Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 8B:
Radiation Protection Supporting Document

September 2014

History of Revisions

Revision Number	Date	Details of Revisions
01	December 2011	Initial release Draft Environmental Impact Statement (DEIS)
02	September 2014	FINAL Environmental Impact Statement

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Abbreviations

AADNC	Aboriginal Affairs and Northern Development Canada
ALARA	As Low As Reasonably Achievable
BEIRS	Biological Effects of Ionizing Radiations
CED	Collective Effective Dose
CED/T	Collective Effective Dose per Tonne of U_3O_8 Production
CNA	Canadian Nuclear Association
CNSC	Canadian Nuclear Safety Commission
DJ	Dominique Janine
DP	Dominique Peter
DNA	Deoxyribonucleic Acid
ERA	Ecological Risk Assessment
HHRA	Human Health Risk Assessment
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
km	Kilometer
M Kg	Million Kilograms
M lbs	Million pounds
mSv	milliSievert
NNWS	Non-Nuclear Weapons State
Sum C	Saskatchewan Uranium Miner's Cohert
TMF	Tailings Management Facility
U	Uranium
U_3O_8	Uranium Concentrate
UNSCEAR	United Nation Scientific Committee on the Effects of Atomic Radiation
UV	Ultraviolet
WL	Working Level
WLM	Working Level Month
γ	gamma

1 Introduction

1.1 Approach to Radiation Protection Supporting Document

Uranium is a naturally occurring radioactive material which has been mined in Canada since the 1930s however the Kiggavik Project (Project) proposes to be the first uranium mining operation in Nunavut. The effects of radiation exposure on human and environmental health are a key concern related to the mining of uranium. AREVA has endeavored to provide relevant radiation exposure and protection information to stakeholders for their consideration in the evaluation of the Project.

Exposure of workers and the public to radioactivity has undergone extensive evaluation within the *Human Health Risk Assessment* (HHRA, presented in Volume 8 and Appendix 8A), and the planned operational activities to manage radiation exposures and keep doses to radiation as low as reasonably achievable (ALARA), are described within the *Radiation Protection Plan* for the Kiggavik Project (Appendix 2Q). Exposures to environmental components are addressed within the *Ecological Risk Assessment* (ERA, presented in Appendix 8A).

This *Radiation Protection Supporting Document* is written to provide supplementary information to address interests expressed by stakeholders during public consultation activities conducted by AREVA. The information presented in this supporting document is drawn primarily from publically available sources and references have been provided to connect stakeholders with a variety of national and international organizations concerned with radiation protection.

1.2 Issues Identified in Stakeholder Engagement

Project-specific issues and concerns identified during Inuit, government and stakeholder engagement broadly include a number of topics related to radiation exposure.

Those topics addressed within the *Human Health Risk Assessment* are:

- Potential health hazards of uranium[1],[2];

[1] EN - BL HS Nov 2010: *What can happen to the body after prolonged exposure to radiation?*

- Radiation monitoring of people and areas in the open pits, underground mines and mill[3],[4];
- Radiation doses to workers and the public[5];
- Radiation monitoring off site[6];
- Radiation dose limits, reporting and controls in place to protect people[7];
- Background Radiation;
- By-products of uranium mining and its potential effects to environment and people[8];
- Properties of Uranium concentrates [9],[10]e.g. radiation properties, hazards, protection of workers and public during transport, storage and transfer of Uranium concentrates;
- Properties of uranium[11], e.g. types of radiation emitted, radon daughters, detection, internal and external hazards, ability to explode, units of measure;
- Regulation of uranium mining in Canada and Nunavut[12]; and,
- Potential impact of uranium entering the food chain[13],[14], e.g. plants, caribou, humans.

Those topics addressed within this supporting document are:

- History of uranium mining in Canada[15];
- Radiation protection performance in Saskatchewan, including AREVA's operating experience at Cluff Lake and McClean Lake;
- Past uranium miners health studies[16];
- Nuclear Non-proliferation[17]; and,
- Alternative uses of Uranium, e.g. medical and cancer treatments.

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[2] EN - CH HS Nov 2010: *What is the main sickness for uranium mining?*

[3] EN - CI OH Nov 2013: *Radiation of underground workers vs open pit?*

[4] EN - KIV OH Oct 2009: *Working in the mill, what about radiation?*

[5] EN - RB OH Nov 2010: *How much radiation does a driller receive?*

[6] EN - CH OH Nov 2010: *Radioactive dust will travel downwind to Rankin Inlet.*

[7] EN - BL OH Oct 2012: *What will you do to protect worker's health?*

[8] EN - RI KIA Apr 2007: *So the tailings, are they more of a health hazard?*

[9] EN - RB HS Nov 2013: *How dangerous is it itself?*

[10] EN - BL NIRB APR 2010: *Concerns about the storage of concentrated uranium at the dock in Baker Lake and potential impacts to people.*

[11] EN - CH OH Oct 2012: *What is a dangerous amount of radiation?*

[12] EN - CI KIA Feb 2010: *How often would inspections occur?*

[13] EN - RI KIA Apr 2007: *I rely on caribou and fish. Does that mean I will get sick more?*

[14] EN - WC KIA Apr 2007: *Are you prepared to mitigate fish contamination?*

[15] EN - WC OH Nov 2013: *About 20 years ago I heard of uranium miners getting cancer?*

[16] EN - KIV OH Oct 2009: *Have there been any health studies done in terms of people who work in the mines?*

[17] EN - RB NIRB Apr 2010: *The community would like to know what the uranium will be used for.*

2 Uranium Mining Experience in Canada

2.1 Early Uranium Mining in Canada

Uranium mining began in Canada on the shores of Great Bear Lake in the Northwest Territory at Port Radium in 1933. The uranium ore was mined to extract radium, a radioactive decay product of uranium, used in the treatment of cancer (Bothwell 1984). At that time, uranium was considered a waste product and discarded. In 1940, during World War II, the Port Radium mine began providing uranium for research purposes to develop the first nuclear weapon by allied forces. Through the 1940s and 1950s, the demand for uranium was driven by military needs, and by research in the development of nuclear power. The Port Radium mine continued to produce uranium until 1960. It re-opened and produced silver from 1964 to 1982, when it was closed. Remediation of the site was completed in 2008 [AADNC 2011].

Similarly, in Ontario, radium was extracted from ores in the Bancroft area in the 1930s and subsequently uranium was extracted in the 1950s through to the 1980s. The Elliot Lake area in Ontario became an active uranium producer in the 1950s. Uranium was produced from several production centres in these areas through to 1996 when the last mine at Elliot Lake was closed (CNA 2010).

2.2 Uranium Mining In Saskatchewan

The first mining of uranium ores in northern Saskatchewan began in the 1950's, in the area around Beaverlodge Lake. At one point, there were several mines, both large and small, in the Uranium City area. Mines on the north shore of Lake Athabasca operated up until 1982. Through the 1970s and 1980s, new uranium mines were developed in the Athabasca Basin, south of Lake Athabasca. The Rabbit Lake mine began production in 1975, followed by the Cluff Lake Mine in 1980 and the Key Lake Mine in 1983. Production from Rabbit Lake continues today from ores mined at Eagle Point, and the Key Lake mill continues production from ore extracted at McArthur River. After 22 years of operation, the Cluff Lake Mine ceased production in 2002 and has subsequently been decommissioned (CNA 2010).

McArthur River is the largest high-grade uranium deposit in the world. McArthur River began production mining in 1999 and has produced 191 Mlbs of U_3O_8 (Uranium Concentrate commonly referred to as Yellowcake) to date. The average grade of McArthur River ore is over 15% U_3O_8. Remotely operated equipment is used to mine the deposit to reduce worker exposure to high grade ore. The ore is processed at the Key Lake mill located about 80 kilometers south of the McArthur River mine (Cameco 2011).

The McClean Lake mine site, operated by AREVA, began uranium ore mining in 1995 and mill processing began in 1999 with ore extraction from several open pit mines. The McClean Lake mill has been designed to receive high-grade ore from the Cigar Lake mine site. Production from Cigar Lake is anticipated in 2014.

Cigar Lake is the second largest high-grade uranium deposit in the world. Ore mined at Cigar Lake will be transported by road to the McClean Lake mill as a slurry in specialized transport containers. The Cigar Lake deposit has an average grade of approximately 17% U_3O_8.

3 Radon Exposure

Section 3 demonstrates the advancement of radon knowledge in mining and how radiation protection has evolved to the point where uranium mining is amongst the safest and best regulated of the resource industries.

3.1 Radon

Radon is a gaseous decay product of uranium which is released from uranium ore. Radon release is found everywhere due to the ubiquity of uranium. Radon and its progeny can be inhaled, giving the recipient an internal source of radiation exposure. Approximately 50% on the natural background radiation dose in Canada is due to naturally occurring radon gas exposure. Uranium mining potentially exposes workers to higher levels of radon gas. To protect workers from radon exposure, ventilation systems are used. In mining, radon levels in workplaces have been typically measured in terms of Working Levels (WL) and exposures calculated in terms of Working Level Months (WLM), that is, a WLM is the radiation dose received from exposure to 1 WL for a working month of 170 hours. These historical units are still used in Canada and other countries. Currently, radon exposures in units of WLM are converted to units of effective dose, in mSv, using the dose conversion factor of 1 WLM = 5 mSv. The ICRP has recently indicated that, based on updates to epidemiological studies, the dose conversion is likely to change by a factor of 2 to approximately 1 WLM = 10 mSv.

3.2 Standards Development

The health and safety standards employed in the uranium mines of the past reflected the understanding of radiological conditions in the mines at the time. Smaller mines had no, or limited, mechanical ventilation systems and as a result radon-222 progeny concentrations in the earliest era of mining would have been very high. Measurements of radiation levels and exposures were limited during the early era of uranium mining and government regulations were minimal. Through the 1930s and 1940s, radiation exposure limits were set to avoid directly observable effects.

As governments and the Canadian uranium mining industry became aware of the hazards presented by radiation exposure, particularly to concentrations of radon-222 progeny in Canadian uranium mines, working conditions in the mines began to improve. In the 1950s, exposure limits were developed to limit the incidence of cancer and hereditary effects. It was in the 1950s, as a result of epidemiological evidence from Japanese atomic bomb survivors, that the concept of keeping doses as low as reasonably achievable (ALARA) was developed and implemented (ICRP 2007). Correspondingly, improvements were made in government regulatory standards and in radiation safety practices throughout the Canadian uranium mining industry. The summary document "*Setting*

Radiation Requirements on the Basis of Sound Science: The Role of Epidemiology" (CNSC 2011a) has been prepared by the Canadian Nuclear Safety Commission (CNSC) to describe how the nuclear regulator has considered health research in the development of radiation protection standards in Canada.

The occurrence of health effects in people exposed to radiation led a group of concerned radiobiologists and physicists to create the International Commission on Radiological Protection (ICRP) in 1928. Since that time, the ICRP has developed, and continues to develop, concepts and philosophies which provide for the safe management of activities involving the use of ionizing radiation.

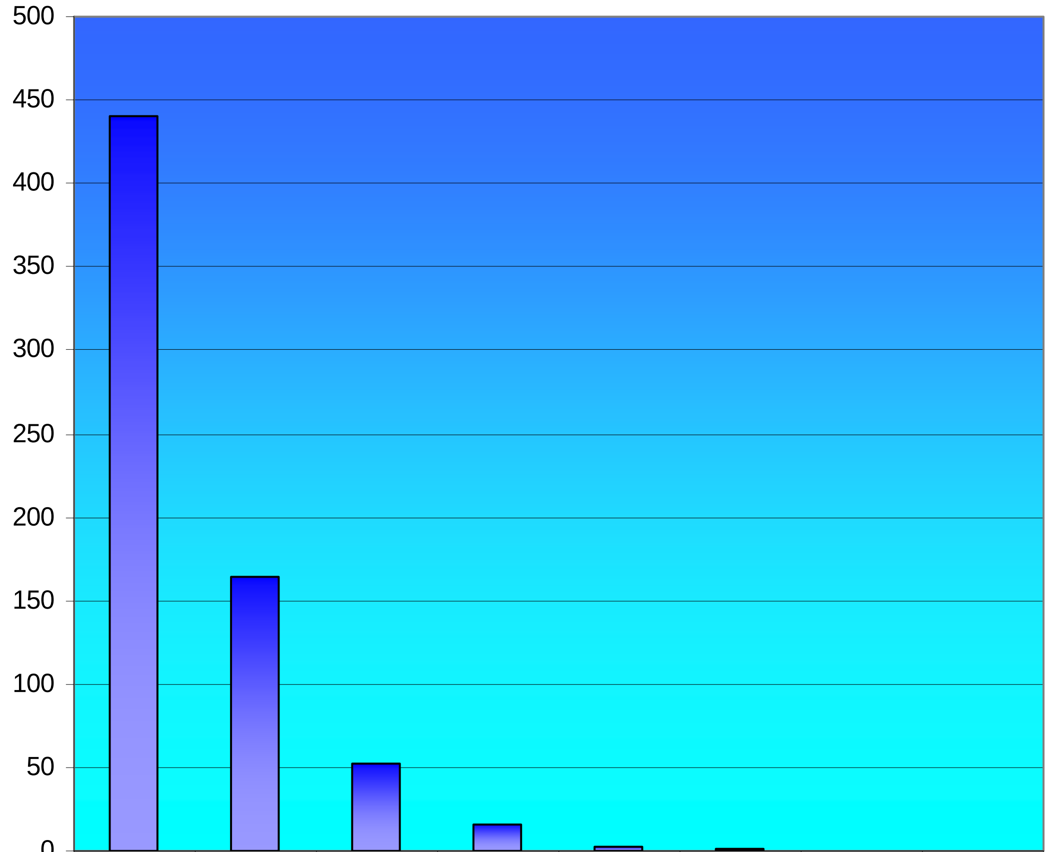
The ICRP has published a number of documents recommending measures to be incorporated in national regulations on radiological safety and providing practical guidance for users of ionizing radiation. ICRP publications reflect the latest scientific knowledge and evidence about the effects of radiation on living organisms. These ICRP publications are revised periodically as the science of radiation protection advances. The ICRP updated its general recommendations most recently in 2007 (ICRP 2007). It is the ICRP recommendations which establish the basic principles of radiation protection, as well as radiation dose limits for workers and the general public.

In Canada, standards for radiation protection are established within the Radiation Protection Regulations, administered by the CNSC. Generally, the CNSC adopts the advice provided by the ICRP within its regulations.

3.3 Improvements in Radon Exposure

Figure 3.1 below presents average annual radon progeny exposures in Canadian underground miners beginning in the 1940s, through to the modern era of mining. Over that period, radon progeny exposures have been reduced by a factor of 1000. These improvements have been achieved by:

- Installing mechanical ventilation to provide the mine with clean air, and remove contaminated air,
- Installing ducting to the work areas to carry, and remove, air to the places where it is most needed,
- Establishing dose limits for workers,
- Developing standards for workplace air quality,
- Monitoring the air quality at various locations in the mine to ensure the work atmosphere is maintained at acceptable levels, and
- Monitoring radon progeny exposures to individual workers using personal alpha dosimeters.



	1940s	1950s (Early)	1950s (Late)	1960s	1970s	1980s	1990s	2000s
Radon (WLM)	440	164	52	16	2.3	0.8	0.5	0.4

Radon Exposure (WLM)

Information extracted from: INFO-0813, Radon and Health, Canadian Nuclear Safety Commission, March 2011.

Figure 3-1 Radon Exposure in Canadian Uranium Mines

3.4 The Eldorado Cohort Study

A cohort is a group of people who have had an exposure to a risk factor, and are then followed over a period of time to be observed for a particular health effect. Various cohort studies of uranium miners have been conducted to examine the relationship between exposure to radon decay products and the risk of lung cancer. The Eldorado cohort study is an important Canadian study which has examined the exposure of Eldorado employees to radiation, in particular radon decay products, and evaluated the relationship between exposure and disease, in particular, lung cancer. Eldorado operated uranium mines at Port Radium in the Northwest Territories and at Beaverlodge Lake near Uranium City in Northern Saskatchewan, as well as a uranium refinery and conversion plant in Port Hope, Ontario. The Eldorado cohort study began in the 1980s and now includes a cohort of 17,660 Eldorado uranium workers employed between 1932 and 1980. To continue to improve our understanding of radiation risk, radiation exposure cohort studies are periodically updated as new information becomes available. The most recent update to the Eldorado uranium workers study followed up through 1999 and was recently published in Radiation Research (Lane 2010). The study reported an excess of lung cancer in miners from the early era of uranium mining relative to the general Canadian population.

3.5 Feasibility of the Modern Saskatchewan Uranium Miners Cohort

Previous epidemiological studies of miners occupationally exposed to radon decay products have indicated a relationship between lung cancer risk and radon exposures. Radon exposures in Saskatchewan mines since 1975 are present but at much lower levels than in the previous studies. For example, the average radon decay product exposure to male workers in the Eldorado uranium miners' cohort study was 100 WLM (Lane 2010); miners in the operating uranium mines currently are anticipated to receive less than 1 WLM of exposure (SENES 2003).

The Saskatchewan Uranium Miner's Cohort (SUMC) Study Group commissioned a study to assess the feasibility of an epidemiological study on miners working at the Cluff Lake, Rabbit Lake, McArthur River, Key Lake and McClean Lake mine sites (SENES 2003).

The study used simulations to evaluate a hypothetical cohort of individuals to predict the number of expected lung cancers resulting from anticipated radon exposures using an excess relative risk model. Results were compared to baseline lung cancer risk.

The study concluded that:

- Given the low occupational exposures and the risk model considered in this study, the modeled excess risk to modern-day miners attributable to radon exposure was small compared to the baseline lung cancer risk.

- With perfect information on exposures and correct baseline lung cancer rates, there is almost no chance that an epidemiological study would detect a statistically significant excess risk due to radon exposures.

3.6 Canada's Contribution to International Studies

The Eldorado study has made an important contribution to the understanding of radiation exposure internationally. The United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has included it amongst 10 other miner studies conducted worldwide on the effects of radon decay product exposure (UNSCEAR 2008). The work of UNSCEAR contributes to the development of recommendations for the protection of workers and the general public made by the International Commission on Radiological Protection. Similarly, the Eldorado cohort study was pooled with other studies in Canada, and international studies, within the report "Health Effects of Exposure to Radon" prepared by committee on Biological Effects of Ionizing Radiations (NAS 1999).

4 Radiation Protection Performance in Uranium Mining

Workers at uranium mine sites whose workplace radiation exposure is anticipated to exceed the dose limit for the general public are classified as Nuclear Energy Workers. The *Radiation Protection Regulations* (CNSC 2000a) and the Uranium Mines and Mills Regulations (CNSC 2000b) prescribe requirements for measurement of radiation doses and workplace exposure rates. Results of radiation protection monitoring are routinely reported to the Canadian Nuclear Safety Commission and made available to the public. Additionally, Health Canada maintains the National Dose Registry, which contains radiation dosimetry information for occupationally exposed persons in Canada, including the uranium mining sector. Radiation dosimetry is conducted by third party service providers and entered into the National Dose Registry. Mining companies are required to provide radiation dose measurement results to their workers and any individual may request their own dose history directly from Health Canada.

4.1 Sources of Information on Radiation Protection Performance

People have expressed concerns, during community engagement, regarding *perceived risks involving uranium mining* (EN – BL NIRB Apr 2010[18], IQ - RIJ 2011[19],[20], EN – BLOG Dec 2010[21], EN – WC OH Nov 2013[22], EN – RI OH Nov 2012[23]). Sections 4.2 - 4.3, extracted from CNSC documents as well as the National Dose Registry, provide insight into the modern day uranium mining industry.

The radiation protection performance of uranium mining is monitored by the Canadian Nuclear Safety Commission (CNSC) and made public through several publications, including:

- Nuclear industry reports, such as:

[18] EN – BL NIRB Apr 2010*: If this mine goes ahead it will employ people, but need to protect and mitigate impacts to the environment and workers.*

[19] IQ – RIJ 2011: *Concerns with the health risks associated with uranium mining and AREVA's resistance to reveal negative impacts of the mining process.*

[20] IQ – RIJ 2011: *A community member noted that they are not necessarily against mining but they want a clear understanding on uranium and its dangers.*

[21] EN – BLOG Dec 2010: *Is it safe to work at a uranium mine?*

[22] EN – WC OH Nov 2013: *About 20 years ago I heard about uranium miners getting cancer. Will that happen here? People will be afraid because they have heard uranium causes cancer.*

[23] EN – RI OH Nov 2012: *Is it hazardous to mine?*

    - INFO-775, Occupational Dose Data for Major Canadian Nuclear Facilities (CNSC 2009b)
- Sector specific reports, such as:
    - Annual Report on Uranium Management Activities (CNSC 2009c)
- Special publications describing industry regulation and performance, such as:
    - Uranium Mining: Facts on a Well-Regulated Industry (CNSC 2009a)
    - INFO-0813, Radon and Health (CNSC 2011b)

Each year, Health Canada publishes “Report on Occupational Radiation Exposures in Canada” which tabulates radiation exposures from all industry sectors.

4.2 Observations from CNSC Publications

The following observations have been extracted from CNSC publication *Uranium Mining: Facts on a Well-Regulated Industry* (CNSC 2009a) and are the Canadian nuclear regulators own observations on uranium mining:

- *Studies demonstrate that present-day uranium workers, and the public living near a uranium mine or mill, are as healthy as the general Canadian population.*
- *While underground mine workers receive the highest radiation doses, in 2008, the average annual dose to miners was 4.0 mSv and the maximum dose was 10.9 mSv, well below acceptable dose limits.*
- *Risk of getting lung cancer from working in current uranium mines is low because current radon exposures are low; therefore, the risk is low and is comparable to the risk of the general Canadian population.*
- *Studies have shown that uranium mining and milling activities do not increase radon levels above background levels in the environment away from the mine site.*
- *Studies and monitoring have shown there are no significant impacts to the health of the public living near uranium mines and mills.*
- *Strict environmental monitoring programs identify and manage environmental effects and keep them limited to mine and mill areas.*

The following observations are extracted from the CNSC Publication *INFO-0813: Radon Quick Facts* (CNSC 2011b):

- *Long-term exposure to elevated levels of radon increases the risk of developing lung cancer, which is why the CNSC ensures that the air quality in a uranium mine is strictly controlled with good ventilation.*
- *Current uranium mines require engineering design and control processes to evacuate radon in order to limit exposures to safe levels.*

- *As a result, the lung cancer risk for today's uranium mining and processing workers is the same as that for the general Canadian public.*
- *Presently, worker exposures to radon in the uranium mining and processing industry are as low as, or only slightly greater than, public exposure from natural radon.*
- *The level of radon in the environment near uranium mines is similar to radon levels monitored in background locations.*
- *Radon exposure to members of the public from CNSC-regulated activities is virtually zero.*

4.3 Observations from Health Canada Publications

The National Dose Registry is a centralized radiation dose record system maintained by the Radiation Protection Bureau of Health Canada. It contains radiation dose information from many different occupations, including doses from the nuclear energy industry, university research, medical occupations, and other occupationally exposed workers. The Canadian Nuclear Safety Commission requires radiation exposures in uranium mines to be monitored and results reported to the National Dose Registry. Workers can request a report of their dose history from Health Canada at any time.

Each year, Health Canada publishes a report on occupational radiation exposures in Canada which includes statistical summaries of radiation doses received in all occupations. From the most recent report, it is observed that:

- The average annual dose received in the uranium mining industry was less than the dose limit set for members of the general public of 1 mSv.
- The average dose to underground miners was approximately 2.5 mSv.
- Approximately 50% of the radiation dose received by the uranium mining industry is from radon gas exposure.
- There has been a decreasing trend in worker doses for the 10 year period from 1997 to 2006, presented in Table 4.1.

Table 4-1 Radiation Exposures in Uranium Mining 1997 to 2006

Job Category	Statistic	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Uranium mine electrician	# Workers		8	16	8		4			1	25
	Average (mSv)		0.18	0.27	0.15		0.00			0.05	0.04
Uranium mine mill maintenance	# Workers	169	186	207	185	162	183	209	309	310	448
	Average (mSv)	2.71	2.13	1.36	1.68	1.66	1.24	1.01	0.85	0.68	0.45
Uranium mine mill worker	# Workers	256	272	306	273	258	249	260	274	285	240
	Average (mSv)	2.62	2.05	1.47	2.03	2.10	1.66	1.35	1.59	1.00	1.19
Uranium mine nurse	# Workers	10	18	24	17	14	11	13	14	23	27
	Average (mSv)	0.16	0.24	0.06	0.11	0.11	0.11	0.21	0.17	0.04	0.09
Uranium mine office staff	# Workers	140	177	196	179	170	149	145	223	286	422
	Average (mSv)	0.23	0.19	0.24	0.18	0.16	0.17	0.15	0.16	0.10	0.08
Uranium mine support worker	# Workers	153	296	467	327	176	143	144	230	350	348
	Average (mSv)	3.51	1.79	1.29	1.19	1.11	1.37	1.77	1.21	0.89	0.88
Uranium mine surface maintenance	# Workers	224	222	287	207	190	203	231	301	385	1010
	Average (mSv)	0.51	0.57	0.51	0.61	0.81	0.49	0.47	0.42	0.27	0.20
Uranium mine surface miner	# Workers	245	116	108	88	47	46	42	36	73	158

Job Category	Statistic	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	Average (mSv)	0.93	0.73	0.59	1.34	2.15	1.53	1.19	0.45	0.83	0.30
Uranium mine surface personnel	# Workers	123	164	222	187	177	173	182	232	280	384
	Average (mSv)	0.31	0.52	0.41	0.64	0.61	0.41	0.52	0.34	0.33	0.18
Uranuim mine surface support worker	# Workers	352	375	302	296	335	331	369	568	795	1303
	Average (mSv)	0.65	0.60	0.30	0.30	0.28	0.19	0.17	0.15	0.12	0.10
Uanium mine underground maintenance	# Workers	103	137	204	195	115	128	158	142	190	210
	Average (mSv)	1.49	1.13	0.92	0.70	0.46	0.74	1.01	1.00	0.60	0.57
Uranium mine underground miner	# Workers	353	361	344	284	161	196	273	206	258	371
	Average (mSv)	6.05	3.27	3.13	2.57	2.29	2.65	2.74	3.71	1.73	1.74
Uranium mine underground personnel	# Workers	340	213	150	110	72	82	97	94	125	132
	Average (mSv)	0.92	0.92	1.08	0.89	0.49	0.77	1.07	1.31	0.60	0.67
Uranium mine visitor	# Workers	249	306	399	185	132	151	120	10	53	61
	Average (mSv)	0.13	0.06	0.10	0.21	0.41	0.34	0.14	0.05	0.02	0.02
	# Workers	2717	2843	3216	2533	2009	2045	2243	2639	3413	5114
	Total (mSv)	4943	3594	3245	2745	2003	1895	2186	2351	1826	2134
	Average (mSv)	1.82	1.26	1.01	1.08	1.00	0.93	0.97	0.89	0.53	0.42

Reference: Health Canada, 2008 Occupational Exposure to Radiation

The collective effective dose (CED; i.e. the sum of all doses to all workers) attributable to mining activities for the period 1997 to 2006 is plotted in Figure 4.1, together with the collective effective dose per tonne of U_3O_8 production (CED/T). The downward trend through the late 1990s illustrates both a decline in radiation exposure and increase in mining productivity on a dose basis. The lower level of collective dose has been maintained due to the increased production from low-dose open pit sources, and the mining of high grade underground deposits at the highly productive McArthur River mine using remote mining techniques.

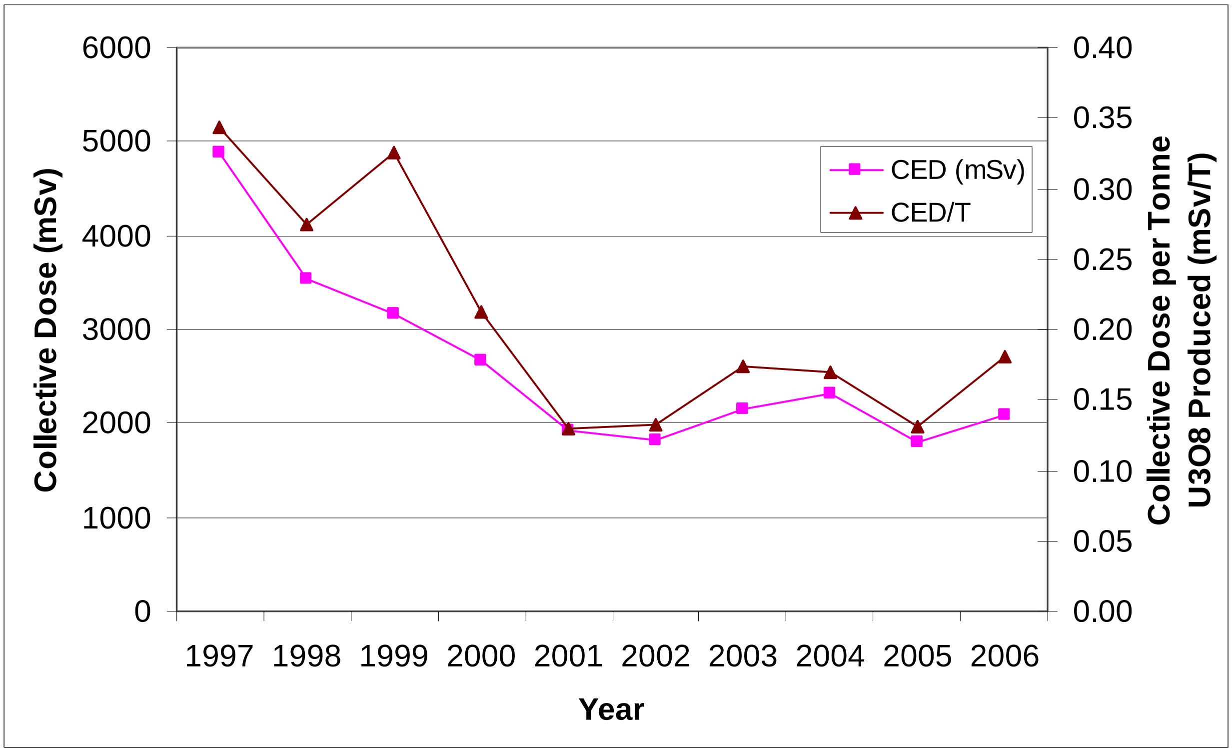


Figure 4-1 Summary of Collective Dose Statistics 1997 to 2006 (AREVA 2007)

5 AREVA's Operational Experience in Canada

AREVA has operated two uranium mine sites in northern Saskatchewan, at Cluff Lake and McClean Lake. Both operations have demonstrated optimization of radiation doses through the ALARA principle. The sections which follow provide a brief history of the sites, radiation dose trends coinciding with the period of the 2008 Health Canada report discussed in Section 4, and examples of ALARA initiatives conducted to optimize radiation exposures.

5.1 Cluff Lake

5.1.1 Overview

Cluff Lake is located in the Athabasca Basin of northern Saskatchewan, approximately 75 km south of Lake Athabasca and 15 km east of the Alberta border. The mine site, which commenced uranium production in 1980, included a mill, 4 open pit deposits and 3 underground mines. In 2002, after 22 years of operations producing a total of 62 M lbs of U_3O_8, ore reserves were depleted and the Cluff Lake Operation was subsequently decommissioned.

Open pit operations used conventional drill, blast, muck and haul techniques. Open pit operations started in 1979 with the D Pit and continued through August 1997 until completion of open pit mining with the extension of the Dominique Janine pit. All mining activities post August 1997 took place underground. Table 5.1 provides a summary of uranium mining parameters for each of the deposits.

Table 5-1 Open Pit Mining Production at Cluff Lake Operation

Open Pit Deposit	Years in Operation	Grade (%)	Production (TU)
D mine	1979-1981	2.954	4,447
Claude mine	1982-1989	0.33	2,348
Dominique Janine North (DJN)	1988-1991	0.317	646
Dominique Janine Extension (DJX)	1994-1997	0.299	1,182

Underground mining operations began at Cluff Lake in 1983 with the development of the OP mine. The method employed underground was a conventional underhand cut-and-fill stoping method. In this entry mining method, miners worked within the active stopes and in relative close proximity to the ore. Only small openings are created and were then backfilled before further openings were developed to their side or below them. Among the underground workforce, miners spend the most time at the stope face, thus represented the group of underground workers with the highest potential for radiation exposure. Table 5.2 summarizes mine production values for the underground mines.

Table 5-2 Underground Mine Production Values at Cluff Lake Operation

Underground Mine	Years in Operation	Average Grade (%)	Production (TU)
OP	1981-1984	0.363	173
Dominique Peter (DP)	1984-1999	0.803	9,309
Dominique Janine (DJU)	1994-2002	1.296	5,681

5.1.2 Radiation Protection Performance

Radiation protection performance of the Cluff Lake Operation for the 10 year period leading to the completion of production in 2002 is presented in Figure 5.1. Average doses over the period were reduced by approximately 50% while the collective dose to the work force was sharply reduced beginning in 1997 with the implementation of a dose reduction strategy, discussed in the next section. Collective dose values are used to capture the overall radiation exposure, which results from an activity. The collective effective dose value is normalized using a measure of production to evaluate the productivity of an activity in radiation protection terms, i.e. collective radiation dose per unit of production.

Figure 5-1 Radiation Protection Performance for the Cluff Lake Operation

5.1.3 Dose Reduction Strategy: Cluff Lake Underground Operations

In 1997, the maximum exposed worker, an underground miner, received a dose of 31 mSv. At the time, the Atomic Energy Control Regulations limited worker radiation doses to no more than 50 mSv per year. With the adoption of recommendations made by the ICRP (ICRP60), enacted by the Radiation Protection Regulations which came into force in 2000, annual radiation doses to workers were limited to no more than 50 mSv per year, and an additional limit of 100 mSv over a 5 year span was applied. In anticipation of the regulatory change, and at the demand of the nuclear regulator, AREVA (then COGEMA) implemented an ALARA strategy to reduce the maximum value to less than 17 mSv and drive downward the total collective dose to the workforce. The focus was specifically on reducing underground miners' gamma exposure. Gamma exposure dominated the underground workforce and miners' exposure to radon progeny and long lived radioactive dust were found to be low and well controlled; exposure to gamma radiation was higher and more variable.

Cluff Lake's strategy shifted from limiting miner exposure to gamma from a daily administrative limit (as previously done) to procedures based on workplace measurements and engineering controls. These procedures incorporated engineered dose reduction measures that related to ventilation improvements, reduction of gamma exposure, increased mechanization and added shielding features.

This strategy was based on six milestones which included:

1. An internally established maximal annual individual dose target of 17 mSv for the underground miners (a 45 % dose reduction compared to the highest individual dose of 30.7 mSv in 1997);
2. A new procedure for *Limiting Miner Exposure to Gamma Radiation During Stope Advance* based on the engineered dose reduction measures and the 17 mSv dose target;
3. A new Procedure for *Limiting Miner Exposure to Baseline Gamma Radiation in the Mine*;
4. A daily maximum administrative limit for gamma of 0.11 mSv and a corresponding operational guideline of 0.09 mSv;
5. An annual target ratio collective dose to mine production of 1.2 person.mSv/tU;
6. An increase in mechanization of the mining operation, and
7. Strategic use of spray-on concrete (aka shotcrete) to provide shielding from gamma radiation, that is, operations staff balanced the radiation dose saved through the application of shotcrete with the radiation dose received by workers applying the shotcrete.

In brief, the two procedures listed above related to engineering controlled mining activities and shielding options at the stope face in proximity to the ore, in the stope access ramps and around the general mine site. Both consisted of a set of action levels for gamma radiation that triggered the type of equipment and/or shielding to be used.

The Radiation Protection framework included operational reviews, i.e., formal weekly exposure meetings and training. Worker dose estimates were calculated for internal control purposes, i.e. compliance with Code of Practice (COP) and ALARA assessment. Table 5.3 depicts reductions in doses for workers.

Table 5-3 Comparison of Underground Worker Effective Doses

Year	Maximum Effective Dose for UG Worker (mSv)	Collective Dose/Tonnes U Mined (person.mSv/tU mined)
1997	31	1.6
1998	14.7	1.07
1999	14.8	0.8
2000	14.8	0.3
2001	11.9	0.17

The key engineered measures that led to the reduction in doses included:

- Ventilation improvements (e.g., bulkhead construction/repairs and ventilation equipment and configuration);
- Reduction of gamma radiation in stopes and stope accesses (e.g., shotcrete on walls and ceilings, clean up residual mucks on roadbeds, and roadbed placement);
- Increased mechanization: mini-jumbo drill and other mini-jumbo applications (e.g., shotcrete placement, utility vehicle, and explosives loading);
- Steel shielding plate on scoop; and
- Mobile steel plates for shielding.

5.1.4 Results

The rapid and successful implementation of this strategy lowered the radiation dose to underground workers to a maximum annual individual dose of approximately 15 mSv. In addition the underground workforce collective dose with corresponding target ratio per tonne of uranium mining production of 1.2 person.mSv/tU. In comparison, the maximal 1997 individual dose was about 31 mSv and the ratio of the collective dose per tonne of uranium production was about 1.6 person.mSv/tU.

5.2 McClean Lake

5.2.1 Overview

The McClean Lake ore body was discovered in 1979, followed by the discovery of the JEB ore body in 1982. Subsequent exploration has identified a cluster of deposits, named Sue A through Sue E, as well as the Caribou deposit. Open pit mining of the JEB ore body began in 1995 and, once the ore was removed, the JEB pit was developed as a tailings management facility (TMF). Open pit mining of the Sue C ore body began in 1997, followed by mining of the Sue A, E and B deposits.

The JEB mill at McClean Lake was constructed between 1995 and 1998 to process the ore from the JEB and Sue deposits, as well as the McClean Lake orebodies, Midwest, and Cigar Lake mines. Ore grades from the Cigar Lake mine will range up to 30% uranium, with a nominal grade of approximately 20% uranium. The JEB mill, designed with radiation protection features for processing high grade ores, uses a leaching and solvent extraction recovery process to extract and recover a uranium product from ore.

Open pit mining operations started in 1995. Open pits already mined are listed below along with production dates:

Open Pit Operation	Ore Production (Years)	Average Grade (% U)	Production (Tonnes U)
JEB	1995-1997	1.413	2,068
Sue C	1997-2002	2.15	14,033
Sue A	2005-2006	0.64	684
Sue E	2005-2008	0.79	3,797
Sue B	2008	0.41	624

5.2.2 Radiation Protection Performance

Radiation protection performance for the McClean Lake Operation for past 10 year period is presented in Figure 5.2. Though the annualized dose limit for workers in uranium mining is 20 mSv/year, the average doses over the period have been maintained at or below the dose limit or 1 mSv/year set for members of the general public. The McClean Lake mill has the benefit of radiation protection design features, which reduce radiation exposures primarily through engineering controls rather than work practices. Efforts in the optimization of radiation protection have focused on evaluating work practices to ensure individual doses are maintained ALARA, as discussed in the next section.

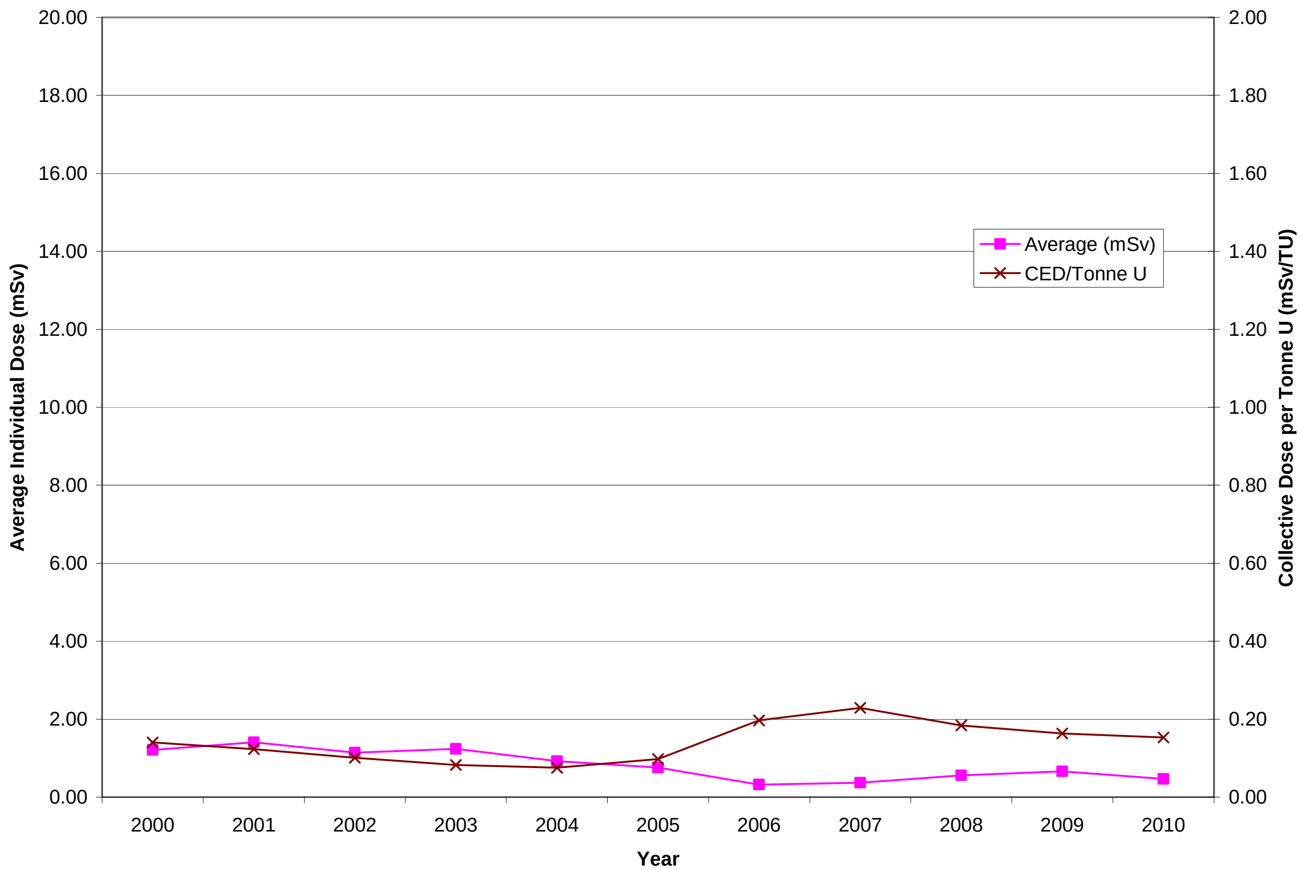


Figure 5-2 Radiation Protection Performance for the McClean Lake Operation

5.2.3 ALARA in Practice: Optimizaton in the McClean Lake Mill

The mill reached full production by 2000. From 2000 through 2005, the mill produced approximately 2.7 M kg of U_3O_8 (6 M lbs) per year from ores which have ranged from 2.9 % U in 2000 to 1.2 % U in 2005. Collective worker doses related to the mill operations ranged from 250 mSv to 160 mSv during this period. It was observed that approximately 60% of the collective dose was attributed to four 'front-end' production areas: mill feed, ore receiving and grinding, leaching and counter current decantation. In the front-end production areas, the uranium is present with its decay products, including radium, radon and radon decay products. In the back-end circuits, these decay products have been removed resulting in a less hazardous process solution.

The mill design includes several features to protect workers from external gamma radiation and airborne radioactive materials such as enclosed slurry handling and processing systems and state of the art shielding and ventilation features. AREVA has committed through its policy on radiation protection to keep doses to radiation as low as reasonably achievable, social and economic factors considered. In enacting this policy, as series of dose reduction studies were conducted at the McClean Lake mill to identify opportunities to further reduce worker exposure to radiation. Though radiation doses during operations to date have been well below regulatory limits, benefits from dose reduction efforts are expected to be magnified by future production scenarios, which include higher ore grades and production levels.

The continual process of dose evaluation and reduction efforts focused primarily on the 'front-end' production areas as the majority of the collective dose was attributed to these areas. Radiation Protection staff evaluated radiation exposures from the three major contributors: external exposure to gamma radiation, and internal exposure from inhalation of long-lived radioactive dusts (LLRD) and radon progeny (RnP).The evaluation activities were generally as follows:

1. A review was conducted of the routine radiological monitoring data collected since mill start-up in June 1999. Gamma, radon progeny, and long-lived radioactive dust data were reviewed to identify trends with ore grade and time.
2. Additional radiometric measurements were conducted to evaluate specific sources identified within the mill area.
3. A review of worker dosimetry information was conducted to evaluate the contribution from each dose component (gamma, RnP, LLRD).
4. Job observations were conducted by radiation protection staff to determine the time taken to conduct each activity and quantify the corresponding exposures.
5. Interviews were held with operators and supervisors to better understand the activities conducted in the each mill area.
6. From the job observations, the highest exposure activities were targeted for potential improvements and evaluations were conducted to estimate the impact of the potential dose reductions.

5.2.4 Results

At McClean Lake, radiation exposures began at very low levels, and have been maintained at these low levels throughout the operating history to date. Post-2005, production levels at the facility decreased to less than 50% of the pre-2005 levels. The downward trend in collective effective dose (CED) indicates a reduction in overall worker exposure, however the slight increase in CED per tonne illustrates that this overall radiation dose is insensitive to the change in production level and, as a result, the CED/tonne increases because of the reduction in the denominator.

Recommendations for reducing radiation exposure primarily involved changes to facility and equipment design, reducing time in radiation areas, reducing dose rates through strategic placement of shielding features such as lead wrapping, improving work practices and use of specialized detection equipment. Further, the evaluation process contributed to worker education, awareness and participation.

Overall, conducting the evaluation of process areas has brought a better understanding of ALARA to all personnel as the process of optimizing radiation protection. From these evaluation activities, personnel at McClean Lake Operation can identify specific examples of ALARA at work.

5.3 Conclusions

The following general conclusions can be made based on AREVA's uranium mining experience in Canada.

- AREVA has experience in operating underground and open pit mining operations, and in milling the ores to produce a concentrate.
- AREVA has applied the principle of radiation dose optimization at both the Cluff Lake and McClean Lake Operations to keep doses as low as reasonably achievable.
- Control of radiation exposures through facility design, planning and work procedures attains worker doses well below the dose limit set by the Canadian Nuclear Safety Commission.

6 Sources of Radiation Protection Educational Information

6.1 IAEA

The International Atomic Energy Agency (IAEA) has developed a variety of educational and training resource materials, programs and activities in radiation protection and nuclear safety. The IAEA offers materials online and delivers on-site training programs.

Information on IAEA education and training can be found at: http://www-ns.iaea.org/training/

6.2 CNSC

The Canadian Nuclear Safety Commission has developed a collection of educational resources specifically relating to the nuclear industry in Canada. Resources are developed for all age groups.

Information on CNSC education and training can be found at:

http://nuclearsafety.gc.ca/eng/educational-resources/index.cfm

6.3 CNA

The Canadian Nuclear Association is an industry association, which provides educational resources for student and training modules for instructors through its website. The CNA also publish resource materials on the nuclear industry in Canada.

http://www.cna.ca/curriculum/cna_general_res/

7 Uses of Uranium and Ionizing Radiation, Apart from Nuclear Energy

The following information is summarized from the AREVA publication, All About Nuclear Energy (Barre 2003).

7.1 Medical Uses of Radiation

Radiation is used in three main medical fields:

- Radiology. This concerns X-ray photography, in which rays penetrate the body and are absorbed to varying degrees depending on the density of tissues encountered;
- Radiotherapy, for targeted destruction of tumors. Cancer cells reproduce more quickly than healthy cells; therefore the metabolism of their DNA is much more intense, and the fragility of the molecules with regard to irradiation makes them more sensitive to brief exposure to high doses of radiation. There are several types of radiotherapy: external irradiation with X-rays, electron accelerator, or internal irradiation using cesium, iridium, etc. The tricky part is to precisely deliver the dose to the tumor without damaging healthy tissues;
- Nuclear medicine. Radioactive medicinal drugs injected into patients are specifically trapped by the organs studied. An image is obtained by simply placing the body in front of detectors called "γ-cameras": this is called radioisotope scanning. With the same process, one can deliver therapeutic doses, for instance by using iodine-131 to cure thyroid cancers.

7.2 Industrial Uses (Excluding Power Generation)

Radiation has many industrial applications, including:

- using radioactive material to examine welds (radiography);
- radiometric gauges are used to check the filling level in tanks, liquid levels, the thickness, density, or uniformity of a material;
- ionization detectors are used to reveal the presence of gases in the atmosphere;
- some materials can be toughened by industrial irradiation. This has applications in the field of medicine, textiles, plastics, wood, etc.
- industrial tracers are used to detect leaks and follow water flows,
- photosensitive products incorporated into paints, varnishes, inks, adhesives, and sealing compounds can be instantaneously cured or dried by exposure to UV irradiation. This not

only steps up the productivity of the shops concerned, but also enhances the mechanical strength of treated surfaces (examples: magazine covers, credit cards, posters, metal foil packing, industrial assemblies, etc.).

7.3 Food Processing

Food products can be ionized with gamma or X-rays to preserve them by sterilization. Some vegetable species have been improved by high-irradiation mutation (short-stemmed Italian corn, for instance). Irradiation treatments have been used to sterilize Tsetse fly populations and fight Sleeping Sickness.

8 Nuclear Weapons & Non-Proliferation

Canada does not possess nuclear weapons, nor does it intend to. This policy was announced by C.D. Howe, Prime Minister William Lyon MacKenzie King's cabinet minister in 1945 (HOC 1945), and has been consistent with each successive government since. Canada is committed to the peaceful use of nuclear energy.

8.1 Non-Proliferation

Canada is party to the Treaty on the Non-Proliferation of Nuclear Weapons (IAEA 1970) as a non-nuclear weapons state (NNWS). In accordance with this treaty, Canada has agreed to accept safeguards, administered by the International Atomic Energy Agency, on all nuclear material used in Canada's peaceful nuclear activities. Canada was the first country to bring the comprehensive safeguards agreement with the IAEA into force in 1972. Under safeguards agreements, Canada provides the IAEA with comprehensive information on Canada's nuclear industry and grants IAEA inspectors access to nuclear facilities for the purposes of monitoring of nuclear materials and activities. These safeguards agreements with the IAEA are in force in over 170 countries around the world. Canada, through the Canadian Nuclear Safety Commission, obliges nuclear facilities operators to safeguards through facility operating licences, The Nuclear Safety and Control Act and the Nuclear Non-proliferation Import and Export Control Regulations.

The CNSC has established an accounting and control system to monitor the transfer, import and export of nuclear materials, which contributes to IAEA monitoring of nuclear materials. Furthermore, Canada is obligated to ensure that nuclear exports to non-nuclear weapons States are subject to IAEA safeguards. CNSC document, "Nuclear Safety in Canada" (CNSC 2004) provides an overview of Canada's safeguard obligations and controls of non-proliferation.

8.2 Kiggavik Project

The uranium mines and mill proposed by the Kiggavik Project, as with all other uranium mine sites and nuclear facilities, will be subject to safeguard activities by the CNSC and IAEA, which include:

- Nuclear material accounting,
- Security of nuclear materials,
- Facility inspections, and
- Export controls.

9 Summary

Mining and processing of radioactive ores has been conducted in Canada since the 1930s. Over the history of uranium mining in Canada there has been continual improvement in the protection of workers from occupational hazards such as radiation exposure. Today, uranium mining is amongst the safest and best regulated of the resource industries.

The sources of radiation exposure and its effects are well understood and the system of radiation protection is mature and robust. Recommendations made by the International Commission on Radiological Protection are adopted in Canada and integrated into regulations, which govern the nuclear industry.

Canadian epidemiological studies have contributed to the understanding of radiation effects, especially those related to radon exposure in uranium mines. There has been a 1000 fold reduction in radon exposures in uranium mining over the past 70 years resulting in radon exposures to modern miners, which are only slightly greater than natural exposures.

AREVA has developed uranium mining experience in Canada through the Cluff Lake and McClean Lake Operations. The principle of optimizing radiation protection to maintain worker doses ALARA has been integrated into engineering design and work practices at AREVA, evidenced by examples of dose reduction activities at both Cluff Lake and McClean Lake Operations.

International organizations such as the International Atomic Energy Agency provide educational and training materials on the nuclear fuel cycle and on radiation protection. The Canadian Nuclear Safety Commission and the Canadian Nuclear Association provide similar materials.

In addition to the generation of nuclear power, uranium and other radioisotopes are used for medical diagnosis and treatment, several industrial uses, and in food processing.

Canada is committed to the peaceful use of nuclear energy. Canada has entered into safeguard agreements with the International Atomic Energy Agency to prevent the proliferation of nuclear weapons.

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