Environmental Impacts of Different Uranium Mining Processes

Government of Alberta

Environmental Impacts of Different Uranium Mining Processes

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Executive Summary

Canada is a world leader in uranium production. Currently, all Canadian production originates from Saskatchewan's unconformity deposits associated with the Athabasca Sandstone Basin. There is potential for uranium mine development in other Canadian provinces including Alberta as well as the territories. From available geological information, the primary potential in Alberta is in the north east, where the Athabasca Basin extends into Alberta, and in the south west where the potential for sandstone-hosted uranium deposits has been a focus of exploration activities. A third type of economic deposit may be discovered in the Canadian Shield region bordering the Northwest Territories.

A review of technological options for successful recovery of uranium from a yet-to-be discovered deposit in Alberta has been completed. The environmental control technologies applicable to conventional uranium mine development are outlined and evidence presented shows that Canadian advanced state-of-the art technologies and management practices result in high levels of protection of the public and the natural environment.

In Situ Leaching (ISL) technology, which is widely used in the United States and other countries, may be applicable to the recovery of uranium from potential sandstone-hosted deposits in southern Alberta. Although specific ISL technology has not previously been proposed in Canada, there is detailed information available from United States' experience that would be applicable in Alberta. It can be reasonably expected that the application of this American technology, adapted for site specific Alberta conditions, would result in a high level of environmental protection as well as safe conditions for workers and the general public.

Although licensing of nuclear facilities in Canada is primarily under the jurisdiction of the Canadian Nuclear Safety Commission (a federal agency), in addition to controlling all mineral exploration activities, the province of Alberta could play a key role in the Environmental Assessment process for any new facility. Also public consultation could involve significant input from Alberta Agencies. A proposal for an ISL or conventional uranium mine facility could be expected to be met with a variable level of public acceptance, which would require detailed explanation of the potential risks and benefits.

Supplying uranium for the generation of electricity consumers is an activity that Alberta can consider to meet the increasing energy demands, an activity that is also relatively low in greenhouse gas emissions. As nuclear energy regains acceptance in Canada and around the world, demand for uranium climbs, and with it so does the economic feasibility of uranium mining in Alberta.

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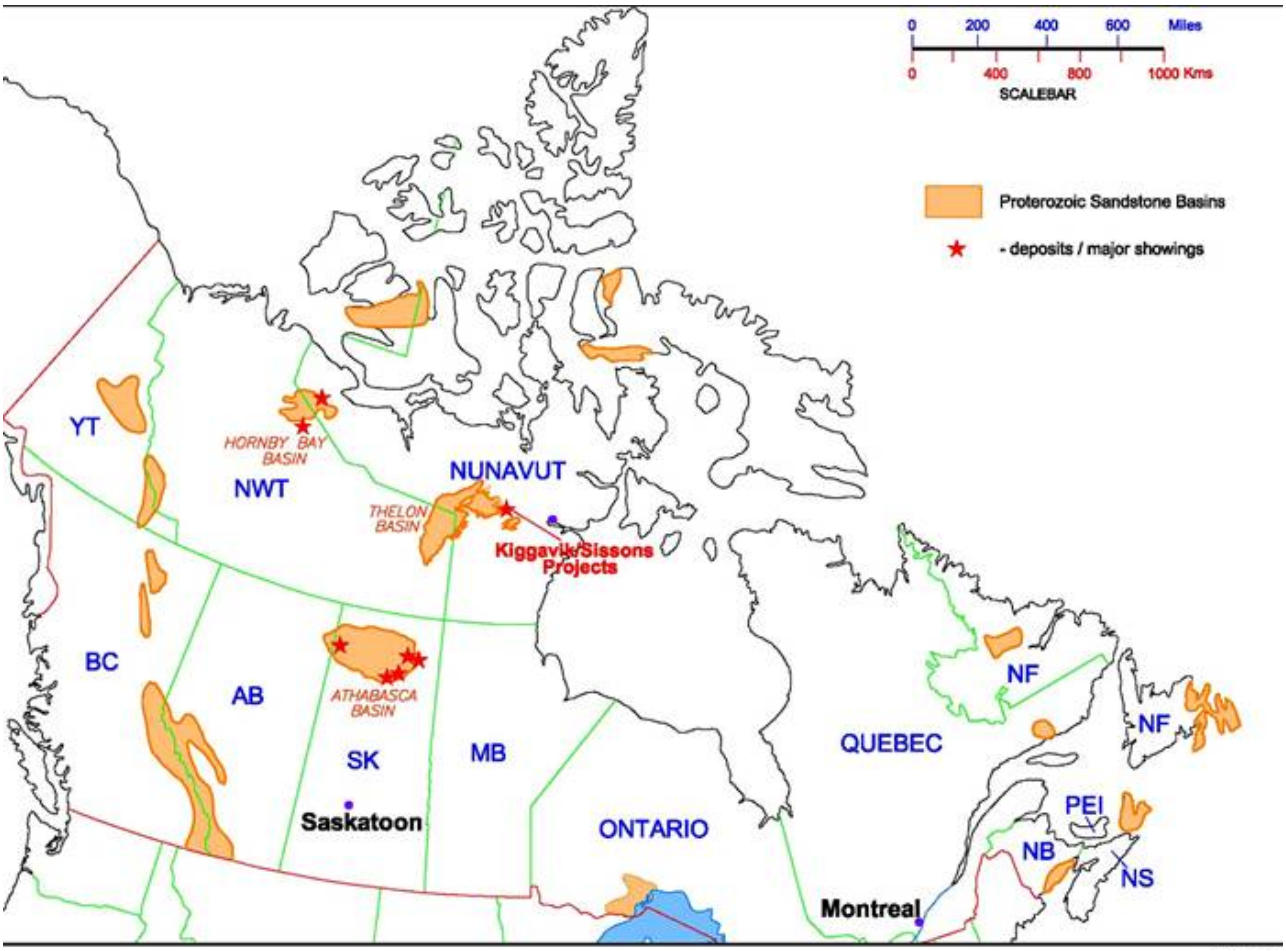
1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

With the recent and sustained increase in the price of uranium, as measured by the "spot" and long term delivery price for uranium (as U_3O_8) (currently greater than $90/lb), there has been a surge in exploration for uranium deposits in Canada and throughout the world. About 150 companies listed on Canadian stock exchanges include uranium in their exploration objectives. Forty-four companies have exploration properties in or near the Athabasca sandstone basin, the location of the world's highest known grade uranium mines and deposits.

Although there are other proterozoic basins in Canada (see Figure 1-1), to date, discoveries of high grade deposits (ranging up to over 20% U) have been limited to the Athabasca basin. Several lower grade discoveries and defined deposits are associated with the Thelon and Hornby basins, the best known being the Kiggavik and Scissons deposits in Nunavut that await development.

FIGURE 1-1
PROTEROZOIC SANDSTONE BASINS IN CANADA



The Athabasca basin extends from Saskatchewan into Alberta. The Alberta portion of the basin was subject to intense exploration in the 1970's, the last period when uranium prices were high enough, at $40/lb, to sustain interest from exploration companies and investors.

In light of renewed interest in uranium mine development in Alberta, this report provides a review of the environmental and permitting issues that may be associated with such a development for Alberta Environment.

1.2 PROJECT SCOPE

As requested by Alberta Environment (RFP #AB-2007-02825), this report covers the following related to the potential development of new uranium mines in Alberta:

(a) review of the state of current uranium exploration, mining and milling processes worldwide;

(b) identification of the possible processes to be pursued in Alberta;

(c) determination of the substances released during exploration, mining and milling, as well as the environmental impact and risks associated with these activities to air, water and groundwater and implications for soil reclamation and remediation;

(d) review of current national and international emission limits and environmental management approaches applicable to the sector for the emissions of concern;

(e) review of the latest technologies to control or mitigate the emissions of concern and all the related capital and operation costs; and

(f) recommendations regarding early wins and achievable options to reduce emissions while providing an economic benefit.

In addition, factors driving uranium mine development, such as nuclear energy development, were considered.

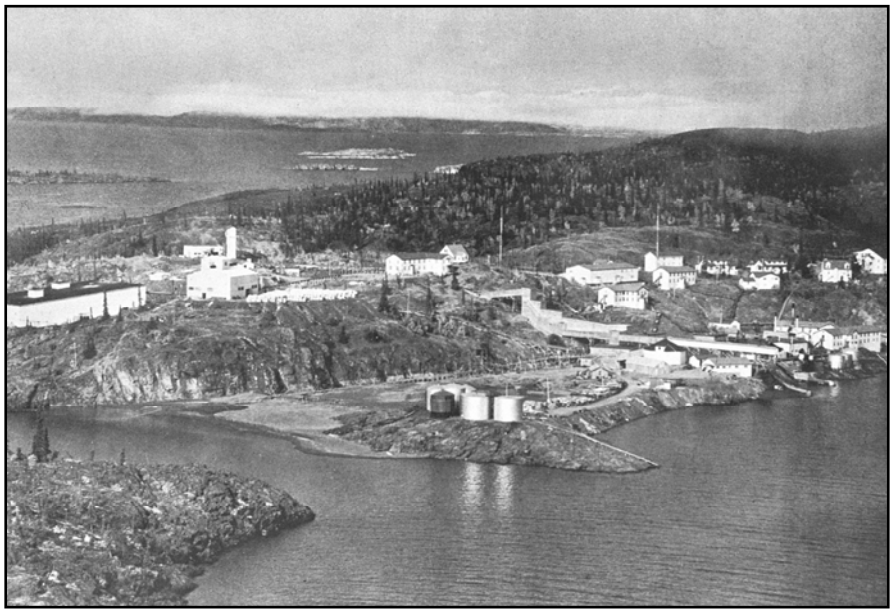
2.0 GLOBAL CONDITIONS OF THE URANIUM MINING INDUSTRY

2.1 HISTORICAL

The international uranium mining industry started in the 1930's with the development of a market for radium. Uranium mines were developed in Canada (Port Radium, Northwest Territories) and in the Belgian Congo. Uranium minerals from these mines were concentrated and shipped to refineries for the removal of radium. Radium, or ^{226}Ra, is the fifth radioactive decay element in the ^{238}U radioactive decay chain. The radium market later declined due to oversupply and the Port Radium mine was closed.

Later, with the development of atomic weapons, the demand for uranium increased dramatically. The government of Canada nationalized the Port Radium mine and it was reopened in 1944 (Figure 2-1). From that time until the early 1960's, the United States and European military demand for uranium was high and this fostered the development of uranium mines around the world. In Canada, this included the development of three uranium mining and processing operations at Uranium City, Saskatchewan, 10 mines at the Elliot Lake, Ontario camp, and three in the Bancroft area of eastern Ontario.

FIGURE 2-1
PORT RADIUM MINE, GREAT BEAR LAKE 1940's



The United States was the largest producer of uranium in the western world for 20 years (Figure 2-2). Canada has always been an important producer and presently produces the most uranium of any country in the world, including the former Soviet Block countries (Figure 2-3).

FIGURE 2-2
WESTERN URANIUM PRODUCTION

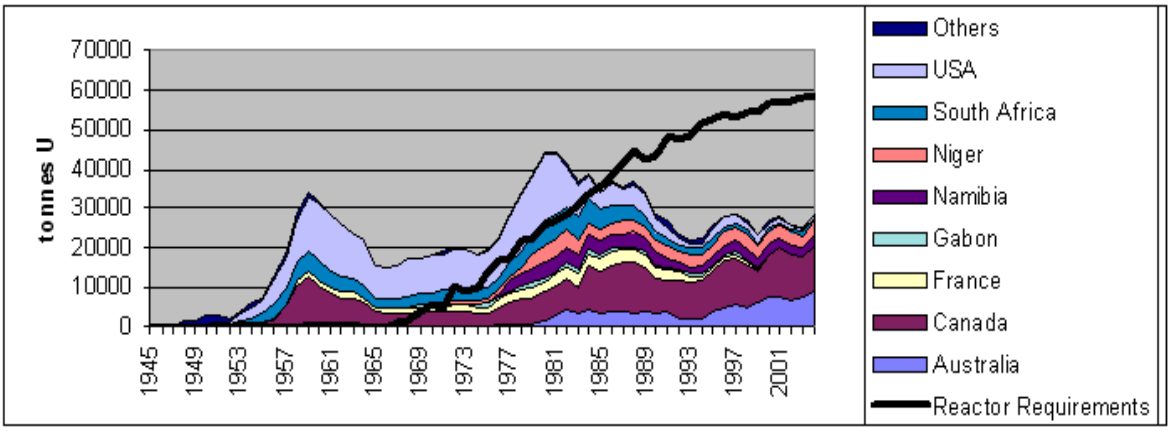
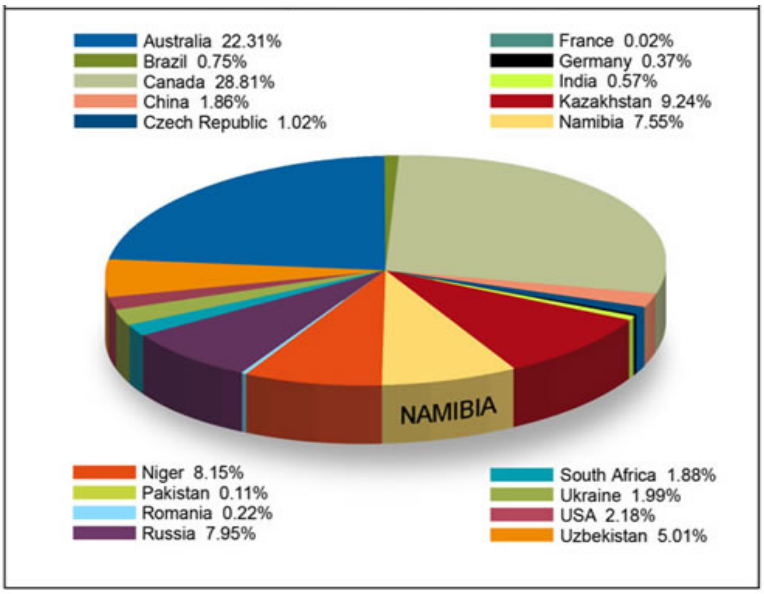


FIGURE 2-3
WORLD PRIMARY PRODUCTION OF URANIUM OXIDE



Courtesy Rio Tinto

Historically, Alberta has played an important role in Canadian uranium production. Mines in the Northwest Territories were supplied from Edmonton and Waterways (Fort McMurray) until the late 1970's. From 1984 to 1987, a process plant owned and operated by Earth Sciences Inc. recovered uranium as a by-product from a phosphoric acid plant in Calgary. This facility is currently subject to a Canadian Nuclear Safety Commission (CNSC) license to ensure long term monitoring and care.

2.1.1 Extraction Methodologies

Until 1980, uranium mining operations in Canada included one open pit mine (Gunnar, in Northern Saskatchewan) and 17 underground mine facilities. With the exception of the Gunnar mine located in the Uranium City, Saskatchewan area, all of these facilities have been closed out under CNSC licenses. A combination of *in-situ* leaching and surface heap leaching was attempted at the Agnew Lake uranium mine located 50 km east of the Elliot Lake, Ontario uranium camp. However, because of poor economics, the facility was closed out in 1983 and the property returned to the Province of Ontario[1].

Mining technology gradually evolved from hand operated equipment to mechanized drills and haulage equipment. Uranium was first recovered in a mill at Port Radium by gravimetric processes and hand cobbing. Pitchblende, the most common uranium mineral in ore, has a high specific gravity and responded reasonably well to jigs and sorting tables. Larger rocks were hand sorted. By the early 1950's, an acid leach plant was installed at Port Radium and the dissolved uranium was recovered by a solvent extraction processes, the first process of its kind in the world. In the 1960's, most of the other mines recovered uranium from ground ore by leaching it with sulphuric acid combined with an oxidant. The dissolved uranyl sulphate complex was contacted with ion exchange resins. After elution, uranium was precipitated from the concentrated solution with magnesia or ammonia. The resulting yellow product was dried and shipped to the Canadian refinery in Port Hope, Ontario. The exception to the acid leach process was an alkaline leach process at the Beaverlodge mine in northern Saskatchewan. Alkaline leaching was used at Beaverlodge because of the presence of high concentrations of carbonate minerals in the ore.

The mining and uranium recovery technologies used in Canada were historically used in all other uranium-producing countries in the world. Exceptions were the use of underground stope leaching in East Germany and *in-situ* leaching (ISL) facilities in Czechoslovakia and Kazakhstan.

2.1.2 Waste Management

Waste management practices at uranium mines have significantly evolved. Earliest practices disposed of mine water, tailings and waste rock in the most convenient way, often deposited on the ground or into nearby water bodies without treatment or containment. Gradually, the environmental impacts of waste management practices were given serious consideration in Canada and internationally, including the collection and treatment of effluents. In Elliot Lake,

[1] This is one of three former producing uranium mining properties that have been returned to the Crown. Others are Port Radium and Rayrock in the Northwest Territories.

Ontario, acid rock drainage (ARD) in uranium tailings became a serious environmental issue that required action. Acidification of the Serpent River watershed had occurred as a result of pyrite oxidation in exposed tailings. The successful remedy for the acid problem was the use of large quantities of lime, water covers over the tailings to prevent further oxidation and the treatment of contaminated waste streams to remove suspended solids, acidity and ^{226}Ra.

At many historic mine sites in Canada, regardless of the mineral that was being recovered, large quantities of wastes, principally tailings, remain on the surface. However, despite the minimal attention and care allocated to waste management at uranium mine sites in the early days, with the remedial measures that have been undertaken at these old mine facilities, the risks to people and the environment have consistently been assessed as small. Lessons learned include the need to:

- assess the chemical and physical aspects of solid and liquid mine wastes;
- provide long term containment for tailings;
- avoid mixing other wastes with tailings and waste rock;
- minimize the need for long term treatment and maintenance of structures;
- place mine wastes into mined-out pits, wherever possible; and
- design for closure.

There have been examples where groups and individuals opposed to uranium mining and nuclear energy have exaggerated the mistakes of the past. Images of poor practices coupled with allegations of health and environmental effects have resulted in public demand for moratoria on uranium exploration and mine development.

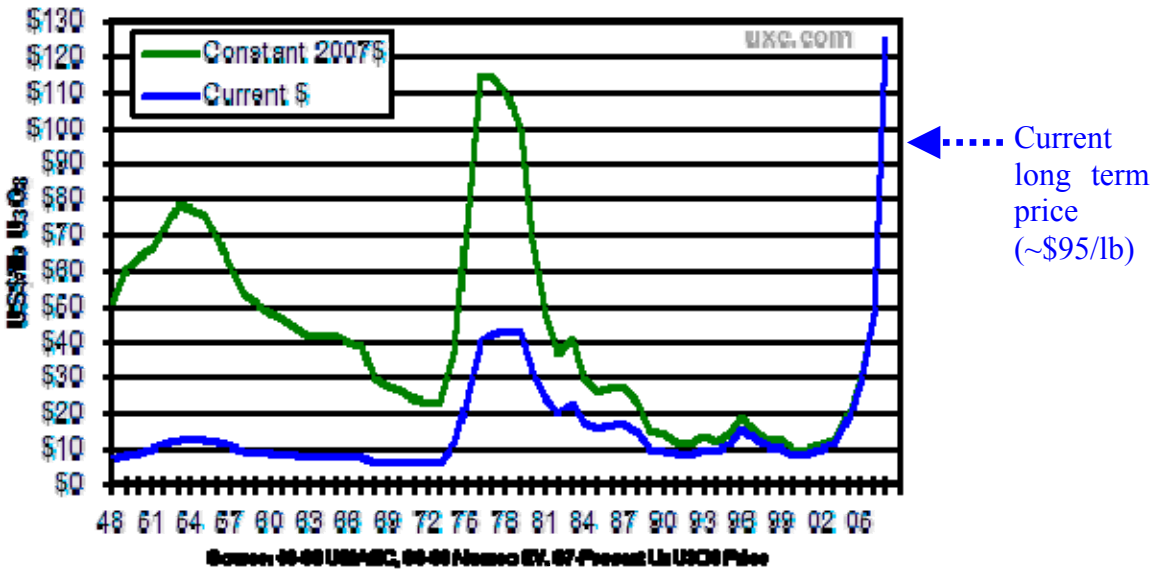
2.1.3 Health and Safety

Working conditions in the early uranium mines in Canada, as well as in other countries, have been recognized as inadequate compared to today's standards. This is particularly true with respect to air quality in historic underground mines where ventilation was inadequate. Radiological conditions (radon daughters as well as direct radiation) combined with tobacco smoking and siliceous dust resulted in negative impacts on the health of uranium mine workers. Similar poor working conditions also existed in the past in other types of mines such as gold, iron and fluorspar, resulting in negative health impacts. In contrast, modern uranium mines currently operating in Canada and around the world do so under much stricter control and monitoring of working conditions. These conditions are stipulated in operating permits and licenses issued by state authorities. In Canada, this control and monitoring is performed by operating companies and confirmed by provincial, territorial and federal agencies.

2.2 FACTORS PRODUCING THE CURRENT HIGH DEMAND FOR URANIUM

The principal factor that is causing the current high price for uranium is the predicted shortage in the supply of nuclear fuel for existing and planned nuclear reactors, and those currently under construction (Figure 2-2). The spot market price exceeded \$40/lb U_3O_8 in the 1970's, which is comparable to the current price of about \$90/lb when inflation is considered as shown in Figure 2-4.

FIGURE 2-4
HISTORICAL URANIUM PRICES[2]



2.2.1 Renaissance of Nuclear Energy

2.2.1.1 Acceptability - Nuclear versus Conventional Energy Sources

The generation of electricity using nuclear energy is regaining favour worldwide for several reasons, including:

- depletion of conventional sources of energy (e.g., gas and oil in the North Sea);
- concerns about cost of and dependence on fossil fuels from potentially unstable regions of the world;
- the need to reduce gaseous and solid emissions from conventional energy sources, particularly coal; and

[2] The Ux Consulting Company, LLC. (http://www.uxc.com/review/uxc_g_hist-price.html)

- the desire to reduce greenhouse gas (GHG) emissions.

Renewable energy sources, such as wind, wave and solar power, can be part of the electricity production mix. When compared to conventional thermal and hydroelectric sources, however, these renewable sources are hampered by fluctuating daily availability, typically low power generation capacity and site-specific public opposition based on social and environmental concerns (e.g., aesthetics, effects on biota, etc.). Nuclear power provides consistent availability (typically 85 to 95%), high generation capacity, and the possibility of being safely located close to large electricity consumers, eliminating long power line corridors.

Recently, the Government of the United Kingdom announced plans to expand the use of nuclear energy (U.K. Department for Business, Enterprise and Regulatory Reform, 2008) and a private-public sector consortium announced plans for a second nuclear power plant in New Brunswick (CBC News, 2008). The renewed interest in nuclear energy presents an opportunity for Canada, as it is the biggest producer of uranium oxide (Figure 2-3), and for Alberta, given the as-yet-undeveloped uranium deposits that lie within its borders (see section 2.3.1, below).

In August, 2007, Energy Alberta applied to the Canadian Nuclear Safety Commission (CNSC) for a Licence to Prepare a Site for the future construction and operation of a new nuclear power plant near the community of Peace River, Alberta (Canadian Nuclear Safety Commission, 2007a). This would be Alberta's first nuclear power facility. It is speculated that as much as 70% of the electricity produced would be used in the production of oil from the oil sands (Daily Commercial News and Construction Record, 2007).

On March 13, 2008, Bruce Power, which operates nuclear power plants in Ontario, announced the completion of acquisition of Energy Alberta (The Globe and Mail, 2008). Bruce Power also announced a $10-billion plan to build as many as four reactors in the Peace River district of Alberta.

2.2.1.2 Climate Change and Nuclear Power

Electrical energy produced from nuclear power plants results in negligible CO_2 emissions during operation and minimal emissions even when the full life cycle of the nuclear fuel and facilities is considered (mining, refining, power plant construction, operation and closure). A general comparison of the full life cycle GHG emission rates from various energy sources is shown in Table 2-1.

TABLE 2-1
GHG EMISSIONS FROM ELECTRICITY PRODUCTION[3]

Generating Technology	kg CO_2 equivalent*/MWH	
	Maximum	**Minimum**
Coal	1300	970
Oil	800	760
Natural Gas	670	440
Solar – Photo Voltaic	280	100
Wind	48	9
Hydroelectric – Reservoir	240**	16
Hydroelectric – Run of River	20	4
Nuclear	20	9

* CO_2 equivalents represent the sum of all GHG's (such as NO_X and SO_X where produced) calculated for their global warming potential, over the life of the facility.
**Calculated for a new facility in a tropical forest environment

While the precise GHG emission rate associated with nuclear energy production depends greatly on site-specific details, it is clear that the rate is less than that of other electrical generating styles, especially thermal generation.

2.2.2 The Transition in Sources of Uranium

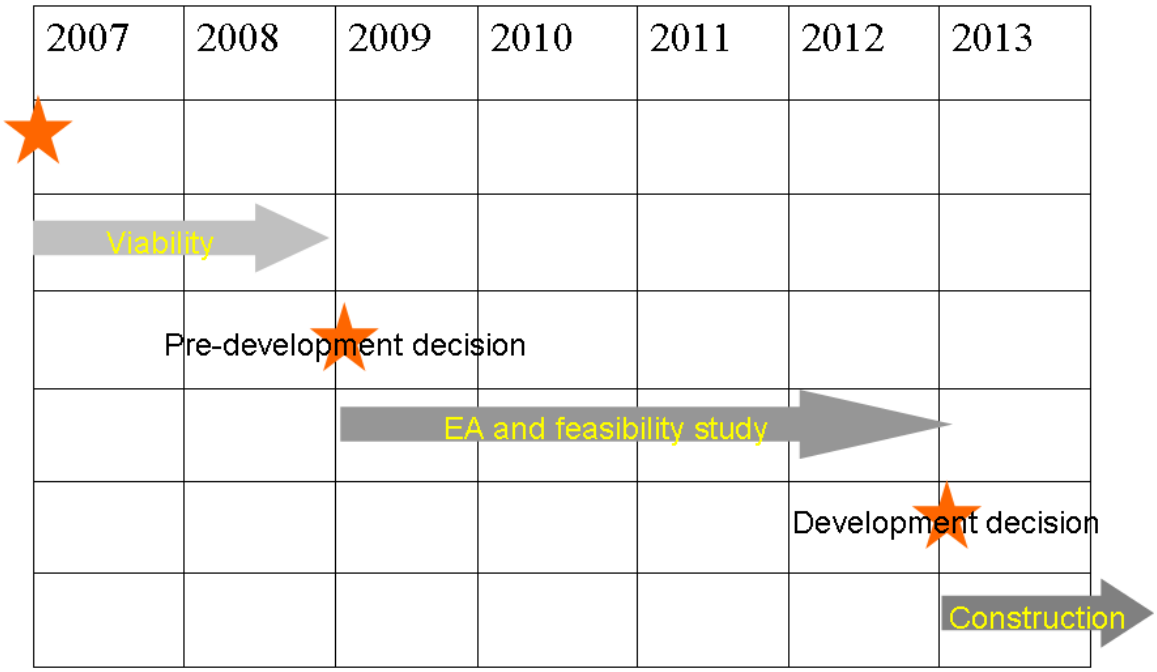
As shown in Figure 2-2, in recent years the supply of uranium from mines is less than half of what is needed to meet the requirements of nuclear reactors. This shortfall has been met by three sources: a reduction in stockpiles of uranium - primarily those held by utilities; conversion of weapons-grade uranium to nuclear reactor fuel - principally from Russian sources; and the recovery of uranium from spent fuel. The reduction in stockpiles and conversion of weapons grade uranium to nuclear reactor fuel will continue for some time; however, the need for supplies of new uranium is reasonably certain.

Canada has good potential uranium resources, and well-defined regulatory regimes. However, when considering the aggregate of the time for confirmation of resource, environmental assessments, licensing and construction times, the commissioning of a uranium mine facility in Canada typically takes 10 or more years. For example, the Cigar Lake deposit in Saskatchewan was discovered in 1981 and is estimated to contain 340 million lbs U_3O_8 at a grade of 17.5% U_3O_8 (Jefferson et al., 2007). The deposit is about 450 metres below surface in ground conditions that have been challenging from a mining perspective.

Figure 2-5 illustrates a typical timeline for development of a known mineral resource.

[3] Source: International Atomic Energy Agency (IAEA) Bulletin 42/2/2000

FIGURE 2-5
ESTIMATED DEVELOPMENT TIMELINE FOR A URANIUM RESOURCE IN CANADA

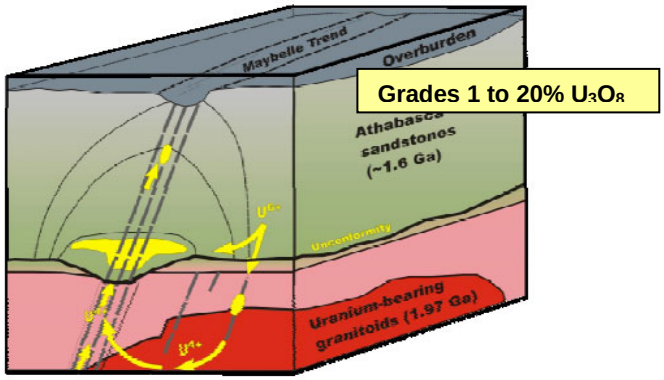


2.3 URANIUM EXPLORATION AND THE URANIUM MINING INDUSTRY IN CANADA

Exploration for uranium deposits is widespread across Canada and is ongoing in all provinces and territories except Prince Edward Island. As well, activity related to uranium exploration is low in Nova Scotia due to a moratorium being in effect (Nova Scotia Department of Natural Resources, 2008). Exploration is particularly intense in the Athabasca (Alberta) and Thelon basins as well as in regions associated with former production. The numerous proterozoic sandstone basins in Canada (Figure 1-1) are preferred targets for uranium exploration.

There are currently three uranium mine facilities operating in Canada: Areva's McLean Lake operation and Cameco's Rabbit Lake and McArthur River mines and the Key Lake mill. Three deposits are currently under development and subject to initial licensing: the Midwest Lake, Cigar Lake and Millenium deposits, all in Saskatchewan. All of these high-grade deposits are unconformity deposits located in the Athabasca Basin. A general outline of an unconformity uranium deposit is shown in Figure 2-6.

FIGURE 2-6
UNCONFORMITY URANIUM DEPOSIT, ATHABASCA SANDSTONE BASIN[4]

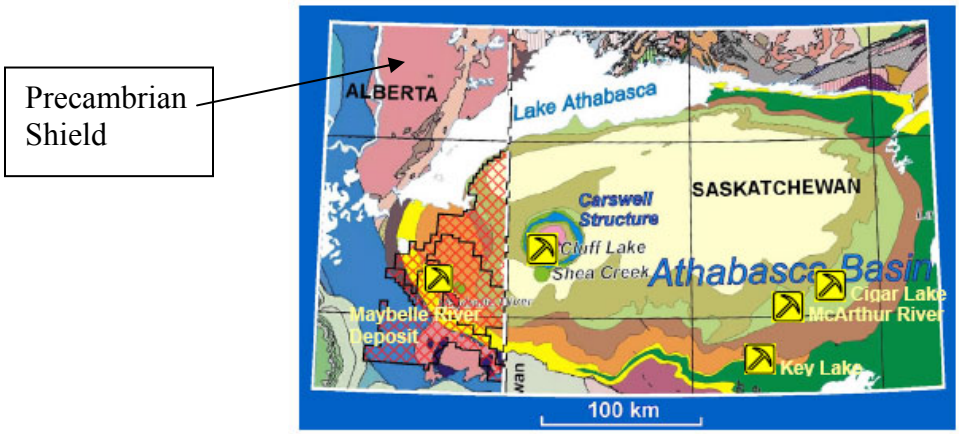


Note: Ga = giga annum (SI nomenclature meaning "billion years").

2.3.1 Exploration for Uranium in Alberta

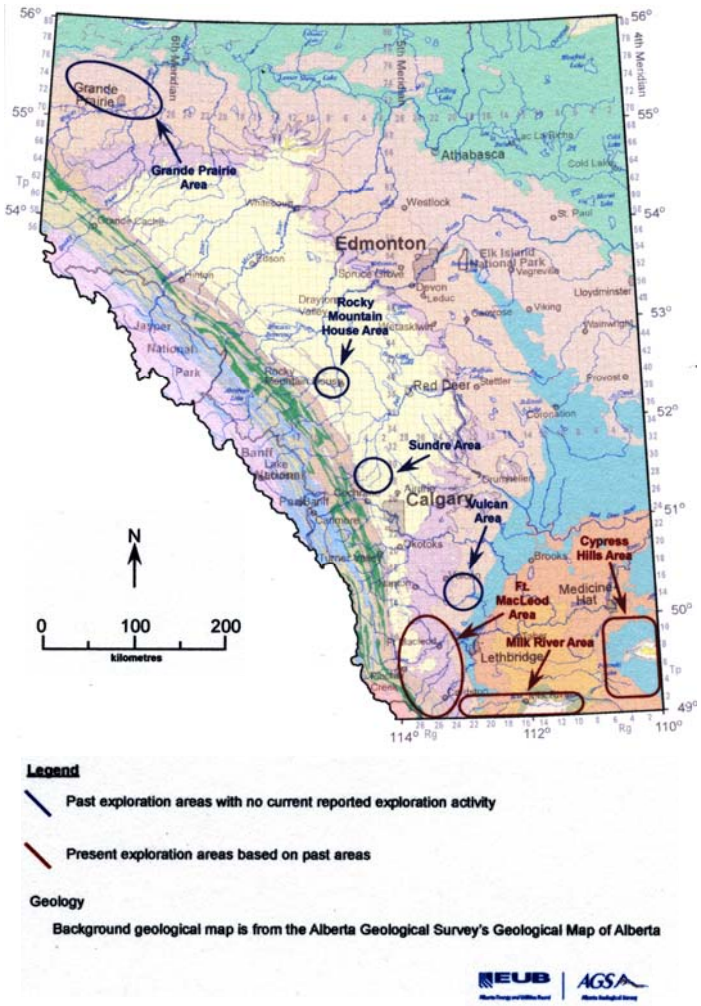
Several uranium deposits were identified in Alberta following intense exploration in the 1970's and other deposits have been identified as a result of recent exploration. Exploration activity in Alberta has been focussed in three areas: the Precambrian Shield area of north-eastern Alberta where literally hundreds of radioactive anomalies have been identified, the Alberta portion of the Athabasca sandstone basin where the Maybelle River deposit has been located, and in south-western Alberta where the presence of sandstone-hosted deposits of uranium has been detected (Matveeva and Anderson, 2008). The general locations of the Athabasca basin deposits are shown in Figure 2-7 while those in southern Alberta are shown in Figure 2-8. The most promising is the Maybelle River deposit where an intersection is reported to contain 21% U_3O_8 over five metres (Winfield et al., 2006). This deposit has elemental contents similar to others in the Athabasca basin - elevated concentrations of arsenic, nickel, lead and molybdenum.

FIGURE 2-7
URANIUM DEPOSITS IN THE ATHABASCA BASIN OF ALBERTA



[4] Alberta Geological Survey (2008)

FIGURE 2-8
URANIUM EXPLORATION IN SOUTHERN ALBERTA[5]



Exploration for uranium includes several methods, such as:

- radiometric surveys, including surface and down-hole gamma measurements and radon emanation;
- surveying and mapping;
- remote sensing;
- sampling of soils, sediments, rocks, air (for radon) and water; and
- drilling and coring, as shown in Figure 2-9.

[5] Matveeva and Anderson (2008)

FIGURE 2-9
DRILLING AND CORING FOR MINERALS

In order to locate deposits that are typically deep underground, current practices used in exploration for uranium are technically sophisticated. The exploration industry and regulators have become increasingly aware of public sensitivity to issues surrounding uranium and radioactivity. As a result, exploration methods are as non-intrusive as possible. Drill holes are routinely backfilled with cementitious materials and precautions are taken to prevent the dispersion of radioactivity.

A general outline of requirements for mineral exploration is shown in Table 2-2 below.

Table 2-2
General Regulatory Requirements for Mine Exploration in Alberta

Responsible Alberta Government Department	Authorization Required
Energy Coal & Mineral Development	Metallic and Industrial Mineral Permit
	Metallic and Industrial Mineral Lease.
Sustainable Resource Development	Mineral Surface Lease
Sustainable Resource Development, Land Administration Division	Exploration Licence
	Exploration Permit
Land Administration Division, Dept. of Sustainable Resource Development	Approval for exploration project involving environmental disturbance
Energy Coal & Mineral Development	Authorization for testing of samples > 20 kg

2.4 CANADIAN AND INTERNATIONAL URANIUM MINING AND EXTRACTION TECHNIQUES

There are four methods for the production of uranium concentrate, also known as yellowcake.

1. Conventional open pit and underground uranium mines combined with surface ore milling facilities. Ore is mined by drilling and blasting or, as is the case in high grade mines, cut out by remotely operated boring machines and brought to the mill for chemical leaching of uranium from ore that has been finely-ground. Although alkaline agents have been used at some locations, sulphuric acid combined with an oxidant is the only lixiviant that is currently being used.
2. *In-situ* leaching (ISL). This method involves the pumping of a leaching agent into porous rock, typically sandstone, where uranium has been concentrated by natural processes. The porous ground is typically isolated by impermeable structures above and below the uranium deposit. Sodium carbonate/bicarbonate is the uranium lixiviant currently used in

the United States where the deposits are associated with high carbonate content. Sulphuric acid is used in ISL operations in Kazakhstan and in Australia.

3. By-product recovery from mineral processing operations. The Olympic Dam polymetallic mine in Australia contains about 0.03-0.06% U_3O_8. To extract the uranium, conventional heavy metal concentration processes (grinding and flotation) are used, followed by leaching of the uranium with sulphuric acid. Some gold deposits in South Africa contain sufficient quantities of uranium (0.01 to 0.08% U_3O_8) to warrant extraction. The gold-uranium process typically uses cyanide leaching for gold, followed by acid leaching for uranium.
4. By-product recovery from phosphoric acid production. Many marine-originating phosphate deposits in the world (e.g., Florida, Morocco) contain uranium that can be recovered from the process streams in a facility that produces phosphate chemicals and fertilizers. No such by-product uranium is being recovered at the present time, but several plants are being considered in the United States and North Africa.

Uranium resource development in Alberta will be subject to the following constraints.

- **Grade of the deposit (% U_3O_8):** The grades of ore that have been exploited in Canada range from 0.1% U_3O_8 (Elliot Lake) to over 20% U_3O_8 (Saskatchewan unconformity deposits). Lower-grade deposits may be economically viable if either open pit conventional mining or ISL methods are used, or if other metals are also recovered. Due to concerns about residual radioactivity, however, heavy metal recovery and sale has not been possible for some high-grade uranium deposits in Saskatchewan that contain substantial quantities of cobalt and nickel.
- **Adequacy of recoverable reserves:** Uranium reserves are measured in lbs U_3O_8 or tonnes of U metal. A measured reserve of several million lbs U_3O_8 or thousands of tonnes of U is generally required by the industry and the financial markets in order to be considered a mineable resource.
- **Accessibility:** The uranium resources must be physically accessible and on land that is not subject to land use restrictions, i.e., lands that are not designated as parkland, wildlife and First Nations reserves, or that are subject to unresolved land claims. As an example, the Thelon Wildlife Sanctuary restricts mineral exploration in a major part of the Thelon sandstone basin.
- **Permission to mine or extract uranium:**
    - Jurisdictional - Nova Scotia does not permit exploration for uranium as a result of a moratorium that has been in effect since the mid 1980's. A similar moratorium was in place in British Columbia from 1980 to 1987.

- Environmental and Permitting - The environmental assessment and licensing processes for a new uranium mine facility can be exceptionally rigorous and may take several years to complete (see Figure 2.5).
- Social - A key component of a successful environmental assessment process is the acceptance by local people of any proposed development involving uranium or nuclear technology. In many countries, including Canada, interest and lobby groups may strongly oppose uranium mine development and the use of nuclear power.

- **Cost and timing:**
  - Development - Development can be both costly and time consuming (Figure 2.5). As noted above, the Cigar Lake deposit was discovered in the early 1980's and to date about $1 billion has been spent on development without producing any uranium. Similarly the Midwest Lake deposit in Saskatchewan and the Kiggavik-Scissons deposits in Nunavut were explored and defined over 25 years ago. Currently the environmental assessment and licensing process for a conventional uranium mine is estimated to be 7-10 years or more. The high costs and long lead times can limit the ability of junior mine developers to develop a uranium mine facility.
  - Operation and Closure - Because of factors such as strict requirements for radiation protection and environmental management, operational and closure costs are significantly higher than those for other types of mineral mines.
- **Contracts to market the uranium product:** Uranium is typically sold under long term contracts and at prices that may differ from current or "spot" prices. Contracts to supply product would normally follow assurance that a mine developer could obtain the necessary permits and licensing as well as financing and insurance.

Based on indicated and potential uranium resources in Alberta, three basic techniques for uranium resource recovery are likely, depending on the depth of the ore from the surface, the grade of ore and the ground conditions:

- conventional open pit or underground mining combined with milling,
- remotely-controlled underground mining combined with milling, and
- *in situ* leaching.

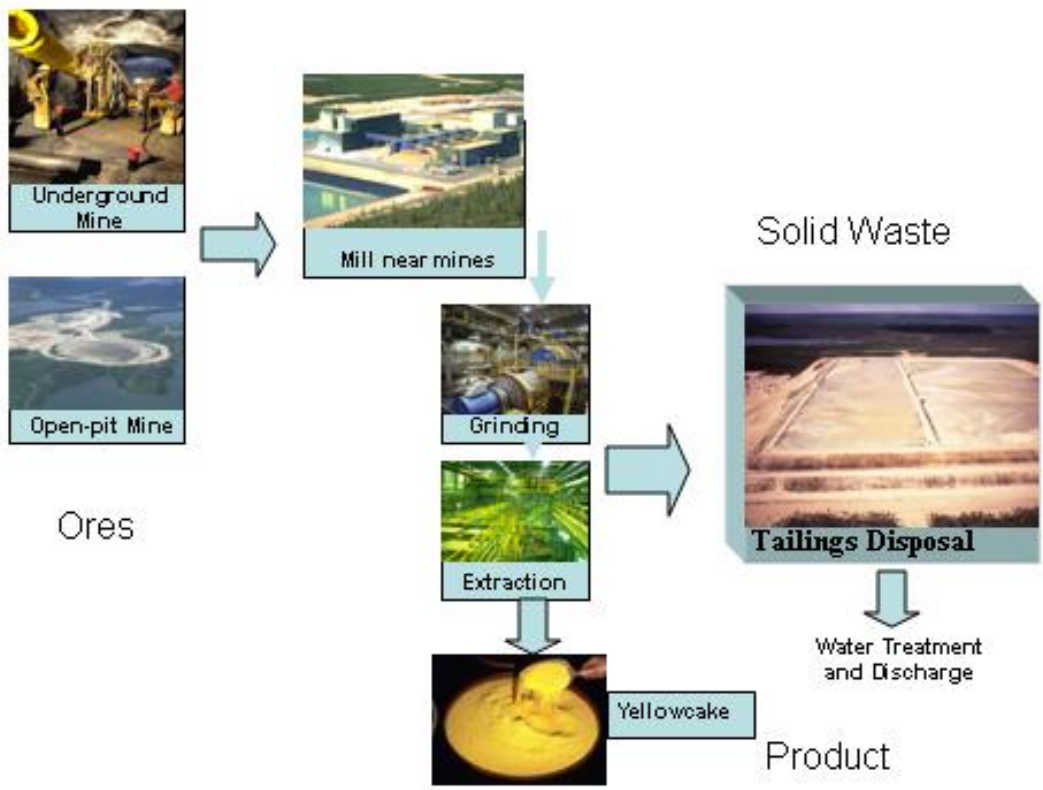
2.4.1 Conventional Mining and Milling

The conventional mining and milling process is represented in Figure 2-10. Mining can be undertaken by either underground or open pit methods. Open pit mining is applicable to a wide range of ore grades and is typically more economical than underground mining, however, it is

generally more applicable to concentrated shallow deposits. Underground mining is more applicable to deeper deposits including vein-type deposits.

Uranium recovery from the ore is usually achieved by oxidative sulphuric acid leaching of finely ground ore followed by solvent extraction, which involves contact between an organic liquid and an aqueous liquid containing the dissolved uranium. The uranium is transferred from the aqueous to the organic liquid; minor amounts of other metals remain in the aqueous liquid. The uranium is stripped from the loaded organic solvent and precipitated as a uranium oxide (yellowcake). Solid tailings result from the process and contaminated water is produced from the mines, the tailings management area and general site drainage. Both the tailings and the contaminated water require careful management to comply with environmental protection criteria (as described in Section 5, "Control Technologies for Emissions of Concern"). Air emissions from the mines, mill and waste management areas also require careful monitoring and management.

FIGURE 2-10
CONVENTIONAL MINING AND MILLING PROCESS



It is likely that conventional mining and milling would be applied to the low- to medium-grade ores that could expected to be found in Alberta. Low-grade ores could include those classified as vein-type that may be found in the Canadian Shield region of north-western Alberta. The

potential also exists for a sandstone-hosted deposit in southern Alberta, similar to the sandstone hosted Blizzard deposit in British Columbia. Such a deposit could be mined by conventional open-pit methods.

2.4.2 Remotely Controlled Mining of High Grade Unconformity Deposits

If the ore deposit is too deep for open pit mining, underground mining methods are used. The deep high grade unconformity deposits (e.g., the McArthur River and Cigar Lake high grade deposits in Saskatchewan) are situated in hydraulically porous, low strength rock structures that preclude the use of conventional mining methods. The remedy for this challenge is to solidify the ground by freezing (Figure 2-11) and remove the ore with remotely controlled boring machines. The cavities resulting from the boring are backfilled with cemented fill.

The ore fragments are further reduced in size to a mixture that can be pumped to the surface and trucked as slurry to an ore processing facility. Although the deposit specifics are not publicly available, the polymetallic Maybelle River type deposits may be developed and mined using sophisticated methods similar to those used at McArthur River. The location of the processing plant and waste disposal facilities can be selected based on local environmental, social and economic considerations.

FIGURE 2-11
GROUND FREEZING FOR MINING AT McARTHUR RIVER

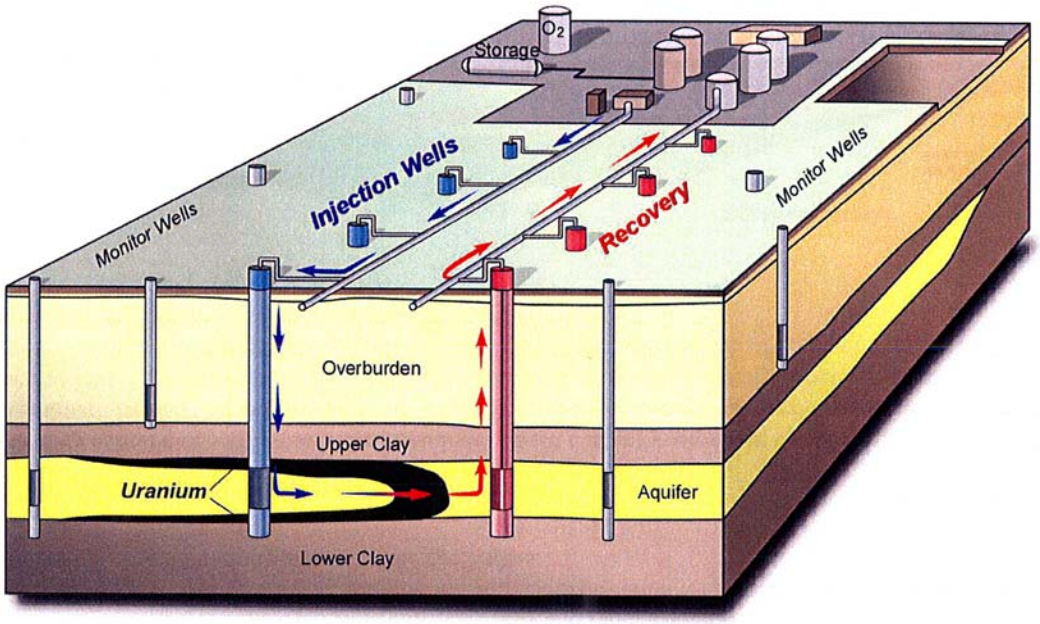
2.4.3 *In Situ* Leaching (ISL)

The geological setting of the sandstone formations in southern Alberta is similar to that of Wyoming and Colorado, where operations and development planning are underway to recover the uranium using *in situ* leaching (ISL) technology. ISL, or in situ recovery (ISR) as it is known in the United States, is generally considered to be much less intrusive than conventional mining

for clusters of low grade deposits (0.05% to 4% U_3O_8). This technology has never been used in Canada, but at two of the now-closed-out mines in Elliot Lake, Ontario, stope leaching was practiced, i.e., broken ore was leached with acid that primarily originated from the bacteria-enhanced oxidation of pyrite in the ore. The stope leaching practice was possible because of the relatively flat and continuous nature of the orebody and its accessibility, through openings, for conventional mining. A major challenge was the need to ventilate extensive areas to permit worker entry without the use of self-contained breathing apparati (SCBAs).

ISL or ISR operations recover uranium from deposits without human access or breaking of rock in the mineralised zones. This type of uranium deposit typically forms over very long time periods (thousands to millions of years), where groundwater containing small amounts of uranium comes into contact with a zone of chemical reduction (typically a carbon-rich structure), and the uranium precipitates out of solution. Often the zone of transport and deposition are sealed off by low permeability zones above and below the uranium deposit. The schematic of a typical ISL operation is shown in Figure 2-12.

FIGURE 2-12
GENERAL ARRANGEMENT OF ISL URANIUM RECOVERY[6]



ISL technology involves the injection of a leaching solution containing either sodium carbonate/bicarbonate or sulphuric acid together with an oxidant, such as oxygen or peroxide, into a uranium enriched zone. The uranium in the deposit is oxidized from the insoluble U^{4+} to the soluble U^{6+} state and is dissolved as either a uranyl tricarbonate complex or a uranyl sulphate

[6] Matveeva and Anderson (2008)

complex. The solution containing the dissolved uranium is then conveyed to a recovery plant by pipeline. At the plant the uranium is removed from the solution by ion exchange or solvent extraction methods and the spent solution is regenerated and returned to the extraction zone via injection wells.

The number of operational ISL facilities in the United States increased from 2 to 5 over the period 2003-2006. Underground mines also increased from 1 to 5 over the same time period (U.S. Energy Information Administration, 2008). As of the end of 2006, there were five operational uranium ISL plants, another five in the process of permitting and licensing or on standby, and one in the reclamation stage. Production capacities of the operational facilities ranged from 800,000 to 5,500,000 lbs yellowcake/y. (Table 2-3 gives statistics for some of these facilities.) Although little data is available regarding the depth of currently operating ISL operations, within the Irigaray area (Powder River Basin, Wyoming), mineralized uranium deposits are typically encountered at depths from 100 to 300 ft below the ground surface (Cogema Mining Inc., 2004).

TABLE 2-3
UNITED STATES URANIUM IN SITU LEACH PLANTS BY OWNER, CAPACITY, AND OPERATING STATUS AT END OF YEARS 2003-2006[7]

ISR Plant Owner	ISR Plant Name	Production Capacity[a] (lbs yellowcake per year)	2006 Operating Status
Cogema Mining, Inc.	Christensen Ranch	- -	Reclamation
Crow Butte Resources, Inc.	Crowe Butte	1,000,000	Operating
HRI	Church Rock	1,000,000	Partially permitted and licensed
HRI	Crownpoint	1,000,000	Partially permitted and licensed
Mestena Uranium LLC	Alta Mesa	1,000,000	Operating
Power Resources, Inc.	Smith Ranch-Highland	5,500,000	Operating
South Texas Mining Venture, LLP	Hobson	1,000,000	Standby
Uranium One/Energy Metals	La Palangana	1,000,000	Permitting
Uranium Resources Inc. (URI)	Kingsville Dome	1,000,000	Operating
URI, Inc.	Rosita	1,000,000	Standby
URI, Inc.	Vasquez	800,000	Operating
	Total Production Capacity:	**14,300,000**	

Notes:

Data based on most recent Form EIA-851A or Form EIA-851Q survey. An operating status of "operating" and "operational" usually indicates the ISR plant was producing uranium concentrate at the end of the period.

Sources: Energy Information Administration: Form EIA-851A and Form EIA-851Q, "Domestic Uranium Production Report."

[7] U.S. Energy Information Administration (2007)

2.4.3.1 Operation of an ISL Facility

ISL operations in the United States use the carbonate/bicarbonate leaching method, and could reasonably be expected to be the method used in an Alberta ISL operation. The raw materials for the process include soda ash (sodium carbonate), carbon dioxide, oxygen or hydrogen peroxide and, sometimes, minor amounts of magnesium oxide for precipitation of yellowcake. Sulphuric acid is used as the leaching agent in other regions of the world where the uranium deposits are low in carbonate mineral content and the salinity of the groundwater is relatively high.

There are two key physical factors for the permitting and successful operation of ISL:

1. containment of the leaching agents in the zone allocated for underground leaching, and
2. successful restoration of groundwater chemistry upon completion of the uranium recovery.

Containment of the leaching agents depends on the permeability of the surrounding underground area and the ability to generate a negative hydraulic gradient in the leaching zone. As shown in Figure 2-12, the uranium deposits are often isolated vertically by hydraulically low-permeability structures. Lateral isolation of the leach field is maintained by removing uranium-loaded leaching fluid faster than barren leaching fluid is reinjected. Excess fluid is removed from the process either by evaporation, reverse osmosis of a bleed stream or injection of barren leach solution into a deep saline aquifer.

Important social and environmental considerations in the development of ISL include:

- containment of radioactivity, particularly radon;
- minimization of waste disposal; and
- protection of surface and groundwater resources.

Section 3.8 discusses potential releases and public concerns related to ISL operations.

2.4.4 Byproduct Recovery

Small amounts of uranium can be removed from the phosphoric acid process stream of a phosphate fertilizer plant. This technique was used by Earth Sciences Inc. in Calgary from 1984 to 1987, but the uranium recovery ended when the associated fertilizer plant was closed. No re-emergence of byproduct recovery is anticipated in Alberta in the near future.

3.0 POTENTIAL RELEASES FROM URANIUM EXPLORATION AND MINING

Predominant concerns associated with uranium mining relate to the release of and exposure to radioactivity. Other concerns include the release of toxic metals and the waste products of mining and milling, in particular chemicals, greenhouse gases, tailings, contaminated water and hazardous and industrial wastes.

3.1 UNITS OF RADIATION

Radiation associated with uranium mining is produced in the form of alpha or beta particles, and/or gamma radiation. Units of radioactivity are expressed in becquerels (Bq) where:

1 Bq = 1 disintegration per second.

When ionising radiation is absorbed by an object or a person, the absorbed dose is expressed in units of joule per kilogram (J/kg) and its special name is gray (Gy). Different types of radiation have different biological impacts for the same absorbed dose. When the absorbed dose is multiplied by a factor characterizing the relative biological effectiveness of the radiation, the resulting quantity is called the dose equivalent, and its name is sievert (Sv). However, the dose equivalents to the various organs and tissues of the body contribute differently to the overall health detriment resulting from the irradiation of the body. When the tissue-weighted equivalent doses in all specified tissues and organs are summed, the "effective dose" is determined. The effective dose is also expressed in units of sievert (Sv), or more commonly mSv (1/1000 of a Sv) or µSv (one millionth of a Sv). The overall detriment or risk of the radiation exposure is considered to be proportional to the effective dose. For example, radiation dose limits primarily refer to effective dose. Unless otherwise specified, the term "dose" when used in this report is intended to mean "effective dose".

3.2 BACKGROUND RADIATION

Uranium is a naturally occurring element and is present in all soils, rocks, as well as surface and ground waters. Typical concentrations found in various natural sources are shown in Table 3-1.

TABLE 3-1
URANIUM CONCENTRATIONS IN VARIOUS SOURCES

Source	Concentration
Atlantic Ocean	0.003 ppm
Soft Rocks - limestone	2 ppm
Hard Rocks – granite	4 ppm
Earth's surface	3 ppm
Low grade ore	1000 ppm (0.1% ore)
High grade ore	200,000 ppm (20% ore)

Typically, uranium occurs at background levels of a few parts per million (ppm) but at or near uranium deposits, uranium is present at higher concentrations. Anomalous concentrations of uranium in waters and sediments are used by exploration geologists to locate potential deposits that may be economically interesting.

All living things are continuously exposed to ionizing radiation from cosmic rays and naturally occurring radionuclides in air, water and food, and to gamma radiation from radionuclides in rocks, soils and construction materials. The level of exposure to natural radioactivity varies widely, depending mostly on location and partly on diet.

Typical levels of natural radiation exposure for people in Canada are shown in Figure 3-1. In Canada, radiation exposures from natural sources total about 2 millisieverts per year (mSv/y). The range in radiation dose from cosmic sources illustrates the potential variability across the country, with the dose from cosmic radiation in Victoria, British Columbia being 350 μSv/y, and the dose in Calgary, Alberta being 560 μSv/y (Grasty and LaMarre, 2004). The prime source of radon in homes originates from the soils and rocks below the structure.

FIGURE 3-1
NATURAL BACKGROUND RADIATION

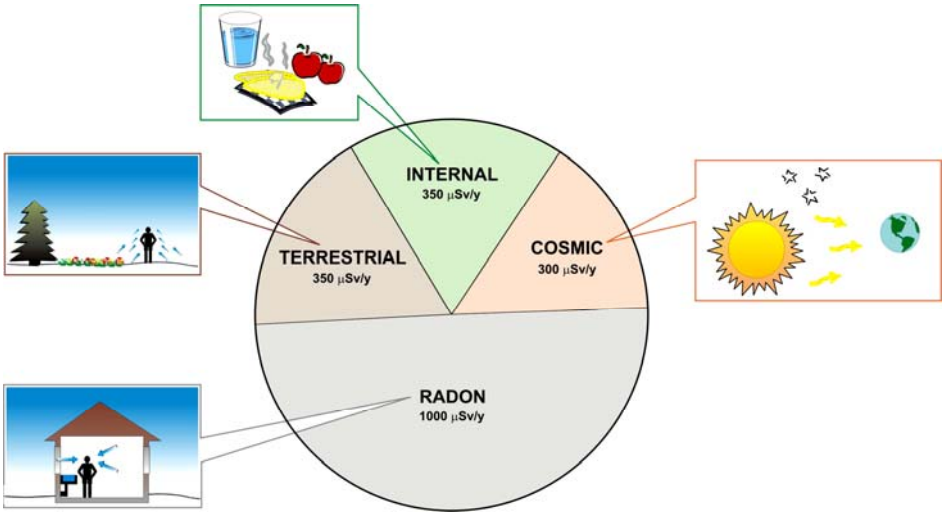
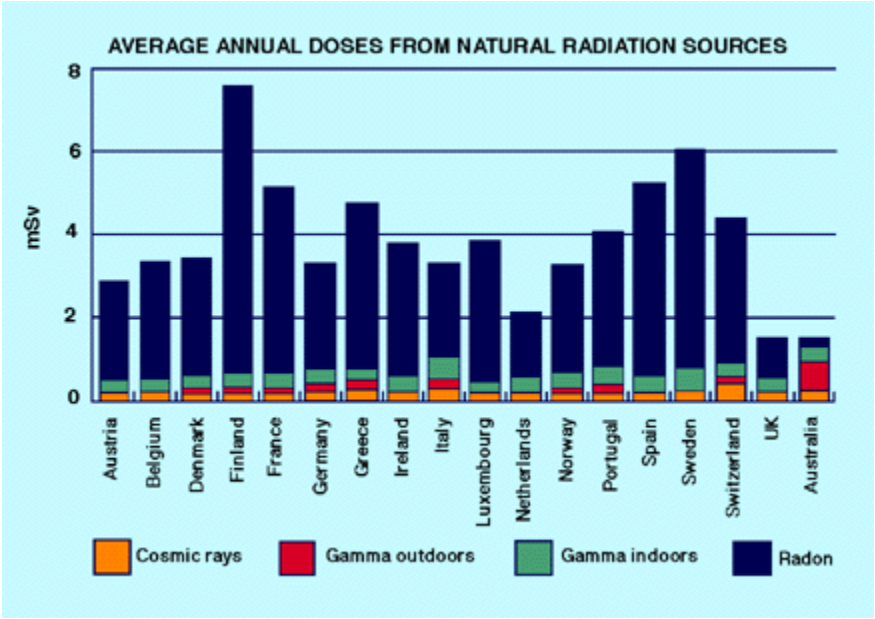


FIGURE 3-2
WORLDWIDE AVERAGE ANNUAL DOSES
FROM NATURAL RADIATION SOURCES[8]



[8] World Nuclear Association (2008a)

As well as the dose from natural background radioactivity, additional dose can be received from medical diagnoses and from the normal workplace. Medical exposures can range up to 600 μSv/y while airline workers, flying 20 hours per month, receive over 5,000 μSv/y (5mSv/y).

Uranium is one of the principle sources of natural radiation. The uranium decay series results in ionizing radiation and produces new elements, both radioactive (such as radon, ^{222}Rn, a radioactive gas), and radium (^{226}Ra), and non-radioactive (such as lead, ^{207}Pb, the end product of the decay series). The decay process produces three types of ionizing radiation: alpha, beta and gamma. Alpha radiation can only penetrate the surface of the skin, but it is a potential hazard if inhaled or ingested. Beta radiation can penetrate tissue more deeply (up to a few cm), while gamma radiation is the most intrusive form and can pass through the body. Exposure to ionizing radiation is controlled by limiting the time a person spends exposed to a source, using radiation shielding and removing air-borne radioactivity through ventilation.

3.3 RISK FROM BACKGROUND RADIOACTIVITY

According to the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), the risk of cancer from ionizing radiation is about $5x10^{-5}$ per mSv, averaged over all ages and both sexes. Accordingly, for a lifetime of exposure, the theoretical risk from exposure to natural background radiation would be on the order of 1% (i.e., 2 mSv/y x 75 y x $5x10^{-5}$/mSv).

3.4 RADIOACTIVITY AND RADIATION NEAR A URANIUM DEPOSIT

Persons living in the vicinity of uranium deposits may receive some incremental exposure from the natural radioactivity in the area, from exploration activities and from mining, should mine development proceed. To date in Canada, public exposures from uranium exploration and mining have been a small fraction of the allowable public dose limit. For example, experience has shown that exploration workers may be exposed to incremental doses of 10 to 20 μS/y, which is trivial compared with the annual dose of about 2000 μSv/y (2 mSv/y) from natural background radiation.

Methods of controlling environmental and health and safety aspects of the uranium mining industry are typical of any other type of mining, with the added protection required to minimise exposure to radioactivity. Conventional environmental and health and safety monitoring and management programs must be adapted to include evaluation and control of radioactivity. These programs must include monitoring of exposure to radioactivity, of radioactive emissions and of radioactivity in the environment. Permit requirements for uranium exploration should therefore be similar to other mines with additional conditions/requirements to monitor for radioactivity and to limit the dispersion of radioactive substances in the environment.

Public concern associated with potentially negative environmental, human health and safety effects from exploration and development can be considerable and passionate. This means that a high level of due diligence and care needs to be taken from exploration through to eventual resource exploitation, especially when there is competition for land use, or when the exploration is to be carried out close to peoples' homes or in environmentally sensitive locations. Considerable consultation with stakeholders will very likely be necessary in these circumstances.

3.5 POTENTIAL RELEASES FROM EXPLORATION

Uranium exploration activities include the following:

- geophysics, i.e., ground and aerial surveys;
- soil and water sampling;
- radiological studies, e.g., radon release from soils, down-hole logging and surface scanning;
- drilling and core sampling;
- core storage;
- test pitting and trenching;
- construction of adits and shafts for underground exploration; and
- extraction of bulk samples for metallurgical testing.

Several of the above activities have the potential to result in incremental releases of radioactivity and contamination to the environment by:

- increasing the rate of radon gas emissions to air from core/drill cuttings/open holes and stockpiles;
- contamination of water and air by emissions from core/drill cuttings/open holes and stockpiles;
- leaching of radioactive elements and metals from core/drill cuttings/open holes and stockpiles;
- ground water contamination caused by drilling holes through "clean" aquifers into uranium bearing zones; and
- surface water contamination from dewatering activities.

Exposure to radiation during exploration is a potential concern for drillers and geologists who handle core samples. Radiation safety programs should be established to ensure doses are below

acceptable levels. In addition to radiation control, environmental matters common to all mining exploration camps and exploration activities should be monitored, e.g., water, waste and sewage management, control of acid generating rock, containment of ammonia and nitrogen compounds from explosives, fuel oil, etc.

Exploration activities are subject to permits from Alberta Energy and permission of the landowner if the surface rights are privately held. It is also common practice to consult with First Nations peoples who may have traditional or treaty rights to the land in question.

Shipment of radioactive materials from drill sites to laboratories will require permits from the Canadian Nuclear Safety Commission (CNSC). Advanced exploration programs that involve the construction of a shaft or a decline for extraction of bulk samples or test mining would normally require a licence from the CNSC. The licensing procedure is detailed and could be subject to public review.

3.6 POTENTIAL RELEASES FROM CONVENTIONAL URANIUM MINING

Mining methods for uranium are often typical of conventional mining methods used for other metals. This is particularly true for the lower grade uranium reserves found in Canada outside the Athabasca basin in Saskatchewan. Differences arise primarily in the air ventilation needs for underground mines and methods to control exposure to ionizing radiation. In high grade, underground mines, remote mining methods are used to control exposure and reduce occupational risks that arise from poor ground conditions. Freezing and concreting is used to stabilize poor ground and minimize ground water inflow.

For both low and high grade uranium mines, open pit methods are preferred where ground conditions, ore depth and waste-to-ore ratios permit. For deep deposits, underground mines would be necessary. Recently in Saskatchewan, the use of mined out pits to permanently dispose of mill process tailings has been successfully demonstrated (see Section 4.4 for details).

The primary environmental and public concerns associated with uranium mining, over and above those encountered with mining of other metals, include:

- increased radon gas emissions to air (from ventilation shafts/stockpiles);
- radioactive contamination of water from minewater discharges, dewatering well discharges and leaching from stockpiles;
- management of waste rock that may generate acid or leach metals;
- radioactive dust emissions from crushing, blasting, stockpiles, transportation of ore and waste;

- radioactive contamination of groundwater caused by drilling holes through "clean" aquifers into uranium-bearing zones;
- surface water contamination from dewatering activities (where required);
- soil contamination.

Releases to the environment are expected to be assessed in detail before permits and licenses are issued by the Province of Alberta and the CNSC. The permits and licenses will cover a broad range of conditions to ensure that the health and safety of workers and the public are protected and that the environment is not deleteriously affected during operation and upon closure.

3.7 POTENTIAL RELEASES FROM CONVENTIONAL PROCESSING OF URANIUM ORES

Process plants receive crushed ore from mines and stockpiles or in some cases slurry (from underground mines) for processing. The following are the primary operations associated with processing.

1. Ore preparation, which involves crushing, grinding, classification and thickening of ore slurry in preparation for leaching.
2. Solubilising the uranium from the ore (leaching) is typically done with sulphuric acid supported by an oxidant in solution. Leaching dissolves the uranium and when the aqueous liquid is separated from the leach residue it forms a pregnant solution. The residues (tailings) are neutralized and sent to a tailings management facility for disposal.
3. Product concentration most often involves clarification and concentration of the pregnant solution by solvent extraction or ion exchange processes. The concentrated pregnant solution is sent to precipitation while the barren solution, or raffinate, is recycled or sent for treatment and disposal with tailings.
4. In yellowcake production, ammonia, peroxide or magnesium oxide is commonly used to precipitate hydrated uranium oxides (yellowcake, see Figure 3-2) from the concentrated solution. The yellowcake is dried, partially calcined and packaged in 170 L drums for transport to conversion plants.

FIGURE 3-3
YELLOWCAKE

Recovery of uranium in solution from mines and from surface heap leaching operations has been practiced in Canada in the past. According to this method, crushed or blasted ore is leached using a dilute sulphuric acid solution. The uranium-bearing leachates are subsequently sent to the product concentration stage in preparation for yellowcake precipitation. A common concern about heap leaching is the potential loss of the leaching fluid to the ground or to the air. However engineering controls can effectively mitigate this concern.

Prior to use as reactor fuel, yellowcake must be further processed to remove minor impurities and to prepare a product suitable for nuclear fuel fabrication. In Canada, Cameco operates a refinery to further purify yellowcake into UO_3 and a conversion facility that converts UO_3 to UO_2 for shipment to uranium fuel fabricators in Canada, and also converts UO_2 to UF_6 for shipment to enrichment facilities in the United States or overseas. Canadian-sourced uranium is used to make fuel for nuclear reactors designed to generate electricity.

The primary environmental issues associated with uranium ore processing are:

- solid residue management, i.e., of tailings and barren/raffinate neutralisation sludges;
- tailings water and barren solutions;
- gaseous emissions from the process;
- radon emanations from tailings; and
- process chemical releases.

Public concerns about uranium mining and milling usually focus on the potential release of radioactivity from process tailings into the air and water and the potential effect on plants, animals and humans.

Tailings differ from the source rock because they are fine particles rather than solid rock and, because the uranium has been removed, they are approximately 15% less radioactive than the original ore. Tailings contain essentially all of the radionuclides originally in the ore with the exception of the recovered uranium. Because the half lives of many of these nuclides are long (e.g., thorium-230 has a half life of 80,000 years), the deposits will remain radioactive for a long time. Neutralized barren and raffinate solutions are also disposed with tailings. The sludges from the liming of these solutions are a mixture of gypsum, iron hydroxide and other metal precipitates. The combined tailings typically have lower settled density than many traditional tailings materials.

Tailings are usually placed in engineered structures or in mined-out pits near the mine and mill facilities. Complete and secure containment of the tailings has to be carefully addressed. Wind dispersion and radon evolution need to be controlled. Structures that are built to contain tailings must be stable for a long time and must not be subject to leakage, erosion or failure. If the tailings are deposited in mined-out pits, the pit enclosure must be designed to prevent the escape of contaminants.

The tailings from processing some uranium ores also have the potential for release of non-radioactive substances into the environment such as:

- heavy metals like nickel and copper;
- arsenic and selenium; and
- acidity generated from the oxidation of pyrite in tailings when it is exposed to air and water.

3.8 POTENTIAL WATER-BORNE RELEASES FROM CONVENTIONAL URANIUM MINES AND MILLS

Waste water treatment is required during all phases of uranium mine development, but it is highly site-specific, depending on ore mineralogy, extraction process chemistry and the local biological environment. Potential water-borne contaminants (listed with methods typically used to control them) include:

- radionuclides - radium-226, lead-210 and uranium (precipitation with barium and iron);
- heavy metals - copper, nickel, zinc, lead (precipitation with lime);

- suspended solids (settling, flocculation, and filtration);
- arsenic, selenium, vanadium, molybdenum (co-precipitation with iron);
- ammonia (gaseous evolution and pH adjustment to reduce toxicity);
- dissolved salts (reverse osmosis, infrequently).

3.9 POTENTIAL RELEASES AND PUBLIC CONCERNS ASSOCIATED WITH *IN SITU* LEACHING

Releases of radiation and other contaminants from ISL are inherently smaller than for conventional mining and milling because no ore is mined, removed, hauled or stored, no waste rock or mill tailings are produced, and no wind-blown particulates are generated. ISL facilities can also produce "zero discharge" with respect to quantities of water released to the environment. Potential radiation doses at ISL operations are lower by orders of magnitude than those that may result from conventional mining/milling of uranium. Experience in the United States shows that concerns raised by members of the public about ISL are typically the same as those normally associated with conventional uranium mining and milling, despite the fact that many of the dose pathways relevant to conventional mining/milling are not present in ISL. As such, it is anticipated that the potential doses to members of the public who live near ISL facilities will be lower than for those living close to conventional operations.

ISL extraction involves dissolution of uranium without removing the ore from its subsurface environment[9]. A leaching solution is injected into a uranium enriched zone, oxidizing and dissolving it in situ so that it can be piped to a recovery plant. At the plant, uranium is removed from the solution. The primary source of potential contamination from ISL operations is the leaching solution (either acidic or alkaline), which is used to selectively recover uranium from the host rock. Some amounts of other heavy metals and elements including the radioisotopes and progeny of uranium, thorium, radium, and radon, as well as non-radioactive elements such as arsenic, vanadium, zinc, selenium, and molybdenum, are also mobilized from the ore during the leaching process. The injection of the leaching solution into the uranium-containing zone of an aquifer has the potential to contaminate adjacent groundwater. If this solution is spilled it could contaminate surface waters as well. The approval of an ISL facility in Alberta would include assurance that the leaching solution is isolated during operations, that residual leaching solution is neutralized, and that the overall facility is decommissioned in an acceptable way.

[9] In conventional milling, the ore is brought to a mill where a leaching agent, typically sulphuric acid is added to a finely ground ore-water mixture. The uranium is leached from the solids and the uranium-depleted solids are separated and disposed as tailings. The solution, containing the uranium is then processed in a way similar to that used in ISL. The uranium is removed from the aqueous solution by a solid ion exchange resin, or a liquid organic solvent.

Potential releases and concerns related to ISL that must be addressed include:

- contamination of aquifers by leaching chemicals and dissolved metals, including uranium;
- release of radioactive substances, including radon, from leaching fluids;
- release of dissolved metals other than uranium, such as vanadium;
- spillage of chemicals;
- disposal of excess liquids from the leach field by evaporation or deep well injection; and
- land use restrictions.

Among these potential problems, early (1970s-1980s) ISL operations in Wyoming and Texas specifically encountered difficulties related to leaking wells due to casing damage (e.g., Irigary, Wyoming, possibly due to injection pressures that were too high, but not monitored), gypsum scale buildup on injection well screens, problems with estimation of permeability of sands, fungal growth, inadequate capacity of the process plant and evaporation pond (e.g., Nine Mile Lake, Wyoming). In Texas, the presence of hundreds, or sometimes thousands, of old exploration boreholes was a key cause of excursions into shallow groundwater systems, and insufficient capacity within Texas to accept the volume of solid wastes (pipes, machinery, buildings, pond liners, filters, salts, etc.) at the time of decommissioning. Since Texan ISL facilities primarily used ammonia in the leaching solution, removing ammonia from the aquifer presented a major challenge, for example, at the Bruni ISL mine, which also experienced numerous leachate spills and excursions, as well as spills from wastewater ponds on the ground surface or into shallow zones above the ore zone due in part to damaged plastic liners (Mudd, 1998). However, the application of modern technology appears to have overcome these kinds of concerns.

The main risks to workers at ISL facilities may be attributable to potential accidents at the site. The principal risk to the public would result from potential contamination of surface and ground water used for drinking and agriculture.

According to analyses conducted by the United States Environmental Protection Agency (Mackin et al., 2001), radiological risks to workers at ISL operations can arise from:

- thickener tank failure, which can pose an inhalation risk to workers if spills are not cleaned up before the contaminants are allowed to dry;
- yellowcake dryer accidents (fire/explosion, spillover, release of gases), which can pose a significant inhalation hazard to the onsite worker if the yellowcake is allowed to dry;

- exposure to pregnant lixiviant or loaded resin, which could pose a radiological hazard as an external exposure source and/or present the possibility of inhaling elevated levels of radon-222 in the unlikely event that a spill were not cleaned up immediately;
- failure of near-surface piping and subsequent runoff into containment ponds, which would not likely pose an inhalation hazard because radon gas would be diluted by ambient air, but the external component could be similar to indoor exposure to pregnant lixiviant.

Failure of near-surface or surface piping systems which transfer the pregnant lixiviant from the well field area to the processing facility can also potentially result in contamination of drinking water sources by runoff to surface waters or absorption into soil and possible subsequent infiltration to groundwater (U.S. Environmental Protection Agency, 2007).

The release of radon from ISL facilities is possible during the construction of well fields and during operations from processing of leaching solutions. Other potentially radioactive materials include solid wastes from ISL operations, e.g., process solids, contaminated soils, scrap equipment, debris and personal protective equipment.

Section 4.5 discusses methods to control contaminants of concern in ISL processes.

4.0 CONTROL TECHNOLOGIES FOR EMISSONS OF CONCERN

4.1 RADIATION DOSE

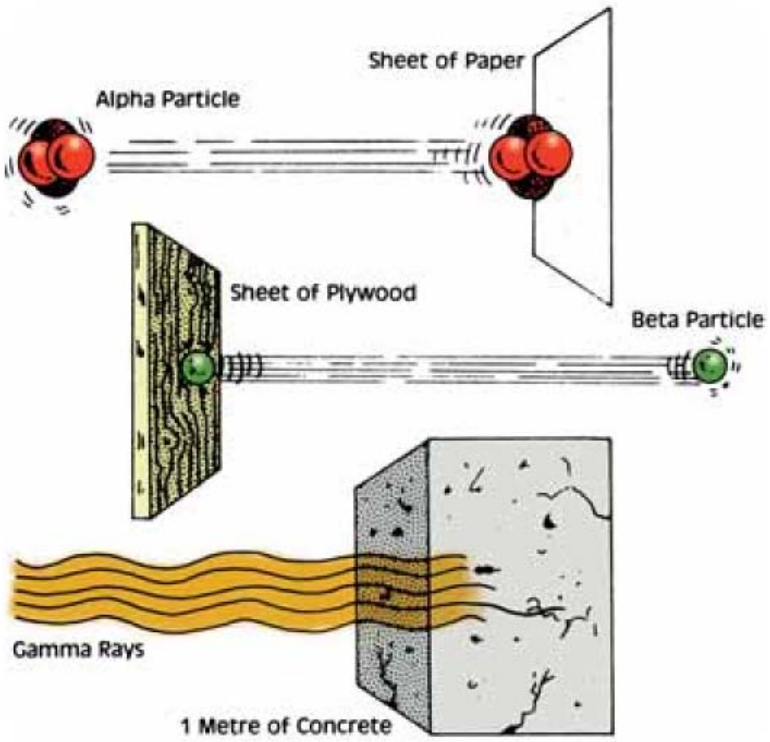
Radiation dose is expressed in terms of energy received per unit weight. As noted above in Section 3.1, different types of radiation have different biological impacts, or potential health detriment to the various organs and tissues of the body. Tissue-weighted equivalent doses in all specified tissues and organs are summed the resulting quantity is called the effective dose and is quantified by the unit sievert (Sv). The risk presented by radiation exposure is considered to be proportional to the effective dose. In this report, “dose” is intended to mean “effective dose”.

4.1.1 Shielding

Through radioactive decay (e.g., uranium), radiation is released in the form of gamma, beta and alpha radiation. Radiation shields of various kinds can be used to prevent or minimize exposure, including during uranium mining and milling. Shielding of alpha radiation can be accomplished by a simple sheet of paper while beta radiation can be stopped by a piece of plywood, glass or aluminium. Gamma radiation (like X-rays) can penetrate more materials and requires thicker and denser shielding (e.g., concrete, soil, lead or water). Figure 4-1 illustrates the penetrating ability of the three kinds of radiation. Alpha and beta radiation emitters are usually only a

concern when they are taken into the body by inhalation or ingestion, while gamma radiation can also be a hazard when it is outside the body.

FIGURE 4-1
PENETRATING ABILITY OF DIFFERENT TYPES OF RADIATION



Intensely radioactive materials are therefore often stored or handled under water, or by remote control in rooms constructed of thick concrete or lined with lead. Lead glass shields, glove boxes and remote handling equipment are used to protect employees where handling of gamma-emitting substances is required.

4.1.2 Time of exposure

In accordance with the ALARA principle, radiation dose can be kept to a minimum by reducing the amount of time an individual is exposed to the radiation source.

4.1.3 Ventilation

In open pit mines, natural ventilation is sufficient to reduce radon concentrations in ambient air to acceptable levels. In an underground mine, forced air ventilation systems are required to achieve the same result. The system installed at Olympic Dam in Australia keeps radiation doses

from radon daughters low, with an average exposure of less than 1 mSv/y. Canadian doses (in mines with high-grade ore) average about 2 mSv/y (see Figure 4-1 above).

CNSC uranium mines and mills regulations require that adequate ventilation be installed in enclosed areas and that safety measures be in place in the event of malfunction of the ventilation system. In most mines, keeping doses to low levels is achieved with straightforward ventilation techniques coupled with rigorously enforced procedures for hygiene.

Strict isolation, ventilation and personal hygiene standards protect workers from exposure to uranium oxide concentrate. If it is ingested, it has a chemical toxicity similar to that of lead oxide. Both lead and uranium are toxic and affect the kidneys. The body progressively eliminates most lead and uranium via the urine. As such, in effect, the same precautions are taken for uranium mines and mills as for a lead smelter, employing the use of respiratory protection in particular (World Nuclear Association, 2006).

4.1.4 Distance

The intensity of radiation decreases exponentially with distance from its source. Therefore, members of the public are only exposed to trivial amounts of radiation from uranium mines.

4.1.5 Containment

Highly radioactive materials are confined and kept out of the workplace and environment behind multiple barriers. Rooms have negative air pressure so that any air leaks occur into the room from the outside.

4.2 AQUEOUS EMISSIONS

4.2.1 Control of aqueous emissions from conventional mining and milling operations

Appendix A illustrates the water treatment process used at the Cigar Lake mine, a representative example of water treatment methods employed in conventional mining and milling operations. Run-off from the mine stockpiles, tailings ponds and waste liquors from the milling operation are collected in secure retention ponds for isolation and removal of heavy metals, radionuclides or other contaminants. Water treatment involves the addition of chemicals to settle out contaminants, and filters to separate remaining suspended solids. Chemicals for water treatment typically include lime, iron sulphate, barium chloride and flocculants. The final product is clean water. The treated clean water is collected in holding ponds and thoroughly tested before being released to the environment. Water quality criteria, set to protect the health of humans and aquatic biota (fish, plants and animals), must be met to ensure that local and downstream water quality is not adversely affected. Treatment sludges are collected and typically disposed of with

tailings. During the operational phase, water may be used to cover the tailings while they are accumulating (World Nuclear Association, 2008a), and excess water needs to be treated before discharge on an ongoing basis. A typical water treatment plant arrangement, with holding ponds, is shown in Figure 4-2.

FIGURE 4-2
WATER TREATMENT AND HOLDING PONDS AT A SASKATCHEWAN MILL SITE

Additional measures to protect water quality involve, for example, routing of clean surface and ground waters around facilities and zones of contamination. Mining and milling facilities are in turn isolated from surface and ground waters. Contaminated waters are recycled as much as possible. Chemicals and oils are isolated, and explosives are carefully managed to avoid spillage of ammonia.

4.2.2 Ancillary Water Treatment and Management Processes for Conventional Uranium Mine Facilities

Although several alternate water treatment processes have been investigated, the only other process that has been used to a significant extent at a uranium mine facility is reverse osmosis (RO). RO is applicable where the total dissolved solids (e.g., sulphate) and metal contents (e.g., nickel, uranium) are low, such as in ground water pumped from wells surrounding mines. These wells are typically used to hydraulically isolate tailings facilities in mined-out pits.

4.2.3 Water Treatment at ISL Facilities

In order to isolate the underground leach field during operations, a negative water balance is required, in other words, more water needs to be pumped out than injected in. The options to deal with this excess water include the following.

- Chemical treatment and discharge: This is usually not favoured because of the salinity of the waters, and the difficulty of chemically removing many salts.
- Evaporation: Water naturally evaporates from ponds, or the process can be accelerated with evaporation equipment. While technically feasible, this method can result in undesirable radon releases.
- Reverse osmosis: This is a method of purifying water using specialized membranes. It is technically and environmentally favourable, but its use is restricted in the United States because of social concerns about liquid effluents.
- Injection into saline aquifers: This method is suitable where local geological conditions and local jurisdictions permit.

4.3 ATMOSPHERIC EMISSIONS

A primary concern from the public about all uranium mine facilities is the release of radon gas. Radon is a noble gas and is very difficult to capture due to its extremely low reactivity. The management strategy for radon release focuses on the control of radon evolution, particularly from tailings facilities. The principal method for control of radon emissions from tailings is the use of soil and water covers.

At processing facilities, wet scrubbers and dust collectors are used to remove contaminants from stacks. Fugitive emissions are typically diminished by rigorous engineering of yellowcake driers and calciners, and the imposition of strict controls and monitoring measures.

Dust from mines and mine operations is controlled by the use of wetting agents, principally water, when ambient temperatures are warm enough to do so (i.e., above freezing).

At ISL facilities, radon is contained by using pressurized and sealed process equipment. The radon in the leaching solution is returned to underground.

4.4 TAILINGS AND WASTE ROCK

Tailings and waste rock management is the most important environmental issue for a new conventional uranium mine, raising the most public concern and requiring detailed engineering and risk assessment. Residual radioactivity must be contained to minimise risk to the environment and to people. Elements that require special attention are radium (^{226}Ra), which is a solid, and radon (^{222}Rn), which is a gas. Radium is the precursor or "parent" of radon, which

emits alpha radiation. Even though alpha radiation has limited penetration because it is easily shielded, it is important that the sources of alpha radiation be contained to prevent them from being absorbed through the inhalation of radon gas or dust.

Environmental protection measures at uranium tailings facilities include physical containment of radioactivity from uranium tailings, and collection and treatment of water from tailings. In order to ensure containment of the radioactivity from uranium tailings, covers over and liners under the tailings are installed. Water and soil are good shields for alpha, beta and gamma radiation and can greatly reduce the release of radon from the tailings. In practice, radiation levels from the ore and tailings are usually low. At the Olympic Dam mine in Australia, direct gamma exposure comprises about half the miners' total dose and approximately a quarter of the total dose for workers in the mill (World Nuclear Association, 2006). On completion of the mining operation, it is normal practice in Australia for the tailings dam to be covered with roughly two metres of clay and topsoil and for a vegetation cover. At the Ranger and Jabiluka mines in North Australia, as much of the tailings as possible will be returned to mined-out pits or to underground openings, as was done at the now-rehabilitated Nabarlek mine. Measurements taken at the tailings containment facilities of high-grade uranium mining operations in Canada show that radiation and radioactivity levels usually drop to natural background levels within short distances (less than 1 km) from the site.

Through decades of study and experience, it has been proven that physical containment of tailings should be accomplished either through the design of containment structures that will be effective for a long time or through the return of tailings into the mine from which the ore was removed. In Saskatchewan, where most mining and milling facilities are extracting high-grade ores, current practice is to deposit tailings into mined-out pits using specially designed techniques. Where ores contain high concentrations of uranium, smaller volumes of tailings are produced and these tailings will normally fit into the pit. Tailings are returned to the mine and isolated by water cover during operations, to be replaced by rock and soil cover at closure. This approach is considered best practice for high-grade ores, as contaminants are permanently contained in the location from which they were previously removed. An example of in-pit disposal is the engineered “pervious surround” in hard rock used for tailings disposal at Rabbit Lake, Saskatchewan (Figures 4-3 and 4-4). In this system, the pit wall is lined with crushed rock and sand. Tailings are then placed into the pit. Water from the tailings is pumped out and returned to the mill for use in the milling process and the tailings become compacted. When the pit is filled, the tailings will be covered with a layer of sand and crushed rock and the lake water level will be restored. The compacted tailings will remain safely in the pit, below the bottom of the lake. Groundwater will follow the path of least resistance and flow through the crushed rock and sand but not through the compacted tailings. The groundwater will not be contaminated because it flows around the tailings (Cameco, 2008). Similar approaches have been used at the

McLean Lake and Key Lake mines in Saskatchewan. This method could be considered in Alberta for conventional mining and milling processes.

FIGURE 4-3
PERVIOUS SURROUND

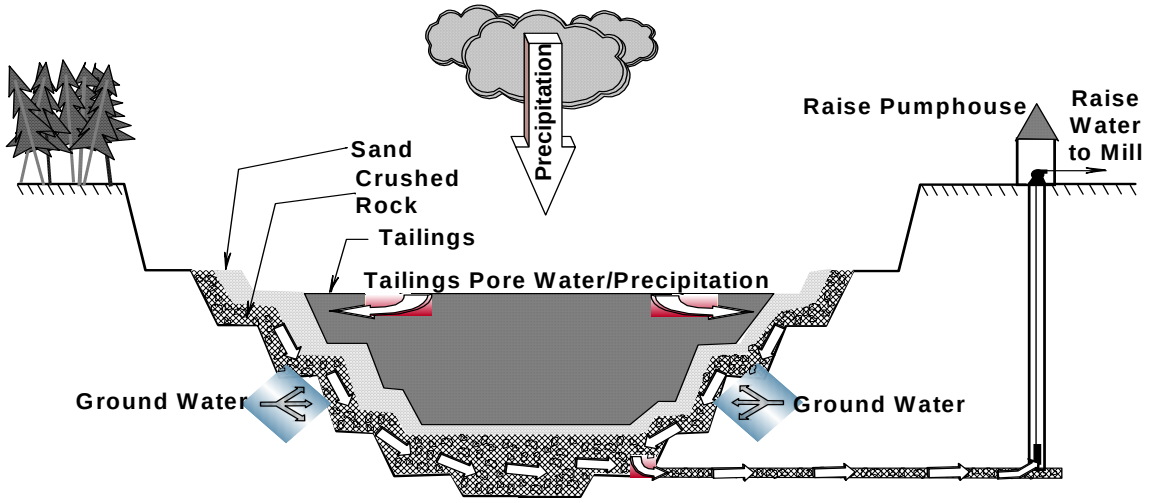


FIGURE 4-4
IN-PIT DISPOSAL AT RABBIT LAKE, SASKATCHEWAN

Any new uranium mining and milling facility in Canada will be expected to consider in-pit disposal, but this approach may not be suitable for operations extracting lower grade ores.
Extraction of low grade ores results in high volumes of tailings being produced, and since these operations typically involve underground mines, there is no pit in which to deposit tailings.

Under these circumstances, surface disposal of tailings is preferred, as it is the "lowest risk option" (as required by the CNSC and EA processes). It is also economically feasible, whereas the cost of digging a pit large enough to contain the tailings would be prohibitive to any new project. Surface disposal of tailings was the approach used at the now-decommissioned Cluff Lake mine. Figures 4-5 and 4-6 show Cluff Lake tailings during operation and after decommissioning, respectively.

FIGURE 4-5
CLUFF LAKE TAILINGS DURING OPERATION (WATER COVER)

FIGURE 4-6
DECOMMISSIONED CLUFF LAKE TAILINGS COVERED WITH CLEAN SOIL

The Cluff Lake mine closed in 2002. Upon decommissioning, the tailings were covered with ~ 1 m of clean soil to reduce gamma radiation and radon gas release (Areva Resources, 2006). Site reclamation was completed in 2006, at which time water quality parameters indicated that

treatment was not required, and would not be required in the long term. No water treatment has been needed since 2005. Nonetheless, the site will be monitored for several more years as a precautionary measure.

4.5 ISL: CONTROL OF CONTAMINANTS OF CONCERN

As mentioned in section 3.8, although airborne emissions and solid wastes are generated by ISL operations, the primary environmental consideration with ISL is avoiding groundwater contamination from the orebody (World Nuclear Association, 2008a). In order to detect and minimize this potential contamination, ISL facilities drill monitoring wells outside of the main well-field at a distance sufficient to detect any excursion events. Excursions do not often become problematic to the external water supply as long as they are detected and cleaned up within a reasonable time period, well shafts are effectively cased, and proper monitoring well stations have been established. Along with well monitoring techniques, general practice at ISL facilities is to limit the injection of lixiviant so that it is always slightly less in volume than the product solution that is pumped out of the aquifer. This operating policy effectively precludes excursions caused by overloading the aquifer, and the subsequent expansion and redistribution of the water (U.S. Environmental Protection Agency, 2007).

As discussed in section 3.8, potential chemical and radiological hazards to workers from accidents and spills can be greatly reduced simply by prompt and thorough cleaning of spilled solutions and materials, and paying particular attention to preventing exposure of workers to dried yellowcake and other contaminants.

ISL facilities must go to great lengths to restore groundwater to levels consistent with pre-operational baseline conditions upon closure and decommissioning, to protect water quality outside the recovery zone. Prior to the development and operation of an ISL facility, therefore, extensive baseline sampling is carried out to quantify water quality parameters that will later serve as the basis for setting groundwater restoration goals. Typical baseline water quality parameters include cations (ammonia, calcium, magnesium, potassium, sodium), anions (bicarbonate, carbonate, chloride, fluoride, sulphate, nitrate), trace and minor elements (arsenic, heavy metals, radium-226, etc.) and general parameters such as dissolved solids, alkalinity, conductivity and pH. In the United States, ISL licences include detailed specifications for baseline, operational and post-operational groundwater sampling and analysis programs sufficient for the purposes of operational monitoring, identification, control and clean-up of excursions, and groundwater restoration after uranium recovery.

Restoration involves removing or rendering immobile constituents added to native groundwater for uranium recovery and those mobilized during the recovery process. Chemical treatment is sometimes used to reverse or inhibit reactions initiated during the recovery phase. Two basic

approaches have been used, both of which employ the same injection/extraction well fields and equipment used in uranium recovery.

1. Groundwater sweep. Water from the surrounding formation is drawn into the mined area by continuous pumping from the extraction wells. This method is often the preliminary means of removing lixiviant. Recovered groundwater is conveyed to an evaporation pond or deep disposal well. Note that evaporation ponds may not be suitable in more northern climates where evaporation capacity may be limited, therefore enhanced evaporation or a combination of evaporation and deep well injection may be more appropriate.
2. Reverse osmosis (RO). Untreated groundwater is pumped across a specialized membrane to separate solute molecules from recovered groundwater and concentrate them into a smaller volume of brine. The RO-treated water is then circulated through the production zone.

A third step in groundwater restoration may involve aquifer recirculation, i.e., aquifer water is pumped and reinjected without treatment.

Chemical reductants (e.g., hydrogen sulphide gas, sodium hydrogen sulphide (NaHS) or disodium sulphide (Na_2S)) may be used to attenuate trace metals and oxidized anions such as sulphate and nitrate. Alternately, bioremediation involves the stimulation of naturally occurring bacteria that reduce oxygen levels and/or produce reductants. Addition of nutrients such as sugars, alcohols, fats or proteins increases the abundance of micro-organisms *in situ* that reduce metals indirectly (by production of reductants such as hydrogen sulphide) or directly by dissimilatory reduction of the oxidized states of uranium, selenium, iron, etc., precipitating them in place. (Dissimilatory reduction means that the bacteria use the oxidized form of the metal in question as a terminal electron acceptor in a redox reaction that generates energy they can use to drive biological processes. The nutrients introduced in bioremediation act as electron donors in the same redox reaction.) Bioremediation effectively duplicates nature's process of mineral deposition and results in accelerated groundwater restoration while decreasing consumption of groundwater pumped from well fields during restoration activities.

When subsurface geology at the site is conducive to injection of liquids, deep well injection is often the preferred method for disposal of ISL/ISR liquid waste due to its efficiency, smaller land use requirements (than for evaporation ponds), and elimination of the need for off-site transport. Wells must be engineered, however, to ensure that subsurface fracturing of the injection zone does not incur and that waste does not migrate vertically from the intended injection zone. Typically, these wells are 3,000 to 10,000 ft deep and inject into porous, permeable aquifer horizons amenable to fluid injection. TDS of deep aquifer waters normally exceed 10,000 mg/L; TDS of injectant can range from 10,000 to 50,000 mg/L. The target formation must have an

overlying confining layer precluding hydraulic communication with overlying water-bearing zones.

Upon decommissioning of an ISL installation, wells are plugged and abandoned, process facilities removed, and any affected surface areas are reclaimed and revegetated in accordance with the reclamation plan. In general, the land then readily reverts to its previous uses.

5.0 NATIONAL AND INTERNATIONAL DOSE AND EMISSION LIMITS

5.1 RADIATION DOSE LIMITS

Related to exploration activities and any potential uranium mine development, the primary public concern usually centres on radioactivity. Below is a concise description of radioactivity from Naturally Occurring Radioactive Materials (NORM) associated with uranium deposits. The Canadian NORM Guidelines (2000)[10] provide guidance for managing radiation doses from NORM.

5.1.1 Dose Limits for NORM

The Canadian NORM Guidelines recommend that workers and the public be divided into two groups for the purpose of specifying dose limits:

1. occupationally exposed workers, and
2. incidentally exposed workers and members of the public.

Dose limits presented in the NORM guidelines are defined in terms of incremental dose, which is the dose associated with working, over and above doses from natural background radiation and from medical diagnosis procedures. Doses to exploration or uranium mine workers may arise from radioactivity that is taken into the body through inhalation or ingestion of radioactive dust or from gamma radiation from sources outside of the body.

5.1.2 Dose Limits for Occupationally Exposed Workers

Occupationally exposed workers are employees who are exposed to NORM sources of radiation as a result of their regular duties. Doses should not exceed a total effective dose of 100 mSv over a five-year period with a maximum dose of 50 mSv in one year. The limit for a pregnant

[10] Health Canada (2000)

worker, once pregnancy has been declared to her employer, is 4 mSv for the remainder of the pregnancy.

5.1.3 Dose Limits for Incidentally Exposed Workers and Members of the Public

Incidentally exposed workers are employees whose regular duties do not include exposure to NORM sources of radiation. They are considered members of the public who work in an occupational exposure environment. The dose limit for these workers, as well as other members of the public, is 1 mSv/y.

In addition to controlling doses to within the exposure limits, the ALARA principle (As Low As Reasonably Achievable, with economic and social factors taken into account) should be applied to further minimize the dose received by a worker. ALARA is achieved through the development of best work place practice and technology protocols based on dose targets.

The recommended maximum dosages for uranium mine workers and the public were established by the International Commission for Radiological Protection (ICRP), according to the following three basic principles.

- Justification: No practice involving exposure to radiation should be adopted unless it produces a net benefit to those exposed or to society in general.
- Optimisation: Radiation doses and risks should be kept as low as reasonably achievable, with economic and social factors taken into account.
- Limitation: The exposure of individuals should be subject to dose or risk limits above which the radiation risk would be deemed unacceptable.

These principles apply to the potential for accidental exposures as well as predictable normal exposures.

The maximum exposure levels recommended by the ICRP are observed by many countries around the world, including Canada, Australia and the United States. Monitoring at high grade uranium mines in Saskatchewan has shown exposure levels less under the limits as shown in Figure 4-1. The radiation dose to members of the public from uranium mine activity is shown in Figure 4-2. All exposures were well below the limit of 1 mSv/y.

FIGURE 5-1
AVERAGE AND MAXIMUM RADIATION DOSE SASKATCHEWAN MINE WORKERS 2006

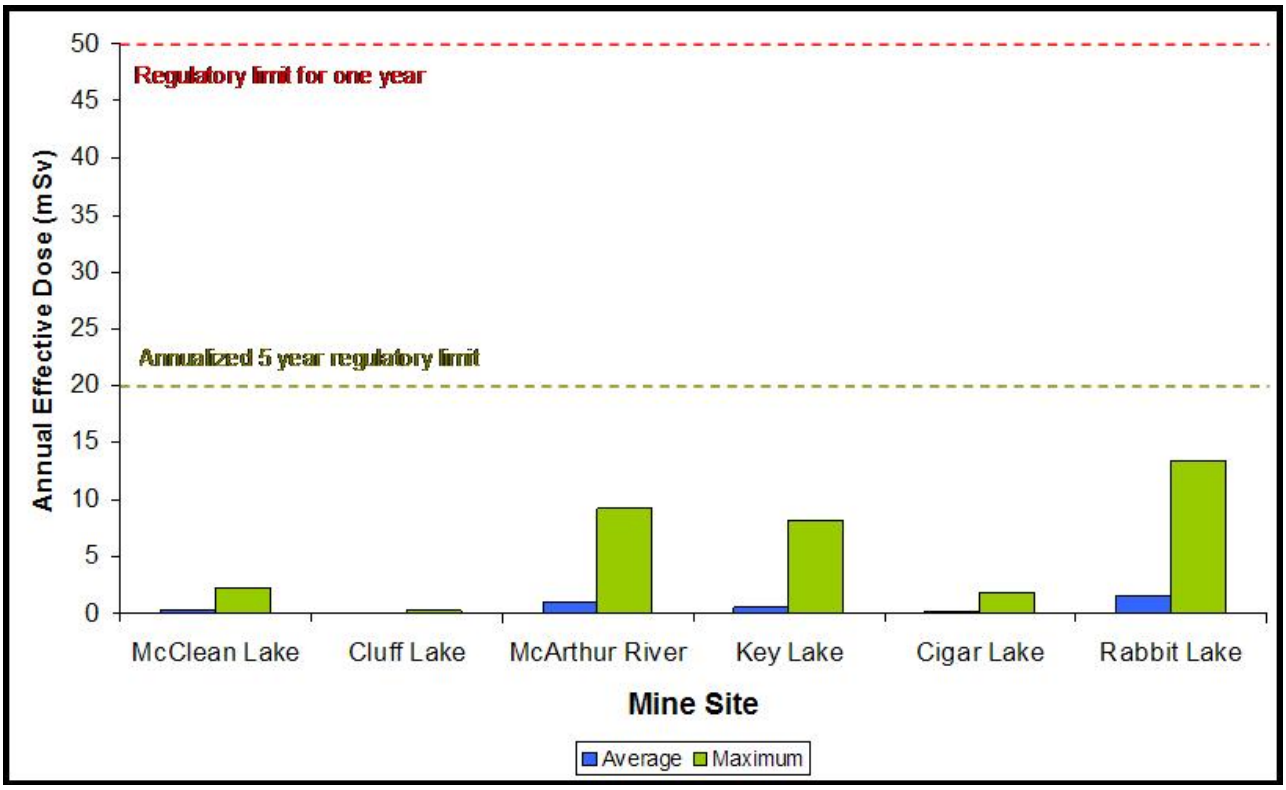
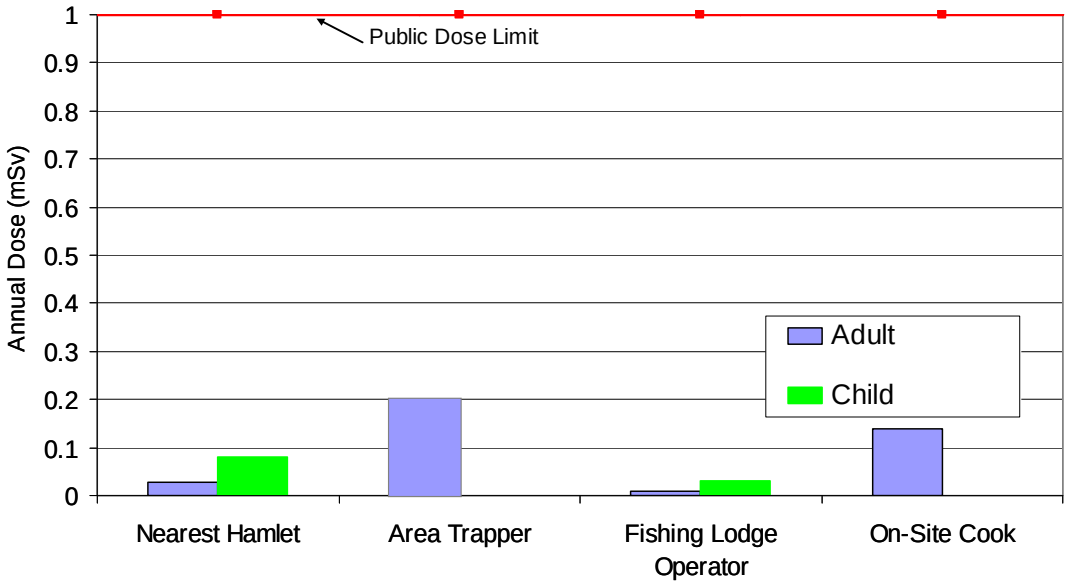


FIGURE 5-2
RADIATION DOSES TO MEMBERS OF THE PUBLIC FROM URANUM MINING IN SASKATCHEWAN 2006



Alberta's Radiation Protection Regulation specifies maximum annual dose limits for ionizing radiation for both radiation workers and members of the general public. These dose limits are established internationally by the International Commission for Radiological Protection (ICRP) and are in agreement with the dose limits specified in the Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM). In Alberta, radioactive material is not classified as a hazardous waste; it is excluded under section 3(a) of the Waste Control Regulation because radioactive materials are regulated under the federal *Atomic Energy Control Act* by the CNSC.

The working level month (WLM) has been used as a measure of dose for exposure to radon and radon decay products. One WLM is approximately equivalent to 3700 Bq/m^3 of ^{222}Rn in equilibrium with its decay products. Exposure to 0.4 WLM has been used as the maximum permissible level for workers. Continuous exposure during working hours to 0.4 WLM would result in a dose of 5 WLM over a full year, corresponding to about 50 mSv/y whole body dose for a 40-hour week. In mines, the dose to individual workers is now kept below 1 WLM/y (10 mSv/y), and typically averages half this amount.

Globally, mining company employees are not typically exposed to radiation doses in excess of the limits set out by the ICRP. In general, the maximum dose received is about half of the 20 mSv/y limit with the average being about one tenth of the limit. By comparison, in some areas of India and Europe, natural doses may be as high as 50 mSv/y without any evidence of adverse effects. Figure 3-2 presents the average annual doses of radiation from natural sources

from around the world. Mean exposures of approximately 750 mSv/y in some East German mines from 1946 to 1954 resulted in thousands of cases of lung cancer (World Nuclear Association, 2006). Some comparative radiation doses and effects are provided in Table 5-1.

TABLE 5-1
RADIATION DOSE AND POTENTIAL EFFECT[11]

Dose	Effect
2 mSv/y	Typical background radiation.
up to 5 mSv/y	Typical incremental dose for airline crew in middle latitudes.
9 mSv/y	Exposure by airline crew flying the New York - Tokyo polar route.
20 mSv/y	Current limit (averaged) for nuclear industry employees and uranium miners.
50 mSv/y	Former routine limit for nuclear industry employees. Dose rate which arises from natural background levels in several places in Iran, India and Europe.
100 mSv/y	Lowest level at which any increase in cancer is evident. Above this, the probability of cancer occurrence increases with dose.
350 mSv/lifetime	Criterion for relocating people after Chernobyl accident.
1,000 mSv/cumulative	Would probably cause a fatal cancer years later in 5 of every 100 persons exposed (i.e., if the normal incidence of fatal cancer were 25%, this dose would increase it to 30%).
1,000 mSv (single dose)	Causes (temporary) radiation sickness such as nausea and decreased white blood cell count but, not death. Above this, severity of illness increases with dose.
5,000 mSv (single dose)	Would kill about half those receiving it within a month.
10,000 mSv (single dose)	Fatal within a few weeks.

5.1.4 Impacts on Biota

According to the CNSC, the development of benchmarks for radiation protection of nonhuman biota is not as mature as the development of benchmarks for hazardous substances due to the historic assumption that protecting humans from radiation is sufficient to protect the environment. The primary concern with respect to the protection of nonhuman biota is the total radiation dose to the organisms that results in deterministic effects. Benchmark values for mean radiation doses have been derived for some nonhuman organisms. More attention may be focussed on environmental effects in the future because some species are more sensitive to radiation than others (Sheppard et al., 2004).

[11] World Nuclear Association (2008b)

5.2 WATER QUALITY LIMITS

Mining operations and disposal of mining waste can release radionuclides, metals and other contaminants to the aquatic environment. In Canada, a key set of regulations have been established by Environment Canada, and are monitored according to the parameters set out in the Metal Mining Effluent Regulations (MMER) of the federal *Fisheries Act*. Table 5-2 summarizes maximum authorized concentrations (MAC) of various contaminants in mining effluents, including Radium-226.

TABLE 5-2
AUTHORIZED LEVELS OF MINING EFFLUENT PRESCRIBED BY THE MMER*

Deleterious Substance	Units	Maximum Authorized Monthly Mean Concentration	Maximum Authorized Concentration in a Composite Sample	Maximum Authorized Concentration in a Grab Sample
Arsenic (As)	mg/L	0.5	0.75	1.0
Copper (Cu)	mg/L	0.3	0.45	0.6
Cyanide (CN)	mg/L	1.0	1.5	2.0
Lead (Pb)	mg/L	0.2	0.3	0.4
Nickel (Ni)	mg/L	0.5	0.75	1.0
Zinc (Zn)	mg/L	0.5	0.75	1.0
Radium 226	Bq/L	0.37	0.74	1.11
Total suspended solids (TSS)	mg/L	15	22.5	30
Percentage of non-acutely lethal effluent**	100%			
pH range	6.0 - 9.5			

*All concentrations are total values.
**For the purposes of the MMER, non-acutely lethal means survival of at least 50% of rainbow trout subjected to 100% concentration effluent for a period of 96 hours.
Source: MMER

Alberta Surface Water Quality Objectives (SWQO's) do not address radionuclides. Instead, Alberta uses the CCME Canadian Water Quality Guidelines (CWQG) for substances not addressed under the Alberta SWQO's. CCME guidelines for Canadian Drinking Water Quality contain primary and secondary lists of natural and artificial radionuclides. For example, the maximum acceptable concentrations of ^{226}Ra, ^{210}Pb and ^{230}Th in drinking water are 0.6 Bq/L, 0.1 Bq/L and 0.4 Bq/L, respectively. The CWQG's for Protection of Aquatic Life do not address radionuclides, nor do the CWQG for Agricultural Use, although the latter recommends maximum acceptable concentrations of uranium in irrigation water (10 µg/L) and in livestock

water (200 µg/L). The same concentrations are listed in the Alberta SWQO's for agricultural waters.

Relevant Saskatchewan SWQO's, adapted from the CCME guidelines, are listed in Table 5-3.

TABLE 5-3
SASKATCHEWAN SURFACE WATER QUALITY OBJECTIVES FOR URANIUM, ALPHA AND BETA ACTIVITY

Parameter	Maximum Acceptable Concentration (MAC)
Uranium	0.02 mg L^{-1}
Gross alpha activity	0.1 Bq L^{-1}
Gross beta activity	0.11 Bq L^{-1}

In general, water quality targets are typically well below regulatory limits, in accordance with the ALARA principle. As an example, Table 5-4 presents 2004 water quality data for treated water from the McArthur River Mine in Saskatchewan.

TABLE 5-4
DISCHARGE WATER QUALITY, McARTHUR RIVER HIGH GRADE URANIUM MINE, 2004

Element	Feed to Treatment	Treated Discharge	Metal Mining Effluent Regulations
Copper mg/l	0.031	0.001	0.3
Lead mg/l	0.14	0.002	0.2
Zinc mg/l	0.041	0.008	0.5
Uranium mg/l	0.87	0.038	--
Radium226 Bq/l	23	0.063	0.37

5.3 AMBIENT AIR AND ATMOSPHERIC EMISSION STANDARDS

Atmospheric impacts from mining and milling come from the production of particulate matter and radon. Particulate matter (dust) is generated from several sources including transportation, tailings, mine ventilation and milling operations. Particulate matter can be inhaled by mine workers or transported away from the mine or processing site and potentially inhaled by members of the public. Radon and radon daughters are important airborne substances that must be controlled. Workers in modern Canadian mines are exposed to 800 times less radon gas than

in the past. As a result, the risk of uranium workers developing lung cancer from exposure to radon gas is now as low as the risk to the general public (Canadian Nuclear Safety Commission, 2007b). This decrease in radon gas exposure can be attributed to modern control technologies, especially ventilation, and various types of covers (water, clay, vegetation) that are used to prevent weathering and windblown particles.

SO_X and NO_X are emitted to the atmosphere during uranium mining and processing, but their effects are expected to be minimal because of very tight controls on air emissions (Health Canada, 2004). SO_X emissions would be produced by a sulphuric acid plant at a minesite burning elemental sulphur to produce SO_2. NO_X emissions may originate from diesel engines and potentially from the ammonia that is used to precipitate uranium from solution and later volatilized in the calcining process.

Section 13, subsection (4) of the CNSC Radiation Protection Regulations indicates that 60 Bq/m^3 of radon is equivalent to the 1 mSv/y dose limit for members of the public. Sixty Bq/m^3 above background should therefore be considered as a radon-in-air concentration limit for public exposure.

6.0 A SUCCESSFUL, ECONOMIC APPROACH TO CONTROLLING EMISSIONS AT A NEW URANIUM PRODUCTION FACILITY

Considerations for economic success in controlling emissions at a new uranium production facility will include the following:

- design of processes that apply proven and reliable technologies;
- effective communication with project stakeholders;
- streamlined environmental assessment and permitting;
- application of best management practices, including periodic revision for continuous improvement; and
- design and financial assurance for closure.

6.1 PROJECT DESIGN

The Canadian uranium mining industry has demonstrated that emissions from conventional uranium mine facilities meet the most stringent standards, and that the exposure of workers and the general public to contaminants and radiation are well below accepted limits. The impact on the natural environment from uranium mining is also demonstrably low. The high performance of Canadian uranium mines is evident at facilities extracting low to medium and high grade uranium resources, both of which (high and low grade deposits) may be discovered in Alberta.

A project proponent would likely consider the practices currently applied in Saskatchewan, adapting them only for site-specific conditions.

For potential ISL development, the technologies successfully used at recent ISL operations in the United States would reasonably assure the protection of water resources and prevent the dispersion of radioactive materials on surface.

6.2 Environmental Assessment and Permitting

For uranium mine developments in Canada and in the United States, the completion of environmental assessments (EAs), public consultations and permitting can be costly and take considerable time. Ecological and human health risk assessments with pathways analyses are essential tools in the environmental assessment process. Agencies of the Province of Alberta, CEAA, MPMO[12] and the CNSC could facilitate streamlining the EA, consultation and permitting processes by working closely together.

6.3 Application of Best Management Principles

Successful application of best available emission control technologies at an operating uranium mine or ISL facility can be enhanced by two key principles:

- use of operational management principles that include continuous improvement such as ISO 14000; and
- establishment of fully-funded, independent monitoring committees that include local people, to ensure that all emission control objectives are fully met.

6.4 Provision for Closure

The Province of Alberta would require project proponents to include in the project proposal, design and financial assurance for closure. For conventional uranium mining and milling facilities, this would include provision for removal of all site infrastructure, restoration of disturbed land, and long-term stabilisation of mine openings, waste rock and tailings. For ISL facilities, closure would include removal and decontamination of surface facilities, neutralisation and stabilisation of the leaching zone(s) and plugging of all wells.

For both conventional and ISL facilities, site monitoring would be required for many years and would be licensed by the CNSC. Experience across Canada has shown that monitoring could continue for several years before the CNSC would issue a license to abandon the property.

[12] MPMO – Major Project Management Office, a recent (October 2007) initiative of the Government of Canada, is being established to improve the performance of the federal regulatory system for major natural resource projects.

7.0 CONCLUSIONS

Canada is a world leader in uranium production. Uranium mining technology is well advanced in Canada to protect people and the environment. As a result, radiation exposures and doses to uranium exploration and mine workers, and to the public, from uranium mine development, operation and closure are well below limits. Advanced engineering practices keep environmental disturbances to a minimum.

Supplying uranium for the generation of electricity from nuclear energy is an activity that can be considered in Alberta to meet increasing demands for energy that has low greenhouse gas emissions. As nuclear energy regains acceptance in Canada and around the world, demand for uranium climbs, and with it so does the economic feasibility of uranium mining in Alberta. Extensive prospecting for uranium has shown the potential that economic deposits may exist in the province.

Regulatory measures for uranium mining are well developed at the international and national levels. In Canada, all existing uranium- and nuclear-related developments are very strongly regulated, involving multiple permits and licences in addition to comprehensive environmental assessment by provincial and federal authorities. Streamlining of the process would reduce costs and cut the time required to license a facility. Although some measures are in place to regulate mining in general at the provincial level, Alberta has yet to modify its regulatory framework to address uranium mining in particular. For conventional uranium mining, the approach used in Saskatchewan could be adopted to suit Alberta's needs. Since no framework yet exists in Canada for the regulation of *In Situ* Leaching (ISL) facilities, modification of the United States model can be considered for ISL projects. In addition, site specific, local initiatives, such as current land use, might need to be considered in the development of in situ recovery methods.

Consultation will be an essential component of any successful approach to the future development of uranium mining facilities in Alberta. Local residents play a vital role in the decision-making process; public opposition to uranium mining can be considerable, which could result in lengthy licensing delays and even cancellation of a project. Consultation establishes a means to discuss and resolve issues, and to ensure that any proposed uranium development projects will take into account effects on current and traditional land use. It also helps facilitate public access to verifiable scientific information, on the basis of which to make informed decisions regarding individuals' support for (or opposition to) various aspects of a proposed project.

Effective regulation of uranium mine developments in Alberta will successfully blend together the interests of the Province with the existing requirements of national and international regulatory bodies. At the same time, it will facilitate incorporation of the priorities of local

residents and groups, while ensuring the application of best available practices for the protection of individuals and the environment. With a strong, streamlined regulatory process in place for uranium mining, Alberta and Albertans will be well positioned to pursue the economic benefits of uranium mine developments in a manner that is both safe and clean.

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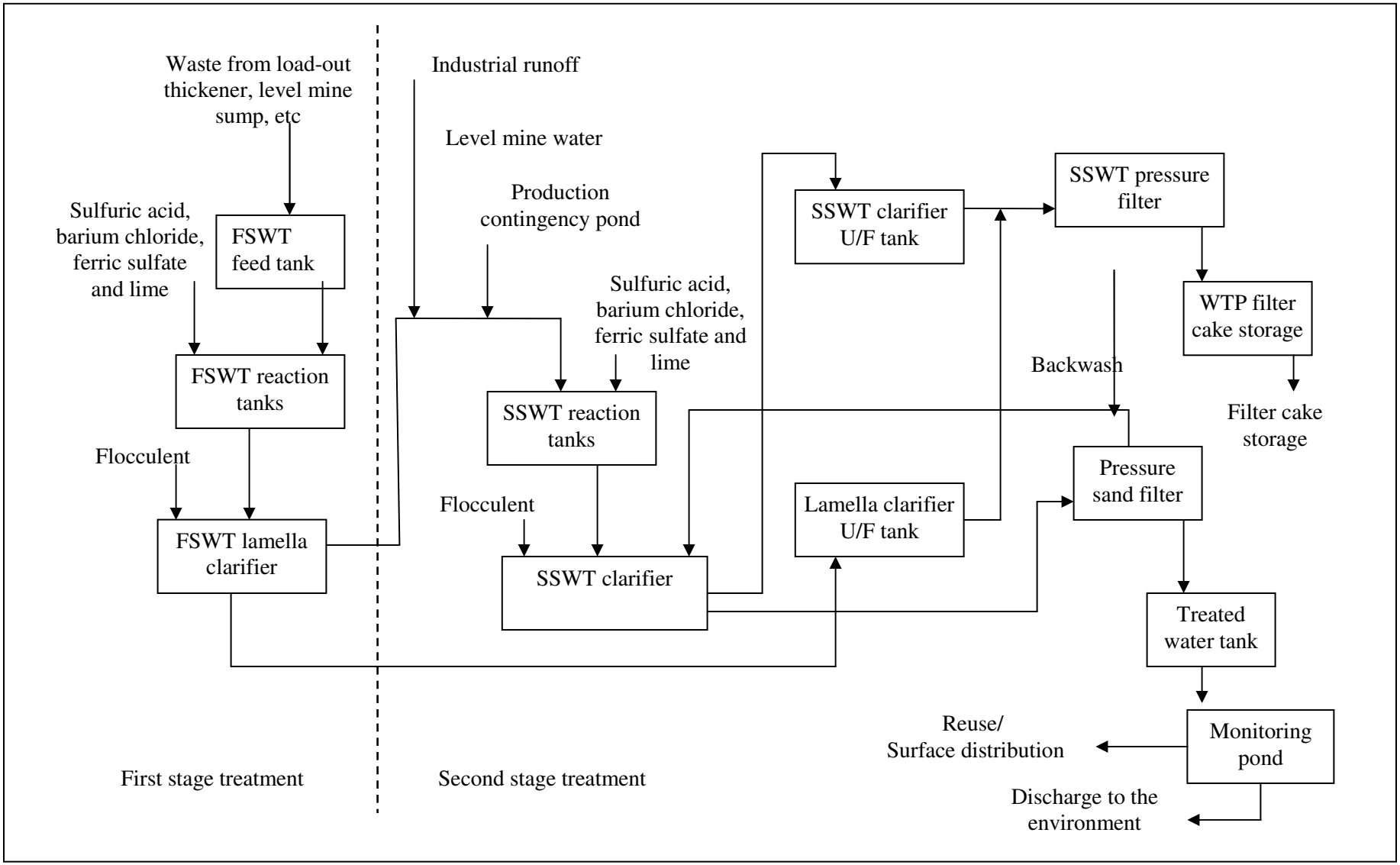
APPENDIX A

Cigar Lake Water Treatment Process

CIGAR LAKE WATER TREATMENT