degradation, vulnerability of the transportation network and measures to adapt. Based on the current knowledge about climate change (temperature rise of 4 to 7 °C in the next 100 years), the study predicted that the temperature at the top of permafrost will approach or exceed 0 °C in severe areas by 2055 and in significant portions of the transportation system by 2025. This means a higher potential for the formation of depressions and sloughing of embankments of the all-season roads. Other potential impacts include impact on dikes, bridges and culverts, more rapid spring run-off resulting in wash-outs, impacts on runways and airstrips and increasing the occurrences of freezing rain and freeze/thaw cycles impacting safety of airstrips. Mitigating these impacts will require additional equipment, labour and materials to maintain the integrity of transportation infrastructure.

On the winter roads, increasing temperature has greatly impacted the operation in recent years. Warmer temperatures have shortened winter road seasons. Natural ice formation is delayed, which in turn delays the application of heavy equipment for snow removal (to allow for more freezing). Thinner ice restricts the weight and load that can be transported on ice roads.

Ferry crossings are also affected by changes in water levels and river morphology. Increased rain events generate more sediment resulting in changing bathymetry and river dynamics. Changes in meltwater quantity and timing present uncertainties in the operation of ferries. Ice bridges are impacted by freeze up dates and a decreasing trend has been observed in ice thickness (from one meter down to 60 cm).

The Kiggavik Project will consider climate change considerations in various management plans. Permafrost and sub-grade temperatures will be monitored and climate change factors will be incorporated into the engineering system. The climate change plan will follow an adaptive management approach to include present uncertainties in the projected climate change trends and impacts.

4.2.1.5 Drivers Training

Truck drivers will have sufficient training for driving on northern roads and it is expected that this level of training would reduce the accident rates.

4.2.2 Marine Transport and Handling

4.2.2.1 All Cargo

The Transportation Safety Board of Canada provides statistics on marine occurrences for Canadian waters. The occurrences have been classified based on accident type, vessel type, and geographic region among others (Transport Canada 2008). Canadian marine vessel accidents and accident rates have been provided for the period of 1999 to 2008, during which the maximum accident rate was 25 accidents per million vessel-kilometres. The accident rate for commercial vessels is reported at 6.9 accidents per million vessel-kilometres between 2003 and 2008. Transport Canada statistics also show a total of 3.3 accidents of all perils per 1000 commercial vessel movements (Transport Safety Board of Canada 2010)[2]. Fishing vessels statistics have been disregarded in these statistics.

[2] http://www.tsb.gc.ca/eng/stats/marine/2010/ss10.asp

The marine insurance industry provides statistics on comprehensive loss. Reports published by the Nordic Marine Insurance Statistics (NoMIS) and the International Union of Marine Underwriters (IUMI) were reviewed.

The total number of vessels insured by NoMIS in 2009 was 8,475, which represents 17% of the entire world fleet (Cefor 2010). The NoMIS-insured container ship fleet consisted of an average of 1826 vessels per year between 2000 and 2008. The average frequency of accident claims for all types of accidents, all vessels between 2004 and 2008 was 0.15 claims/vessel/year. Accident claims which may contribute to container losses were 21.9% of all accidents (fire and explosion 1.8%, heavy weather 3.5%, other 16.6%). Accident frequency for containers is therefore estimated as follows:

Accident frequency = Average claim frequency for all vessels * Fraction to cause container loss = 0.15 * 0.219 =0.033 container loss /vessel/year

This was adjusted for the average small container vessel carrying 660 TEU for 50 trips per year in a comparable north European trade carries, which resulted in an accident frequency of 1 x 10^{-6} container loss/TEU (for one vessel). This is an extremely low frequency.

The IUMI have provided an overview of the world fleet statistics for total loss and serious loss accidents for the period of 1998 to 2007 (IUMI 2008). The total average number of container ships over this period was 6,125/year, which represents 38% of the world fleet of all vessels. Accident claims that may contribute to container losses were 21% (fire and explosion 12%, heavy weather 5%, other 4%). The average number of serious and total losses per year for all vessels and accidents was 581 between 1998 and 2007. Accident frequency for containers is therefore estimated as follows:

Loss frequency = all accidents x fraction likely to cause container loos * percentage total fleet/number of container ships = 581*0.21*0.38/6125 = 0.007

This was adjusted for the average small container vessel carrying 660 TEU for 50 trips per year in a comparable north European trade carries, which resulted in an accident frequency of 1 x 10^{-6} container loss/TEU (for one vessel). This is an extremely low frequency.

A Canadian shipping company with extensive arctic experience was also consulted. They claim that in 15 years they have never lost a container overboard due to bad weather or actually dropping a container. They have had at least one container fail due to overloading of the container by the client. During trips to the arctic the vessel's route is generally coastal giving the master ample opportunity to seek shelter or reduce speed when experiencing heavy weather. Containers have been damaged by forklift operators missing fork pockets and piercing the sides of containers with the lift forks. The damage to the containers is slight and container contents are normally not damaged. A number of container shipping companies have stated that the major cause of damage to cargo within the container is due to improper loading of the container contents. Another cause for container accidents is the structural failure of the container due to corrosion. There were no definitive statistics found that dealt with container failures.

4.2.2.2 Oil Spills

Historical data was used to estimate the frequency of oil spills, including oil carried as fuel and as cargo. These data have been summarized by Transport Canada (2010b). For bunker fuel spills, there have been a statistically significant number of incidents in Canada; however, there have been very few significant accidents involving tanker cargoes, so international data has been used for these predictions.

Factors affecting the accident rate for a bunker fuel spill include the density of traffic and navigational hazards in the area, as well as number of bridges and other fixed objects which can affect the potential for a collision. The likely frequency of bunker oil spills has been estimated based on historical data, specifically the Marine Information System (MARIS) database. Except for fishing vessels, there have been few accidents in the MARIS record (post 1985) that would have led to a spill. In fact, for all 10-100 tonnes tug barges, there has been only one accident in the 20-year record, for an annual frequency of 0.05 (Transport Canada 2010b) per a total of 100 tugs and barges 10-100 in gross tonnage travelling in Canadian waters (Canadian Transportation Agency 2009).

Historical tanker oil spill rates are provided in Table 4.2. These spill rates were combined with the volume of oil transported to produce an expected spill frequency based on these historical statistics.

Table 4.2 Historical Oil Spill Rates from Tankers

Spill size (billion barrels)	Spill Rate (per billion barrels of oil transported)		
	In port	**At sea**	**Total**
1 to 49	31.61	40.39	72
50 to 999	6.8	8.7	15.5
1,000 to 9,999	1.29	1.52	2.81
10,000 to 99,999	0.049	0.164	0.213
100,000 to 199,999	0.043	0.086	0.129
>200,000	0.022	0.043	0.065

4.2.2.3 Lightering

Lightering will be conducted for the project if Chesterfield Inlet is selected as an intermodal site.

The safety record of lightering has been excellent for fuel transfer in U.S. waters in recent years, as evidenced by the very low rate of spillage of oil both in absolute terms and compared with all other tanker-related accidental spills. The USCG data for 1984-1996 indicate that few spills occurred during lightering on U.S. coasts, and the average spill volume was only 26 barrels (1,095 gallons). Recurring causes of spills that appear to be directly related to lightering include valve failures, tank overflows, and hose ruptures. During 1993 to 1997, no spills were reported on the east or west coasts of the US, and only seven spills (accounting for less than 0.003 percent of the total volume lightered) were reported in the Gulf of Mexico (CETS 1998). Based on these numbers, accident frequency during lightering (Chesterfield option) is not considered to be different from frequencies during fuel transport to a tank farm and subsequent loading (Churchill option).

4.2.3 Air Transport

For air transportation accidents, accident statistics for worldwide commercial jet airplanes - heavier than 60,000 pounds maximum gross weight- were used. Accident Rates have been expressed as a measure of accidents per million departures. Departures (or flight cycles) were used as the basis for calculating rates, since there is a stronger statistical correlation between accidents and departures than there is between accidents and flight hours, or between accidents and the number of airplanes in service, or between accidents and passenger miles or freight miles (Boeing 2009).

Accident rates reported from 1959 through 2008 are reported for different aircraft types with a maximum of 5.91 accidents per million flights worldwide (excluding the aircraft type no longer in service). Of these, 43% of the accidents have occurred during takeoff and climb, 16% during cruise and 41% during descent, approach and landing. The accident rates can therefore be simplified as 2.54×10^{-6} per takeoff, 9.5×10^{-7} for en route phase and 2.42×10^{-6} per landing. These are extremely low accident frequencies.

4.2.4 Conditional Probabilities

4.2.4.1 Accident Severity

Head-on collision accidents occurring during transportation by trucks are classified as being in one of three severity classes: minor, moderate or severe (Holmes and Naver 1974). Table 4.3 shows this classification. Minor accidents include those collisions and non-collisions at low speed and short duration of fire and other accidents with short fires. Moderate accidents included combinations of speed and fire of intermediate intensity. Severe accidents include combinations of speed and fire of large intensity. All roll-over accidents are considered moderate to severe.

Given the maximum allowable speed for the haul trucks on all-weather roads is 80 km/hr (~50 mph) on the road, no head-on collision accidents falling into the severe category are expected and this category can be excluded from further analysis. Of the remainder, only statistics related to travel at 30 to 50 mph are relevant, given the expected speed for the trucks. Based on statistics for 30 to 50 mph accidents, the fraction of minor and moderate accidents expected on the road are estimated to be 0.984 (0.479/[0.479+0.008]) and 0.016 respectively. On the winter road, all potential accidents will be of minor severity, unless the accident results in ice break and sinking the truck and subsequent release of chemical into water.

Table 4.3 Accident Severity Classes for Transportation via Trucks

Severity	Speed	Fire	Fraction of Accidents [a]
Minor	0 - 30 mph	0 - < 1/2 hr	0.229
	30 - 50 mph	0	0.479
	Other	0 - < 1/2 hr	0.104
TOTAL			0.812
Moderate	0 - 30 mph	1/2 - 1 hr	
	30 - 50 mph	< 1/2 hr	0.008
	50 - 70 mph	0 - < 1/2 hr	0.175
	Other	1/2 - 1 hr	
TOTAL			0.183
Severe	0 – 30 mph	> 1 hr	
	30 - 50 mph	1/2 - 1 hr	
	50 - 70 mph	1/2 - 1 hr	
	> 70 mph	0 - > 1 hr	0.005
	Other	> 1 hr	
TOTAL			0.005

a) Fractions less than 0.001 are not entered in the table

4.2.4.2 Containment Failure

The drums used for transportation of yellowcake are subject to strict regulations governing the transport of radioactive substances developed by the Canadian Nuclear Safety Commission (CNSC) and Transport Canada. These regulations are based on the regulations published by the IAEA in the *Regulations for the Safe Transport of Radioactive Material*, which sets the standards for the international community. The transportation of yellowcake by road in Canada, must comply with the *Transport of Dangerous Goods Regulations* and the *Packaging and Transport of Nuclear Substances Regulations*. These contain all the regulations issued by the government of Canada to ensure that dangerous goods are transported in such a way as to ensure the safety of people, goods and the environment. An aircraft accident is assumed to result in breach of all drums of yellowcake in the container on board.

4.2.4.3 Ice Breakage

If the winter road is used properly during the freezing season, transportation via trucks will not have any impact on the water bodies along the route. The probability of ice breakage, for example due to improper use (exceeding permitted truck weight, speed limit, travel outside the freezing period, etc.), and drowning of containers in water, is considered very low. In the Northwest Territories, since 1989, which is as far back as the collision database goes; there was only one collision that occurred on a winter road where a vehicle broke through the ice. This occurred in January 2000 on the Highway #3 Ice Crossing near Fort Providence when a Super B train full of fuel broke through the ice. All of the fuel was recovered (NWT DOT 2010b). Assuming a total of 2 truck accidents on ice roads per year (NWT DOT 2010a) for the period of 1989 to 2010, the probability of ice breakage on this road will be estimated at 1 breakage/(2 accidents/year x 21 years) or 0.024.

4.2.4.4 Fire and Explosion

Fire and explosion incidents during transportation of hazardous material in the US are recorded for each hazardous material class by the U.S. Department of Transportation Pipeline and Hazardous Material Safety Administration Office of Hazardous Materials Safety (OHMS 2010). Annual quantity of hazardous materials transported within the U.S are available from the U.S. Census for the years 2002 and 2007 (U.S. Census 2010).

These two datasets were used to estimate fire and explosion incident rates for transportation of explosives (e.g. ammonium nitrate), flammable liquids (diesel, kerosene, etc.), flammable solids (e.g. sulphur), oxidizers (e.g. hydrogen peroxide) and toxic materials (e.g. solvents).

Table 4.4 shows the quantity of hazardous materials transported in the U.S. via trucks in 2007. It also shows the number of fire and explosion incidents reported in 2007 for transportation of these materials via trucks. Incident rates estimated based on these values are also provided.

Table 4.4 Estimated Fire and Explosion Incident Rates

Hazardous Class	Transported in 2007 by truck (Million Ton.Miles)	No. of Incidents in 2007		Incident per Million Ton.Miles	
		Fire	Explosion	Fire	Explosion
Class 1- Explosives	858	0	0	0.001 [a]	0.001 [a]
Class 3- Flammable liquids	55,934	31	15	0.001	0.0003
Class 4- Flammable solids	1,301	1	0	0.001	0.0002 [b]
Class 5- Oxidizers	2,200	2	2	0.001	0.001
Class 6- Toxic materials	849	1	0	0.001	0.0005

a) based on nine fire and seven explosions reported over 10 years
b) based on two explosions reported over 10 years

4.3 Estimated Frequency of Release, Fire and Explosion

4.3.1 Yellowcake Transportation

4.3.1.1 Release Frequency on Roads

The frequency of rollover and truck crashes along different road options for the yellowcake was estimated using the following set of calculations:

$$\text{Transport Rate} = \text{Number of trucks} \times \text{Length of route} \times \text{Truck load}$$

Assuming, 343 trucks per year of yellowcake (14 tonnes/truck) over 10 km of road is:

$$\text{Transport Rate} = 343 \times 10 \times 14 = 48,020 \text{ tonne} - \frac{\text{km}}{\text{yr}}$$

The frequency of rollover and crash is estimated as follows based on the selected statistics:

$$F_{rollover} = 4.4 \times 10^{-4} \times 48,\frac{020}{1000000} = 2.1 \times 10^{-5} \text{ per year}$$

$$F_{crash} = 5.3 \times 10^{-4} \times 48,\frac{020}{1000000} = 2.6 \times 10^{-5} \text{ per year}$$

The frequencies estimated are considered very conservative as the traffic volume on these roads will be very low.

The overall frequency of a release from a trucks head-on collision (or crash) and roll-over on land were estimated using estimated accident frequencies (Table 4.5) and conditional probabilities. Conditional probability of containment failure as a result of a truck accident was considered 0.2 for minor and 0.5 for moderate accidents.

There will be no water crossing on this road.

4.3.1.2 Release Frequency of Aircraft Crash

Aircraft crash frequencies were estimated based on the number of flight operations, and the frequency that an aircraft will crash (see section 4.2.3). The frequencies for accidents during transportation of yellowcake to the Points North airport are shown in Table 4.5.

Table 4.5 Estimated Crash Frequencies (per year) for Air Transportation of Yellowcake

Airports and Route	No. of Flights	Takeoff	In-flight	Landing
Pointer Lake- Points North	343	8.7E-04	3.2E-04	8.3E-04

The consequence analysis for airplane crash will consider the probability that a plane might crash in a remote area where it may take some time before emergency response crew reaches the crash site. During this period, the released yellowcake may be exposed on land, and a heavy storm may wash away the exposed yellowcake. In addition, terrestrial receptors can be exposed to yellowcake.

Crash on water will have more substantial consequences. The Pointer Lake and the Points North airports are close to water bodies of various sizes**Error! Reference source not found.**). Therefore, an accident during takeoff or landing may result in an aircraft crashing into water. In addition, an in-flight accident may result in a crash into water. The frequency of crash into water was estimated based on the area covered with water in the landing/takeoff or flight corridor.

In Pointer Lake airstrip, the proposed runway is parallel to Pointer Lake for about half of the runway length. Therefore, a conditional probability of 0.5 is considered for a crash into water. In Points North airport, the planes takeoff from and land towards the direction of a lake (200 ha in area). A conservative conditional probability of 0.5 was considered for crash into water during landing/takeoff in Points North airport. The width of the flight corridor was considered twice the wingspan plus the skid distance. Based on U.S. DOE (2006), representative wingspan for commercial air carriers is 98 ft (30 m), and the mean skid distance for commercial aviation is 1440 ft (439 m). The width of the flight corridor was therefore estimated at about 1 km.

The estimated frequencies for crash of aircrafts into water are shown in see Table 4.6.

Table 4.6 Estimated Frequencies of Crash into Water for Air Transportation of Yellowcake

Airports and Route	Flight Corridor Area (km^2)		Accident Frequency (/year)		
	Total	Water	Takeoff	In-flight	Landing
Pointer Lake- Points North	764	250	4.4E-04	1.1E-04	4.2E-04

An aircraft accident is assumed to result in breach of all drums of yellowcake in all containers on board.

4.3.2 Transportation of Fuel, Reagents and Supplies

4.3.2.1 Release Frequency on Roads

4.3.2.1.1 On Land

The frequency of rollover and truck crashes along different road options for the fuel and reagents was estimated using the following set of calculations:

$$\text{Transport Rate} = \text{Number of trucks} \times \text{Length of route} \times \text{Truck load}$$

For example, the rate for transport of 1483 trucks per year (35 tonnes per truck) of sulphur over 108 km of road (all weather road to the dock) is:

$$\text{Transport Rate} = 1483 \times 108 \times 35 = 5605740 \text{ tonne} - \frac{\text{km}}{\text{yr}}$$

The frequency of rollover and crash is estimated as follows based on the selected statistics:

$$F_{rollover} = 4.4 \times 10^{-4} \times \frac{5605740}{1000000} = 2.5 \times 10^{-3} \text{ per year}$$

$$F_{crash} = 5.3 \times 10^{-4} \times \frac{5603740}{1000000} = 3.0 \times 10^{-3} \text{ per year}$$

The results for this and other road options are summarized in Table 4.7**Error! Reference source not found.**. The frequencies estimated for crash on the four dedicated road options (Kiggavik to Baker Lake) are considered very conservative as the traffic volume on these roads will be very low.

The overall frequency of a release from a trucks head-on collision (or crash) and roll-over on land were estimated using estimated accident frequencies and conditional probabilities. Conditional probability of container failure was assumed 1 for these containers.

4.3.2.1.2 Near or in Waterbodies

Under most circumstances, a release of reagents and supplies to land, away from a water body, will be easily contained in a localized area. Following initial containment, it will be possible to excavate impacted material and reduce contamination. As such, there will be a localized, transient impact for any releases from trucks exclusively on land.

Releases to water present the potential for longer-range transport of material away from the accident location. This potential is reduced under the conditions when streams and lakes adjacent to the water body are frozen. However, it is conservatively assumed that the energy of impact may be sufficient to break through the ice layer (except for travelling on the ice roads where the ice thickness is significant).

Accident rates therefore need to be adjusted to reflect the portion of the transportation route where there is a risk of release to a water body. **Error! Reference source not found.**To calculate the frequency of an accident involving a loaded truck, the frequency of accidents along the road, is prorated for the exposed length of the road. It should be borne in mind that the frequency estimates do not take into account operational procedures adopted by AREVA to reduce accident rates below normal commercial rates, which will include:

- Radio communications to assist traffic flow;
- Suspension of truck movement on the road during poor weather conditions and wildlife migrations; and
- Controlled speeds with maximum speeds of 80 km/h on gravel road sections.

The overall frequency of a release from a trucks head-on collision and roll-over in water were estimated using estimated accident frequencies and conditional probabilities. Conditional probability of container failure was assumed 1 for these containers. The results are summarized in Table 4.7.

Table 4.7 shows that the frequencies of spill near water (due to roll-over or crash) can be up to 1.6 x 10^{-4} per year for diesel fuel, and 1.5 x 10^{-4} per year for sulphur on the longest routes. The frequencies are more than an order of magnitude lower (with a maximum of 2 x 10^{-5} per year) for other materials as the quantities transported are much lower.

4.3.2.2 Frequency of Fire and Explosion

Frequency of fire and explosion incidents for transportation of hazardous materials was estimated using the incident rates provided in Table 4.4. The results are shown in Table 4.7 for various materials and road options.

Estimated frequencies of fire for various materials on different routes vary between 1 x 10^{-6} to 3.0 x 10^{-6} per year (except on very short routes). Estimated frequencies for explosion vary between 5 x 10^{-7} and 3 x 10^{-6} per year for the most part, with the highest frequencies attributable to hydrogen peroxide.

Table 4.7 Estimated Frequency of Release, Fire and Explosion during Transportation of Fuel and Reagents via Trucks

a) Fuel

	On Land				In or Near Water	
Route	**Rollover**	**Crash**	**Fire**	**Explosion**	**Rollover**	**Crash**
All-weather road to proposed dock	2.4E-03	3.0E-03	1.4E-06	6.6E-07	1.3E-04	1.6E-04
Baker Lake airport to proposed dock	6.2E-04	7.5E-04	3.5E-07	1.7E-07	4.7E-05	5.6E-05
Winter road	2.2E-03	2.7E-03	1.3E-06	6.1E-07	3.2E-05	3.9E-05

e) Hydrogen peroxide

	On Land				In or Near Water	
Route	**Rollover**	**Crash**	**Fire**	**Explosion**	**Rollover**	**Crash**
All-weather road to proposed dock	1.9E-04	2.3E-04	2.8E-06	2.8E-06	1.0E-05	1.2E-05
Baker Lake airport to proposed dock	4.7E-05	5.7E-05	7.2E-07	7.2E-07	3.6E-06	4.3E-06
Winter road	1.7E-04	2.1E-04	2.6E-06	2.6E-06	2.5E-06	3.0E-06

f) Sulphur

	On Land				In or Near Water	
Route	Rollover	Crash	Fire	Explosion	Rollover	Crash
All-weather road to proposed dock	2.3E-03	2.8E-03	1.7E-06	3.3E-07	1.3E-04	1.5E-04
Baker Lake airport to proposed dock	5.9E-04	7.1E-04	1.5E-06	8.5E-08	4.4E-05	5.4E-05
Winter road	2.1E-03	2.6E-03	1.5E-06	3.1E-07	3.1E-05	3.7E-05

g) Ammonium nitrate

	On Land				In or Near Water	
Route	Rollover	Crash	Fire	Explosion	Rollover	Crash
All-weather road to proposed dock	7.8E-04	9.5E-04	1.9E-06	1.6E-06	4.2E-05	5.1E-05
Baker Lake airport to proposed dock	2.0E-04	2.4E-04	4.8E-07	4.1E-07	1.0E-05	1.8E-05
Winter road	7.2E-04	8.7E-04	1.7E-06	1.5E-06	1.0E-05	1.2E-05

h) General Supplies (including gasoline, lubricants, hydraulic fluids, solvents, oil)

	On Land				In or Near Water	
Route	Rollover	Crash	Fire	Explosion	Rollover	Crash
All-weather road to proposed dock	3.4E-05	4.1E-05	1.4E-06	6.6E-07	1.8E-06	2.2E-06
Baker Lake airport to proposed dock	8.6E-06	1.0E-05	3.5E-07	1.7E-07	6.5E-07	7.8E-07
Winter road	3.1E-05	3.8E-05	1.3E-06	6.1E-07	4.5E-07	5.4E-07

4.3.2.3 Frequency of Release during Marine Transport

Frequency of release of fuel (from tanker or fuel bunker) during marine transport was estimated using accident rates provided in section 4.2.2 and the number or ships/barges shown in section 2.2.2. Estimated spill frequencies are provided in Table 4.8.

Table 4.8 Estimated Spill Frequency for Fuel

Spilled Material	In Port	At Sea
Diesel fuel (cargo)	9.5E-03	1.2E-02
Fuel (bunker)	7.0E-03	

4.4 RELEASE QUANTITIES FOR YELLOWCAKE

All aircraft crashes are conservatively assumed to result in release of 100% of the content of all drums on board, i.e. 35 drums or 15,750 kg.

5.0 RECEPTORS AND EXPOSURE CHARACTERISTICS

The assessment of potential consequences of accidents was completed through an exposure assessment, which couples the results of the transport and fate analysis (section 5.2.3) with pathways modelling (section 6.2.2) to estimate exposure levels to ecological species of interest as well as human receptors. This section summarizes the considerations taken into account in the pathways analysis.

5.1 RECEPTOR CHARACTERIZATION

In order to define receptors of interest, environmental media that may be impacted as a result of the Project transportation components were defined based on bounding accident scenarios.

The most severe consequences of a spill of yellowcake or hazardous materials would be realized if an accidental spill occurred into a water body. While numerous lakes and streams exist in the study area, it is not practical to assess the potential effects of a spill on this number of potential receptors. Thus, the current assessment focuses on only the most important water bodies based on size and proximity to communities (i.e., Thelon River and Baker Lake).

As discussed previously, accidents on land involving truck transport were not considered to pose any substantial risk as immediate containment and safe clean-up of any potential spills is expected. Accidents on land involving air transport were considered to pose a substantial risk through soil exposure when occurring in the remote area south of the Kiggavik site en-route to the Points North airport in Saskatchewan.

Receptors of interest or Valued Ecosystem Components (VECs) that are discussed in this document were chosen based on the following considerations: their presence in the impacted areas; their ecological and cultural significance to the area; and, whether they are likely to be impacted by a spill event. The selected aquatic and terrestrial VECs and their habitats are discussed below.

5.1.1 Aquatic Habitat and Species

Various surveys indicate that surface waters in the Project area remain ice-covered for most of the year, with ice thawing in June (smaller lakes) and July (larger lakes). Ice begins forming again by September. The water temperature data indicate that the lakes are typically cold, monomictic lakes during the ice-free season. Monomictic lakes are not thermally stratified and vertical mixing occurs, which is supported by relatively uniform temperature, dissolved oxygen, pH and conductivity measurements. Temperatures within the lakes show little variation with depth during the summer ice-free period.

The results of chemical analyses show that generally, the Project area waters are relatively low in both conductivity and concentrations of most dissolved substances. Low nutrient (phosphorous) concentrations suggest that local lakes are relatively unproductive (i.e., oligotrophic or ultra oligotrophic).

The following aquatic species that occur in the Baker Lake were considered in the impact assessment:

- Aquatic Plants
- Benthic Invertebrates
- Forage Fish
- Predatory Fish

<u>Aquatic Plants:</u> Aquatic plants in most lake ecosystems (e.g., pondweed) constitute the majority of the primary producer biomass. Aquatic plants are consumed by several species of aquatic based animals thereby forming a link between aquatic and terrestrial ecosystems. Besides being an important food resource, aquatic plants provide habitat to aquatic organisms.

<u>Benthic Invertebrates:</u> Due to the association of benthic invertebrates with sediments in aquatic ecosystems, they are at greatest risk in terms of sediment contamination. Benthic invertebrates both live and feed within sediments and therefore may be exposed to constituents through ingestion of sediment bound constituents and also through exposure to interstitial waters within the sediment. In addition, benthic invertebrates may also reside in the water column where exposure to constituents may also occur.

Benthic invertebrates provide a link between aquatic and terrestrial ecosystems. Chironomidae (midge) larvae are usually the most abundant benthic invertebrate taxa present in aquatic ecosystems in the northern climate. Many species feed on decaying organic matter and thereby form an important link between the decomposer level and primary consumers. Furthermore, midge larvae are a main food source for small/juvenile fish and larger omnivorous fish. The adults are capable of flight and are frequently consumed by birds and bats. This life stage provides an important link between aquatic and terrestrial ecosystems in the region.

<u>Fish:</u> Fish species that are likely to be dominant in Baker Lake are lake trout and whitefish while fourhorn sculpin, longnose sucker and Arctic char have also been caught in Baker Lake. Humpback and round whitefish, cisco, slimy and spoonhead sculpin, and lake chub area also common.

Ecological receptors at the secondary consumer level include forage fish, which feed primarily on benthic invertebrates and are an important food source of larger predatory fishes. Tertiary consumers are found at the top end of the aquatic food chain and consist of larger piscivorous (predatory) fish species such as Arctic char and lake trout. These predatory fish consume other fish species. Predatory fish are also an important component of the human food chain.

5.1.2 Terrestrial Habitat and Species

The study area is located in the Keewatin lowland ecoprovince of the Southern Arctic ecozone and occurs within the "Barrenlands" where heath tundra, rock-boulder fields and lakes and ponds dominate the landscape. Since the study area is above the tree line, the tallest vegetation is characterized by dwarf birch and willows. Small ericaceous shrubs, sedges, cottongrasses, lichens, mosses and a few herbaceous species are the most common plant species.

The area lying south of the Kiggavik site along the aviation route to Points North Airport in Saskatchewan falls within the Taiga Shield and Boreal Shield ecozones. The terrain of the Taiga Shield is typically flat or rolling hills with thousands of lakes, ponds, wetlands and other water features, while long eskers and uplands are also common. The northern edge of the ecozone is delineated by the treeline north of which more typical arctic tundra begins. Trees such as spruce, pine, alder, birch, willow, tamarack, fir, aspen, and poplar commonly grow in the Taiga Shield while other plants such as ericaceous shrubs, cottongrass, lichen, mosses, sedges, Labrador tea, water lilies, cattails, and other aquatic plants, berries, juniper, cinqfoil, etc. are also common. Exposed bedrock, endless forests, and rushing rivers characterize the Boreal Shield with coniferous trees typically found in the northern portions of the ecoregion. Other plant types that grow in the Boreal Shield include ericaceous shrubs, mosses, willow, alder, Labrador tea, blueberry, bog rosemary, cottongrass, sedges, berries, shield fern, goldenrod, water lilies and cattails.

The terrestrial species considered in the impact assessment were caribou and arctic ground squirrel. In addition, three semi-aquatic terrestrial species that obtain their food and water primarily from the aquatic environment were also considered in the assessment: sandpiper, merganser and tundra swan.

<u>Sandpiper:</u> Sandpipers are small shorebirds that feed on small invertebrates. Least, Baird's and pectoral sandpipers have been observed in the study area. Of these, least sandpiper is considered "Sensitive" in Nunavut.

<u>Tundra Swan and Merganser:</u> Waterfowl (e.g., ducks, geese, swans) are often the most exposed ecological receptors, since their diet is almost entirely obtained from the aquatic environment.

The waterfowl diet includes aquatic vegetation, fish, and aquatic (benthic) invertebrates. The tundra swan, which primarily consumes aquatic plants, has been observed in the study area.

<u>Caribou:</u> Barren-ground caribou is one of the most important wildlife species, both biologically and culturally, in the Baker Lake area. Caribou have traditionally been the primary food source for Inuit in the region since other Inuit foods (such as seals, walrus, whales and geese) are relatively scarce or rare in the Baker Lake area. Caribou from at least five herds, Beverly, Ahiak, Qamanirjuaq, Wager Bay and Lorillard, may occur within the study area at various times of the year.

Caribou are herbivores and are thus mainly exposed to contaminants via atmospheric deposition on terrestrial vegetation. Herbivores convert vegetable matter to animal protein, and in turn are consumed by omnivores and carnivores.

<u>Arctic Ground Squirrel:</u> Arctic ground squirrel is a small mammal that has been observed in the study area. These squirrels typically consume browse and herbaceous vegetation and play a significant role in food chain effects since they are part of the diet of larger predatory species. As herbivores, they are mainly exposed to contaminants via atmospheric deposition on terrestrial vegetation.

Characteristics of terrestrial receptors (including semi-aquatic receptors) used in the pathways analysis are provided in Table 5.1. As seen from the table, the only pathway of exposure considered for Caribou 1 was water ingestion as the fraction of all food sources were set to zero. The only pathway of exposure considered for Caribou 2 and arctic ground squirrel was soil consumption. In each case, the food consumption rate was adjusted to reflect the fraction of the food diet that corresponds to soil consumption while the water ingestion rate was set to zero. Exposure to these species was considered to be short-term (10 days) and it was assumed that during this time only contaminated water or soil would be consumed (i.e., fraction of time = 1). The exposure to semi-aquatic species (i.e., sandpiper, merganser, and tundra swan) was considered to be long-term due to the on-going consumption of contaminated sediments, and the fraction of time spent in an impacted area was assumed to be one-third of the year (i.e., fraction of time = 0.33). As a conservative assessment, no sediment remediation was considered.

Table 5.1 Terrestrial Ecological Receptor Characteristics

Receptor	Body Weight (kg)	Fraction of time at site	Food consumption (kg ww/d)	Water (L/d)	Fraction of Food: Sediment	Fraction of Food: Soil	Fraction of Food: Aquatic plants	Fraction of Food: Benthic invertebrates	Fraction of Food: Fish	Fraction of Food: Other
Sandpiper	0.03	0.33	0.03	0.01	0.04	-	-	0.96	-	-
Tundra Swan	7	0.33	1.0	0.22	0.01	-	0.75	0.24	-	-
Merganser	1.47	0.33	0.37	0.08	0.004	-	-	-	0.996	-
Caribou 1	135	1	6.5	8	-	0	-	-	-	0
Caribou 2	135	1	0.2	0	-	1	-	-	-	0
Arctic Ground Squirrel	0.8	1	0.003	0	-	1	-	-	-	0

Source: SENES (2008); Food consumption and water ingestion characteristics of Caribou 1, Caribou 2 and arctic ground squirrel were modified for the current assessment.

5.1.3 Human Receptors

Human receptors may be impacted by routine operations or accidental releases. During routine transportation of yellowcake to and from Kiggavik, operators of transport vehicles and people residing in close proximity to the storage area were selected as human receptors.

The potential effects of a yellowcake spill into Baker Lake were assessed on individuals who may obtain drinking water from Baker Lake (i.e., Baker Lake community). As no long-term exposure to contaminated soil is accessible for caribou (immediate soil clean up), meat consumption was not considered as an exposure pathway.

5.2 EXPOSURE CHARACTERIZATION

The estimation of exposure of VECs to potentially hazardous constituents involves the identification of constituents of potential concern (COPC) and exposure pathways and the prediction of exposure conditions. These factors are discussed below.

5.2.1 Constituents of Potential Concern (COPC)

Exposure to radionuclides was assessed for radionuclides present in yellowcake. These include U-238, Th-234, Pa-234, Pa-234m, U-234, U-235 and Th-231. Some of these radionuclides are progenies of others, and depending on the dose coefficients used, they may be included in the assessment implicitly.

Chemical toxicity was assessed quantitatively for exposure to uranium in the spilled yellowcake. Assessment of exposure to other chemicals (including hydrocarbons in the fuel, amine, isodecanol, hydrogen peroxide, ammonium nitrate and sulphur) was completed qualitatively.

5.2.2 Exposure Pathways

5.2.2.1 Ecological Receptors

Ecologically, exposure to COPC occurs through both direct and indirect pathways. Aquatic organisms for example receive direct exposure as a result of changes in COPC concentrations in the water and/or sediments. Indirect exposure occurs via consumption of water, sediment, aquatic plants and/or aquatic biota that have been affected by releases of COPC to the environment in treated effluent discharges, contaminated runoff or groundwater or as a result of accidental spills. Thus, different patterns of exposure and differential sensitivity to COPC by organisms in complex food webs can result in ecological impacts that cannot be estimated accurately from considerations of direct effects alone.

Estimates of exposure can be provided by direct measurement or estimated using environmental transport models of varying complexity (e.g., Bartell et al. 1981, 1983; Burns et al. 1982; Mackay 1991). In this assessment, estimates of potential exposure in water and sediment were obtained from a pathways analysis which traced the movement of yellowcake through the surface water environment of Baker Lake. Exposures were predicted considering both background levels of the COPC in the environment (i.e., background levels in water and sediments) and the source contributions of the COPC at the receptor locations.

In the case where yellowcake is released to a water body, dispersion through water and sediment will occur. As a result, aquatic species (benthic invertebrate, aquatic plants, fish) will be directly exposed to uranium and radioactivity in the water column and/or sediment. Exposure to semi-aquatic species (merganser, sandpiper and tundra swan) will occur through the ingestion of water and consumption of sediment as well as aquatic species and to caribou through the ingestion of water. In the case where yellowcake is released to land, caribou and arctic ground squirrel may be exposed through the incidental ingestion of soil prior to the implementation of any clean-up procedures or remedial actions.

Figure 5-1 provides a schematic of exposure pathways for semi-aquatic species. Table 5.2 provides a summary of the exposure assumptions that were made for each ecological species included in the assessment. As seen from the table, it was assumed that exposure resulting from contaminated water would be of a short-term duration as high contaminant concentrations in water resulting from a spill would be diluted quickly. On the other hand, exposure resulting from contaminated sediment was assumed to be of a long-term duration as residual yellowcake will persist in sediment for a long period of time. Semi-aquatic species were assumed to spend four months of the year (33%) in the area and to migrate south in the winter (SENES 2008). All other species were assumed to remain in the contaminated area for their respective duration of exposure (100%). With respect to caribou and arctic ground squirrel it was assumed that 1% of the uranium contained in yellowcake ingested through soil was bioavailable. This conservative fraction was chosen based on the 0.2% fraction recommended for slow processes involving uranium by the International Commission on Radiological Protection (ICRP 1994) and the low solubility of yellowcake in water (<1%).

Figure 5-1 Exposure Pathways for Semi-Aquatic Species

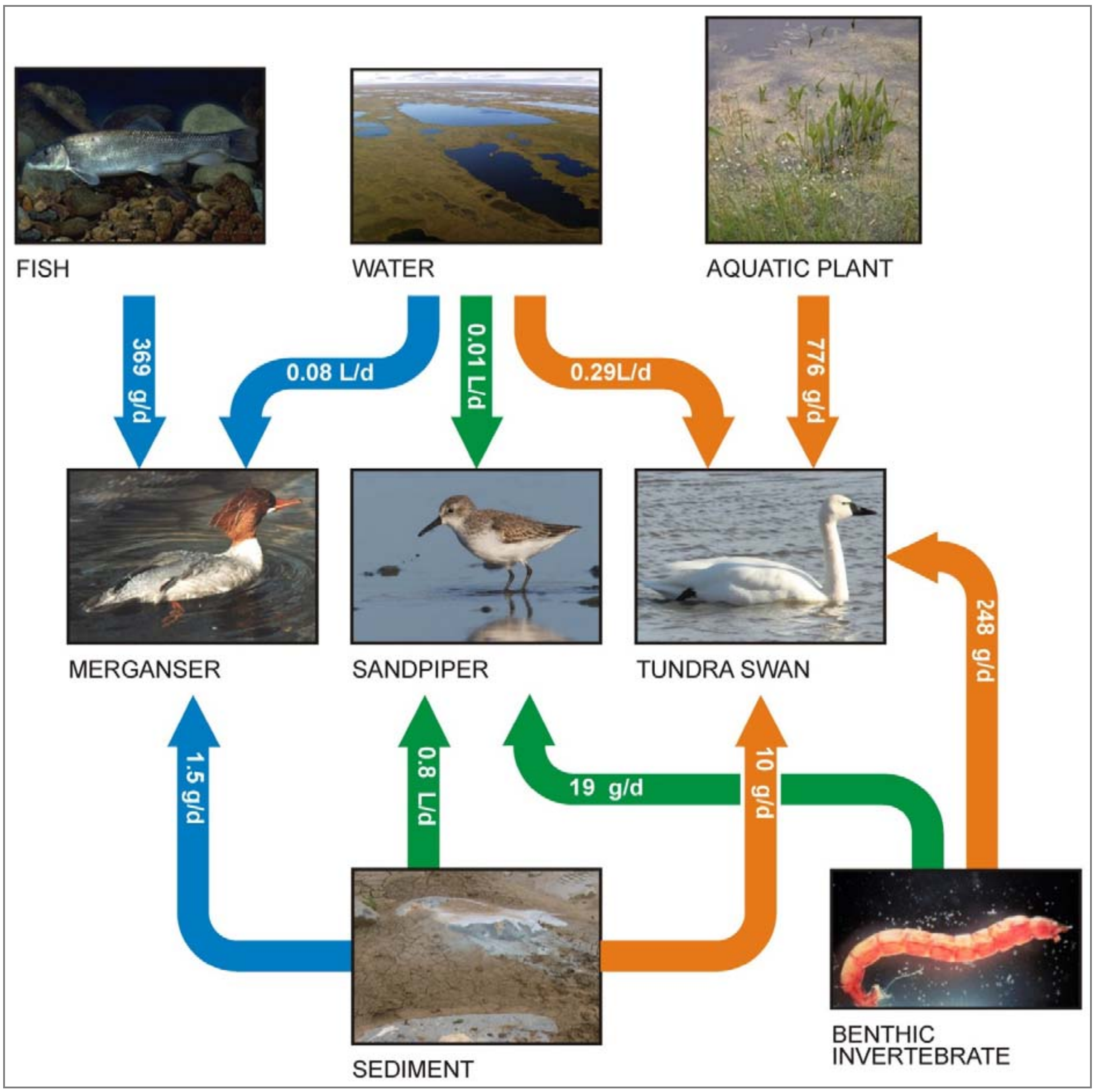


Table 5.2 Exposure Assumptions

Species	Uranium Exposure			Radiological Exposure			
	Pathway	Exposure Duration	Fraction of Time Exposed	Internal Pathway	External Pathway	Exposure Duration	Fraction of Time Exposed
Aquatic Plants	Exposure to water	Short-term	100%	Uptake from water	Leaves: exposed to water Roots: exposed to sediment	Long-term	100%
Benthic Invertebrates	Exposure to water and sediment	Long-term	100%	Uptake from water	Exposure to sediment	Long-term	100%
Forage Fish	Exposure to water	Short-term	100%	Uptake from water	Exposure to water and sediment	Long-term	100%
Predatory Fish	Exposure to water	Short-term	100%	Uptake from water	Exposure to water	Short-term	100%
Merganser	Uptake from water, fish and sediments	Long-term	33%	Uptake from water, fish and sediments	-	Long-term	33%
Sandpiper	Uptake from water, benthic invertebrates and sediments	Long-term	33%	Uptake from water, benthic invertebrates and sediments	-	Long-term	33%
Tundra Swan	Uptake from water, aquatic plants, benthic invertebrates and sediments	Long-term	33%	Uptake from water, aquatic plants, benthic invertebrates and sediments	-	Long-term	33%
Caribou 1	Uptake from water only	Short-term (10 days)	100%	Uptake from water only	-	Short-term (10 days)	100%
Caribou 2	Uptake from soil only (1% U bioaccessibility)	Short-term (10 days)	100%	Uptake from soil only	-	Short-term (10 days)	100%
Arctic Ground Squirrel	Uptake form soil only (1% U bioaccessibility)	Short-term (10 days)	100%	Uptake from soil only	-	Short-term (10 days)	100%

5.2.2.2 Human Receptors

During routine transportation of yellowcake to and from Kiggavik, operators of transport vehicles and people residing in close proximity to the storage areas may be exposed to external radiation. The exposure durations will depend on the travel/handling time (see Section 6.1.1 for details).

The potential effects of a yellowcake spill into Baker Lake were assessed on individuals who may obtain their drinking water from Baker Lake (i.e., Baker Lake community). As such, the assessment focused on a toddler, a child and an adult resident of Baker Lake that are exposed to uranium and radionuclides in drinking water. The exposure duration was conservatively assumed to be one week as residents would quickly be warned to stop drinking water from Baker Lake in the case of a spill. Due to the short-term and transient nature of a yellowcake spill in water, accumulation of COPC in fish tissue would be limited; hence, fish ingestion by human receptors was not considered in the exposure assessment.

5.2.3 Transport and Fate Analysis

This section defines the uranium concentrations that will be available for exposure of terrestrial and aquatic receptors as a result of yellowcake spill on land or water.

5.2.3.1 Release to Lakes

5.2.3.1.1 Small Lake

Release of uranium or other materials to a small lake is considered to deteriorate water and sediment quality of the lake to the extent that the water body loses its value as a habitat and will need remediation. Access of wildlife to the lake will be restricted if an accident occurs until a time when the water and sediment have been properly remediated.

Assuming that dilution is the dominant dispersion and transport mechanism in small lakes, the size of water bodies delineating a “small lake” was estimated as follows:

For a yellowcake solubility of 1%, release of one container of yellowcake (about 15.6 tonnes of yellowcake or 13.4 tonnes of uranium) will cause the uranium concentration to exceed the water quality guidelines of 15 µg/L (SENV 2006), in a 8.9 million m^3 lake. The yellowcake dispersing in 5 cm of sediment in a 340 ha lake exceeds the sediment quality guideline of 104.4 µg/g (Thompson et al. 2005). These lake sizes were estimated as follows:

$$Lake\ volume = \frac{13400\ kg\ uranium \times 0.01\ soluble}{15\frac{\mu g}{L}} \times 10^6 \left(\frac{\mu g}{kg} \times \frac{m^3}{L}\right) = 8.9\ \times\ 10^6\ m^3$$

and

$$Lake\ Area = \frac{13400\ kg\ uranium \times 0.99\ insoluble}{104.4\frac{\mu g}{g} \times 10^{-6}\frac{g}{\mu g} \times \left[0.05\ m\ deep\ \times 2500\frac{kg}{m^3}\ dense \times (1 - 0.7\ void)\right]} = 3.4\ \times\ 10^6\ m^2 = 340\ ha$$

The above estimates indicates that a release into a lake smaller than the above sizes will cause the water quality guidelines to be exceeded.

5.2.3.1.2 Large Lake

There are a number of large lakes close to the air traffic route between Kiggavik site and Point North. Among these lakes, Baker Lake was selected for further analysis as it is used by both ecological and human receptors. Potential impacts from release of yellowcake in the Chesterfield Inlet or the port of Churchill will be bound by impacts caused by release in Baker Lake as the latter is a smaller water body.

A spill of yellowcake to a large lake (Baker Lake) may have transient and long-term implications. During a relatively short period of time, the quality of water in the near-field area of spill may be impacted in a way that makes it unsuitable for drinking or supporting aquatic life. In the long term, the released material needs to be cleaned-up and the area remediated.

Concentration of uranium in a large lake was estimated for release of one or six containers of yellowcake on the shores (half of which is partially and half is completely compromised). Input data and assumptions used in calculations, as well as the results are provided here.

The lake currents velocity was estimated using monthly flows and water level in Baker Lake. Monthly flows were estimated using values available for the Thelon River (Table 5.3) adjusted for additional drainage area between the monitoring station on the river and the Baker Lake dock location. The drainage area up to the monitoring station is 152,000 km^2 (Environment Canada 2006) and the additional drainage area was estimated at about 3000 km^2. Mean water level in Baker Lake dock area was considered at five meters (which is one of the criteria for site selection for the dock).

Table 5.3 Monthly Discharge Rate and Water Level for Thelon River below the Outlet of Schultz Lake, 1983-2005

Month	Monthly Discharge (m^3/s)			Water Level (m)		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**
Jan	276	454	619	24.07	24.31	24.63
Feb	228	397	536	24.03	24.24	24.57
Mar	226	371	529	23.94	24.17	24.54
Apr	232	385	543	24.00	24.16	24.43
May	238	414	546	24.04	24.18	24.33
Jun	914	1910	3470	24.74	25.66	26.99
Jul	1480	2440	3440	25.88	26.22	26.46
Aug	829	1350	1820	25.01	25.25	25.61
Sep	729	1140	1610	24.61	25.04	25.56
Oct	591	1000	1440	24.43	24.87	25.39
Nov	522	678	982	24.35	24.55	24.91
Dec	386	530	850	24.15	24.36	24.76
Mean Annual	671	926	1200	23.94	24.75	26.99

The Lake's width in the vicinity of the dock was measured on existing maps at about 4000 m, resulting in a cross sectional area of 20,000 m^2, and a current velocity of 0.09 m/s.

Stokes' settling velocity was estimated at 46 m/d for the 13.2 µm particles. For a lake depth of five meters, the time for a particle to settle is calculated at about 2.6 hours, during which the particle has been transported about 820 meters downstream assuming a flow rate of 0.09 m/s. The larger particles would travel about 300 meters downstream under these conditions.

This calculation was repeated for low flow and high flow conditions and the results are provided in Table 5.4. Under high flow conditions, the maximum estimated distance for the deposition of particulates is approximately 1.2 km from the spill site in the Baker Lake.

Table 5.4 Estimated Travel Distances for Yellowcake Particulates in Baker Lake

Parameter	Fine particles			Coarse particles		
	Min flow	**Avg flow**	**Max flow**	**Min flow**	**Avg flow**	**Max flow**
Water depth (m)	5.0	5.0	5.0	5.0	5.0	5.0
Time to settle (hrs)	2.6	2.6	2.6	1.0	1.0	1.0
Travel distance before settling (m)	472	816	1234	190	328	496

The sediment quality assumptions and results are shown in Table 5.5. The results presented in the table are a summary of the three flow conditions for fine and coarse particles released. The maximum predicted uranium concentrations in the lake sediments occurred under low flow conditions for the coarser particles released to water. In the consequence assessment, area-weighted averages of fine and coarse particle concentrations for the average flow conditions were used. Table 5.6 shows the estimated pore water quality. The results for water column are shown in Table 5.7.

Table 5.5 Estimated Uranium Concentration in Sediment following Yellowcake Containers Spill in Baker Lake

Parameter	Fine particles			Coarse particles		
	Min flow	Avg flow	Max flow	Min flow	Avg flow	Max flow
Volume of impacted sediment (m^3)	4.7E+04	8.2E+04	1.2E+05	1.9E+04	3.3E+04	5.0E+04
Released yellowcake quantity (kg) [a]	15,750	15,750	15,750	15,750	15,750	15,750
Released yellowcake volume (m^3)	7.6	7.6	7.6	7.6	7.6	7.6
Fraction of impacted sediment which is yellowcake	5.3E-04	3.1E-04	2.0E-04	1.3E-03	7.8E-04	5.1E-04
Uranium concentration in sediment after the spill (µg/g)	456	264	175	1132	655	433

Note:
a) 50% of the material is fine and the rest consists of coarse particles

Table 5.6 Estimated Average Uranium Concentration in Porewater following a Yellowcake Container Spill in Baker Lake (µg/L)

Min flow	Avg flow	Max flow
2.64	1.5	1.02

Table 5.7 Estimated Uranium Concentration in Water following a Yellowcake Container Spill in Baker Lake

Parameter	Min flow	Avg flow	Max flow
Uranium release rate (g/s)	47.64		
Lake flow rate (m^3/s)	1008	1744	2636
Percent water impacted	5%	10%	25%
Water concentration (mg/L)	8.04	2.34	0.6

Water and sediment concentrations of uranium **estimated** for release of one container of yellowcake into a large lake were used as input to the pathways analysis presented in Section 0.

5.2.3.2 Release on Land

The bounding scenario for release of yellowcake on land and subsequent exposure of terrestrial wildlife (e.g. Caribou) is defined as a scenario in which an aircraft carrying yellowcake crashes in a remote area. As a result of such a crash, the entire content of a container is assumed to disperse in the effective area. The effective area represents the ground surface area that if an unobstructed aircraft were to crash within the area, it would impact the features in the area, either by direct fly-in or skid into the features. Based on the U.S. DOE (2006), representative wingspan for commercial air carriers is 98 ft (30 m), and the mean skid distance for commercial aviation is 1440 ft (439 m). The width of the effective area was considered twice the wingspan plus the skid distance (about 1 km). Therefore, it was assumed that the yellowcake will be dispersed on are area of 1 x 1 km^2.

Over this area, there will be hot spots of uranium concentrations, as well as areas with lower concentrations. For the purpose of this assessment, it was assumed that yellowcake is dispersed homogenously over the entire area, in a five centimetre layer, i.e., 15750 kg of yellowcake (35 drums of 450 kg) will be dispersed in 50,000 m^3 of soil. For a uranium content of 85% and a typical soil density of 1500 kg/m^3, the soil concentration of uranium in the area is estimated at about 180 mg/kg of soil.

Caribou was assumed to be exposed to uranium in soil after the aircraft crash up until the remediation activities start. This period was assumed to be one week. Soil concentration of uranium estimated for release of one container of yellowcake on land was used as input to the pathways analysis presented in Section 0.

Before the remediation efforts begin, the area will be quarantined and access of wildlife to the exposed yellowcake will be eliminated. The impacts will therefore be of a near-field and short-term nature.

5.3 HAZARD ASSESSMENT (TOXICITY REFERENCE VALUES)

Due to the difficulty in measuring direct effects on populations of ecological species, “measurement endpoints” are adopted to provide a framework for the evaluation of predicted effects. A measurement endpoint is defined as “…a quantitative summary of the results of a toxicity test, a biological study, or other activity intended to reveal the effects of a substance” (Suter 1993). In lieu of direct assessment endpoint effects measures, the adoption of measurement endpoints provides a consistent basis for the evaluation of potential effects due to exposure to constituents.

Measurement endpoints are commonly selected at the individual level of biological organization, and are typically based on exposure responses that are meant to act as a proxy for population and community characteristics such as reproduction and abundance (Environment Canada 1997). Such measurement endpoints are commonly based on literature-derived toxicity dose-response relationships, examined through laboratory experimentation (i.e., the response of a particular organism to a certain level of exposure). When derived from toxicity studies, such measurement endpoints are often referred to as toxicity benchmarks or toxicity reference values (TRVs).

For the assessment of potential effects on ecological species, the TRVs are used in risk assessments to judge whether the predicted (estimated) exposures (or doses or intakes) may potentially have an adverse effect on the species. A discussion of selected literature and the associated TRVs consulted in this assessment is provided in the following sections.

For the assessment of potential effects on human health, the exposure assessment compared predicted uranium levels in the impacted water downstream of a spill site to drinking water quality guidelines, which are based on the protection of even the most sensitive individuals against adverse effects from continuous exposure. Radiation doses were compared to CNSC and Health Canada dose limits.

5.3.1 Radioactivity

For the ecological risk assessment component, the assessment of effects from exposure to radioactive constituents involved estimation of the combined (total) dose that a VEC may receive from radionuclides taken into the body as well as from exposure to radiation fields in the external environment. In addition, it is standard practice to take into account differences in the effects of alpha, beta and gamma radiation. These factors are discussed below.

5.3.1.1 Relative Biological Effectiveness (RBE)

Radiation effects on biota depend not only on the absorbed dose, but also on the relative biological effectiveness (RBE) of the particular radiation (i.e., alpha, beta or gamma radiation). For example, alpha particles can produce observable damage at lower absorbed doses than gamma radiation. Thus, in order to estimate the potential harm to non-human biota from a given absorbed dose, the absorbed dose is multiplied by an appropriate radiation weighting factor. This in turn is derived from an experimentally determined RBE. In this assessment, the terms “RBE” and “radiation weighting factor” are used interchangeably.

For the purposes of human radiological protection, each component of the absorbed dose to a tissue or organ is weighted according to the radiation quality. The appropriate relative biological effectiveness (RBE) value for biota is the subject of on-going scientific discussion. Although an

RBE of 20 is used for human radiation protection, according to the review by UNSCEAR (1996):

> *"In the case of wild organisms, however, it is likely to be deterministic effects that are of greatest significance, and for alpha radiation the experimental data for animals indicate that a lower weighting factor, perhaps 5, would be more appropriate; the weighting factors for beta and gamma radiation would remain unity." (para. 18)*

A review of the literature by Trivedi and Gentner (2000) concluded that:

> *"since the majority of studies report RBE values less than or equal to 10 for endpoints, and doses and dose rates that are more ecologically significant, a value of 10 might be appropriate for weighting doses to evaluate the impact of alpha emitters at the population level, if any".*

Also, the U.S. DOE (2000) reviewed the issue and recognized that the critical biological endpoint of concern in radiation exposures of biota appears to be deterministic, and that the radiation weighting factor for deterministic effects is substantially less than the corresponding average quality factor used in radiation protection of humans (i.e., 20). Based on this information, U.S. DOE concluded that the radiation weighting factor for deterministic effects appears to lie in the range of about 5 to 10. However, as interim guidance, they recommend the use of an RBE of 20 in the proposed standard (U.S. DOE 2000).

It should be noted that uncertainty remains concerning the most appropriate RBE values for assessing risks to non-human biota. The RBE values depend on the radiation quality, the biota under consideration, the endpoint being considered and the reference photon energies. The RBE values selected to develop protection criteria should correspond to the endpoint being protected (e.g., health of a population).

A wide range of RBE values for internally deposited alpha particles has been published. The PSL2 assessment (EC/HC 2003) suggests an RBE of 40. A report of the (former) Advisory Committee on Radiological Protection (ACRP 2002) suggested a nominal RBE value of 10 with a range of about 5 to 20 for non-human biota (ACRP 2002). A recent report of the European Community suggests using an RBE of 10 to illustrate the effect of alpha RBE. For the purposes of this assessment, uncertainty associated with the choices of RBE is acknowledged and a range of RBE values of 10 and 40 were used to illustrate the effects of this uncertainty.

5.3.1.2 Aquatic Radiation Benchmarks

For radioactivity, the International Atomic Energy Agency suggests a dose rate of 10 mGy/d as the reference dose level below which population effects to aquatic biota would not be expected (IAEA 1992). This value is also suggested in UNSCEAR (1996). The following paragraphs outline the rationale for using 10 mGy/d and indicate that there is ongoing debate on the appropriate dose rate limit.

The NCRP (National Council on Radiation Protection and Measurements) in Report 109 (U.S. NCRP 1991) recommends 0.4 mGy/h (9.6 mGy/d) for the protection of aquatic biota. The NCRP states that a chronic dose rate of no more than 0.4 mGy/h (9.6 mGy/d) to the maximally exposed individual in a population would ensure protection of the population. The NCRP report also includes recommendations that if modelling and/or dosimetric measurements indicate a dose level of 0.1 mGy/h (2.4 mGy/d), then a more detailed evaluation of the potential ecological consequences to the endemic population should be conducted. The 1992 review by the IAEA (Technical Report No. 332) also concluded that limiting the dose rate to individuals in an aquatic population to a maximum of 10 mGy/d would provide adequate protection for the population.

A number of reviews on the effects of radiation on aquatic organisms were published prior to the publication of NCRP 109 (Anderson and Harrison 1966; Polikarpov 1966; Templeton *et al.* 1971; Chipman 1972; IAEA 1976; Blaylock and Trabalka 1978; Egami 1980; NRCC 1983; Woodhead 1984). In those reviews, deleterious effects of chronic irradiation were not observed in natural populations at dose rates of 0.4 mGy/h (9.6 mGy/d) or less, over the entire history of exposure to ionizing radiation. Taking into consideration the combined results from laboratory and field studies, it appears that reproductive and early developmental systems of vertebrates are most sensitive to chronic irradiation in both aquatic and terrestrial environments. Invertebrates appear to be relatively radioresistant. Effects on aquatic organisms, not necessarily detrimental when evaluated in the context of population dynamics, were detected at dose rates in the range of 1 to 10 mGy/d.

The U.S. DOE (2000) concluded that applying the aquatic dose limits suggested by the U.S. NCRP (1991) and IAEA (1992) would ensure protection of aquatic populations. UNSCEAR (1996) suggests that chronic dose rates of up to 400 µGy/h (10 mGy/d) to individuals in aquatic populations are unlikely to have a detrimental effect at the population level.

The CNSC recommends that a dose limit value of 6 mGy/d be applied for benthic invertebrates (Bird *et al.* 2002; EC/HC 2003).

As indicated by the brief reviews of the literature cited above, the selection of reference dose levels for aquatic biota is a topic of ongoing discussion. In light of this, the reference dose levels of 6 mGy/d and 10 mGy/d are proposed for benthic invertebrates.

5.3.1.3 Terrestrial Wildlife Radiation Benchmarks

A level of 1 mGy/d is generally used as an acceptable level for terrestrial biota. In 1992, the IAEA (1992) published the results of an assessment of the effects of acute and chronic radiation on terrestrial populations and communities. They reached several general conclusions regarding chronic radiation: reproduction is likely to be the most limiting endpoint in terms of population maintenance, and irradiation at chronic dose rates of 1 mGy/d or less does not appear likely to cause observable changes in terrestrial animal populations. Also, they concluded that irradiation at chronic dose rates of 10 mGy/d or less does not appear likely to cause observable changes in terrestrial plant populations. However, reproductive effects in long-lived species with low reproductive capacity may require further consideration. The U.S. DOE (2000) has suggested that applying the terrestrial dose limits suggested by IAEA (1992) would be protective of terrestrial species populations. UNSCEAR (1996) suggests that chronic dose rates below 400 µG/h (10 mGy/d) are unlikely to affect mortality in the population and that dose rates below 40 µGy/h (1 mGy/d) are unlikely to cause a loss of reproductive capacity.

The CNSC has provided a dose rate guideline of 3 mGy/d as an appropriate limit for small mammals and terrestrial plants (Bird *et al.* 2002; EC/HC 2003). This limit is based on reproductive endpoints for small mammals. In the absence of data for avian species, the CNSC suggest that the dose limit for small mammals should also apply.

From the above discussion, it is recognized that the selection of reference dose levels is a topic of ongoing debate; therefore, dose limits of 1 mGy/d and 3 mGy/d were selected for the assessment of impacts on terrestrial biota.

5.3.1.4 Human Radiation Benchmark

Assessment of radiation exposures to members of the public is commonly based on estimation of the incremental (above-background) effects of the project or site. Such assessments consider the radiation dose received from direct exposure to gamma radiation as well as the dose received from the inhalation and ingestion of radionuclides.

The human receptor model converts radionuclide intake by the human receptors from the various pathways into a radiation dose. The CNSC radiation dose limit for a non nuclear energy worker (NEW) or a member of public is 1 mSv/yr (1000 µSv/y) over natural background levels. The guideline for a NEW is 100 mSv for five years, i.e., an average of 20 mSv/y (CNSC 2000).

The Canadian guidelines for the management of naturally occurring radioactive materials (NORM) recommend a dose limit of 1 mSv/y (1000 µSv/y) for members of the public and incidentally exposed workers (employees whose regular duties do not include exposure to

NORM sources) as a result of a work practice (Health Canada 2000). For occupationally exposed workers, the dose limit is 20 mSv/y. The guidelines also recommend a "dose constraint" of 0.3 mSv/y (300 μSv/y) to account for the possibility of exposures from other sources without the annual limit being exceeded. When the estimated dose to a member of the public is less than 0.3 mSv/y and to the worker is less than 1 mSv/y, "no further action is needed to control doses or materials" (Health Canada 2000). If the estimated dose exceeds these constraints, then more site-specific dose assessment should be undertaken to assess if the dose constraints will be exceeded.

5.3.2 Non-Radionuclides (Uranium)

For the non-radioactive constituents, toxicity reference values are based on exposure levels in the case of aquatic species and total intakes (or doses) for terrestrial species. It is assumed that the entire amount of each constituent taken into the stomach and/or lungs of a terrestrial species is transferred into the body stream of the species, unless otherwise stipulated. For instance, the bioaccessibility of uranium contained in yellowcake ingested through soil by caribou and arctic ground squirrel was assumed to be 1%. This conservative fraction was chosen based on the 0.2% fraction recommended for slow processes involving uranium by the International Commission on Radiological Protection (ICRP 1994) and the low solubility of yellowcake in water (<1%).

Since the exposure to many species was considered to be short-term as COPC concentrations in water would quickly be diluted and spills on land would quickly be contained or cleaned-up, acute toxicity reference values were used in many instances.

5.3.2.1 Aquatic Toxicity Reference Values

There is little knowledge on the toxicity of uranium to the species indigenous to northern Canada, and on how the toxicity is affected by water hardness. Vizon SciTec Inc. has carried out testing on the toxicity of uranium to six indigenous species in northern Saskatchewan over a range of water hardness values, the results of which are presented in their 2004 report, *Final Report on the Toxicity Investigation of Uranium to Aquatic Organisms* (VST 2004). The Toxicology Centre at the University of Saskatchewan has also presented the results of their uranium toxicity testing study in their 2007 report, *Uranium Toxicity to Regionally-Representative Algae and Invertebrate Species* (Liber et al. 2007). These data were considered appropriate for the Kiggavik area.

In all, 12 organisms were examined in the two studies mentioned above, 10 of which were tested under chronic exposure, 2 of which were tested under acute exposure and 1 of which was tested under both conditions (see Table 5.8). Acute exposure was defined as 72 hours (algae species) or 96 hours (fish species), while chronic exposure varied from 6 to 31 days. Details on the experimental methodologies are provided in the afore-mentioned reports (VST 2004, Liber et al. 2007).

The endpoints that were determined from these studies include:

- LC25/50 – the median lethal concentration of uranium (mg U/L) that is estimated to be lethal to 25 or 50% of the test organisms;
- EC25/50 – the concentration of uranium (mg U/L) at which organisms exhibit a 25 or 50% reduction in a biological response (i.e., embryo viability, reproduction, adults emerged); and/or
- IC25/50 – the concentration of uranium (mg U/L) at which organisms exhibit a 25 or 50% reduction in a biological measurement (i.e., growth, reproduction).

The acute studies from both sources found that *Hyalella azteca* and *Selenastrum capricornutum* were the most sensitive species to uranium exposure under acute conditions. The LC25 value for *Selenastrum capricornutum* resulted in the lowest TRV value of 0.06 mg/L and this value was adjusted to an LC20 value of 0.05 mg/L, which has been selected as the TRV for aquatic plants. For fish, there is an LC50 value for rainbow trout fry (predatory fish) of 3.9 mg/L, which when adjusted by linear extrapolation results in a TRV of 1.6 mg/L. For forage fish, the LC25 is 1.9 mg/L, which results in a TRV of 1.5 mg/L.

There are no acute TRVs for benthic invertebrates thus chronic values were examined. The chronic LC50 for *Hyalella azteca* was 0.03 mg/L, which is used as the acute TRV (VST 2004; Liber et al. 2007).

Table 5.8 Summary of Studied Organisms for Aquatic TRVs

Group	Organism	Common Name	Acute	Chronic
Aquatic Plants	*Selenastrum capricornutum* [1,2, 3]	green algae	✓	
	Cryptomonas erosa [2]	green algae		✓
	Chlamydomonas reinhardtii [2,4]	green algae	✓	
	Lemna Minor [1]	Duckweed		✓
Zooplankton	*Ceriodaphnia dubia* [1,2]	water flea		✓
	Daphnia magna [2]	water flea		✓
	Simocephalus serrulatus [2]	water flea		✓
Benthic Invertebrates	*Hyalella azteca* [1,2]	N/A		✓
	Chironomus tentans [2]	N/A		✓
	Corynoneura spp. [2]	N/A		✓
Fish	*Oncorhynchus mykiss (fry)* [1]	Rainbow Trout	✓	
	Oncorhynchus mykiss (ELS) [1,5]	Rainbow Trout		✓
	Pimephales promelas [1]	Fathead Minnow	✓	✓

Note:
1 - Data from Vizon SciTec Inc. (VST 2004).
2 -Data from Toxicology Centre, University of Saskatchewan (Liber et al. 2007).
3 - Also known as *Pseudokirhneriella subcapitata*
4 - Test endpoints could not be calculated because a reduction in cell growth was not observed at the highest uranium concentration tested. No results are presented for this organism.
5 - ELS is early life stage; rainbow trout embryo/alevin
- No data available; not tested

5.3.2.2 Semi-Aquatic and Terrestrial Species Toxicity Reference Values

The TRVs used for semi-aquatic ecological receptors (sandpiper, tundra swan and merganser) are for chronic exposure since exposure to these species will include sediment-related pathways over a relatively long period of time.

To determine possible effects on semi-aquatic ecological receptors, Lowest Observable Adverse Effect Level (LOAEL) and No Observable Adverse Effect Level (NOAEL) toxicity reference values and Estimated No-Effects Values (ENEVs) from the CNSC were used. NOAELs and ENEVs are generally used for screening level type assessments whereas LOAELs are used to determine potential effects on ecological species in more comprehensive site-specific assessments when more realistic estimates of species exposures have been made (Sample et al., 1996).

In the absence of toxicity data for most of the terrestrial species, data for laboratory animals are generally used. For avian receptors, the test species are generally ducks or chicks. Existing data were collected from the U.S. DOE database by Sample et al. (1996).

Background information for the toxicity reference values developed for the test species are provided in Table 5.9. The information includes test species, study duration and toxicological endpoint for those COPC for which toxicity data are available.

Haseltine and Sileo (1983) conducted a study of black ducks with depleted metallic uranium, and derived a NOAEL of 16 mg U/(kg d) since no effects were observed at any dose level. In the absence of other data, the CNSC mammalian ENEV for uranium (which is based on kidney effects in mice) was also used for avian species.

The selected TRV for caribou and arctic ground squirrel is an acute one since these species will potentially be exposed to the spilled yellowcake (uranium) in water or soil for a short period of time. There are very few acute exposure laboratory studies related to uranium exposure for mammals. Studies by Domingo et al. (1987) in rats and mice obtained LD50 values of 114 and 136 mg U/(kg d). Domingo et al. also looked at reproductive endpoints in mice and derived a LOAEL of 3 mg/(kg d). This LOAEL, which is related to maternal reduced weight gain and food consumption and increased relative liver weight, is close to the chronic NOAEL discussed in the paragraph above and is not considered appropriate for use for the short-term exposure and therefore the LD50 value of 114 mg U/ (kg d) was considered as a basis for deriving a short-term TRV. An uncertainty factor of 10 was used to ensure the protection of individual species and thus a short-term uranium TRV for mammals of 11.4 mg U/(kg /d) is proposed. Table 5.10 summarizes the toxicity reference values used in this study.

Table 5.9 Summary of Toxicity Data from Laboratory Bird Studies for Uranium

Parameter	Description
Source of Reference Values	Sample et al. (1996)
Original Reference	Haseltine and Sileo (1983)
Chemical Species	depleted metallic U
Test Species	black duck
Body Weight (g)	1250
Study Duration	6 wks
Endpoint	mortality, body weight, liver and kidney effects
Comments	The study was less than 10 weeks and only considered to be subchronic.
Logic	No effects observed at highest dose level of 160 mg U. Therefore considered a subchronic NOAEL. 10 for conversion from subchronic to chronic exposure.
NOAEL (mg/kg/d)	16
LOAEL (mg/kg/d)	-

Table 5.10 Toxicity Reference Values for Exposure of Ecological Species to Uranium

Receptor	Guideline	Comment
Aquatic Plants	0.05 mg/L	Acute TRV
Benthic Invertebrates	0.03 mg/L	Chronic TRV (acute TRV was not available in the literature)
Predatory Fish	1.6 mg/L	Acute TRV
Forage Fish	1.5 mg/L	Acute TRV
Sandpiper, Tundra Swan and Merganser	NOAEL: 16 mg/kg.d ENEV: 0.5 mg/kg.d	Chronic TRV (exposure to sediment-related pathways will be long-term)
Caribou and Arctic Ground Squirrel	LOAEL: 11.4 mg/kg.d	Acute TRV

5.3.2.3 Human Receptor Toxicity Reference Values

The uranium Canadian Drinking Water Quality Guideline was used as the benchmark for the assessment of human receptor exposure to uranium. The guideline value for uranium is 20 µg/L (Health Canada 2008).

5.3.3 Sediment Benchmarks

Uranium exposure to benthic invertebrates from sediments was assessed against the toxicity benchmarks from Thompson et al. (2005), which are specific to uranium-bearing regions of Canada (e.g., northern Saskatchewan and northern Ontario) and are considered Canadian Nuclear Safety Commission (CNSC) working reference values. Thompson et al. (2005) used the Screening Level Concentration (SLC) approach to derive Lowest Effect Level (LEL) and Severe Effect Level (SEL) concentrations for nine metals and metalloids (arsenic, chromium, copper, lead, molybdenum, nickel, selenium, uranium and vanadium), which are naturally occurring substances often released to the aquatic environment during the mining and milling of uranium ore. The data were collected in uranium ore-bearing regions of northern Saskatchewan and Ontario where most Canadian decommissioned or operating uranium mines and mills are located. Benthic communities were considered to be not adversely affected if there was less than a 20% reduction in abundance and species richness relative to the reference. Benthic communities were considered to be severely affected if there was a greater than 40% reduction in these two indices. Two statistical methods were used by Thompson et al. (2005) to define the percentiles corresponding to LEL and SEL. A "weighted method" produced somewhat higher values than a "closest observation method". When the predictive ability of the sediment quality guidelines was assessed, all of the LELs derived using the weighted method, with the exception of the chromium LEL, were found to be highly reliable (>85% accuracy) in predicting sites unimpacted by uranium mining/milling. Caution is to be employed when using the SEL values as they may not be a reliable predictor of potential effects.

The LEL and SEL values for uranium are shown in Table 5.11.

Table 5.11 Sediment Quality Guidelines for Uranium

Benchmark	Uranium
Lowest Effect Level (LEL) (µg/g)	104.4
Severe Effect Level (SEL) (µg/g)	5874.1

Source: Thompson et al. (2005)

6.0 CONSEQUENCE ASSESSMENT

6.1 POTENTIAL IMPACTS OF ROUTINE OPERATION

Potential impacts of routine operations (transport of materials to and from Kiggavik) are limited to external radiation dose to human receptors in close proximity of yellowcake containers. In the absence of an accidental release, none of the ecological species will be exposed to yellowcake during transportation. Routine transport of fuel and reagents will not expose any of the receptors to these materials.

6.1.1 Receptors and Exposure Scenarios

Yellowcake is transported in 55- gallon steel drums. During transport, the drums are loaded in a 20' sea-container which also acts as a secondary containment.

The external dose was estimated for workers and a member of the public who may be exposed to yellowcake in the following scenarios:

<u>1- Forklift operator loading 35 drums of yellowcake into a sea-container which has already been placed on a truck or is on the ground to be loaded into an aircraft</u>

A forklift operator will be exposed to one drum which is being loaded into the sea-container and exposed to drums already in the container when loading the drum into the sea-container. A forklift operator was conservatively assumed to be exposed to a full sea-container.

The estimated exposure time for a forklift operator to move a drum onto the forklift and into the sea-container was two minutes per drum. It was conservatively assumed that one forklift operator operates the forklift to move all the drums for each trip. The operator then spends approximately two minutes in the sea-container to unload the drum from the forklift. Therefore, the estimated exposure time is approximately 140 minutes per trip (i.e., 70 minutes (two minutes per drum x 35 drums) to move a drum onto the forklift and into the sea-container and another 70 minutes to unload the drum from the forklift).

A forklift operator will load drums to fill 343 sea-containers which will be transported air.

<u>2- Truck driver transporting a sea-container with 35 drums</u>

A truck driver is expected to make 343 trips per year (i.e., 343 sea-containers); each trip is 10 km and will take 15 minutes assuming an average speed of 40 km/hr. In addition, a truck driver will perform an inspection prior to departure and upon arrival at the destination; each inspection was assumed to take 5 minutes.

<u>3- Pilot transporting a sea-container with 35 drums</u>

A pilot of a Hercules cargo plane is expected to make 343 trips per year (i.e., 343 sea-containers), each trip is expected to take 75 minutes assuming an average speed of 602 km/hr (i.e., 374 mph/hr which is the speed of a Hercules C-130, Global Aircraft 2010).

<u>4- Driver of a heavy duty forklift</u>

A forklift driver in the storage area will be exposed to 14 sea-containers. These 14 sea-containers are in 2 containers (Length) by 7 containers (Width) arrangement. The forklift drivers will spend 140 minutes in the storage (i.e., 10 minutes per sea-container x 14 sea-containers in the storage area).

<u>5- A member of the public near the storage area</u>

A member of the public (resident at Points North) was assumed to live 100 m from the storage area and spend time indoors and outdoors. A member of the public is exposed for four weeks of a year (during which yellowcake is stored at Points North before transport via truck) and spends 6.25% of the time outdoors (adult, Health Canada 2004).

The external dose assessment was performed using MicroShield Version 8.02 (Grove Software 2008). The assumptions used in the MicroShield runs for each scenario are described below.

6.1.2 Exposure Characteristics

6.1.2.1 Source Geometry

6.1.2.1.1 Drums of Yellowcake

This geometry was used to estimate the effective dose rate to a forklift operator that is exposed while moving a drum from the truck onto the forklift and into a sea-container.

The dimensions of a steel drum are 85.1 cm (height), 57.2 cm (diameter) and 0.12 cm (wall thickness.

For MicroShield calculation, a cylinder volume - side shields was used for the source geometry. As mentioned, a forklift operator moves 35 drums containing yellowcake to fill a sea-container.

6.1.2.1.2 Sea-containers

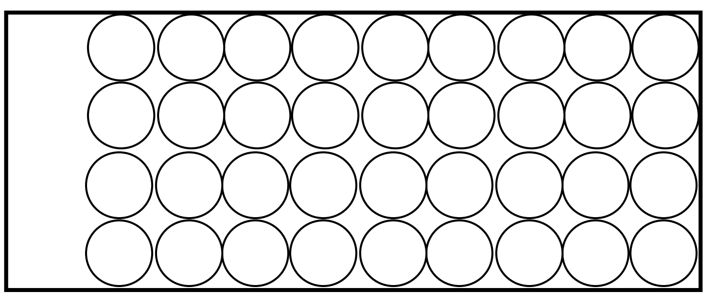
The sea-container geometry (drums containing yellowcake in a sea-container) is common to many receptors. The internal dimensions of a 20 foot sea-container according to (Bluefreight 2009) are 590 cm (L) by 235 cm (W) by 239.3 cm (H).

Other source geometry assumptions included:

- The walls of the sea-containers are 0.65 cm thick steel; and,
- The wall of the cab (of the truck hauling sea container or the aircraft cockpit) was assumed to provide an equivalent of 1/16th inch (0.15 cm) thick steel.

There are 35 drums of yellowcake inside a sea-container. However, a regular geometry was required for the MicroShield model; therefore, sea-container was assumed to contain 36 drums. The maximum numbers of drums that can fit along the width is 4 drums. Therefore, there are 9 drums along the length. For the MicroShield calculation, the source geometry used was a rectangular volume; the drums were arranged in a 9 (length-wise) by 4 (width-wise) configurations as shown in Figure 6-1. The dimensions of the source are 514.8 cm (length) by 228.8 cm (width) by 85.1 cm (height).

Figure 6-1 Drums Containing Yellowcake in Sea-Container



6.1.2.1.3 Storage

There are 14 sea-containers arranged in 2 containers (length) by 7 containers (width) arrangement in the storage area

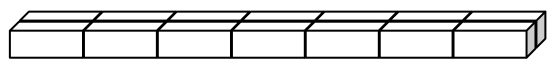
Based on the internal dimensions of a 20' sea-container, the dimensions of 14 sea-containers in 2 containers (Length) by 7 containers (Width) arrangement are 1,180 cm, 1,645 cm and 239.3 cm (height).

Other source geometry assumptions included:

- The walls of the sea-containers were 0.65 cm thick steel; and,
- The wall of the cab (of the heavy-duty forklift) was assumed to provide an equivalent of $1/16^{th}$ inch (0.15 cm) thick steel.
- The walls of the storage building were 0.046 cm thick steel (CSSBI 2008)

For the MicroShield calculation, the source geometry used was a rectangular volume; the configuration of the sea-containers in the storage area is shown in Figure 6-2.

Figure 6-2 Storage Area Containing 14 Sea-Containers



6.1.2.2 Source Material and Density

Yellowcake was conservatively assumed to be 100% U_3O_8. The density of yellowcake is 2.055 g/cm^3 (Cohen 2005).

For a sea-container, adjustments were made to the source density to account for the extra air gap created by using a rectangular volume to represent multiple drums. The source density was multiplied by a factor of 0.785 which is the ratio between the volume of 36 drums and a rectangular volume that encloses 36 drums. Therefore, the bulk density of yellowcake was considered 1.61 g/cm^3.

For storage area, adjustments were made to the source density to account for the extra air gap created by using a rectangular volume to represent 14 sea-containers drums. The source density was multiplied by a factor of 0.237 which is the ratio between the volume of 504 drums (i.e., 36 drums per sea-container (number of drums required for the MicroShield model) x 14 sea-containers) and a volume of 14 sea-containers. Therefore, the bulk density of yellowcake was considered 0.49 g/cm^3.

6.1.2.3 Source Radionuclides

The yellowcake was assumed to have U-238, U-234, and U-235 present at natural abundances. U-238 was assumed to be in equilibrium with its short-lived decay products; Th-234, Pa-234m, Pa-234 (which has a relative concentration of 0.16% of U-238) and U-234. U-235 was assumed to be in secular equilibrium with Th-231. The concentration of each radionuclide was calculated as follows:

$$C_{radionuclide} = A_{radionuclide} \times \rho_{yellowcake} \times F_{U\ in\ U3O8}$$

Where:
C: concentration (Bq/cm^3)
A: activity (Bq/g); provided in Table 6.1
ρ: yellowcake density (2.055 g/cm^3)
F: fraction of uranium in U_3O_8 (0.848)

The concentrations of radionuclides are shown in Table 6.1.

Table 6.1 Activity Concentrations of Radionuclides in Yellowcake

Nuclide	Branching Ratio	Specific Activity (Bq/g)	Concentration (Bq/cm^3)
U-238	1	1.23E+04	2.15E+04
Th-234	1	1.23E+04	2.15E+04
Pa-234	0.0016	1.98E+01	3.44E+01
Pa-234m	1	1.23E+04	2.15E+04
U-234	1	1.23E+04	2.15E+04
U-235	0.046	5.68E+02	9.90E+02
Th-231	0.046	5.68E+02	9.90E+02

6.1.2.4 Dose Points

Dose points refer to the location of receptors in relation to the exposure source, and are described below for receptors exposed to different geometries.

6.1.2.4.1 Drums of Yellowcake

Scenario 1 - Forklift Operator Loading 35 Drums of Yellowcake into a Sea-container

A forklift operator will be exposed to a drum when loading the drum into the sea-containers. A forklift operator was assumed to be 100 cm from the drum. For conservative purposes, a forklift operator was assumed to be located at the centre point of the drum (i.e., half-width and half-height of the source).

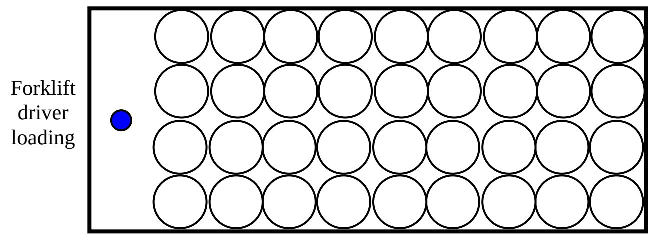
6.1.2.4.2 Sea-Containers

Scenario 1 - Forklift Operator Loading 35 Drums of Yellowcake into a Sea-container

A forklift operator will be exposed to drums already in the container when loading the drum into the sea-containers. A forklift operator was conservatively assumed to be exposed to a full sea-container and was assumed to be 100 cm from the drums in the sea-container. For conservative purposes, a forklift operator was assumed to be located at the centre point of the sea-container (i.e., half-width and half-height of the source).

The dose points for Scenario 1 are shown in Figure 6-3. Note that the figure is not to scale and intended to provide a perspective of the dose points with respect to the source.

Figure 6-3 Dose Point for Scenario 1



<u>Scenario 2 - Truck Driver Transporting a Sea-container with 35 drums</u>

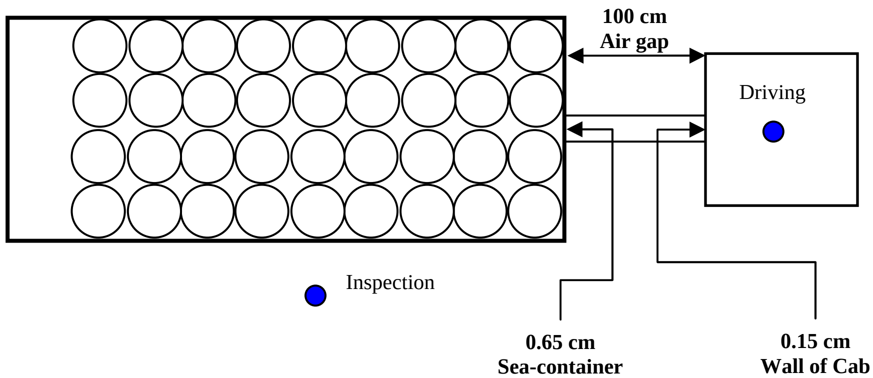
During the transport of yellowcake, a truck driver is exposed while driving the trailer and while performing inspections.

During the time spent driving, a truck driver is located in the cab of the truck and is exposed from behind (i.e., the driver's back towards the width of the source). A driver's cabin was assumed to be 100 cm from the trailer. However, it should be noted that the actual distance from the source was 110.45 cm when the thicknesses of the steel wall of the trailer (0.3 cm), wall of the cab (0.15 cm) and the space between the driver and the back wall of the cab (10 cm) are included. For conservative purposes, a truck driver was assumed to be located at the centre point of the shorter side (width) of the trailer (i.e., half-width and half-height of the source).

A driver inspects the truck prior to departure and upon arrival at the destination. During the inspection, a driver was assumed to be 50 cm away from the side of the truck. In addition, for conservative purposes, a truck driver was assumed to be located at the centre point of the longer side (length) of the trailer (i.e., at half-length and half-height of the source).

The dose points for Scenario 2 are shown in Figure 6-4. Note that the figure is not to scale and intended to provide a perspective of the dose points with respect to the source.

Figure 6-4 Dose Points for Scenario 2

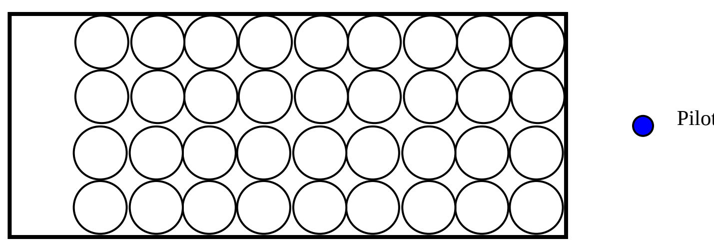


Scenario 3 - Pilot Transporting a Sea-container with 35 drums

A pilot of a Hercules cargo plane was assumed to be 10 m from the front of the sea-container, which was approximately 1/3 the length of a Hercules C-130 (29.3 m, Global Aircraft 2010)

The dose points for Scenario 5 are shown in Figure 6-5. Note that the figure is not to scale and intended to provide a perspective of the dose points with respect to the source.

Figure 6-5 Dose Point for Scenario 3



6.1.2.4.3 Storage Area

Scenario 4 - Driver of a heavy duty forklift

A forklift operator will be exposed to 14 sea-containers in the storage area. A forklift operator was assumed to be 1 m from the sea-containers and exposed to 14 sea-containers all the time which is conservative since the sea-containers are gradually moved into the storage area. Another added conservatism is that a forklift operator was assumed to be located at the centre point of the sea-containers (i.e., half-length and half-height of the source).

Scenario 5- A member of the public near the storage area

A member of the public (resident) was assumed to live 100 m from the storage area and spends time indoors and outdoors. When a resident is indoors, a resident was assumed to be shielded by a studded insulated wall with wood sheeting and aluminum siding (which was assumed to be 5 inches thick.

6.1.2.5 Build-up and Integration

The build-up material (the basis for photon scattering) selected for this calculation was air. The integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were increased until the effective dose converged.

6.1.3 Results

6.1.3.1 Scenario 1 - Forklift Operator Loading 35 Drums of Yellowcake into a Sea-container

The effective doses to a forklift loading 35 drums of yellowcake into a sea-container are shown in Table 6.2. A forklift operator will be exposed to the one drum which is being loaded into the sea-containers and the drums already in the container when loading the drum into the sea-containers. The antero-posterior effective dose rates were used because a forklift operator is exposed from the front while operating the forklift.

Table 6.2 Effective Dose to a Forklift Operator (Scenario 1)

Activity	Hours per trip [a]	Effective Dose Rate (mSv/hr)	Effective Dose (mSv)
Moving a drum into a sea-container which has already been placed on a truck	1.17	1.9E-03 [b]	2.2E-03
Loading a drum into a sea-container which has already been placed on a truck	1.17	8.4E-03 [b]	9.8E-03
		Total Dose per trip [c]	1.2E-02
		Trips per year	343
		Total Dose per year [d]	4.1

a) 2 minute per drum x 35 drums = 70 minutes
b) Antero-posterior geometry (with build-up)
c) Sum of moving and loading effective dose.
d) Total per trip x Trips per year.

6.1.3.2 Scenario 2 - Truck Operator Transporting a Sea-container with 35 Drums

The effective dose to a truck driver driving the truck is shown in Table 6.3. The postero-anterior effective dose rate was used because a truck driver is exposed from behind while driving and the antero-posterior dose rate was used for a truck driver exposure while inspecting the truck.

Table 6.3 Effective Dose to a Truck Driver (Scenario 2)

Activity	Hours per trip	Effective Dose Rate (mSv/hr)	Effective Dose (mSv)
Driving	0.25 [a]	5.5E-03 [c]	1.4E-03
Inspection	0.1 [b]	1.7E-02 [d]	1.7E-03
		Total Dose per trip [e]	3.1E-3
		Trips per year	343
		Total Dose per year [f]	1.1

a) For travelling 110 km at a speed of 80 km/hr
b) 0.25 hours prior to departure and 0.25 hours upon arrival at the destination
c) Postero-anterior geometry (with build-up).
d) Antero-posterior geometry (with build-up).
e) Sum of driving and inspection effective dose.
f) Total per trip x Trips per year.

6.1.3.3 Scenario 3 – Pilot Transporting a Sea-container with 35 Drums

The effective dose to a pilot of a Hercules cargo plane is shown in Table 6.4. The postero-anterior effective dose rate was used because the pilot is exposed from behind while flying the plane. The pilot of a Hercules cargo plane is expected to make 247 or 343 trips per year; the annual effective doses for such trips are shown in Table 6.4.

Table 6.4 Effective Dose to Pilot (Scenario 3)

Activity	Hours per trip	Effective Dose Rate (mSv/hr)	Effective Dose (mSv)
Pilot	1.28 [a]	1.2 E-04 [b]	1.5E-04
		Trips per year	343
		Total Dose per year [c]	0.051

a) 770 km/602 km/hr (speed of Hercules C-130)
b) Postero-anterior geometry (with build-up).
c) Total per trip x Trips per year.

The annual dose to the pilot is less than the dose limits for the member of the public (1000 μSv/year).

6.1.3.4 Scenario 4 - Driver of a Heavy Duty Forklift

The effective dose to a forklift operator exposed to 14 sea-containers in the storage area is shown in Table 6.5.

Table 6.5 Effective Dose to Driver of Heavy Duty Forklift (Scenario 4)

Activity	Hours per operation	Effective Dose Rate (mSv/hr)	Effective Dose (mSv)
Heavy Duty Forklift Driver	0.17[a]	6.9E-02 [b]	0.11
		Operations per year	343
		Total Dose per year [c]	3.9

a) 10 minutes per sea-container for 14 sea-containers in the storage area.
b) Antero-posterior geometry (with build-up).
c) Total per trip x Trips per year.

6.1.3.5 Scenario 5- A Member of the Public near the Storage Area

The effective dose to a member of the public (resident) assumed to be 100 m from the storage area and spends time indoors and outdoors is shown in Table 6.6.

Table 6.6 Effective Dose to Member of the Public (Scenario 5)

Activity	Hours per year	Effective Dose Rate (mSv/hr)	Effective Dose (mSv)
Resident (indoors)	630 [a]	2.8E-05 [c]	0.018
Resident (outdoors)	42 [b]	5.7E-05 [c]	2.4E-3
		Total per year	0.02

a) Based on Health Canada (2004), an adult spends 6.25% of time outdoors and 93.75% of time indoors; exposure duration is three months per year.
b) 1.5 hr/d outdoors (6.25%) for four weeks per year
c) Antero-posterior geometry (with build-up)

The total effective doses for all scenarios are shown in Table 6.7.

The CNSC (2000) radiation dose limit for a member of the public is 1 mSv per year (over natural background levels). The guideline for a NEW is 100 mSv for five years (i.e., an average of 20 mSv/year).

The radiation doses estimated for routine operations in this section are below 1 mSv/y for all members of public.

The forklift operators and truck driver at Kiggavik (Scenarios 1, 2, & 4) will be NEWs; they will not receive radiation doses higher than accepted (i.e. 20 mSv/y) from these operations.

Table 6.7 Effective Dose for All Scenarios for Routine Operation

Scenario	Receptor Description	Total Dose (mSv/y)
1	Forklift operator	4.1
2	Truck driver	1.1
3	Pilot (343 trips)	0.051
4	Driver of heavy duty forklift	3.9
5	Member of the public	0.02

6.2 CONSEQUENCES OF ACCIDENTS

6.2.1 Selected Accident Scenarios

From various credible accident scenarios defined in Section 3.0, a number of bounding accidents were selected for consequence assessment. Table 6.8 provides a list of all credible accidents and identifies which were considered bounding and carried forward to this section.

Table 6.8 List of Credible and Bounding Scenarios

<table>
<tr><th>Material</th><th>Mode</th><th>Credible Scenarios</th><th>Bounding Scenarios</th></tr>
<tr><td rowspan="2"></td><td rowspan="2">Air transport</td><td>Scenario 1: Aircraft crash during takeoff or landing</td><td rowspan="2">Aircraft crash on land and spill on soil, Release to water is bounded by release from marine transportation.</td></tr>
<tr><td>Scenario 2: Aircraft crash during cruising</td></tr>
<tr><td rowspan="3">Transportation of Fuel, Reagents and Supplies</td><td rowspan="2">Transport via Trucks</td><td>Release of materials during traffic accidents</td><td>Release of diesel fuel into water</td></tr>
<tr><td>Fire or explosion</td><td>Fire involving fuel storage and during transportation, explosion during transportation of ammonium nitrate</td></tr>
<tr><td>Marine Transport</td><td>Release of materials in marine environment</td><td>Release of diesel fuel into water</td></tr>
</table>

6.2.2 Yellowcake Transportation

6.2.2.1 Impact on Ecological Receptors

6.2.2.1.1 Methodology

The results of the water and sediment quality predictions were used to assess exposures of ecological species to uranium. The assessment of effects to ecological receptors is made by comparing exposure estimates to TRVs. For example, intake (or dose) estimates are compared to non-radiological TRVs and to dose rate guidelines for radionuclides to assess the risks of adverse health effects for each of the ecological receptors.

In general, the approach taken for estimating the exposure of radiological and non-radiological contaminants to non-human biota is to model the intake of a contaminant by the biota (in mg/d or Bq/d) and then use a transfer factor or TF (d/kg) to obtain a body or flesh concentration where necessary. Many toxicity values for non-radiological contaminants are expressed as intake rates rather than tissue residues. Therefore, the assessment of non-radiological and radiological contaminants can be carried out in parallel with the flesh concentrations being important for estimating internal radiological dose while intakes are used for assessment of non-radiological contaminants.

The concentration of each COPC in species in the first trophic level (aquatic plants, benthic invertebrates and fish) was estimated based on water concentration as follows:

$$C_{species} = C_{water} \times TF$$

The concentration of each COPC in species in the second trophic level (birds, caribou and arctic ground squirrel) was estimated based on water and food concentrations and quantities as follows:

$$C_{species} = \left((C_{water} \times Q_{water}) + \left(\sum [(C_{food} \times F_{food}) \times Q_{food}) \right) \times F_{local} \times TF] $$

Intake of uranium by each species was estimated as follows:

$$I_{species} = \frac{C_{species}}{TF \times BW_{species}}$$

Radiation dose for aquatic species was estimated as follows:

$$D_{equivalent} = D_{internal} \times RBE + D_{external}$$
$$D_{internal} = C_{species} \times DCF_{internal}$$
$$D_{external} = C_{water\ or\ sediment} \times DCF_{external}$$

Radiation dose for semi-aquatic and terrestrial species was estimated as follows:

$$D_{equivalent} = C_{species} \times DCF_{internal} \times RBE$$

where,
C: concentration
Q: quantity
F_{food}: fraction of total food that consists of the specific food item
F_{local}: fraction of total food that is local
TF: transfer factor
I: intake
BW: body weight
D: radiation dose
DCF: dose conversion factor
RBE: relative biological factor

The comparison of intake (or dose) estimates to TRVs or dose rate guidelines is usually undertaken by the calculation of screening index (SI) values. The SI values provide an integrated description of the potential hazard, the exposure (or dose) response relationship and the exposure evaluation (U.S. EPA 1992; AIHC 1992).

For aquatic receptors, the screening index is simply a ratio of the predicted or estimated COPC concentration in water (or sediment) to the TRV for the given aquatic species. For example the estimated concentration for uranium in water divided by the TRV for predatory fish provides the screening index for predatory fish exposed to uranium, as follows:

$$Screening\ Index = \frac{Estimated\ Concentration}{TRV}$$

For terrestrial receptors exposed to non-radionuclides, the screening index is calculated by dividing the predicted intake (based on food intake and composition) by the receptor of interest by the selected toxicity reference value for that receptor, as shown below:

$$Screening\ Index = \frac{Estimated\ Intake}{TRV}$$

For radionuclides, the total dose rate received by an ecological receptor is divided by the reference dose rate to calculate a screening index value, as shown in the following equation:

$$Screening\ Index = \frac{Dose\ Rate}{Reference\ Dose\ Rate}$$

The screening index values derived from these calculations are not estimates of the probability of ecological impact. Rather, the index values are positively correlated with the potential of an effect (i.e, higher index values imply greater potential of an effect). Different magnitudes of the screening index have been used in other studies to screen for the potential ecological effects. A screening index value of 1.0 has been used in most ecological risk assessments (e.g., Suter 1991). Cardwell et al. (1993) suggested an index value of 0.3, based upon a conservative approach designed to account for potential chronic toxicity and chemical synergism. In this study, an index value of 1.0 was used to examine the potential adverse effects of COPC on aquatic and terrestrial receptors.

6.2.2.1.2 Input Parameters

Input parameters used in the exposure estimation are as follows:

- Dietary characteristics
- Transfer factors
- Dose coefficients
- Bioaccessibility factors for soil and sediment.

Dietary characteristics of ecological receptors are provided in Table 5.1.

Transfer factors are empirical values that provide a measure of the partitioning behaviour of a COPC between two environmental media. Transfer factors can describe partitioning between many different media, including water-to-fish, water-to-benthic invertebrates, food-to-animal flesh and other media. Transfer factors (TFs) from the abiotic environment (water, soil) to biota directly relate the concentration in one medium to another. Table 6.9 summarizes the TF values used to calculate concentrations of uranium and radionuclides in environmental media from the abiotic components. Transfer factors for aquatic species are based on available information from the McClean Lake Operation. Transfer factors for semi-aquatic and terrestrial species were estimated using allometric equations based on literature data for reference bird and mammal (SENES 2008).

Table 6.10 shows the selected Dose Coefficients (DCs) for the estimation of dose. The DCs were obtained from Amiro (1997) and Blaylock et al. (1993). DCs for internal and external exposure are provided.

Bioaccessibility factors take into account the fact that only a portion of the constituents present in soil or sediment can be potentially absorbed into the body of animals or people. Bioaccessibility factors were conservatively considered to be 100% for all species and pathways, with the exception of uranium bioaccessibility in yellowcake to caribou and arctic ground squirrel ingested through contaminated soil. This was assumed to be 1% based on the 0.2% fraction recommended for slow processes involving uranium by the International Commission on Radiological Protection (ICRP 1994) and the low solubility of yellowcake in water (<1%).

Table 6.9 Transfer Factors used in the Assessment

a) Water to Aquatic Species

Constituent	Unit	Aquatic Plant	Benthos	Fish
Uranium	mg/kg (ww)/mg/L	170	92	1
Th-230	Bq/kg (ww)/Bq/L	460	90	36
Ra-226	Bq/kg (ww)/Bq/L	1400	1400	27
Pb-210	Bq/kg (ww)/Bq/L	880	330	25
Po-210	Bq/kg (ww)/Bq/L	1500	2300	310

b) Food to Semi-aquatic and terrestrial species

Constituent	Unit	Merganser	Sandpiper	Tundra swan	Caribou
Uranium	d/kg	1.60	29	0.49	0.001
Th-230	d/kg	0.16	2.9	0.05	0.0005
Ra-226	d/kg	0.13	2.5	0.04	0.0002
Pb-210	d/kg	0.32	5.8	0.10	0.001
Po-210	d/kg	3.90	73	1.2	0.01

Table 6.10 Dose Coefficients Used for Ecological Receptors

a) Aquatic Receptors (in mGy/d per Bq/g)

Constituent	Internal - Fish	External - Fish	Internal - Aquatic Plant	External - Aquatic Plant	Internal - Benthos	External - Benthos
U-238+	1.42E-01	1.73E-05	1.42E-01	1.73E-05	1.42E-01	1.73E-05
Th-230	6.58E-02	1.96E-05	6.58E-02	1.96E-05	6.58E-02	1.96E-05
Ra-226+	1.59E-01	8.77E-05	1.59E-01	8.77E-05	1.59E-01	8.77E-05
Pb-210+	6.03E-03	6.05E-05	6.03E-03	6.05E-05	6.03E-03	6.05E-05
Po-210	7.48E-02	9.42E-08	7.40E-02	9.42E-08	7.40E-02	9.42E-08

Note: the radionuclides included in each dose coefficients are as follows:
U-238+ Internal: U-238 + Th-234 + Pa-234m+ U-234 + 0.045 U-235
External: U-238 + Th-234 + Pa-234m+ U-234 + 0.045 U-235 (beta + gamma only)
Ra-226+ Internal: Ra-226 + 0.3* (Rn-222 + ...Po-214)
External: Ra-226 + 1.0* (Rn-222 + ...Po-214) (beta + gamma only)
Th-232+ Internal: Th-232 + ...Po-212/Tl-208 (Th-232 + Th-228 are inputs)
External: Th-232 + Po-212/Tl-208
Ra-228+ Internal: Ra-228 + ..Po-212/Tl-208

b) Terrestrial Receptors (in mGy/d per Bq/g)

Constituent	Internal Dose Coefficient
U-238+	0.14
Th-230	0.066
Ra-226+	0.16
Pb-210+	0.006
Po-210	0.075

Note: the radionuclides included in each dose coefficients are as follows:
U-238+ Internal: U-238 + Th-234 + Pa-234m+ U-234 + 0.045* U-235
Ra-226+ Internal: Ra-226 + 0.3* (Rn-222 + ...Po-214)
Pb-210+ Internal: Pb-210 + Bi-210
Reference: Amiro (1997)

6.2.2.1.3 Results

The results of the ecological risk assessment are provided below for radioactive and non-radioactive (uranium) exposure to aquatic and terrestrial receptors.

Radioactivity

Table 6.11 and Table 6.12 present the results of the aquatic and terrestrial radiological assessments under the different RBE assumptions (10 and 40) for large lake and land scenarios involving aircraft accidents resulting in a yellowcake spill. Radioactivity resulting from background concentrations of radionuclides (i.e., uranium, radium-226, lead-210, polonium-210 and thorium-230) was also included in the calculations.

Table 6.11 Screening Indices for Dose to Aquatic Receptors from Baseline Radioactivity and Yellowcake Spill

Receptor	Ref. Dose (mGy/d)	SI Value		Ref. Dose (mGy/d)	SI Value	
		RBE: 10	RBE: 40		RBE: 10	RBE: 40
Predatory fish	0.6	1.48	5.90	10	0.09	0.35
Forage fish	0.6	1.48	5.90	10	0.09	0.35
Aq. plant leaf	3	5.09	20.31	10	1.52	6.09
Aq. plant root	3	5.09	20.31	10	1.52	6.09
Benthic Invertebrates	6	2.17	8.69	10	1.30	5.21

Note: Highlighted cells indicate an SI exceedance of 1.

Table 6.12 Screening Indices for Dose to Terrestrial Receptors from Baseline Radioactivity and Yellowcake Spill

d) Large Lake

Receptor	Ref. Dose (mGy/d)	SI Value		Ref. Dose (mGy/d)	SI Value	
		RBE: 10	RBE: 40		RBE: 10	RBE: 40
Sandpiper	1	14.34	57.3	3	4.776	19.08
Merganser	1	1.05	4.2	3	0.3498	1.398
Tundra Swan	1	8.04	32.16	3	2.682	10.74

a) Land

Receptor	Ref. Dose (mGy/d)	SI Value		Ref. Dose (mGy/d)	SI Value	
		RBE: 10	RBE: 40		RBE: 10	RBE: 40
Caribou 2	1	<0.001	<0.001	3	<0.001	<0.001
Arctic Ground Squirrel	1	<0.001	0.001	3	<0.001	<0.001

Note: Highlighted cells indicate an SI exceedance of 1.

Table 6.11 summarizes the SI values for aquatic species, i.e., predatory and forage fish, aquatic plant leaves and roots, and benthic invertebrates. As seen from the table, the SI values are exceeded in all scenarios for all aquatic species with respect to the lower reference dose at both RBE values (10 and 40). With respect to the higher reference dose, the SI values are not exceeded for predatory and forage fish species at both RBE values (10 and 40), but are exceeded in all cases for aquatic plants (leaves and roots) and benthic invertebrates. These results indicate that a spill of yellowcake into a large lake could potentially affect the populations of aquatic plants, benthic invertebrates and fish species during transient time shortly after the spill. For fish species, only the more conservative lower reference dose was exceeded.

Table 6.12 summarizes the SI values for terrestrial species, which include waterfowl (sandpiper, merganser and tundra swan) for a large lake scenario and an accident on Land. The results indicate that the terrestrial species potentially at most risk would be the waterfowl, which have an aquatic based diet. As seen from the table, the SI values for all three waterfowl are exceeded for the lower reference dose at both RBE values (10 and 40) following either an accident into a large lake. However, at the higher reference dose the SI value at an RBE value of 10 is not exceeded for the merganser, which, unlike the sandpiper and tundra swan, does not consume benthic invertebrates. The SI values in all cases were below 1 for the caribou ingesting contaminated water (Caribou 1) and for the caribou (Caribou 2) and arctic ground squirrel ingesting contaminated soil.

Uranium

The results assessing exposure to uranium from the various yellowcake spills are summarized in Table 6.13 and Table 6.14 for aquatic species and Table 6.15 for terrestrial species. Uranium exposure resulting from baseline concentrations in water or soil were also included in the calculations. The exposure to all aquatic species, with the exception of benthic invertebrates, was considered to be acute. Since an acute TRV is not available for benthic invertebrates and because their exposure results from sediments as well as water, benthic invertebrate exposure was considered to be chronic. The exposure to waterfowl (sandpiper, merganser and tundra swan) was considered to be chronic due to their ingestion of sediments, while the exposure to caribou (Caribou 1) ingesting water only and caribou (Caribou 2) and arctic ground squirrel ingesting soil only was considered to be acute.

As seen from Table 6.13, a spill will potentially result in adverse effects to all of the aquatic species under assessment.

In addition to being exposed to water, benthic invertebrates reside in sediment, which represents another pathway of exposure to uranium. As seen from Table 6.14, uranium concentrations in large lake sediments resulting from spills of yellowcake would not be high enough with respect to the SEL benchmark for adverse effects to be expected on benthic invertebrates. However, with respect to the LEL benchmark, benthic invertebrates may potentially be at risk in large lake sediments following accidents. As was mentioned in section 5.3.3, while the LEL value is a reliable predictor of uranium sediment concentrations (<LEL value) that will not adversely affect

benthic invertebrates, the SEL value is not considered reliable in predicting concentrations at which potential effects will be expected (>SEL value). At concentrations occurring between the LEL and SEL values (as is this case for most of the assessed scenarios), benthic invertebrates may potentially be adversely affected.

The SI values for terrestrial species are summarized in Table 6.15. With respect to waterfowl that have an aquatic based diet, it can be seen that none of the scenarios would result in potential risks of adverse effects to merganser while the tundra swan and especially the sandpiper may be at risk. Unlike the merganser, the sandpiper and tundra swan both consume benthic invertebrates as part of their diet. A yellowcake spills would result in potential adverse effects to sandpiper when considering both the NOAEL and ENEV TRVs and to Tundra swan for a spill. It is noted that the SI values are calculated based on NOAELs (or ENEVs) as the information to determine a LOAEL (Lowest Observable Adverse Effect Level) is not available. Thus, there is some uncertainty in the analysis and the assessment of potential effects based on NOAELs is expected to be conservative.

The acute assessment of caribou (Caribou 1) ingesting only water impacted by a yellowcake spill indicates that the scenario would not result in potential adverse effects to caribou. Likewise, the acute assessment of caribou (Caribou 2) and arctic ground squirrel consuming only soil impacted by a major yellowcake spill on land indicates that neither species would potentially be at risk under this scenario.

Table 6.13 Screening Indices for Exposure of Aquatic Receptors to Uranium in Water from Baseline Concentrations and Yellowcake Spill

Aquatic Receptor / SI Value			
Aquatic Plants	**Benthic Invertebrates**	**Forage Fish**	**Predatory Fish**
46.32	77.40	1.54	1.45

Note: Highlighted cells indicate an SI exceedance of 1.

Table 6.14 Screening Indices for Exposure of Benthic Invertebrates to Uranium in Sediments from Baseline Concentrations and Yellowcake Spill

Benthic Invertebrates / SI Values	
LEL	**SEL**
4.15	0.07

Note: Highlighted cells indicate an SI exceedance of 1.
LEL – Lowest Effect Level; SEL – Severe Effect Level (Thompson *et al.* 2005).

Summary

The results of the ecological risk assessment indicate that terrestrial species (caribou and arctic ground squirrel) would not be at risk following a short-term major spill of yellowcake onto land from an aircraft accident. Likewise, short-term ingestion of contaminated water resulting from a an accident would not result in potential risks to caribou.

Aquatic plants and benthic invertebrates would be the species at most risk. With respect to semi-aquatic terrestrial species (waterfowl), the sandpiper would potentially be at greatest risk following a yellowcake spill into a Large lake. All three waterfowl species would be at risk following an accident into a large lake.

Table 6.15 Screening Indices Based on Different Benchmarks for Uranium Ingestion by Terrestrial Receptors Resulting from Baseline Concentrations and Yellowcake Spill

Scenario / Benchmark	Terrestrial Receptors					
	Sandpiper [a]	**Merganser [a]**	**Tundra Swan [a]**	**Caribou 1 [b]**	**Caribou 2 [c]**	**Arctic Ground Squirrel [c]**
d) Large Lake						
NOAEL	4.3	0.02	1.1	<0.01		
LOAEL						
ENEV	136.8	0.50	33.9			
e) Land - Major Accident						
NOAEL						
LOAEL					<0.01	<0.01
ENEV						

Note:
[a] Exposure to waterfowl was considered chronic.
[b] Exposure to Caribou 1 was considered acute from ingesting water only.
[c] Exposure to Caribou 2 and arctic ground squirrel was considered acute from ingesting soil only.
Blank cells indicate that the benchmark is not applicable to the receptor and/or scenario.
Highlighted cells indicate an SI exceedance of 1.

6.2.2.2 Impact on Human Receptors

6.2.2.2.1 Methodology

The results of the water quality predictions were used to assess exposures of a resident of Baker Lake to chemical uranium as well as radionuclides.

Estimated uranium concentration in water was compared to the water quality guideline, and estimated radiological dose was compared to the human reference dose.

Dose from ingestion of water was estimated as follows:

$$D_{ingestion} = C_{water} \times Q_{water} \times F_{time} \times DCF_{ingestion}$$

where,
C: concentration
Q: quantity
F_{time}: fraction of time in the area
DCF: dose conversion factor

6.2.2.2.2 Input Parameters

The dose coefficients used in the assessment are those recommended by the International Commission on Radiological Protection (ICRP). Ingestion DCFs depend on the chemical form of the radionuclide and the consequent gut-to-blood transfer factor (f1). The values selected reflect the ICRP Publication 72 (1996) recommended f1 values and DCs for members of the public. These values are provided in Table 6.16.

Table 6.16 Ingestion Dose Conversion Factors for Human Receptors (µSv/Bq)

Constituent	Toddler	Child	Adult
U-238+	0.25	0.185	0.0995
Th-230	0.41	0.31	0.21
Ra-226+	0.96	0.62	0.28
Pb-210+	3.6	2.2	0.69
Po-210	8.8	4.4	1.2

6.2.2.2.3 Results

As seen from Table 6.17, predicted uranium concentrations in a large lake following a yellowcake spill would exceed the Canadian Drinking Water Quality Guideline (Health Canada 2008) for uranium (0.02 mg/L) under both scenarios. The guideline would be exceeded following a spill.

The radiation doses predicted for a child, toddler and adult ingesting large lake water impacted by a yellowcake spill are summarized in Table 6.18. The dose to a toddler and child would be twice as high as that to an adult under the spill scenario. In all cases, however, the dose estimates are well below (<1 µSv/yr) the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1000 µSv/yr for members of the public as well as the Health Canada dose constraint limit of 300 µSv/yr.

Table 6.17 Comparison of Large Lake Uranium Concentrations to Canadian Drinking Water Quality Guidelines

Uranium CDWQG (mg/L)	Uranium Concentration (mg/L)
0.02	2.32

Note: CDWQG – Canadian Drinking Water Quality Guidelines (Health Canada 2008)

Table 6.18 Radiation Dose to Human Receptors Consuming Large Lake Water Impacted by Yellowcake Spill

Dose (μSv/yr)		
Toddler	**Child**	**Adult**
0.20	0.21	0.08

6.2.3 Transportation of Fuel, Reagents and Supplies

6.2.3.1 Frequency analysis

The frequency of transportation of fuel is approximately two orders of magnitude greater than that of yellowcake transportation. Therefore, it is expected that the frequency of traffic accidents (rollover or crash) be two orders of magnitude larger than the frequencies for the yellow cake. Section 4.3.2 provides the frequencies of spill near water (due to roll-over or crash) that can be up to 3×10^{-4} per year for diesel fuel, and 2×10^{-4} per year for sulphur on the longest routes. The frequencies are more than an order of magnitude lower (with a maximum of 2×10^{-5} per year) for other materials as the quantities transported are much lower.

The frequency of release of fuel (from tanker or fuel bunker) during marine transport was estimated at 0.027 per year.

6.2.3.2 Impact Assessment

As indicated before due to the following physical-chemical properties, diesel fuel has been selected as the bounding chemical for spill to land and water.

- Fuel is a liquid that can disperse on the surface of water.
- Diesel fuel is classified as suspected carcinogen by International Agency for Research on Cancer (IARC).
- Diesel fuel is relatively persistent in the aquatic environment.
- Diesel Fuel is not soluble and results in greater chance of exposure for terrestrial receptors
- The quantity and the frequency of diesel fuel transportation is greater than the majority of the chemicals

This section provides an overview of mitigative measures and an assessment of potential environmental effects of release of large amount of diesel fuel in water bodies such as Baker Lake. AREVA has extensive spill prevention plans in place for fuel spills. These plans include the use of containment structures such as booms and temporary berms. Field monitoring is also in place whereby AREVA personnel and the operator of the transportation truck or vessel have to be with the truck while the fuel is being handles. This results in quicker response times in case there is a spill. In the event of a spill, oil absorbent materials may be deployed. If the spill is beyond the capability of AREVA, AREVA may contact an external spill responder for assistance.

6.2.3.3 Surface Water Resources

A spill of fuel to water may result in a change in surface water quality. Following a fuel spill, steps will be taken to reduce and mitigate the local impact of the spill by containing the plume with fuel containment booms and collecting the fuel from the surface of the water. Lake water sampling will also be conducted to monitor the movement of the spilled fuel and its potential to cause an adverse effect on the environment. After clean-up, all collected fuel will be stored, or disposed of safely in accordance with applicable regulations.

The spill is expected to be relatively small temporally and spatially, and no lasting residual effect is expected from this accident scenario, however, as a result of this fuel spill, there may be environmental effects experienced on the aquatic environment.

6.2.3.4 Aquatic Environment

Spill response measures can be hampered for variety of reasons including severe weather conditions. In this case, the plume of spilled fuel may disperse or be washed away from the spill site before it can be completely contained. Eventually any residual fuel will be moved toward the shoreline. With respect to the fish exposure, during the daytime the fish population density is very low compared with the population at the depths greater than 2 m because of the exposure to high energy environment at the surface. During the night, the fish population move to the higher depths. This will allow a timely clean up of the residual fuel from the surface of water while the fish exposure is minimal.

Following a spill, the fuel may be washed to the shoreline where the benthic exposure is possible. The wave action makes the nearshore zone at Baker Lake Dock or Chesterfield Inlet is unfavourable for benthic communities. For the areas with higher densities of benthic invertebrates, the population of such communities, as well as rooted aquatic plants, are expected to recover after the cleanup is completed.

As opposed to the crude oil, diesel fuel does not leave viscous or high density residues on the shore lines that could physically coat the ecological receptors body.

The low exposure characteristics of fuel spill the area allow for timely cleanup of oil residues that are washed to the shorelines.

Therefore, long-term exposure of the aquatic species is not expected from this scenario.

6.2.3.5 Human Health

If the spill cannot be contained locally, the plume of spilled fuel may move toward the intake of a drinking water system. Protection of the drinking water system against a potential fuel spill will involve a multiple-barrier approach that includes:

- Preventive measures to reduce the likelihood of a fuel spill from occurring;
- Mitigative measures to contain the spilled fuel; and
- Notification to the operators of nearby drinking water supply plants for appropriate action.

Advanced notification procedures will be in place to inform applicable drinking water supply plant operators of any spill where there is potential for the contamination of the drinking water supply. The notification will ensure that the operator has adequate time to take precautions and appropriate actions before the plume of spilled fuel reaches the intake of the drinking water supply plant system. The limited nature of the spill that would result from this scenario would add an additional level of protection against contamination concerns.

Adverse effects resulting from a fuel spill on the quality of a community's drinking water are very unlikely and any effects would be mitigated prior to reaching the water supply of those in the community. There are no residual effects anticipated as a result of this scenario.

6.2.4 Fire and Explosion

6.2.4.1 Frequency analysis

Section 4.3.2 provides the frequencies of fire and explosion for various routes. (due to roll-over or crash) that can be up to 1.6 x 10^{-6} per year for diesel fuel, and 2.1 x 10^{-6} per year for ammonium nitrate on the longest routes. The frequencies are more than an order of magnitude lower for other materials as the quantities transported are much lower.

6.2.4.2 Impact Assessment

The following section provides an assessment of potential effects to the environmental components from the bounding fire and explosion as well as the spill of the fire water spill.

6.2.4.3 Surface Water Resources

It is assumed in this scenario that very little of the fuel and deluge water mixture reaches the surface water due to the location of the storage tanks. All of the oil in this case would be spilled to the ground. Some of the spilled oil may reach water bodies via the stormwater pathway. It is anticipated that overflow of the secondary containment system for the storage tanks would be collected by stormwater management systems.

6.2.4.4 Aquatic Environment

In case some oil reached the surface water during a fire, the effects will be bounded by the fuel spill scenario discussed in the previous section.

6.2.4.5 Terrestrial Environment and Human Health

If a fuel truck is involved in a fire, it is anticipated that during a fire, atmospheric release will originate from the diesel fuel and tires of the truck.

In case of a fire following a fuel transportation accident scenario, all efforts would be made to extinguish the fire as rapidly as possible in order to prevent releases to the atmospheric environment. Where possible, berming will be used to contain the firewater, and the direction in which the water is directed will take into consideration the surrounding environment. Following the extinguishing of the fire, cleanup and remediation activities will be undertaken to remove any ground surface that may have been contaminated by the fire water. As this work will begin immediately, it is expected that full cleanup of the surrounding environment will be possible following this accident scenario.

The burning of fuel oil is largely accepted to result in short-term effects at close vicinity of the fire provided that measures are put in place to stop the fire as rapidly as possible in order to minimize the extent of the smoke plume. As a result of the rapid response and the ensuing mitigation measures that will be put in place, it is not expected that there will be residual effects from this scenario.

Environment Canada (EC) cites in-situ burning of oil spills to water as an effective clean-up method, despite the visible smoke plume. Tests for air and water quality during oil burns were completed and it was found that levels of most of the substances that were released through the in-situ burning of crude oil were below human health limits within 500 meters downwind of the source.

7.0 SUMMARY AND CONCLUSION

7.1 CONSEQUENCES OF ROUTINE OPERATION

Potential consequences of routine operation were discusses in Section 6.1. Such impacts are limited to external radiation dose to human receptors in close proximity of yellowcake containers. In the absence of an accidental release, none of the ecological species will be exposed to yellowcake during transportation. Routine transport of fuel and reagents has minimal exposure of humans and ecological receptors..

Various receptors and exposure scenarios were defined for this analysis. Receptors included a forklift operator loading drums of yellowcake into a sea-container, a truck driver transporting a sea-container, a pilot transporting a sea-container, driver of a heavy duty forklift, and a member of the public living near the storage area.

The external dose assessment was performed using MicroShield Version 8.02. The results indicated that the radiation doses estimated for routine operations were below the guideline of 1 mSv/y for all members of public. The forklift operator and truck driver at Kiggavik will not receive radiation doses higher than that accepted for a Nuclear Energy Worker (NEW), i.e., 20 mSv/y.

7.2 ACCIDENT ASSESSMENT

The assessment of risk of transportation of yellowcake, fuel, and reagents involved the assessment of probability of accidents scenarios and the assessment of the impacts of the bounding scenarios that would serve to illustrate the most severe potential consequences. The bounding scenarios are selected based on the following aspects.

- Frequency of the occurrence
- Quantity of hazardous substances involved
- Duration and potential spatial extent of releases to the environment
- Magnitude of the effect on the environment

7.2.1 Transportation of Yellowcake

7.2.1.1 Frequencies

The combine frequencies of crash and rollover along the haul route between the Kiggavik Site and the airstrip was 4.7×10^{-5}.

The in-flight crash frequency of air transport into a large lake was 1.1×10^{-4} per year for Kiggavik- Points North (year round).

7.2.1.2 Consequences

7.2.1.2.1 Routine Operation

Table 6.7 provides the annual dose for all human receptors. The maximum annual dose was for the forklift operator (4.1 mSv).

The CNSC (2000) radiation dose limit for a member of public is 1 mSv per year (over natural background levels). The guideline for a NEW is 100 mSv for five years (i.e., an average of 20 mSv/year). The radiation doses estimated for routine operations in this section are below 1 mSv/y for all members of public.

The forklift operators and truck driver at Kiggavik (Scenarios 1, 2, & 4) will be NEWs; they will not receive radiation doses higher than accepted (i.e. 20 mSv/y) from these operations.

7.2.1.2.2 Accidents (ecological Receptors)

Table 6.11 and Table 6.12 present the results of the aquatic and terrestrial radiological assessments under the different RBE assumptions (10 and 40) for the various River, Large Lake and Land scenarios involving truck, barge and aircraft accidents resulting in a yellowcake spill.

The results assessing exposure to uranium from the various yellowcake spills are summarized in Table 6.13 and Table 6.14 for aquatic species and Table 6.15 for terrestrial species.

The results of the aquatic and terrestrial radiological assessments under the different RBE assumptions (10 and 40) were presented for the large lake and land release scenarios involving aircraft accidents resulting in a yellowcake spill. The results indicated that the Screening Index (SI) values were exceeded in all scenarios for all aquatic species with respect to the lower reference dose at both RBE values (10 and 40). With respect to the higher reference dose, the SI values were not exceeded for predatory and forage fish species at both RBE values (10 and 40), but were exceeded in all cases for aquatic plants (leaves and roots) and benthic invertebrates. These results indicate that a spill of yellowcake into a large lake could potentially affect the populations of aquatic plants, benthic invertebrates and fish species. For fish species, only the more conservative lower reference dose was exceeded.

In addition to being exposed to water, benthic invertebrates reside in sediment, which represents another pathway of exposure to uranium. Uranium concentrations in large lake sediments resulting from a spill of yellowcake would not be high enough with respect to the SEL benchmark for adverse effects to be expected on benthic invertebrates. However, with respect to the LEL benchmark, benthic invertebrates may potentially be at risk in large lake sediments following an accident. While the LEL value is a reliable predictor of uranium sediment concentrations (<LEL value) that will not adversely affect benthic invertebrates, the SEL value is not considered reliable in predicting concentrations at which potential effects will be expected (>SEL value). At concentrations occurring between the LEL and SEL values (as is this case for most of the assessed scenarios), benthic invertebrates may potentially be adversely affected.

The SI values for terrestrial species, which include waterfowl (sandpiper, merganser and tundra swan) and caribou, were provided for large lake scenario, water, and caribou and arctic ground squirrel ingesting soil following a major accident on Land. The results indicate that the terrestrial species potentially at most risk would be the waterfowl, which have an aquatic based diet. The SI values for all three waterfowl were exceeded for the lower reference dose at both RBE values (10 and 40) following an accident into a large lake. However, at the higher reference dose the SI value at an RBE value of 10 was not exceeded for the merganser, which, unlike the sandpiper and tundra swan, does not consume benthic invertebrates. The SI values in all cases were below 1 for the caribou ingesting contaminated water (Caribou 1) and for the caribou (Caribou 2) and arctic ground squirrel ingesting contaminated soil.

With respect to waterfowl that have an aquatic based diet, the spill scenario would not result in potential risks of adverse effects to merganser while the tundra swan and especially the sandpiper may be at risk. The sandpiper would potentially be at risk when considering both the NOAEL and ENEV TRVs, as well as the tundra swan but with respect to the ENEV only.

It should be noted that, the frequencies of the accidents resulting in higher SI values are very low. And the effects are transient in nature and contained within local areas at the vicinity of the spill for most cases. It is expected that the environment fully recovers from such spills after the appropriate response and cleanup following each accident scenarios.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, the air transport crash scenario is unlikely, and may have major consequences. The risk was rated as low. In long-term and following a response to spill, no residual environmental effect is expected.

No significant adverse environmental effects is expected for the truck accident along the haul route between the Kiggavik Site and the airstrip as there is no water crossing along the route and any release to ground can be contained and cleaned effectively.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, this accident scenario is highly unlikely, with minor consequences. The risk is negligible and no residual environmental effects are expected.

7.2.1.2.3 Accidents (Human Receptors)

Predicted uranium concentrations in a large lake following a yellowcake spill would exceed the Canadian Drinking Water Quality Guideline (Health Canada 2008) for uranium (0.02 mg/L) under both scenarios. The guideline would be exceeded by 3 times in the case of a minor spill and almost 20 times in the case of a moderate spill.

The doses to a toddler and child would be twice as high as that to an adult under the spill scenario. In all cases, however, the dose estimates were well below (<1 mSv/yr) the Canadian Nuclear Safety Commission regulatory incremental dose limit of 1000 μSv/yr for members of the public as well as the Health Canada dose constraint limit of 300 μSv/yr. In case of adverse water quality following an accident, drinking water advisory will be in place to prevent the exposure of human receptors to contaminated water during the response to the spill.

7.2.2 Transportation of Fuel and Reagents

7.2.2.1 Frequencies

The frequencies of spill near water (due to roll-over or crash) can be up to 3×10^{-4} per year for diesel fuel, and 2×10^{-4} per year for sulphur on the longest routes. The frequencies are more than an order of magnitude lower (with a maximum of 2×10^{-5} per year) for other materials as the quantities transported are much lower. For small quantities of oil spill from vessels, the frequency of spill is 71 per billion barrels of oil transported.

The frequency of release of fuel (from tanker or fuel bunker) during marine transport was estimated at 0.027 per year.

The frequencies of fire and explosion for various routes can be up to 1.6×10^{-6} per year for diesel fuel, and 2.1×10^{-6} per year for ammonium nitrate on the longest routes. The frequencies are more than an order of magnitude lower for other materials as the quantities transported are much lower.

7.2.2.2 Consequences

7.2.2.2.1 Fuel Spill

A spill of fuel to water may result in a change in surface water quality. Following a fuel spill, steps will be taken to reduce and mitigate the local impact of the spill by containing the plume with fuel containment booms and collecting the fuel from the surface of the water. Lake water sampling will also be conducted to monitor the movement of the spilled fuel and its potential to cause an adverse effect on the environment. After clean-up, all collected fuel will be stored, or disposed of safely in accordance with applicable regulations.

With respect to the fish exposure, during the daytime the fish population density is very low compared with the population at the depths greater than 2 m because of the exposure to high energy environment at the surface. During the night, the fish population move to the higher depths. This will allow a timely clean up of the residual oil from the surface of water while the fish exposure is minimal.

Following a spill, the fuel may be washed to the shoreline where the benthic exposure is possible. The wave action makes the nearshore zone at Baker Lake Dock or Chesterfield Inlet is unfavourable for benthic communities. For the areas with higher densities of benthic invertebrates, the population of such communities, as well as rooted aquatic plants, are expected to recover after the cleanup is completed.

As opposed to the crude oil, diesel fuel does not leave viscous or high density residues on the shore lines that could physically coat the ecological receptors body. In addition, the spill is expected to be relatively small temporally and spatially, and no lasting residual effect is expected from this accident scenario, however, as a result of this fuel spill, there may be environmental effects experienced on the aquatic environment.

Therefore, long-term exposure of the aquatic species is not expected from this scenario.

As for the human receptors, if the spill cannot be contained locally, the plume of spilled fuel may move toward the intake of a drinking water system. Protection of the drinking water system against a potential fuel spill will involve a multiple-barrier approach that includes:

- Preventive measures to reduce the likelihood of a fuel spill from occurring;
- Mitigative measures to contain the spilled fuel; and
- Notification to the operators of nearby drinking water supply plants for appropriate action.

Adverse effects resulting from a fuel spill on the quality of a community's drinking water are very unlikely and any effects would be mitigated prior to reaching the water supply of those in the community. There are no residual effects anticipated as a result of this scenario.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, the fuel (or other reagents) spill into the surface water during marine transport is likely during the lifetime of the project. However, the consequences will be moderate. The risk was rated as moderate in short-term. In long-term and following a response to spill the consequences are minor and the risk is rated as low, no residual environmental effect is expected.

A crash into a small lake may have larger consequences requiring significant clean up effort. However, the likelihood of such accident is highly unlikely.

7.2.2.2.2 Fire and Explosion

In case some oil reached the surface water during a fire, the effects will be bounded by the fuel spill scenario discussed in the previous section. If a fuel truck is involved in a fire, it is anticipated that during a fire, atmospheric release will originate from the diesel fuel and tires of the truck.

In case of a fire following a fuel transportation accident scenario, all efforts would be made to extinguish the fire as rapidly as possible in order to prevent releases to the atmospheric environment. Considering all mitigating activities, it is expected that full cleanup of the surrounding environment will be possible following this accident scenario.

The burning of fuel oil is largely accepted to result in short-term effects at close vicinity of the fire provided that measures are put in place to stop the fire as rapidly as possible in order to minimize the extent of the smoke plume. As a result of the rapid response that is expected to extinguish the truck fire, and the ensuing mitigation measures that will be put in place, it is not expected that there will be residual effects from this scenario.

According to the criteria provided in Table 1.1, Table 1.2, and Table 1.3, the fire and explosion accidents are highly likely during the lifetime of the project. The environmental consequences were judged to be minor to moderate. The risk was rated as low and no residual environmental effect is expected.

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