カナダにおける放射性廃棄物処分の概要とMcMaster大学における処分研究計画

JAEA　地層処分研究開発部門
地層処分コロキウム講演

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コロキウム講演内容

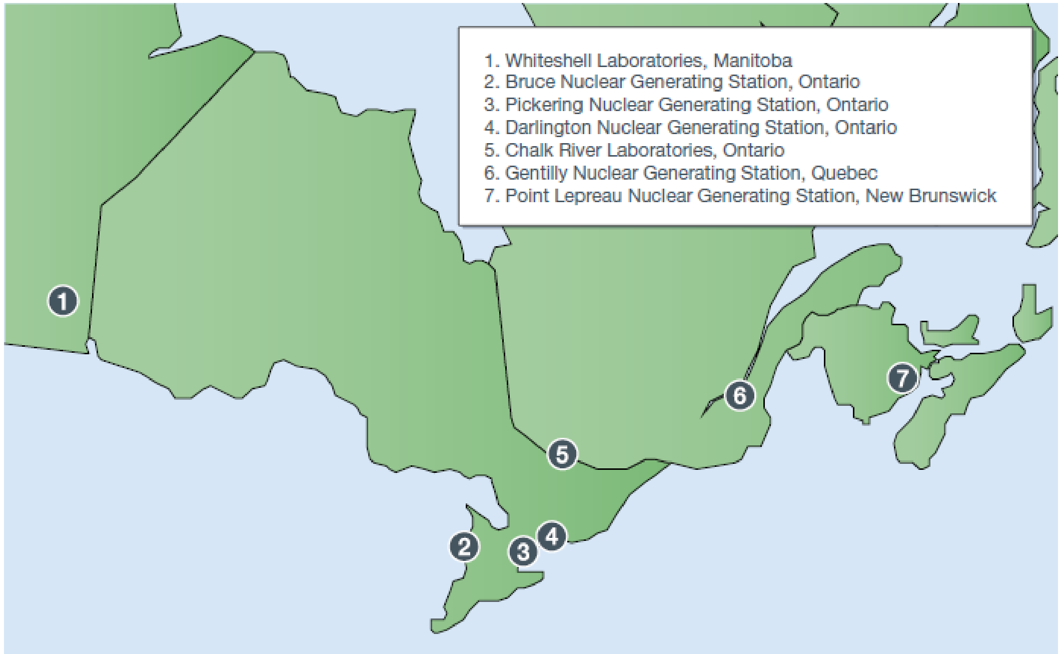
（１）カナダにおける中・低レベル放射性廃棄物処分、ウラン鉱山跡地クリーンアップ、使用済み核燃料処分の概要紹介

（２）カナダにおける使用済み核燃料処分に関連して、NWMO/AECLにおいて実施されているBrine系における核種吸着に関する研究の紹介

（３）McMaster大学における放射性廃棄物処分研究に関する計画の紹介

特に言及がない場合は、図表は NWMO WWW site, OPG WWW site あるいは Bulletin of CNS (Vol.33, No.2, 2012)から引用しています。

http://www.google.com/imgres?hl=ja&sa=X&biw=2560&bih=1480&tbm=isch&prmd=imvns&tbnid=ahX5kKSAYIRWgM:&imgrefurl=http://gotovan.com/manual/view.php%3Fid%3D14&docid=05mzxiALFaZU8M&imgurl=http://gotovan.com/manual/images/map_canada.gif&w=513&h=364&ei=EoiJUM_hB8a0ygHC7YHwDg&zoom=1&iact=rc&dur=29&sig=113005965426162615313&page=1&tbnh=140&tbnw=198&start=0&ndsp=107&ved=1t:429,r:3,s:0,i:76&tx=29&ty=112



Power Reactor Licences

Facility and Location	Type and Number of Units/Capacity	Startup	Status
Pickering Nuclear Generating Station A Pickering, Ontario (OPG)	CANDU-PHW 2 x 500 MW(e)	1971	Shutdown
Pickering Nuclear Generating Station A Pickering, Ontario (OPG)	CANDU-PHW 2 x 500 MW(e)	1971	Operating
Bruce Nuclear Generating Station A Tiverton, Ontario (BP)	CANDU-PHW 2 x 750 MW(e)	1976	Reconstruction
Bruce Nuclear Generating Station A Tiverton, Ontario (BP)	CANDU-PHW 2 x 750 MW(e)	1976	Operating
Pickering Nuclear Generating Station B Pickering, Ontario (OPG)	CANDU-PHW 4 x 500 MW(e)	1982	Operating
Gentilly-2 Nuclear Generating Station Gentilly, Québec (Hydro-Québec)	CANDU-PHW 1 x 600 MW(e)	1982	Operating
Point Lepreau Generating Station Lepreau, New Brunswick (New Brunswick Power Corp.)	CANDU-PHW 1 x 600 MW(e)	1982	Reconstruction
Bruce Nuclear Generating Station B Tiverton, Ontario (BP)	CANDU-PHW 4 x 840 MW(e)	1984	Operating
Darlington Nuclear Generating Station Bowmanville, Ontario (OPG)	CANDU-PHW 4 x 850 MW(e)	1989	Operating

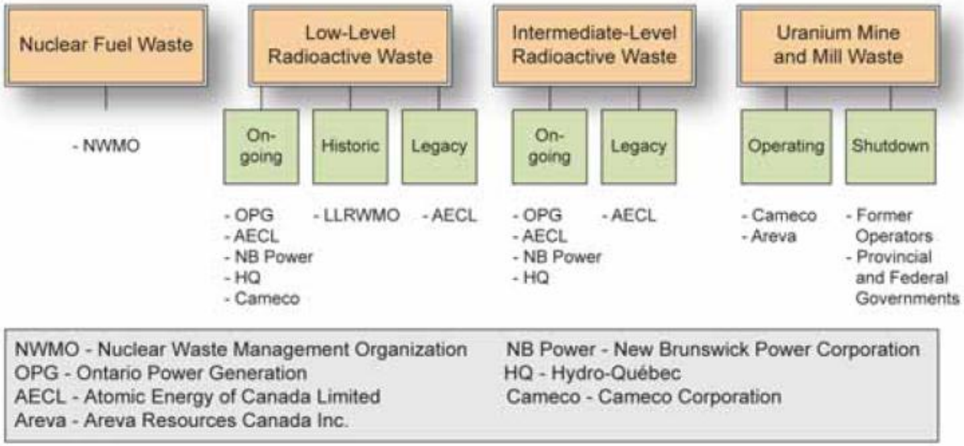


Figure B.2 – Organizations responsible for the long-term management of spent fuel and radioactive waste

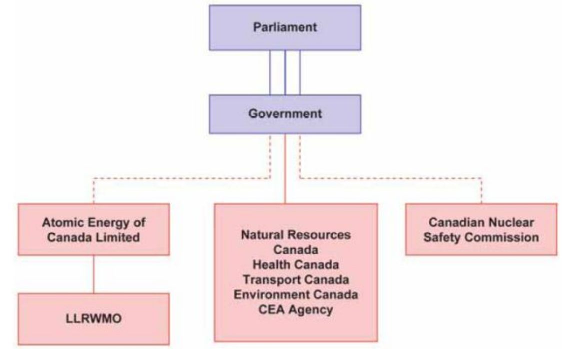


Figure B.1 – The Canadian institutional framework

In Canada, "high-level nuclear waste" refers to used nuclear reactor fuel, sometimes referred to as "spent nuclear fuel" or "nuclear fuel waste". Strictly speaking, discharged power reactor fuel in Canada is neither "waste" nor "spent", since it retains a significant energy potential.

In Canada, "low-level radioactive waste" applies to two categories of waste:
Historic Waste: Contaminated residues and soil from past industrial processes. This material constitutes over two-thirds of Canada's low-level radioactive waste, by volume (about 1.5 million cubic metres). Generally low-level waste is stored in interim storage facilities, awaiting long-term management. One example is the contaminated soil in Port Hope, Ontario, dating back to a radium-refining operation in the 1930's. Responsibility for historic low-level waste has been assumed by the Canadian federal government.

Ongoing Waste: Contaminated material created by nuclear power plants (except used fuel), nuclear research institutions, and medical isotope processing. This material accounts for about 600,000 cubic metres of low-level radioactive waste in Canada. Generators of ongoing low-level waste are responsible for management of their own waste material. Ontario Power Generation has proposed a **Deep Geologic Repository** for its low and intermediate level radioactive waste, to be located at the Bruce site.

Federal oversight of low-level radioactive waste management in Canada is provided by the **Low-Level Radioactive Waste Management Office** (LLRWMO) of **Natural Resources Canada (NRCan)**, which is operated by **Atomic Energy of Canada Ltd. (AECL)**. The LLRWMO's mandate is to: investigate and manage historic waste on behalf of the federal government; provide a user-pay service for the management of ongoing waste (utilizing low-level waste storage facilities at AECL's Chalk River Laboratories); and provide a public information service on low-level radioactive waste in Canada.

A special class of low-level radioactive waste applies to **tailings from uranium mining and milling**, as well as **uranium fuel processing**. Over 200 million tonnes of this waste material exists in Canada, confined at or near the sites where it was created.

By the late 1960s, with uranium known to be an abundant Canadian resource, the focus shifted to a once-through fuel cycle and the direct isolation of the resulting used fuel without reprocessing. The time-scale for this isolation can be separated into ***"interim storage"*** and ***"long-term management"*** requirements.

Since used reactor fuel is compact, solid, small in volume, and stable in a water environment, ***interim storage*** is a fairly straight-forward process. There are about two million used fuel bundles (0.5 m long, weighing 20 kg each) in Canada, which would fill a soccer field to the height of a player.

Canada's long-term nuclear used fuel management program is currently administered by **the Nuclear Waste Management Organization** (NWMO), established in November 2002 under the **Nuclear Fuel Waste Act** (June 2002). Oversight of the NWMO is provided by **Natural Resources Canada**, which has also set up a Nuclear Fuel Waste Bureau to enhance public participation in the decision-making process.

The Nuclear Fuel Waste Act results from the response of the Canadian federal government (December 1998) to the recommendations of the report of the Environmental Review Panel (March 1998) on AECL's nuclear fuel waste management proposal.

The report concluded that the plan for Deep Geological Disposal is technically sound, and that nuclear waste would be safely isolated from the biosphere, but that it remains a socially unacceptable plan in Canada.

The report makes several recommendations, including the creation of an independent agency to oversee the range of activities leading to implementation. The scope will include complete public participation in the process.

Over a study and consultation period of three years the NWMO was mandated to choose among three storage concepts and propose a site:

- Deep underground in the Canadian Shield
- Above-ground at reactor sites
- Or at a centralized disposal area

The final report of the NWMO was released in November 2005, recommending a strategy of "**Adaptive Phased Management**". The strategy is based upon a centralized repository concept, but with a phase approach that includes public consultation and "decision points" along the way, as well as several concepts associated with centralized storage (vs. disposal), and the ability to modify the long-term strategy in accordance with evolving technology or societal wishes. The approach of Adaptive Phased Management was formally accepted by the federal government on June 14, 2007.

Steps in the Process – At a Glance

Getting Ready	**The NWMO publishes the finalized siting process, having briefed provincial governments, the Government of Canada, national and provincial Aboriginal organizations, and regulatory agencies on the NWMO's activities.** The NWMO will continue briefings throughout the siting process to ensure new information is made available and requirements which might emerge are addressed.
Step 1	**The NWMO initiates the siting process with a broad program to provide information, answer questions and build awareness among Canadians about the project and siting process.** Awareness-building activities will continue throughout the full duration of the siting process.
Step 2	**Communities identify their interest in learning more, and the NWMO provides detailed briefing. An initial screening is conducted.** At the request of the community, the NWMO will evaluate the potential suitability of the community against a list of initial screening criteria (outlined on page 30).
Step 3	**For interested communities, a preliminary assessment of potential suitability is conducted.** At the request of the community, the NWMO will conduct a feasibility study collaboratively with the community to determine whether a site has the potential to meet the detailed requirements for the project. Interested communities will be encouraged to inform surrounding communities, including potentially affected Aboriginal communities and governments, as early as possible to facilitate their involvement.
Step 4	**For interested communities, potentially affected surrounding communities are engaged if they have not been already, and detailed site evaluations are completed.** In this step, the NWMO will select one or more suitable sites from communities expressing formal interest for regional study and/or detailed multi-year site evaluations. The NWMO will work collaboratively with these communities to engage potentially affected surrounding communities, Aboriginal governments and the provincial government in a study of health, safety, environment, social, economic and cultural effects of the project at a broader regional level (Regional Study), including effects that may be associated with transportation. Involvement will continue throughout the siting process as decisions are made about how the project will be implemented.
Step 5	**Communities with confirmed suitable sites decide whether they are willing to accept the project and propose the terms and conditions on which they would have the project proceed.**
Step 6	**The NWMO and the community with the preferred site enter into a formal agreement to host the project.** The NWMO selects the preferred site, and the NWMO and community ratify a formal agreement.
Step 7	**Regulatory authorities review the safety of the project through an independent, formal and public process and, if all requirements are satisfied, give their approvals to proceed.** The implementation of the deep geological repository will be regulated under the *Nuclear Safety and Control Act* and its associated regulations to protect the health, safety and security of Canadians and the environment, and to respect Canada's international commitments on the peaceful use of nuclear energy. Regulatory requirements will be observed throughout all steps in the siting process. The documentation produced through previous steps, as well as other documentation that will be required, will be formally reviewed by regulatory authorities at this step through an Environmental Assessment and then licensing hearings related to site preparation and construction of facilities associated with the project. Various aspects of transportation of used nuclear fuel will also need to be approved by regulatory authorities.
Step 8	**Construction and operation of an underground demonstration facility proceeds.** The NWMO will develop the centre of expertise, launched in Step 4, to include and support the construction and operation of an underground demonstration facility designed to confirm the characteristics of the site before applying to regulatory authorities for an operating licence. Designed in collaboration with the community, it will become a hub for knowledge-sharing across Canada and internationally.
Step 9	**Construction and operation of the facility.** The NWMO begins construction of the deep geological repository and associated surface facilities. Operation will begin after an operating licence is obtained from regulatory authorities. The NWMO will continue to work in partnership with the host community in order to ensure the commitments to the community are addressed throughout the entire lifetime of the project.

Description of Steps

Getting Ready

The NWMO publishes the finalized siting process, having provided information and opportunities to brief provincial governments, the Government of Canada, national and provincial Aboriginal organizations, and regulatory agencies on the NWMO's activities.

In preparation to begin the siting process, the NWMO will engage in the following activities and will continue with these activities throughout the site selection process and in parallel with subsequent steps:

- Publish the finalized *Process for Selecting a Site* document which takes into account the suggestions and advice received over the course of the public dialogue. The NWMO will review this process periodically with Canadians throughout the implementation of the siting process to ensure it continues to meet needs and expectations.
- Create a dedicated website to describe activities related to the siting process and post information on progress throughout the process.
- Provide information and opportunities to brief provincial governments and the Government of Canada on the NWMO's activities.
- Provide information and opportunities to brief national and provincial Aboriginal organizations on the NWMO's activities.
- Brief the Canadian Nuclear Safety Commission (CNSC) and other federal and provincial regulatory agencies on the process design, including the approach to site assessment and engagement of citizens. Briefings will be designed to help anticipate the requirements of the licensing processes, including requirements for an environmental assessment, even as new information and requirements may emerge over time.

Step 1

The NWMO initiates the siting process with a broad program to provide information, answer questions and build awareness among Canadians about the project and the siting process.

The NWMO initiates the siting process with a program of information mailings, briefings and activities designed to help build awareness and understanding of the NWMO, the project, steps in the siting process and the criteria to assess suitability of potential host communities.

The NWMO will ensure opportunities to learn more and will both seek opportunities to provide information and respond to requests for information. It will focus its outreach activities on nuclear provinces, including municipalities, the broad public, interested individuals and organizations, and First Nations, Métis and Inuit who have expressed interest in learning more. The information shared in the outreach program will be posted on the NWMO website for broad public access and review.

Activity of this nature is expected to continue throughout the site selection process and in parallel with subsequent steps.

Step 2

Communities identify their interest in learning more, and the NWMO provides detailed briefing. An initial screening is conducted.

A. A community expresses interest in learning more about the process.
A community expresses interest in learning more about the project and steps in the process with a request to the NWMO. For the purpose of expressing interest, "community" is defined as a political entity such as a city, town, village, municipality, region or other municipal structure, Aboriginal government or a combination of these. The request must be made by accountable authorities (for example, elected representative bodies). This may involve existing municipal council of a community, Aboriginal government, the community establishing a new group involving community leaders, or other group as deemed appropriate by the community for learning more about the project.

B. The NWMO evaluates potential suitability of the community against a list of initial screening criteria (outlined on page 30).
Initial screening of the potential suitability of the community based on readily available information and a short list of initial screening criteria will be completed over a **period of 2 to 3 months**. Unless all initial screening criteria can be met at this early point, the community will be excluded from further consideration. Third-party review (described on page 42) is optional, to be initiated upon request of the community.

C. The NWMO provides a detailed briefing to community.
The NWMO provides a detailed briefing, or series of briefings, about the project and the steps in the process to accountable authorities in communities that are interested and not excluded by the initial screening.

D. Communities with potentially suitable sites assess whether they are interested in continuing to preliminary assessment.

Support to community beginning with this step: Should initial screening suggest the community has potential to be suitable for the project and beginning with this step, the community may request and receive resources (funding and information, if desired) from the NWMO for: 1) seeking independent expert advice concerning the project and/or the results of the various site screening and site evaluation stages; 2) augmenting or developing a long-term vision for sustainability; and 3) conducting activities to inform residents and assess interest in the project in the community.

The nature of resources provided will be outlined in a memorandum of understanding between the community and the NWMO.

Step 3

For communities that continue to be interested, a preliminary assessment of potential suitability is conducted.

A. The community informs the NWMO of its interest in a preliminary assessment of its potential suitability.
A community, through its accountable authorities, contacts the NWMO to request preliminary information (in the form of a feasibility study) about whether a geographic area or specific sites in the community have the potential to meet the more detailed requirements for the project. No commitment from the community to participate in the project beyond conduct of the preliminary assessment (feasibility studies) is required. For communities uninterested in proceeding, their involvement in the siting process ceases.

B. The NWMO conducts feasibility studies in collaboration with the community to assess whether the community contains potentially suitable sites.
The NWMO and accountable authorities from the community develop a memorandum of understanding outlining the scope of work, the means by which the NWMO and the community will work together throughout the feasibility studies, the approach to and terms of reference for the third-party review process (described on page 42), the way that citizens will be engaged, and the nature of the funding provided by the NWMO to the community to support the process.

The NWMO, working with the community, will conduct feasibility studies, using pre-established geoscientific and community well-being related criteria, as outlined in Section 6, over a period of **approximately 1 to 2 years** depending on availability of existing information.

The NWMO will provide resources to the community to support the exploration of its interest. The NWMO will publish on its website the results of the feasibility studies, the results of the third-party review and its conclusions on the extent to which sites within the proposed areas are considered suitable should the community decide to proceed to the next step in the process.

C. Communities with potentially suitable sites assess whether they are interested in continuing to detailed site evaluation.
Communities with potentially suitable sites assess whether they are interested in continuing to detailed site evaluation.

Support to communities beginning with this step: The NWMO will encourage interested communities to inform and involve surrounding communities, the region and potentially affected Aboriginal communities and governments as early as possible in conversations about the potential suitability of the community and the site, and interest in hosting the project to help ensure that their issues and concerns are addressed. This engagement will continue throughout the siting process. Beginning with this step, the community (accountable authorities) may request and receive resources (funding and information, as desired) from the NWMO for: 1) establishing a community office for the project; and, 2) conducting activities to inform residents and assess interest in surrounding areas, including First Nations, Métis and Inuit as appropriate.

Beginning with this step, the NWMO will also begin to make funding available to accountable authorities in potentially affected surrounding areas, including First Nations, Métis and Inuit, as appropriate, to support their participation.

The nature of funding provided will be outlined in a memorandum of understanding between the community(ies) involved at this stage and the NWMO.

In brief, what activities are required to assess the suitability of a site?

Over the course of the nine steps, a potential site will be assessed through the following activities:

1. **Initial screening:** At the request of communities, the NWMO will complete a review of available information on the geographic area (Step 2) against a short list of initial screening criteria. Approximately 2 to 3 months will be required to complete this work.

2. **Feasibility studies:** At the preliminary assessment stage (Step 3), the NWMO working with the community will conduct feasibility studies using a list of pre-established criteria identified later in this document. Work will involve desktop studies using available technical and community well-being related information on the geographic areas of potential interest in order to assess, in a preliminary way, whether the community contains sites that may be suitable for developing a safe, underground repository. Work may also involve limited field investigations depending on the extent of existing available information. Approximately 1 to 2 years will be required to complete scientific and technical work at a site, depending on availability of existing information.

3. **Detailed site evaluations:** More detailed site evaluations (Step 4) will involve working with the community to conduct detailed field investigations at selected sites and perform safety assessments. Work will involve geophysical surveys, characterization of the existing environment, testing involving drilling and sampling of deep boreholes, field and laboratory testing and monitoring activities. Approximately 5 years will be required to complete scientific and technical work at a site.

4. **Transportation studies:** The NWMO will identify preferred transportation modes and potential routes associated with each interested community under consideration (Step 4) and will welcome communities along the transportation route as a large group with a shared interest to raise questions or concerns to be addressed in the process.

5. **Local and regional study of the environmental, social, economic and cultural effects of the project:** The NWMO will work with the community and potentially affected surrounding communities, regions and jurisdictional levels (Step 4) in discussions concerning the potential environmental, social, economic and cultural effects associated with locating the project in the community that has expressed interest and has potentially suitable sites. This will include effects that may be associated with transportation.

6. **Regulatory review of a licence to prepare the site and construct the facility:** Regulatory authorities will conduct an independent review of the health, safety and security of persons as well as the environment, and respect for Canada's international commitments on the peaceful use of nuclear energy. The project will proceed only after this work has been completed and all regulatory approvals obtained.

7. **Underground Demonstration Facility:** The NWMO will construct an underground demonstration facility supported by a centre of expertise to provide final confirmation of the characteristics of the site.

Criteria to Ensure Safety

FACTORS AFFECTING SAFETY	PERFORMANCE OBJECTIVES	EVALUATION FACTORS TO BE CONSIDERED
Containment and isolation characteristics of the host rock	1. The geological, hydrogeological, chemical and mechanical characteristics of the site should: » promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; » promote long-term contain-ment of used nuclear fuel within the repository; and » restrict groundwater movement and retard the movement of any released radioactive material.	1.1 The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events. 1.2 The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities. 1.3 The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system. 1.4 The hydrogeological regime within the host rock should exhibit low groundwater velocities. 1.5 The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement. 1.6 The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without signi-ficant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

FACTORS AFFECTING SAFETY	PERFORMANCE OBJECTIVES	EVALUATION FACTORS TO BE CONSIDERED
Long-term stability of the site	2. **The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes, including earthquakes and glacial cycles.**	2.1 Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term. 2.2 The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository. 2.3 The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository. 2.4 The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.
Repository construction, operation and closure	3. **The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.**	3.1 The strength of the host rock and in-situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. 3.2 The soil cover depth over the host rock should not adversely impact repository construction activities. 3.3 The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.

FACTORS AFFECTING SAFETY	PERFORMANCE OBJECTIVES	EVALUATION FACTORS TO BE CONSIDERED
Human intrusion	4. The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.	4.1 The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. 4.2 The repository should not be located within geological formations containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.
Site characterization	5. The characteristics of the site should be amenable to site characterization and site data interpretation activities.	5.1 The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.
Transportation	6. The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from storage sites to the repository site.	6.1 The repository should be located in an area that is amenable to the safe transportation of used nuclear fuel. 6.2 The repository should be located in an area that allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

Criteria to Assess Factors Beyond Safety

FACTORS BEYOND SAFETY	EVALUATION FACTORS TO BE CONSIDERED
Potential social, economic and cultural effects during the implementation phase of the project, including factors identified by Aboriginal Traditional Knowledge	Sites will be evaluated against the extent to which positive and negative effects on the host community can be addressed during the implementation phase of the project, including the following areas: » Health and safety of residents and the community » Sustainable built and natural environments » Local and regional economy and employment » Community administration and decision-making processes » Balanced growth and healthy, livable community
Potential for enhancement of the community's and the region's long-term sustainability through implementation of the project, including factors identified by Aboriginal Traditional Knowledge	Sites will be evaluated against the extent to which positive and negative effects of the project on long-term sustainability of the host community and region can be addressed in the following areas: » Health, safety and inclusiveness/cohesion of the community » Sustainable built and natural environments » Dynamic resilience of the economy » Community decision-making processes » Balanced growth and healthy, livable community
Potential to avoid ecologically sensitive areas and locally significant features, including factors identified by Aboriginal Traditional Knowledge	Sites will be evaluated for the following: » Ability to avoid ecologically sensitive areas and locally significant features
Potential for physical and social infrastructure to adapt to changes resulting from the project	Sites will be evaluated for the following: » The availability of physical infrastructure required to implement the project » The ability of the community, and the social infrastructure it has in place, to adapt to changes resulting from the project » The NWMO resources required to put in place physical and social infrastructure needed to support the project
Potential to avoid or minimize effects of the transportation of used nuclear fuel from existing storage facilities to the repository site	Sites will be evaluated for the following: » The availability of transportation routes (road, rail, water) and the adequacy of associated infrastructure and potential to put such routes in place » The availability of suitable safe connections and intermodal transfer points, if required, and potential to put them in place » The NWMO resources (fuel, people) and associated carbon footprint required to transport used fuel to the site » The potential for effects on communities along the transportation routes and at intermodal transfer points

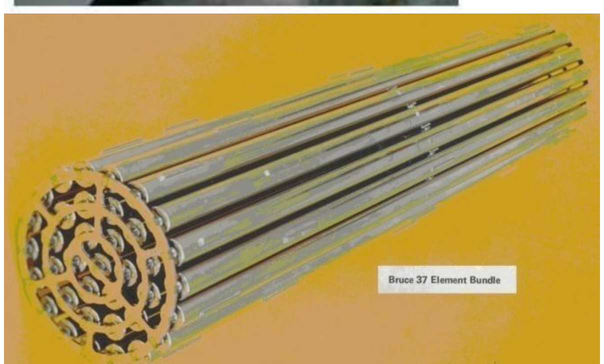

SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
Communities in Step 2
Learning More/ Initial Screenings
6. Nipigon
8. Manitouwadge
10. White River
12. Blind River
13. Elliot Lake
14. North Shore
15. Spanish
16. Arran-Elderslie
17. Saugeen Shores
19. Huron-Kinloss
20. South Bruce
21. Central Huron
Communities in Step 3
Preliminary Assessments
1. English River First Nation
2. Pinehouse
3. Creighton
4. Ear Falls
5. Ignace
7. Schreiber
9. Hornepayne
11. Wawa
18. Brockton

Step3は2段階から構成
（1）デスクトップでの調査
　　Step2との違いは，より詳細に．　社会的，経済的，コミュニティ的な適合性も．

この段階で，数を絞る．4箇所から5箇所と想定しているが，数はNWMOが決めるものではない．

（2）そのあと，フィールドでの調査へ．
　　1,2箇所に絞られることに．
　　Step3を開始したときから，2,3年でここまで．

その他
・NWMOとしては予算などの観点からタイムラインを決めているが，サイト選定の時間枠はあくまで自治体が決める．内部的には2035年という目標があるが，きっと遅れる．
・Principle，Framework，Transparencyが重要
・とにかく学んでもらう．Face to Faceで．人としての信頼関係構築．時間をかけて．
・住民は安全性のDemonstrationを要求．それに応える研究，技術開発．
・エンドポイントを明確にする．
・社会が何を求めているかを2年かけて，カナダ中で聞いて回った．成果は常に公開．常に社会に対して情報を提供．住民・自治体が決める，というスタンスを崩さない．
・いろいろな場面を想定しての，対話に関する訓練を，全職員にしている．


Bruce 37 Element Bundle

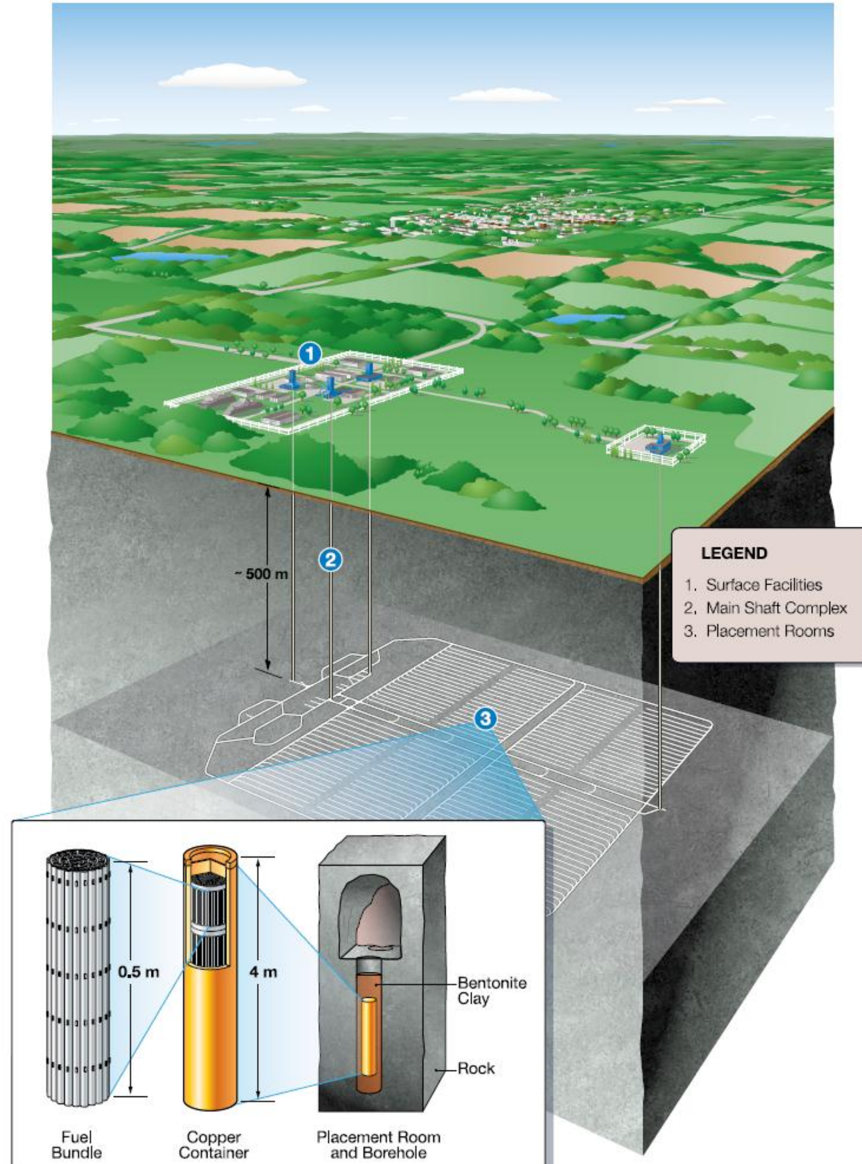

~ 500 m
LEGEND
1. Surface Facilities
2. Main Shaft Complex
3. Placement Rooms
0.5 m
4 m
Bentonite Clay
Rock
Fuel Bundle
Copper Container
Placement Room and Borehole

Figure 3: Example Regions of Potentially Suitable Rock Formations for a Deep Geological Repository in Canada

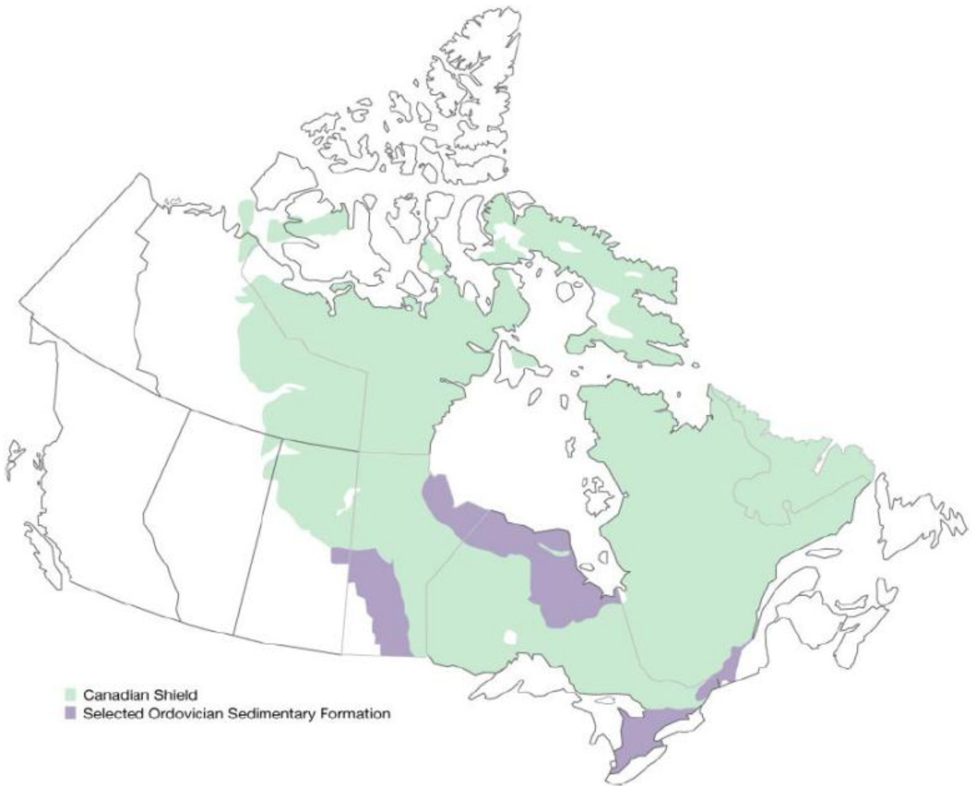


Table 1: Reference Rock/clay Compositions

Argillaceous Limestone	Shale	Bentonite Clay Seal	Bentonite/Sand Seal
2% porosity	7% porosity	100% MX-80 clay Dry bulk density 1.6 Mg/m^3	70% MX-80 clay with 30% silica sand Dry bulk density 1.6 Mg/m^3
Calcite 80 wt% Dolomite 7 wt% Illite 5 wt% Chlorite 5 wt% Quartz 2 wt% Other 1 wt%	Clay 60 wt% - Illite 60% - Chlorite 40% Quartz 30 wt% Feldspars 3 wt% Dolomite 2 wt% Other 5 wt%	Montmorillonite 82 wt% Quartz 3 wt% Felds. & mica 8 wt% Cristobalite/tridymite 4 wt% (pyrite, calcite, illite gypsum) 3 wt%	See previous column for MX-80, diluted by 30 wt% silica sand

Table 2: Reference Sedimentary Groundwater Compositions

Water Name	SR-300	SR-270-PW	SR-270-NaCl	SR-160	SR-20
Nominal pH	6.0	5.8	6.1	6.5	6.5
Redox State	Reducing	Reducing	Reducing	Reducing	Less Reducing
Eh (mV)	-200	-200	-200	-200	90
Solutes					
Na	43,100	50,100	101,200	37,000	4,300
K	3,600	12,500	-	1,780	130
Ca	57,300	32,000	3,700	14,700	1,500
Mg	9,900	8,200	1,300	3,900	900
HCO_3	40	110	180	50	330
SO_4	160	440	2,470	420	1,100
Cl	199,500	168,500	165,000	97,600	11,300
Br	2,000	1,700	-	570	80
Sr	900	1200	-	510	30
Li	7	5	-	7	-
F	2	2	-	5	-
I	90	3	-	90	-
B	-	80	-	-	-
Si	5	4	-	10	-
Fe	30	30	-	30	0.1
NO_3	<10	<10	-	<10	-
PO_4	-	-	-	-	-
TDS (mg/L)	317,000	275,000	273,000	157,000	20,000
***Ionic Strength (mol/L)**	4.5	3.8	3.3	2.5	0.32
Water Type	Ca-Na-Cl	Na-Ca-Cl	Na-Cl	Na-Ca-Cl	Na-Cl

* Ionic strength estimated using PHREEQC (SIT database)

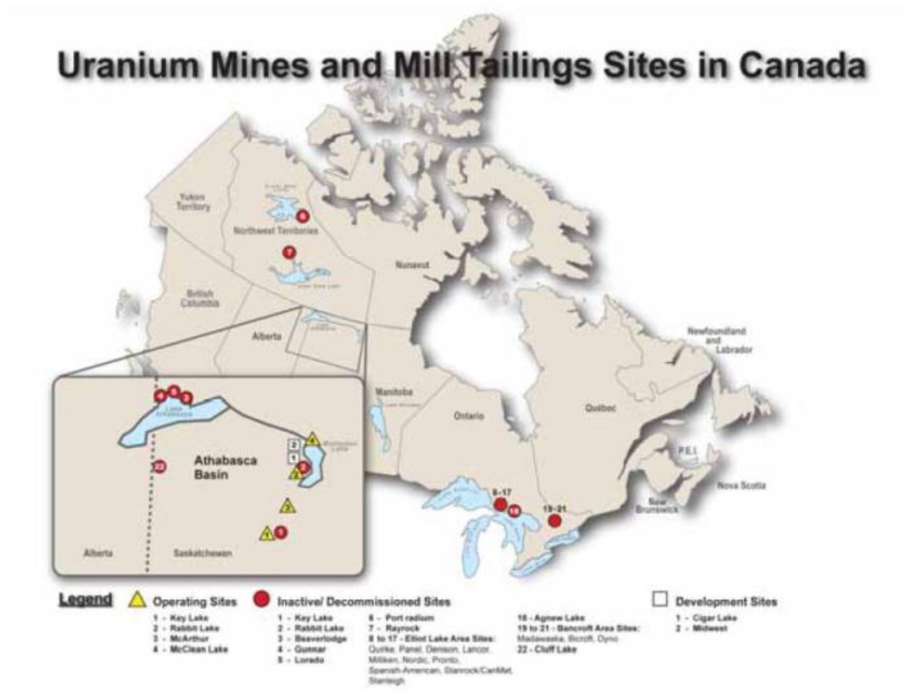


Figure B.3 – Location of operating, inactive and proposed uranium mines and mills

Figure 4-1: Cigar Lake Mineral Property, Project Location

Source: Cameco

Most of the mines were located on or near Lake Athabasca, in Northern Saskatchewan. They did not impose any decommissioning or reclamation criteria on them when these operations ceased operations in the early 1960s.

The governments of Canada and Saskatchewan are now funding the cleanup of these abandoned northern uranium mine and mill sites and have contracted the management of the project to the Saskatchewan Research Council (SRC).

Example of “before” and “after” views of an abandoned satellite uranium mine site in Northern Saskatchewan (Baska Uranium Mine, 2009.)

Some 40 years after abandonment, the satellite sites were found to contain numerous and diverse hazards beyond just the radiation issues that most people would expect.

- Trenches, unstable ground, and liquid seepages,
- Standing or collapsed wooden/concrete structures, pump-houses, and core racks,
- Concrete pads and foundations,
- Ore carts, fuel tanks, water tanks, boilers (encased in asbestos), and cisterns,
- Extensive amounts of waste rock,
- Miscellaneous debris (vehicle chassis, drill rods, steel casings, barrels, pipes, and rails, etc.), and
- Radiation, asbestos, polychlorinated biphenyls (PCBs), explosives, and unknown chemicals.

Gunnar Mine; open pit, circa 1962.

Gunnar Mine; flooded open pit in 20**06.**

The open pit mine was approximately 300 m long, 250 m wide, and ultimately 116 m deep

Demolishing the Gunnar Head-Frame in 2011.

Example of "before" and "after" views of building demolition at the Gunnar site (2010).

"Before" (upper) and "after" (lower) views illustrating clean-up progress at the Gunnar site (2011).

Gunnar Mine and Mill Site

- a 48m head frame and associated mine shaft,
- a mill housing ore bins, crushing/grinding circuit, thickening circuit, leaching circuit, filtration circuit, clarification circuit, ion exchange circuit, precipitation
circuit, and a filtration, drying, and packing circuit,
- laboratories, mixing areas, and storage annex,
- two acid plants and associated storage tanks,
- geology/mine, mine engineering, and heavy equipment maintenance shop buildings,
- water, fuel, and other storage tanks and power generation plants, plus above-ground utilidors for carrying water, sewage and steam, and
- much other unsalvaged major equipment, tanks, concrete floors/pads, structural concrete and steel structures, smaller buildings, scrap steel, and piping.

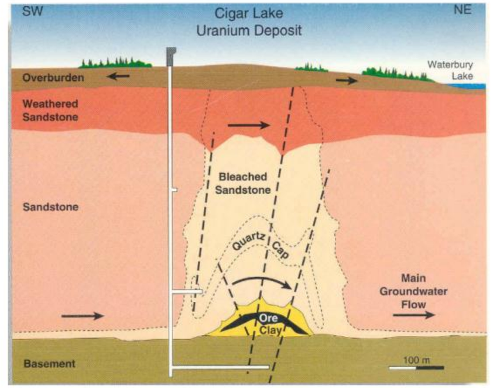
- Almost all of the buildings of all kinds had suffered leaking roofs, major decay, structural weakening and, in many cases partial ceiling collapses,
- A key hazard was created by the ubiquitous presence of asbestos, which was present in structural steel filler, wall insulation, siding, roofing, pipeline and vessel insulation, various other spray-on applications, and even in cinderblock and general litter,
- Other site chemical hazards included process chemicals like sodium hydroxide, magnesium oxide, calcium hydroxide, vanadium pentoxide, elemental sulphur, and Portland Cement (in quantities ranging from bottles, to barrels, to pallets, to tonnes). Less extensive were occurrences of oils and fuels (andspills thereof), paints, Freon, and PCBs.
- Numerous heavy metals and radionuclides are present in the flooded pit, waste rock, tailings and other areas. Many contaminants of potential concern have been identified, the principals being selenium, mercury, and uranium.
- The radiation hazards have been summarized in more detail elsewhere [4]. Many buildings and locations around the site exhibit low gamma radiation levels (i.e., less than about 2 µSv/h at 1 metre), but some of the mill areas, fines piles, tailings areas, and waste rock areas exhibit higher levels. Similarly, some buildings exhibited radon levels requiring action. Both are of concern to a remediation workforce and had to be dealt with.

Next Challenges

- Disposal of the demolition materials,
- Capping of the mine shaft and vent raises,
- General site clean-up and additional surveys and characterizations related to the tailings and waste rock piles,
- Installation of a cover on some or all of the exposed mill tailings (Gunnar and Lorado),
- Rehabilitation of the waste rock piles and any other risk(s) as required,
- Re-vegetation of areas of the rehabilitated site as required, and
- Environmental monitoring during and after rehabilitation.

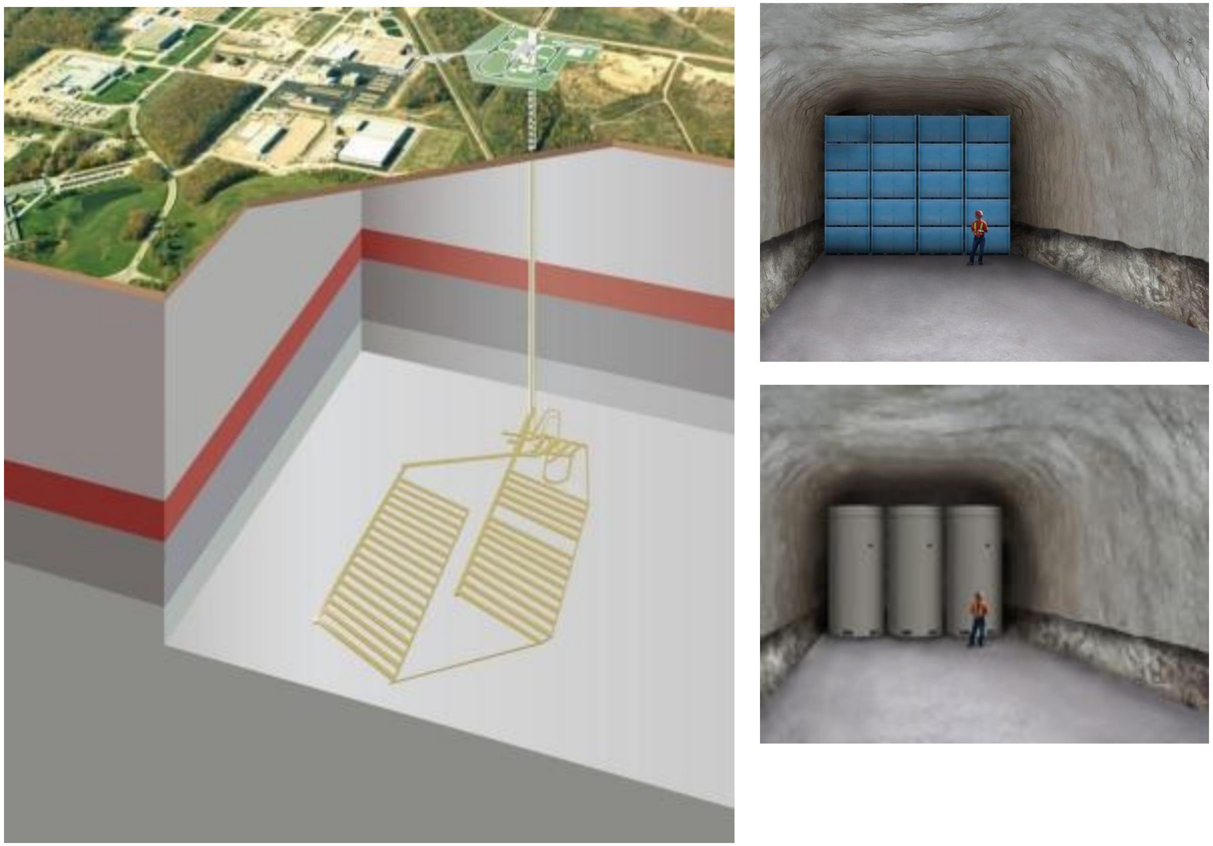
Most of the next steps will continue to require environmental impact assessments and approvals from the responsible provincial and federal authorities, including the Canadian Environmental Assessment Agency and Canadian Nuclear Safety Commission.

The final disposition of the bulk of the debris and other wastes from the demolition and other clean-up activities has not yet been decided. Some materials, like hazardous chemicals are already being taken off the sites and sent for proper destruction at approved facilities. The bulk of the other materials will probably be landfilled in some fashion. It may be possible to use the mined-out pit, and of course there are options involving landfill designs. We are proposing a preferred option and some alternatives and the discussions with funders and regulators is still underway.
(By Laurier L. Schramm, President and CEO, Saskatchewan Research Council)



Cigar Lake uranium deposit recently discovered in northern Saskatchewan, Canada. Representing about 11% of the world's known uranium reserves, Cigar Lake is one of the richest and largest uranium deposits known to mankind. Its significance to the science of waste disposal is due to two factors: (1) it exists in about 98% abundance as uranium dioxide, UO_2, which is the same form as reactor fuel; and (2) the high-grade ore is protected from groundwater by a covering "dome" of clay, which is conceptually similar to Canada's disposal plan. Additionally, the high grade of the ore permits the interaction between the uranium and the host material to be analysed in a highly sensitive and unique manner.

Despite emplacement in highly permeable sandstone host rock, the Cigar Lake ore deposit has survived roughly 1.3 billion years of geologic history, chiefly because of its natural clay buffer. The clay immobilizes the uranium by reducing both the penetration of groundwater into the deposit, and the diffusion of uranium atoms out of the deposit. Remarkably, the deposit has remained intact through several mountain-building episodes (the Rocky Mountains, the Appalachians), the trauma of continental drift, multiple ice ages, and significant uplift caused by the erosion of over 2.5 km of overlying sedimentary rock. In fact, it is so stabilized in its position, currently 430 metres below the surface, that no chemical or radioactive signature can be detected on the ground above it. Since the Canadian waste disposal concept calls for a much less permeable host rock (*batholithic granite*), and a superior clay buffer (*bentonite clay*, rather than Cigar Lake's *illite clay*), the barriers to water movement and radionuclide migration proposed in the Canadian plan are verified by Cigar Lake.



OPG’s Deep Geologic Repository

Ontario Power Generation (OPG) is responsible for the safety management of the radioactive wastes arising from the operation of 20 CANDU reactors in the Province of Ontario.

約160,000 m^3の廃棄物

OPGの動画

In 2002, the Municipality of Kincardine, the host community of the Bruce Nuclear Site, signed a Memorandum of Understanding (MOU) with OPG to jointly study options for the long-term management, at the site, of all L&OLW arising from the operation, refurbishment and decommissioning of OPG-owned reactors in Ontario. All L&ILW generated by these reactors are now in interim storage at OPG's Western Waste Management Facility (WWMF) which is located on the Bruce Nuclear Site, along with the eight reactors currently operated by Bruce Power under a lease agreement. WWMF has safely managed waste for over 40 years.

Kincardine council indicated a preference for the deep repository option and a Hosting Agreement based on this option was negotiated on late 2004.

OPG submitted Environmental Impact Statement (EIS) and licencing documents in 2011.

A public hearing for the DGR Project is anticipated to take place in the first half of 2013.

	OPG's DGR for low and intermediate level waste	NWMO's Adaptive Phased Management for used fuel
Who is the owner of the Project?	• Ontario Power Generation – an Ontario based electricity company	• Nuclear Waste Management Organization – A Canadian company established by Canada's nuclear utilities, as outlined in the *Nuclear Fuel Waste Act*, with specialized expertise in long-term nuclear waste management
What is NWMO's Role?	• NWMO is under contract to OPG to provide technical and other services for the L&ILW DGR through the regulatory approvals process • NWMO will also provide provide design and construction services for the DGR	• NWMO is responsible for implementing APM – the approach selected by the Government of Canada for the long-term management of Canada's used fuel
What type of waste will be emplaced?	• Low and intermediate level waste from OPG-owned or operated nuclear reactors	• Used fuel bundles from Canadian nuclear generating stations and those generated by Atomic Energy of Canada Limited (AECL)
What technical approach will be used to accommodate the waste?	• A Deep Geologic Repository constructed in sedimentary rock in an informed and willing host community.	• A Deep Geological Repository constructed in sedimentary or crystalline rock in an informed and willing host community.
Where will the repository be located?	• Sited on OPG-retained lands within the secured Bruce nuclear site in the Municipality of Kincardine	• As of yet, no location has been selected for a used fuel repository • Currently, 22 communities (three in Saskatchewan, 19 in Ontario) have expressed interest in learning about APM • Additional communities may come forward until September 30, 2012
What is the status of the project?	• DGR documents submitted to federal authorities in Apr. 2011 • Six-month comment period for documents announced Feb. 3, 2012 • Comment period extended on Jun. 13, 2012 • Comment deadline to be announced	• Siting process began in May 2010 and is proceeding • Siting process is anticipated to take about 10 years to identify a preferred safe site

Geologic setting:

The Palaeozoic rocks underlying the Bruce Nuclear Site are comprised of a near-horizontally layered, undeformed sequence of carbonates, shales, evaporites and minor sandstones within the Michigan Basin. This sedimentary sequence is approximately 800 m thick resting on the crystalline Precambrian basement. The repository targeted for a argillaceous limestone formation at a depth of about 680 m below surface. This formation is overlayed by a 200 m layer of low permeability shale. These Ordovician-age shales and limestones are expected to have rock mass hydraulic conductivities between 10^{-13} to 10^{-12} m/s.

Key elements that provide confidence in the safety of the DGR andprotection of the public include:

- The DGR is isolated from surface and drinking waters;
- Low permeability rock formations under and above the DGR provide multiple natural barriers to safely isolate and contain the waste;
- The 450 million-year-old rock formations have remained stable through tectonic events, climate changes and several ice ages, and are expected to remain stable for at least the next few million years;
- The DGR site is within the tectonically stable interior of the North American continent, which is a region characterized by low rates of seismicity where large magnitude earthquakes are unlikely;
- The radioactivity in the low and intermediate level waste will decay with time; most of the waste volume contains primarily shorter-lived radionuclides; and
- The properties of the host rock and shaft seals will limit the movement of radioactivity to very slow rates.

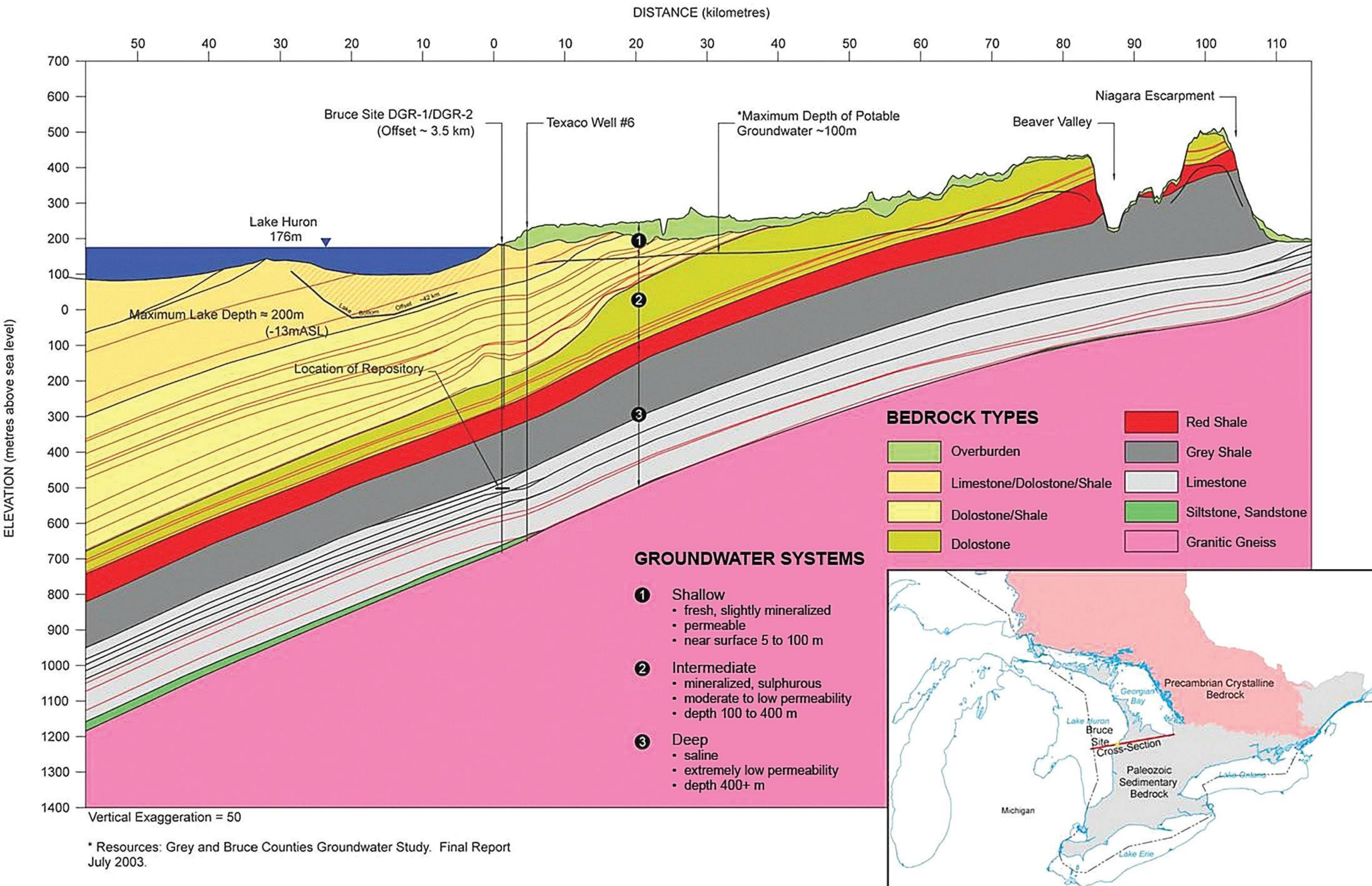

DISTANCE (kilometres)
50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100 110
ELEVATION (metres above sea level)
700 600 500 400 300 200 100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
Bruce Site DGR-1/DGR-2 (Offset ~ 3.5 km)
Texaco Well #6
*Maximum Depth of Potable Groundwater ~100m
Beaver Valley
Niagara Escarpment
Lake Huron 176m
Maximum Lake Depth ≈ 200m (-13mASL)
Location of Repository
BEDROCK TYPES
Overburden
Limestone/Dolostone/Shale
Dolostone/Shale
Dolostone
Red Shale
Grey Shale
Limestone
Siltstone, Sandstone
Granitic Gneiss
GROUNDWATER SYSTEMS
1 Shallow
• fresh, slightly mineralized
• permeable
• near surface 5 to 100 m
2 Intermediate
• mineralized, sulphurous
• moderate to low permeability
• depth 100 to 400 m
3 Deep
• saline
• extremely low permeability
• depth 400+ m
Precambrian Crystalline Bedrock
Georgian Bay
Lake Huron
Bruce Site
Cross-Section
Paleozoic Sedimentary Bedrock
Michigan
Lake Erie
Vertical Exaggeration = 50
* Resources: Grey and Bruce Counties Groundwater Study. Final Report July 2003.

TABLE 1: Summary of Nuclear Fuel Waste in Canada as of June 30, 2011

Location	Waste Owner	Wet Storage (# bundles)	Dry Storage (# bundles)	TOTAL (# bundles)	Current Status
Bruce A	OPG[(2)]	361,206	60,288	421,494	- 2 units operational, 2 units under refurbishment (expected 2012 return to service)
Bruce B	OPG[(2)]	368,773	175,478	544,251	- 4 units operational
Darlington	OPG	334,092	65,631	399,723	- 4 units operational
Douglas Point	AECL	0	22,256	22,256	- permanently shut down
Gentilly 1	AECL	0	3,213	3,213	- permanently shut down
Gentilly 2	HQ	33,533	87,000	120,533	- operational (expected to be shut down for refurbishment in 2012)
Pickering A	OPG	407,280	226,211	633,491	- 2 units operational, 2 units permanently shut down
Pickering B	OPG				- 4 units operational
Point Lepreau	NBPN	40,758	81,000	121,758	- currently undergoing refurbishment (expected 2012 return to service)
AECL Whiteshell	AECL	0	2,268	2,268	- permanently shut down. See Note (1)
AECL Chalk River	AECL	0	4,886	4,886	- mostly fuel from NPD (permanently shut down) and with small amounts from other CANDU reactors. See note (3)
	TOTAL	***1,545,642***	***728,231***	***2,273,873***	Total of: - 17 units in operation - 3 units under refurbishment - 6 units permanently shut down

Notes:

AECL = Atomic Energy of Canada Limited
HQ = Hydro-Québec
NBPN = New Brunswick Power Nuclear
OPG = Ontario Power Generation Inc

(1) 360 bundles of Whiteshell fuel are standard CANDU bundles. The remaining bundles are various research, prototype and test fuel bundles, similar in size and shape to standard CANDU bundles.

(2) Bruce reactors are leased to Bruce Power for operation.

(3) In addition to the totals shown in Table 1, AECL also has some ~22,000 components of research and development fuels such as fuel elements, fuel pellets and fuel debris in storage at Chalk River. While the total mass of these components is small compared to the overall quantity of CANDU fuel, their varied storage form, dimensions, etc. requires special consideration for future handling.

TABLE 2: Summary of Projected Nuclear Fuel Waste from Existing Reactors

Location	Waste Owner	Total June 2011 (# bundles)	Typical Annual Production (# bundles)	Low Scenario (# bundles)	Reference Scenario (# bundles)	High Scenario (# bundles)
Bruce A	OPG	421,494	20,500 (1)	530,000	1,170,000 (4)	1,170,000 (4)
Bruce B	OPG	544,251	23,500 (1)	768,000	768,000	1,497,000
Darlington	OPG	399,723	22,000 (1)	631,000	1,291,000	1,291,000
Douglas Point	AECL	22,256	0 (2)	22,256	22,256	22,256
Gentilly 1	AECL	3,213	0 (2)	3,213	3,213	3,213
Gentilly 2	HQ	120,533	4,500	131,000	268,000	268,000
Pickering A	OPG	633,491	7,200 (3)	797,000	797,000 (5)	797,000 (5)
Pickering B	OPG		14,500 (1)			
Point Lepreau	NBPN	121,758	4,500	121,758	260,000 (7)	260,000 (7)
AECL Whiteshell	AECL	2,268	0 (2)	2,268	2,268	2,268
AECL Chalk River	AECL	4,886	0 (6)	4,886	4,886	4,886
TOTAL (bundles)(8)		**2,273,873**	**96,700**	**3,012,000**	**4,587,000**	**5,306,000**
(t-HM)		***45,000***	***1,940***	***61,000***	***92,000***	***107,000***

Notes:

1) Based on 4 reactors operating.
2) Reactor is permanently shut down and not producing any more fuel.
3) Based on 2 reactors operating.
4) All units at Bruce A are assumed to be refurbished (refurbishment currently under way for 2 units).
5) Pickering reactors assumed to be operated until 2019 only.
6) Future forecasts do not include research fuels. AECL Chalk River does not produce any power reactor CANDU used fuel bundles.
7) Point Lepreau is currently shut down for refurbishment and is expected to re-start in 2012.
8) Totals may not add exactly due to rounding to nearest 1,000 bundles for future forecasts.

a) **Low:** the reactors are shut down at the end of the projected life of the fuel channels (i.e. nominal 25 effective full power years of operation, with some planned life extension maintenance activities;
b) **Reference:** Based on announced life plans for the reactor fleet (i.e. refurbishment or not).
c) **High:** most of the reactors are refurbished with a new set of pressure tubes and other major components, then operated for a further nominal 25 effective full power years. Pickering reactors will be run until 2019

TABLE 3: Summary of Proposed New Reactors

Proponent	Location	In-service timing	Reactor Type(s)	Status
Projects currently undergoing an Environmental Assessment				
OPG	Darlington, Ontario	First unit 2018 (see note 1)	4 x ACR 1000 or 4 x EC-6 or 4 x AP1000 or 3 x EPR (see note 1)	Selected as site for first 2 reactors by Ontario Government EIS report & updated application for a site preparation licence was submitted Sept 30, 2009. [OPG, 2009] Joint Panel Review public hearing conducted in 2011 and report issued on EIS, Aug 2011 [JRP, 2011].
Additional projects in preliminary discussion or previous consideration				
Bruce Power / Energy Alberta	Northern Alberta	First unit assumed 2017	4 x ACR 1000 or 3 x AP1000 or 2 x EPR or 2 x ESBWR	Site preparation licence application submitted to CNSC March 2008, withdrawn 2009. [Bruce Power, 2009b]
Province of New Brunswick	Point Lepreau, New Brunswick	First unit assumed 2020	ACR 1000 ATMEA1 PWR KERENA BWR	Feasibility study being conducted [MZConsulting, 2008] [AREVA, 2010]
Bruce Power Saskatchewan	Saskatchewan (no specific site selected yet)	First unit assumed 2020	ACR 1000 or AP1000 or EPR	Feasibility study conducted by Bruce Power [Bruce Power, 2008b]

Notes:

1) Selection of reactor type for new-build in Ontario was to be made by Ontario Government (Infrastructure Ontario) in 2009. However, although the procurement process was suspended in June 2009 until further notice [Infrastructure Ontario, 2009], in November 2010 the Ontario Government stated that they were still committed to constructing new nuclear units at Darlington. [MEI, 2010]. The EA process continued with public hearings in the spring of 2011 and the Joint Review Panel issued its report on the EIS in August. [JRP, 2011]

a) ***AECL ACR 1000 (Advanced CANDU reactor)***, which is a 1085 MW(e) net heavy water moderated, light water cooled pressure tube reactor. Up to 4 ACR 1000 reactors would be built on the site in two twin unit pairs. This would result in a total lifetime production of approximately 770,400 used fuel bundles (12,480 t-HM).

b) ***AECL EC-6 (Enhanced CANDU 600 reactor)***, which is a 686 MW(e) net heavy water reactor, similar to the existing CANDU 600 reactors at Gentilly-2, Point Lepreau and elsewhere in the world. Up to 4 EC-6 reactors would be built on the site in two twin unit pairs. This would result in a total lifetime production of approximately 1,572,000 used fuel bundles (30,000 t-HM).

c) ***Westinghouse AP1000***, which is a 1037 MW(e) net pressurized light water reactor. Up to 4 AP1000 reactors would be built on the site, which would result in a total lifetime production of approximately 10,800 PWR fuel assemblies (5,820 t-HM).

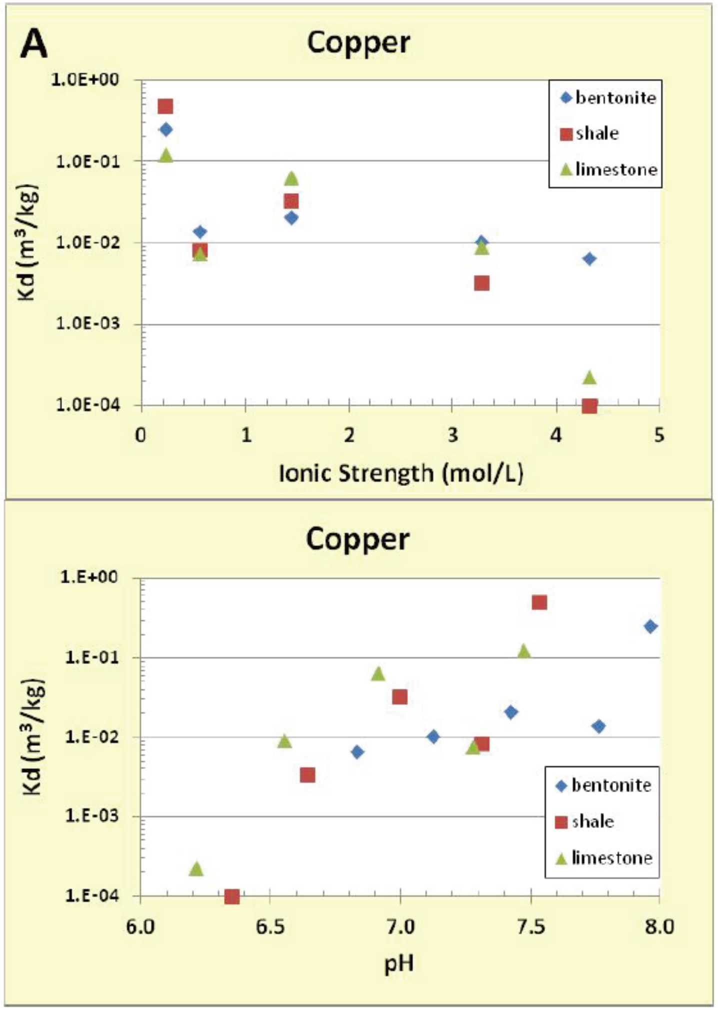
d) ***AREVA EPR (Evolutionary Power Reactor)***, which is a 1580 MW(e) net pressurized light water reactor. Up to 3 EPR reactors would be built on the site, which would result in a total lifetime production of approximately 9,900 PWR fuel assemblies (5,220 t-HM).

カナダ地下水の特徴：Na-Ca-Cl brine solutions with total dissolved solids (TDS) of up to 375 g/L.

現時点での着目核種（Geoscience Groupによると、安全評価グループからの要請で核種を決めた）C, Cu, As, Se, Zr, Nb, Mo, Tc, Pd, Sn, Pb, Bi, Ra, Th, Pa, U, Np, Pu, Am.

固相（まずは堆積岩から。結晶質岩はその次）：bentonite, shale, limestone, illite, chlorite and calcite.

AECLやカナダ国内の大学との共同研究でデータを取得したり、既存のデータベースを調査しBrine系に適用できるデータの評価、自分たちのデータの検証予定。
酸化性雰囲気。
今後、還元性雰囲気でのデータ取得を期待。
来年にも，NWMOは還元性雰囲気での研究について公開入札（U(IV)，Se(-II)など）ps
JAEAともいろいろな形で協力関係を構築したい.

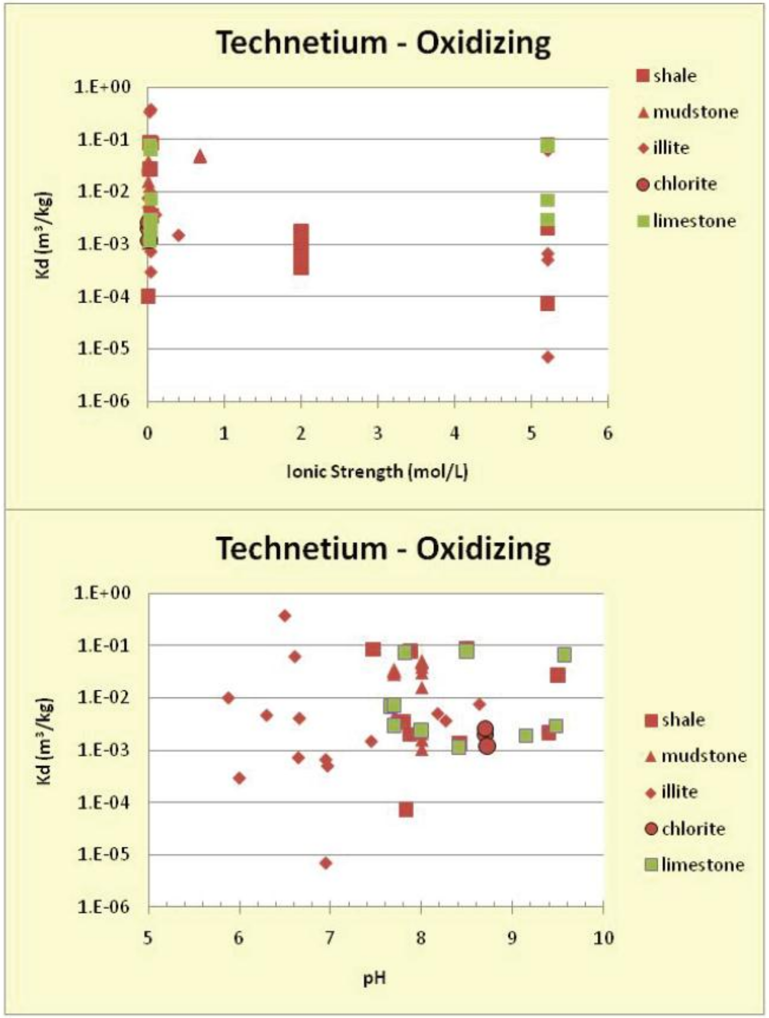


Recommended Sorption Coefficients for Copper

COPPER (II)				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**0.2 to 7.5**	**6.8 to 8.0**	**0.007 to 0.26**	**0.022 (4)**
comment	Vilks et al. (2011)			
Shale	**0.2 to 7.5**	**6.4 to 7.5**	**0.0001 to 0.49**	**0.008 (23)**
comment	Vilks et al. (2011)			
Limestone	**0.2 to 7.5**	**6.2 to 7.5**	**0.0002 to 0.12**	**0.010 (12)**
comment	Vilks et al. (2011)			

Note: The geometric standard deviation is in parentheses beside the geometric mean.

Copper Sorption on Bentonite, Shale and Limestone from Na-Ca-Cl Solutions with Respect to (A) Ionic Strength, and (B) pH (Data are from Vilks et al., 2011)

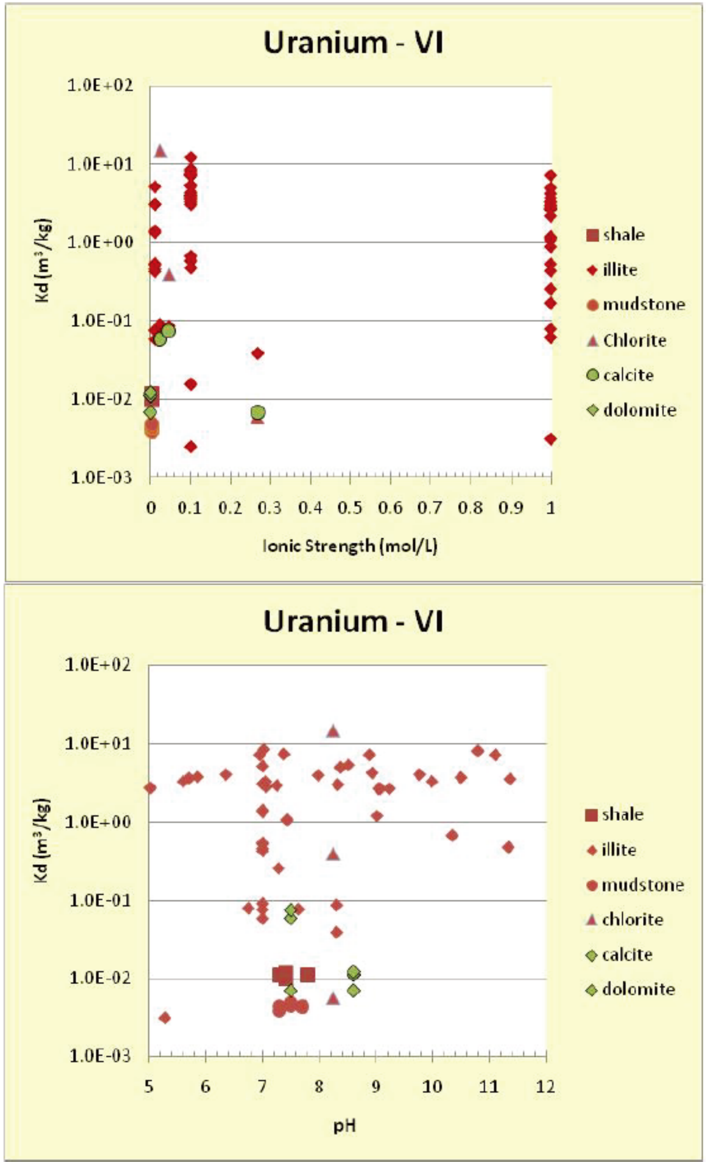


Recommended Sorption Coefficients for Technetium

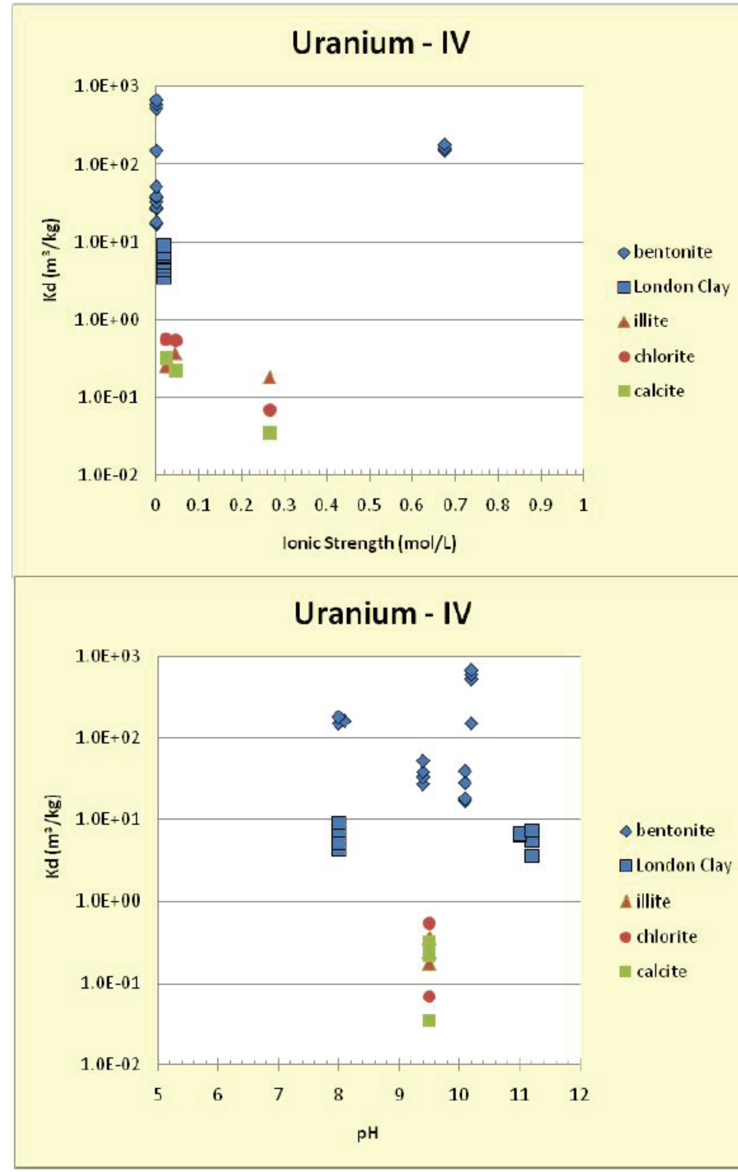
TECHNETIUM (VII) – Oxidizing Conditions				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**5**	**7.6**	**2.6 x 10^{-4}**	**-**
comment	Based on montmorillonite. Mucciardi et al. (1979).			
Shale	**5**	**7.9**	**7.3 x 10^{-5} to 7.9 x 10^{-2}**	**0.0023 (33)**
comment	Mucciardi et al. (1979)			
Limestone	**5**	**7.7**	**3.0 x10^{-3} to 7.5 x 10^{-2}**	**0.012 (5.3)**
comment	Mucciardi et al. (1979)			
TECHNETIUM (IV) – Reducing Conditions				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**0.7**	**8.2**	**4.2 to 10**	**7.2 (1.4)**
comment	Baston et al. (1995, 1997). Data at lower pH would be useful.			
Shale	**0.02**	**8.2**	**0.0007**	**-**
comment	Estimated from sorption measured on chlorite by Allard et al. (1979). Assumed shale contained 60% chlorite. Value seems rather low. Reducing conditions not confirmed.			
Limestone	**0**	**8.5**	**0.017**	**-**
comment	Ito and Kanno (1988); Tenuous due to only 1 data point and very dilute water. Reducing conditions not confirmed.			

Note: The geometric standard deviation is in parentheses beside the geometric mean.

Technetium Sorption Coefficients on Shale, Mudstone, Limestone, Illite and Chlorite Under Oxidizing Conditions



Uranium (VI) Sorption Coefficients on Shale, Calcite, Dolomite, Illite, Mudstone and Chlorite Under Oxidizing Conditions

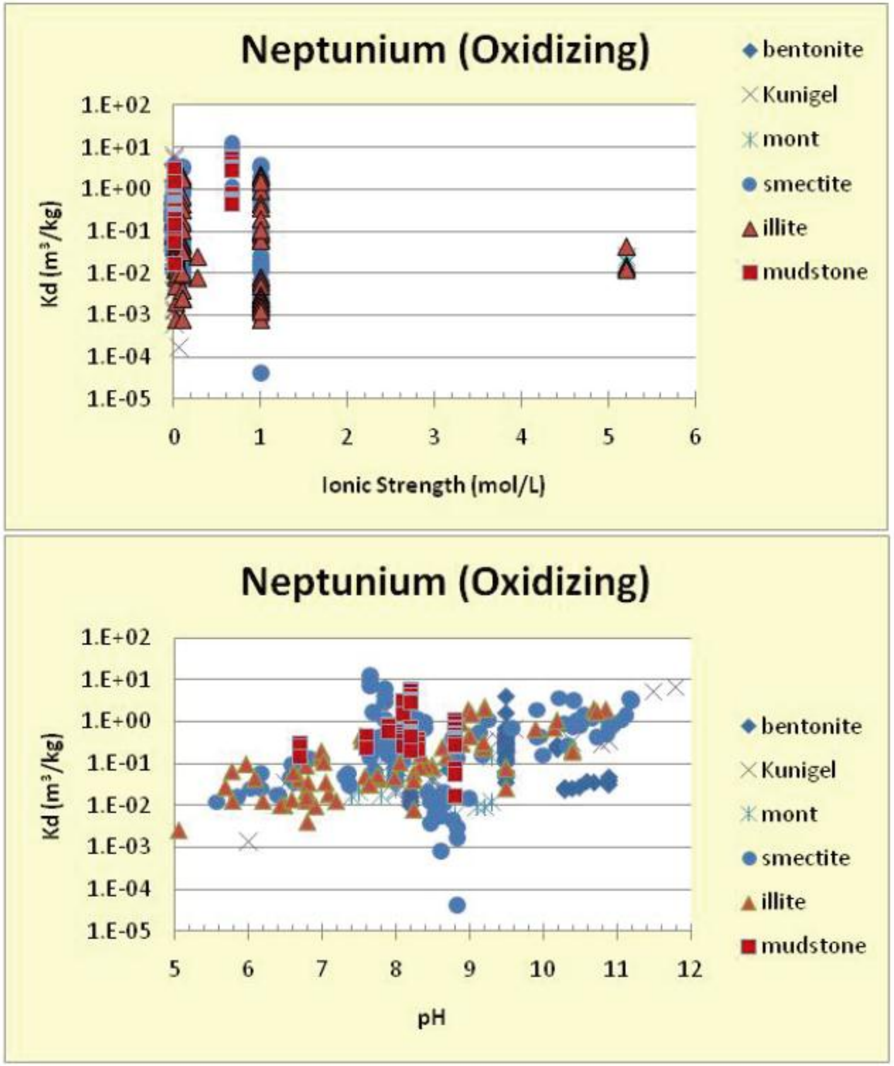


Uranium (IV) Sorption Coefficients on Bentonite, London Clay, Illite, Calcite and Chlorite Under Reducing Conditions

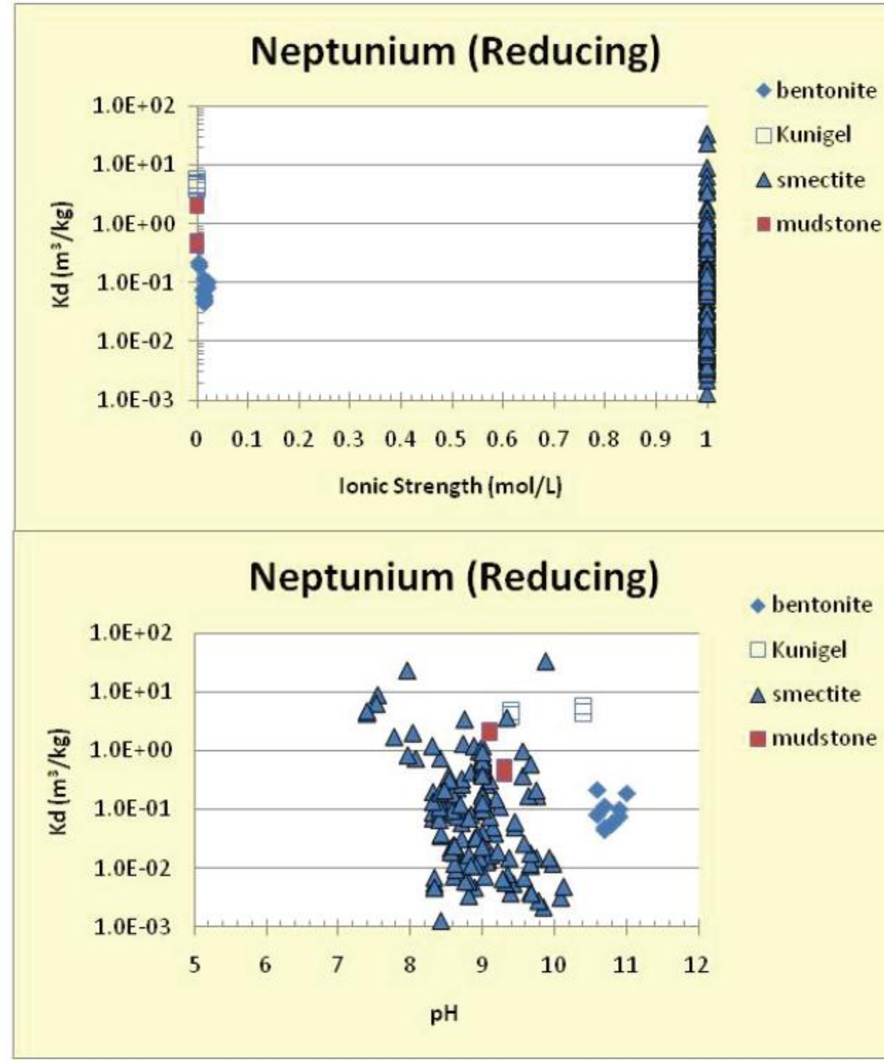
Recommended Sorption Coefficients for Uranium

URANIUM (VI) – Oxidizing Conditions				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**0.2 to 7.5**	**6.0 to 7.5**	**0.014 to 0.57**	**0.13 (7)**
comment	Vilks et al. (2011)			
Shale	**0.2 to 7.5**	**6.0 to 7.5**	**0.002 to 0.051**	**0.010 (6)**
comment	Ordovician shale, Vilks et al. (2011)			
Limestone	**0.2 to 7.5**	**6.0 to 7.5**	**0.002 to 0.017**	**0.006 (3)**
comment	Ordovician limestone, Vilks et al. (2011)			
URANIUM (IV) – Reducing Conditions				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**0.2 to 0.7**	**6.9 to 8**	**40 to 180**	**85 (2.9)**
comment	Baston et al. (1995) and SKB (2006).			
Shale	**0.018**	**8**	**3.7 to 7.7**	**5.3 (1.7)**
comment	Estimated from U(IV) sorption on London Clay measured by Baston et al. (1991).			
Limestone	**0.27**	**9.5**	**0.035**	**-**
comment	Based on U(IV) sorption on calcite reported by Ticknor (1993).			

Note: The geometric standard deviation is in parentheses beside the geometric mean.



Neptunium Sorption Coefficients on Bentonite, Swelling Clays, Illite and Mudstone Under Oxidizing Conditions



Neptunium Sorption Coefficients on Bentonite, Swelling Clay and Mudstone Under Reducing Conditions

Recommended Sorption Coefficients for Neptunium

NEPTUNIUM (V) – Oxidizing Conditions				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**1 to 5.2**	**6 to 7.5**	**0.017 to 0.40**	**0.044 (3.6)**
comment	Mucciardi et al. (1979) and Stammos et al. (1992).			
Shale	**1 to 5.2**	**6.1 to 7.2**	**0.0075 to 0.026**	**0.011 (1.7)**
comment	Based on illite (60%) and assuming no sorption on quartz.			
Limestone	**5**	**neutral**	**0.001 to 0.20**	**0.014 (42)**
comment	Based on values recommended for dololmite by USEPA (1998).			
NEPTUNIUM (IV) – Reducing Conditions				
			K_d Values (m^3/kg)	
	I (mol/L)	pH	Range	Geometric Mean
Bentonite	**1**	**7.4 to 8.0**	**0.84 to 23**	**4.5 (2.9)**
comment	Kitamura and Tomura (2003)			
Shale	**0**	**9.3**	**0.15 to 2.3**	**2.1 (1.1)**
comment	Based on values reported for mudstone by Tachi et al. (1999). The low ionic strength and high pH make this a rough estimate.			
Limestone	**5**	**neutral**	**0.70 to 10**	**2.7 (6.6)**
comment	Based on using Th(IV) as a chemical analog (See Table 17).			

Note: The geometric standard deviation is in parentheses beside the geometric mean.

"Sorption Experiments in Brine Solutions with Sedimentary Rock and Bentonite"
Report No.: NWMO TR-2011-11
Author(s): Peter Vilks, Neil H. Miller and Kent Felushko
Company: Atomic Energy of Canada Limited
Date: December 2011

"Sorption in Highly Saline Solutions – State of the Science Review"
Report No.: NWMO TR-2009-18
Author(s): Peter Vilks
Company: Atomic Energy of Canada Limited
Date: July 2009

"Sorption of Selected Radionuclides on Sedimentary Rocks in Saline Conditions – Updated Sorption Values" : Database is now updating.

"Research on batch and mass transport sorption tests and thermodynamic sorption modeling for elements U(VI), Zr(IV), Se(IV), Pb(II) and Cu(II) in highly saline solutions" is now investigating.

History

Founded in 1887 by Senator William McMaster – first president of the Bank of Commerce

Moved to Hamilton in 1930

University colours: maroon and grey (since 1912)

Strengths

The “McMaster Model” – a student-centred, problem-based, interdisciplinary approach to learning – has been adopted by universities around the world.

With a total sponsored research income of $345 million, McMaster University ranks first in the country in research intensity--a measure of research income per full-time faculty member--averaging $308,000 per faculty member.

Students

21,173 full-time undergraduate students (2009-2010)

3,025 full-time graduate students (2009-2010)

Average entering grade of 84.3 per cent

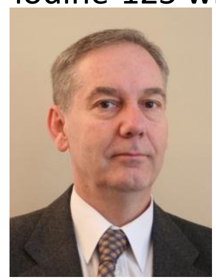
140,000 alumni in 128 countries

Faculty

894 fulltime instructional faculty members, 1,434 (including clinical faculty 96.7 per cent of faculty with PhDs)

天体物理学、その後、原子力工学と材料工学、現在はバイオサイエンス
カナダの学生は、自宅から通えるくらいの範囲の大学を志向する傾向あり。

The McMaster Nuclear Reactor (MNR) began operating in 1959 as the first university-based research reactor in the British Commonwealth. More than 50 years later, MNR remains an integral part of the value chain of a number of industries, providing an array of services which would not otherwise be readily available to our stakeholders. Perhaps most notably, MNR is one of the world's largest suppliers of the medical radioisotope iodine-125 which is used for the treatment of prostate cancer.



Department of Engineering Physics
Faculty member: 16
Undergraduate students: 50/year
Graduate students: app. 30/year（カナダ国籍、永住者が多い。PhDは留学生の割合が増えている。カナダ学生は就職志向大。）

研究領域
Nano- and Micro-device Engineering
Nuclear Engineering and Energy Systems ・・・・ カナダの原子力界はさながらMcMaster村
Photonics Engineering

UNENE（The University Network of Excellence in Nuclear Engineering ）
原子力産業界と原子力系大学（現実には、教育はMcMasterとUniversity of Ontario Institute of Technology）との教育と研究のネットワーク

McMasterでの研究計画

（１）BrineでのNpの化学
- Np(V)のSpeciation、吸着、吸着モデル
- Np(IV)のSpeciation、吸着、吸着モデル
- イオン強度の考え方
- 既存データーベース（RES3Tなど）のデータの評価、自分たちのデータの評価

（２）カナダの土壌、気象条件（氷雪など）でのCsの吸着、輸送モデル

湖でのCs動態

大気中から土壌表面への沈降以降のプロセスモデル

Biosphereにおける安全評価（NWMOではperformance assessmentとは言わない）とのリンク

（３）使用済み核燃料の処分地選定プロセスにおける工学の役割
- First Nationの価値観、移民間の価値観とも整合する安全評価手法
- 原子力新興諸国

カナダについて、この数ヶ月で気付いたこと:

・カナダ人の気質（アメリカのこと、保守性、ケベック、移民。。。）

・原子力に対する見方

・大学の研究と産業界との関係（規制機関との関係）

・First Nationの人々との関係