Update and correction (2014-05-16)

Current Knowledge, Impacts and Mitigation Measures Related to the Exploration and Mining of Uranium Deposits in Québec

Report Prepared for Québec's *ministère du Développement durable, de l'Environnement, de la Faune et des Parcs* and *ministère des Ressources naturelles*

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ABSTRACT

Uranium is a radioactive metal occurring at low concentrations in rocks, water, soil and organisms. Natural uranium has three isotopes: ^{234}U, ^{235}U and ^{238}U. The atomic nucleus of each uranium isotope undergoes a series of transformations following a decay chain composed of elements with fixed radioactive periods – their half-life. The nuclear decay of uranium releases energy in the form of alpha, beta or gamma ionizing radiation. Each type of radiation has an energy that varies according to its nuclear reconfiguration.

Uranium is mined in 22 countries, either as the main substance or as a coproduct of other substances mined, such as phosphorus or rare earth elements. It is extracted by *in situ* leaching, or excavated from underground or open pit mines. Uranium is used to produce radioactive isotopes that benefit several sectors of the medical and agri-food industries. Its main civilian use is electricity production (accounting for 12 % of global electricity production). There are 440 power plants in the world that use nuclear energy, and they consume about 64,000 tonnes of uranium per year. The price of uranium is determined by supply and demand and global demand is on the rise, which accounts for current high prices. Many mining projects being developed in the world have sufficient uranium resources to meet the anticipated medium-term demand.

In Québec there is good potential for uranium deposits. The geological context suggests that uranium mineralization may be present in sandstones, similar to mineralization in Colorado and Saskatchewan, in conglomerates, and in igneous and metamorphic rocks, such as in Namibia. In Québec, uranium resources are estimated at 192,000 tonnes of uranium, 83 % of which are associated with low-grade intrusive rocks. Approximately 5 % of the uranium resources occur in sandstones of the Otish Mountains sedimentary basin, north of Chibougamau.

In Québec, exploration, mining and mine site rehabilitation are administered under the Mining Act and the Environment Quality Act (EQA). All projects related to the commissioning and operation of an uranium mine, or to the construction of a processing plant, among others, are subject to an environmental impact assessment and review procedure under the EQA. Furthermore, all projects that involve a certain threshold for radioactivity must be authorized by the Canadian Nuclear Safety Commission, and are subject to the Nuclear Safety and Control Act and to the Canadian Environmental Assessment Act.

The annual dose received by an organism is expressed in sieverts (Sv). Depending on geographical location, humans receive an annual dose of approximately 3.5 millisieverts (mSv). Of this amount, 2 mSv comes from natural radioactivity (due to the presence of uranium, thorium, potassium and other radioactive elements in the environment) and 1.5 mSv are from anthropogenic sources, mainly related to medical applications. Canada authorizes an additional dose of 1.0 mSv per year for people exposed to radiation from nuclear facilities, including uranium exploration and mining.

The chemical toxicity of uranium is the same for each of its isotopes, unlike its radiotoxicity, which varies from one isotope to another. Uranium is weakly radioactive, such that its impact on the environment is mainly related to its chemical toxicity. Though uranium is not easily bioaccumulated in plants, it may accumulate in organisms of the lower trophic levels, such as invertebrates. The daughters of uranium, like polonium, are also associated with a chemical toxicity, or a radiotoxicity. At the mineral exploration stage, the environmental impact is low and limited to drilling, and only if uranium mineralization is intersected. Recirculating the drilling fluids in a closed circuit can

Province, where Sakami-type basins are thought to contain at least 13,300 t of uranium in two low-grade deposits.

- Uranium can be associated with **intrusive deposits** in alaskites and pegmatites. These deposits are rarely mined given their low grade. However, one of the most important mines in the world is located in Rössing, Namibia, where Rio Tinto is currently mining a very large, low-grade uranium deposit (598 Mt at 245 g/t U_3O_8), of almost 150,000 t U. There are many showings in Québec, particularly in the Grenville Province (in the Basse-Côte-Nord region, in the Mont-Laurier sector) and in the Churchill Province, in the Ungava region. In the Grenville Province, the potential resources are estimated at 28,900 t U divided into six low-grade deposits, and 52,600 t U divided into six very low-grade deposits. In the Churchill Province, two recently discovered areas represent more than 6,000 t U with a low grade.

- **IOCG deposits.** For this type of ore, gold, copper and uranium are mined. Iron may also be recovered, and on occasion rare earth elements. The exceptional Olympic Dam deposit, in South Australia, has an average grade of 204 g/t U_3O_8 for reserves of 8,946 Mt at 0.75% Cu, 0.30 g/t Au and 1.26 g/t Ag. How these deposits formed is still poorly understood, but they have been discovered in many places across the world, and there are many similar showings in Québec, in the Basse-Côte-Nord and in Nunavik.

It is worth mentioning that there are no deposits in Québec formed by the infiltration of meteoric waters. These deposits are very common in warmer climates, at lower latitudes. Québec's climate is not favourable to uranium transport, and the ice cap retreated only very recently (~6,000 to 7,000 years ago). Recent glacial action has resulted in a generally young topography, exposing rocks at surface that have barely been weathered. This does not favour the dissolution of uranium in rocks by water. The occurrence of peat bogs in Québec is also worth mentioning. Peat bogs can trap the traces of uranium or other metals that may be circulating in surface waters.

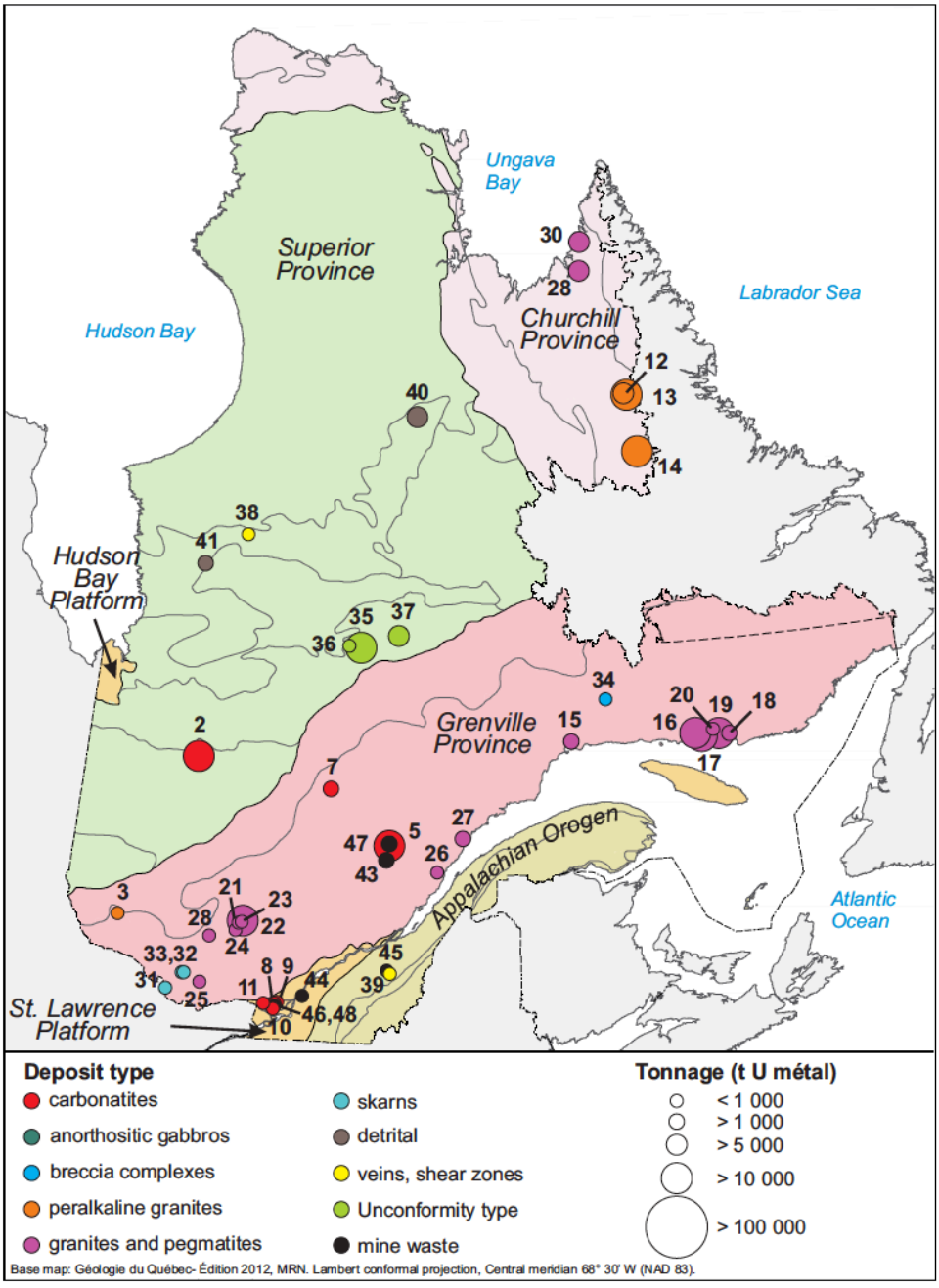
The geochemical map of uranium concentrations in lake bottom sediments, created by the *ministère des Ressources naturelles du Québec*, provides a computer-generated image of potentially uranium-rich zones (Figure 5.4). These uranium-rich zones are shown in Figure 5.4, as well as areas of concentration that remain under-explored. This map only shows concentrations occurring at the surface, and more specifically concentrations where uranium is hosted by refractory minerals or organic matter. The map is therefore an approximation, which can be used to determine broad areas of interest. In fact, the mobility of uranium under oxidizing surface conditions and entrapment within anoxic sediments (oxygen-poor) in the bottom of lakes can generate regional-scale artefacts on the map.

5.3.1 Churchill Province and Labrador Belt

These areas contain three types of mineralization:

- There are rare metal (rare earth elements, zirconium, yttrium, beryllium, niobium, tantalum) and uranium deposits associated with peralkaline granites: 42,509 t U spread across three deposits located in the eastern part of the province, within the Mistasin batholith (1.2 Ga) (Misery Lake, Strange Lake B Zone and Main Zone). The mineral potential for uranium is vast.

- The central northern part of the province (or the Core zone) contains metasedimentary rocks in the Torngat Orogen (Lake Harbour Group). Discoveries were recently made in this area, spurred by the



2: Montviel, 3: Kipawa (Zeus, Lac Sheffield-2), 5: Niobec, Nb Mine, 7: Crevier, 8: Manoka (Oka), 9: Oka, (Zone Bond, Wayfair), 10: St-Lawrence Colombium Mine (SLC), 11: St-André-2, 12: Strange Lake B Zone, 13: Strange Lake Main Zone (Lac Brisson), 14: Misery Lake, 15: Lac Kachiwiss, 16: North Shore / Turgeon, 17: Baie Quetachou, 18: Doran (Lacana), 19: Johann Beetz (Drucourt Est), 20: Lac Caron, 21: Tom Dick (Zone Nord 1), 22: Nova (or Renard or Allied (1-3), 23: Mekoos (or Bear, 3-3D), 24: Lac Hanson, 25: Lac Indien, Bain, 26: Lac Fafard, 27: Anomalie C11r4, 28: Capri-2, 29: Secteur North Rae, 30: Secteur Cage, 31: Grand Calumet / Calumet Contact N°3, 32: Zone Matte, 33: Zone de Camp , 34: Kwyjibo, 35: Matoush, 36: Lac Beaver / Zoran, 37: Lavoie / Indice L, 38: Ganiq, 39: Harvey Hill Cu mine, 40: Dieter Lake / Lac Gayot, 41: Apple, 43: Boues Rouges Usine Vaudreuil - Jonquière, 44: Phosphogypses, Varennes, 45: Harvey Hill, residues, 46: Mine SLC, residues, 47: Mine Niobec, slag, 48: Mine SLC, slag. Uranium showings without a potential resource estimate are not shown.

Figure 5.5: Locations of uranium resources in Québec (Table 5.2).

5.6 THE URANIUM PRODUCTION POTENTIAL OF QUÉBEC

Québec's production potential may come from three different sources:

1. Primary resources where uranium is the main substance;

2. Primary resources where uranium is a coproduct that contributes to the ore's value;

3. Mine waste and tailings available for reprocessing.

We have compiled the mineral data available in the public domain, and compared them with data from the IAEA and MRN. The IAEA lists 17 deposits in Québec in its UDEPO database (resources ranging from 94,400 to 205,000 t U). This dataset is incomplete and contains mistakes, as well as duplicates. Data from the MRN is different, but also incomplete. Data pertaining to resources with uranium as a coproduct was taken from public sources. All primary resources (main substance, coproduct), mine waste and tailings are presented together for the first time in this inventory.

We estimate Québec's uranium resources to be 200,000 t (Tables 5.2 and 5.4). Medium-grade resources in unconformity-related deposits (like those in Saskatchewan), most likely to be mined in the short term, only represent 16,113 t U, the majority of which are in the Matoush deposit, in the Otish Mountains. A few key points regarding mineralization types encountered must be addressed:

- Very high-grade deposits found elsewhere in Canada are exceptions, and mining of these deposits remains limited;
- Of the 192,050 t of uranium resources, 158,613 t are intrusive in origin, which represents **83 % of total uranium resources** inventoried (Table 5.2);
- Of the 158,613 t U of intrusive origin, 71,179 t occur as a potential coproduct of Québec's vast resources of rare earth elements, niobium, tantalum and other rare metals. This represents **45 % of total uranium resources** inventoried
- Aside from the two deposits in the Otish Basin (Matoush and Lavoie), deposits have a low uranium grade (0.3 % U), even a very low (< 0.03 % U).

Table 5.2: Inventory of uranium mineral resources in Québec (2013).

Deposit no.	MRN no.	Name of deposit/site	Mining company	Type of deposit	Tonnage (10^6 t)	U (g/t)	U (t)	Total %
Medium-grade deposits (0.1 to 1.0 % U)								
35	32P16-1001	Matoush	Strateco Resources Inc.	Unconformity	2.27	4871	11067	5.76
37	23D02-1001	Lavoie / Showing L, 38:	AREVA Resources Canada	Unconformity	1.14	4444	5066	2.64
Low-grade deposits (0.03 to 0.1 % U)								
36	32P16-0001	Lac Beaver / Zoran		Unconformity	0.15	933	135	0.07
22	31J14-0005	Nova (or Renard or Allied (1-3)	Nova Uranium Corp.	Alaskite/pegmatite	31.8	*840*	*26712*	13.91
30		Cage Sector	AREVA Resources Canada	Pegmatite/metasomatite	*5*	*800*	*4000*	2.08
31	31F15-0026	Grand Calumet / Calumet Contact No.3	Globex Mining Enterp. Inc.	Skarn	1	678	678	0.35
32	31F15-0014	Matte Zone		Skarn	0.18	661	120	0.06
24	31J14-0013	Lac Hanson	Nova Uranium Corp.	Alaskite/pegmatite	0.54	636	346	0.18
23	31J14-0004	Mekoos (or Bear, 3-3D)	Nova Uranium Corp.	Alaskite/pegmatite	0.52	539	283	0.15
29		North Rae Sector	Azimut Exploration Inc.	Pegmatite/metasomatite	*4*	*500*	*2000*	1.04
40	23M15-0001	Dieter Lake / Lac Gayot	Denison Mines Inc.	Paleoplacer	19.31	487	9405	4.90
33	31F15-0013	Zone de Camp		Skarn	0.17	475	79	0.04
41	33F02-0004	Apple	Strateco Resources Inc.	Paleoplacer	8.5	458	3891	2.03
38	33G13-0010	Ganiq	Midland Exploration Inc.	Vein, shear zone	0.27	435	115	0.06
28		Capri-2	Starfire Minerals Inc.	Pegmatite/metasomatite	1	*424*	*424*	0.22
26	22C04-0002	Lac Fafard		Pegmatite	0.09	395	37	0.02
27	22C11-0001	C11r4 Anomaly		Pegmatite	3.56	300	1068	0.56
Very low-grade deposits (<0.03 % U)								
21	31J14-0001	Tom Dick (Zone Nord 1)	Nova Uranium Corp.	Alaskite/pegmatite	0.27	229	62	0.02
17	12L07-0008	Baie Quetachou	Uracan Resources Ltd.	Alaskite/pegmatite	93.45	*212*	*19811*	6.29
18	12L08-0003	Doran (Lacana)	Entourage Mining Ltd.	Alaskite/pegmatite	10.89	211	2298	0.73
25	31F09-0008	Lac Indien, Bain		Pegmatite	0.13	178	23	0.01
15	22J08-0001	Lac Kachiwiss	Rio Tinto plc (Hathor Expl.)	Alaskite/pegmatite	16.6	136	2258	0.72
19	12L08-0005	Johann Beetz (Drucourt Est),	Gimus Resources Inc.	Alaskite/pegmatite	100	*110*	*11000*	3.49
16	12L07-0003	Côte-Nord / Turgeon	Uracan Resources Ltd	Alaskite/pegmatite	162.15	104	16912	5.37
20	12L08-0001	Lac Caron		Alaskite/pegmatite	2	*100*	*200*	0.06
							117990	**37.48**
Deposits with uranium as a potential coproduct								
34		Kwyjibo (Josette)	SOQUEM Inc.	Breccia complex	*0.8*	*435*	*348*	0.11
8	31G-09-0017	Manoka (Oka)		Alkaline Complex	0.2	*175*	*35*	0.01
13	24A08-0001	Strange Lake Main Zone (Lac Brisson)	Quest Rare Minerals Ltd.	Peralkaline granite	54	146	7884	2.50
39	21L-06-0021	Harvey Hill Cu Mine		Vein, shear zone	0.45	100	45	0.01
3	31L15-0015	Kipawa (Zeus, Lac Sheffield-2)	Matamec Explorations Inc.	Alkaline complex	16.314	62	1011	0.32
2	32F15-0004	Montviel	GéoMégA Resources Ltd	Alkaline complex	250.6	52	13031	4.14
12		Strange Lake B Zone	Quest Rare Minerals Ltd.	Peralkaline granite	492.5	50	24625	7.82
14		Misery Lake	Quest Rare Minerals Ltd.	Peralkaline granite	*200*	*50*	*10000*	3.18
7	32H07-0001	Crevier	MDN Inc.	Alkaline complex	40.792	39	1591	0.51
9	31G-09-0014	Oka, (Zone Bond, Wayfair)	Niocan Inc.	Alkaline complex	*13.85*	*29*	*402*	0.13
11	31G/09-0021	St-André-2		Alkaline complex	*20*	*20*	*400*	0.13
10	31G-08-0003	St-Lawrence Colombium Mine (SLC)	Ressources min. Augyva Inc.	Alkaline complex	16.69	16.9	282	0.09
5	22D-11-0012	Niobec, Nb Mine	IAMGOLD Corp.	Alkaline complex	794.51	*15*	*11918*	3.79
							71572	**22.74**
Mine waste and tailings								
46	31G-08-0003	Mine SLC, scories	Ressources min. Augyva Inc.	Ferroniobium scories	0.065	815	53	0.02
47	22D-11-0012	Mine Niobec, scories	IAMGOLD Corp.	Ferroniobium scories	0.3	482	145	0.05
44		Phosphogypsum, Varennes	Rhodia Canada Inc.	Phosphate residues	2	300	600	0.19
45	21L-06-0021	Harvey Hill, residues		Mine waste	0.3	100	30	0.01
43		Boues Rouges, Jonquière	Rio Tinto ALCAN	Bauxite waste	50	30	1500	0.48
48	31G-08-0003	Mine SLC, tailings	Ressources min. Augyva Inc.	Mine waste	6.156	26	160	0.05
							2488	**0.79**
	Level of confidence:	NI43-101, or high degree of confidence	Medium	Low			**192050**	

Estimates based on public mining data, scientific articles and mineralogical data; all values are expressed as uranium metal (and not as U_3O_8 oxide).

5.7 QUÉBEC'S GLOBAL POSITION

Our inventory indicates that Québec's uranium resources are significant on the global scale. Table 5.3 shows that these resources mainly consist of intrusive deposits, unconformity-related deposits and conglomerate deposits. These last two deposit categories have long been mined in Canada. Table 5.4 demonstrates that there are low- and medium-grade deposits in Québec. In Canada, high-grade deposits have only been discovered at depth and following extensive exploration drilling campaigns. Given Québec's geological environments, there is the potential for comparable resources.

Table 5.3: Deposit types in Canada and abroad compared to Québec.

Deposit type	Production 2007 (t U)	N^{ber} deposits World IAEA	Global resources IAEA (t U)	N^{ber} deposits Canada IAEA	Canadian resources IAEA (t U)	N^{ber} deposits Québec (this inventory)	Québec resources 2013 (t U)
Sandstone deposits	**14,600**	575	**3,993,419**	7	17,286		
Proterozoic unconformity-related deposits	**14,100**	85	1,255,382	57	**757,880**	3	16,268
Breccia complex deposits	3,400	16	**2,309,497**	2	5,570	1	348
Volcanic deposits	3,200	114	555,385	9	53,274		
Intrusive deposits	2,600	78	1,094,545	23	62,681	27	158,613
Metasomatic deposits	1,150	54	952,437	1	680	3	877
Vein or unknown	830	277	1,145,212	14		2	160
Quartz-pebble conglomerate deposits	540	61	1,071,822	21	**434,732**	2	13,296
Surficial deposits	300	62	382,809	0			
Breccia pipe infill deposits	0	17	16,460	0			
Phosphate deposits	0	40	**12,898,130**	0			
Lignite and coal deposits	0	24	314,648	0			
Black shale/schist deposits	0	42	1,199,086	1	9,385		
Total	**40,720**	**1445**	**27,188,842**	**135**	**1,408,752**	**38**	189,562

Sources: IAEA(2), 2014; SIGÉOM database.

Table 5.4: Number of deposits inventoried in the world with proven uranium reserves, according to uranium grade and tonnage. For comparison purposes, the number of deposits in Québec with uranium resources is provided in parentheses. It should be noted that there are few medium- to high-grade deposits (> 0.1 %) in current exploration projects.

	Uranium reserves (t U)				
	< 1000	**1000 - 10,000**	**10,000 - 100,000**	**< 100,000**	**Total**
< 0.03 % U	12 *(8)*	65 *(5)*	32 *(7)*	6	115 *(20)*
0.03 - 0.10 % U	39 *(10)*	96 *(5)*	31 *(1)*	6	172 *(16)*
0.10 - 1.00 % U	139	282 *(1)*	89 *(1)*	7	517 *(2)*
1.00 - 5.00 % U	8	13	10	0	31
>5.00 % U	0	1	0	2	3
Total	**198** ***(18)***	**457** ***(11)***	**162** ***(9)***	**21**	**838** ***(38)***

Sources: IAEA (3), 2009; IAEA (2), 2014.