

Confidence in Safety – South Bruce Site

NWMO-TR-2022-15

March 2022

Nuclear Waste Management Organization

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EXECUTIVE SUMMARY

The Nuclear Waste Management Organization (NWMO) is presently in a multi-year process of identifying a safe site for a deep geological repository for Canada's used nuclear fuel in an area with informed and willing hosts. This is similar to plans in other countries with nuclear power programs, including in particular Finland and Sweden which have approved sites for their planned deep geological repositories.

The fundamental safety objective of the project is to protect humans and the environment, including water, from the effects of radioactive or hazardous substances present in the used fuel. The used fuel radioactivity naturally decreases with time. The deep geological repository, including engineered and natural barriers, provides long-term containment and isolation; in particular while this natural radioactivity decay occurs.

Previous discussions and studies have identified the Revell Site in northwestern Ontario and the South Bruce Site in southern Ontario as candidate repository sites. Municipalities, First Nations and Metis communities in both siting areas are working with the NWMO as part of the site selection process. Neither of the two sites have yet been identified as the preferred site.

This report focuses on the South Bruce Site. It summarizes the results as of early 2022 indicating that this site would be suitable from a technical perspective for hosting a repository. It is intended to support public discussion around site selection.

This report is part of a larger and ongoing site assessment process. Ongoing and future technical work will include further site studies, design development and safety analyses to confirm and extend the results to date. These would ultimately be presented to Canadian federal regulators for an Impact Assessment and a series of licence applications. This is a process that will take years before a final approval to construct could be received. During construction and operations, there will be continued monitoring to ensure that the site is, and remains, suitable for long-term containment and isolation of used nuclear fuel.

The NWMO's assessment of the suitability of the South Bruce Site is based on both intrinsic characteristics of the repository approach, as well as regional geological information and South Bruce Site specific results acquired to date. These are described in more detail within this report, but key points are as follows:

1. The favourable characteristics of the geological setting.

- The preferred host rock is the Cobourg Formation at about 650 m deep, overlain by over 200 m of confining low-permeability shale formations. This Cobourg Formation is a laterally extensive geological formation, extending under much of southwestern Ontario and Michigan, including beneath the entire South Bruce Site. This formation has the depth, breadth and volume to isolate the repository from surface disturbances and changes caused by human activities and natural events.
- No active geological features (e.g., faults) or unfavourable heterogeneities have been identified in the Cobourg Formation at the South Bruce Site to date. This is a favorable indication of the stability of the site and of its ability to contain the used fuel.

- No indication of permeable Cambrian Formation has been found below the South Bruce Site based on first two boreholes. This favorably simplifies the hydrogeology at the South Bruce Site.
- No appreciably flowing groundwater was measured below 325 m depth in the two boreholes to date at the South Bruce Site. This is a favorable indication for very low groundwater flow at repository depth.
- Based on regional data, the South Bruce host rock should be capable of removing the decay heat from the fuel, and withstanding the natural and thermal stresses induced by the repository. Geophysical and geomechanical testing currently underway is expected to confirm this.

2. The stability of the geological setting.

- The Cobourg Formation, and the related formations above and below it at the South Bruce Site, are about 360-485 million years old.
- Porewater chemistry is presently being measured on rock core from the South Bruce Site. Measurements on rock core from the Cobourg Formation collected at the Bruce nuclear site, have indicated that the fluids (including water and gases) within the small pores in this rock have been there for hundreds of millions of years. Similar conditions are expected to be found at the South Bruce Site, and would be favorable for long-term stability.
- The South Bruce Site is located in a stable, seismically quiet setting overlying the Precambrian rocks of the Canadian Shield at the heart of the North American continent, far from tectonic plate boundaries. This is favorable for long-term stability.
- There is currently no indication that the South Bruce Site location will experience extreme rates of erosion, uplift, or subsidence that would significantly perturb the geosphere over the next million years.

3. The low risk of inadvertent future human intrusion into the repository.

- Other than surficial aggregate resources, no known economically exploitable mineral resources, hydrocarbon resources, or salt resources, have been previously identified at the South Bruce Site, and preliminary data from the first two boreholes at the site have not indicated economically significant concentrations of any of these at the site. This reduces the risk of inadvertent future human intrusion into the repository.

4. The site is amenable to geological characterization.

- In southern Ontario, the lateral homogeneity of the sedimentary rock formations is favorable for predicting the overall host rock structure and characteristics from the available and planned studies.

5. The robustness of the multiple barrier system.

- In addition to the favorable geosphere as noted above, the repository includes a series of engineered barriers, in particular the fuel itself, the durable containers and bentonite-clay based seals.
- The used fuels are primarily a durable uranium-oxide solid ceramic material.
- Natural analogues provide evidence that the engineered barrier materials, notably the copper, clay and uranium oxide, are durable over very long times under repository-appropriate geological conditions.
- Studies in Canada and around the world for several decades have provided a strong scientific basis for the safety of deep geological repositories designed around these barriers.

6. The ability to safely construct and operate the repository.

- The Cobourg Formation at about 650 m depth is the proposed host rock for the repository. Mineralogical analyses conducted at the Bruce nuclear site showed that the Cobourg Formation is mostly composed of calcite (i.e., limestone). Given the lateral consistency of this rock formation across southern Ontario, a similar mineralogy is expected at the South Bruce Site. Such mineral composition is favourable for construction of a repository.
- The South Bruce Site has suitable surface area for the construction and operation of DGR surface facilities and excavated rock management area.
- The South Bruce Site has suitable underground area for emplacement of all Canada's projected used fuel.
- A preliminary conceptual design has been developed for the repository facilities and is consistent with international best practice. It is presently being adapted to the site-specific conditions.
- The NWMO Proof Test program is demonstrating the ability to fabricate, handle and place the underground fuel containers. It is informed by related tests in other countries.
- The South Bruce Site is approximately 10 km south of Ontario Highway 9. The Goderich-Exeter Railway rail line is approximately 50 km to the south. Electrical transmission and natural gas distribution are available in the region. There is high confidence that the regional infrastructure can support the construction, operation and closure of the repository.

7. The used fuel can be safely transported to the site.

- The NWMO has a licenced transport package already available for CANDU used fuel. This package is designed and tested to withstand severe accidents. Used fuel has been safely transport in Canada and in other countries for over 50 years.

- The South Bruce site is within 15 km of an existing highway supported by local road network. There is no rail infrastructure within 50 km; direct rail transport is not feasible. An all road and a road/rail combination transportation system are technically feasible for the site.

8. Facility performance will meet regulatory criteria for safety and the protection of the environment.

- All countries which have decided on the long-term management of their used fuel have plans for a deep geological repository for this purpose.
- The Canadian regulatory framework has defined steps and expectations for licencing a repository. It is consistent with international guidance.
- Safety assessment studies to date for other sedimentary rock sites have indicated that a repository in these rocks can perform well, with no impacts on human health. An assessment specific to the South Bruce Site is currently under development, but preliminary indications are consistent with these other studies.
- Baseline monitoring is in-place or underway, including borehole, shallow groundwater, surface water, biodiversity, seismic and meteorological monitoring.
- The site will be monitored for decades during site characterization, preparation, construction and operation, before a decision is made to close the repository. This monitoring will support the repository construction and operations, as well as confirm that the repository is not causing harm to people or the environment, including water.

Overall, based on the assessment results to date, the NWMO is confident that a deep geological repository could be constructed at the South Bruce Site in a manner that would provide safe long-term management for Canada's used nuclear fuel.

More site characterization is required, and is planned should the site be selected. However, the uncertainties that remain are less about the fundamental suitability of the bedrock to safely contain and isolate used nuclear fuel, and more about developing and documenting a thorough quantitative understanding of the site. One area that will require additional effort in the future is the high salinity in the host rocks. While this is a favorable indicator for the stability of the geology, its potential effects on the engineered systems will require additional analysis. The design of the surface and underground facilities will continue throughout site characterization.

The safety of the proposed site would be confirmed through a rigorous regulatory review of the facility design and safety case. The decision-making process and implementation would extend over decades. The associated uncertainties can be addressed within the flexibility of the NWMO's program, including aspects such as monitoring and retrievability. The program, evolving over a long period of time, would have the ability to adjust to new information and technologies to improve understanding and optimize performance.

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ABBREVIATIONS

AECL – Atomic Energy of Canada Limited

APM – Adaptive Phased Management

CANDU – Canada Deuterium Uranium reactor type

CNSC – Canadian Nuclear Safety Commission

DGR – Deep geological repository

EBS – Engineered barrier system

ERMA – Excavated Rock Management Area

GEH BWR – General Electric – Hitachi Boiling Water Reactor

HLW – High-level radioactive waste

IAEA – International Atomic Energy Agency

ILW – Intermediate-level radioactive waste

NWMO – Nuclear Waste Management Organization

PAG – Potentially Acid Generating

RQD – Rock Quality Designation

UDF – Underground Demonstration Facility

UFC – Used Fuel Container

UFPP – Used Fuel Packaging Plant

UFTP – Used Fuel Transportation Package

1. INTRODUCTION

1.1 Background

The Nuclear Waste Management Organization (NWMO) is presently in a multi-year process of identifying a safe site for a deep geological repository for Canada's used nuclear fuel in an area with informed and willing hosts (NWMO 2021). This is similar to plans in other countries with nuclear power programs, including in particular Finland and Sweden which have approved sites.

The Government of Canada selected the deep geological repository approach in 2007, and assigned the NWMO with the task of siting, building and operating this repository. The NWMO has responded with a siting program that includes discussions and planning with communities, and conducting technical and social studies. Early assessments were summarized in a series of reports available on the NWMO website at www.nwmo.ca/studyareas.

These discussions and studies have identified the Revell Site in northwestern Ontario and the South Bruce Site in southern Ontario as candidate repository sites. Neither of the two sites have yet been identified as the preferred site, as there are technical studies and community partnership discussions underway, and decisions to be made by both NWMO and communities.

This report focuses on the South Bruce Site. This site is located approximately 5 km northwest of Teeswater in the Municipality of South Bruce. It is about 30 km from Lake Huron (Figure 1.1 and Figure 1.2)



Figure 1.1: Typical landscape at the South Bruce Site in southern Ontario.

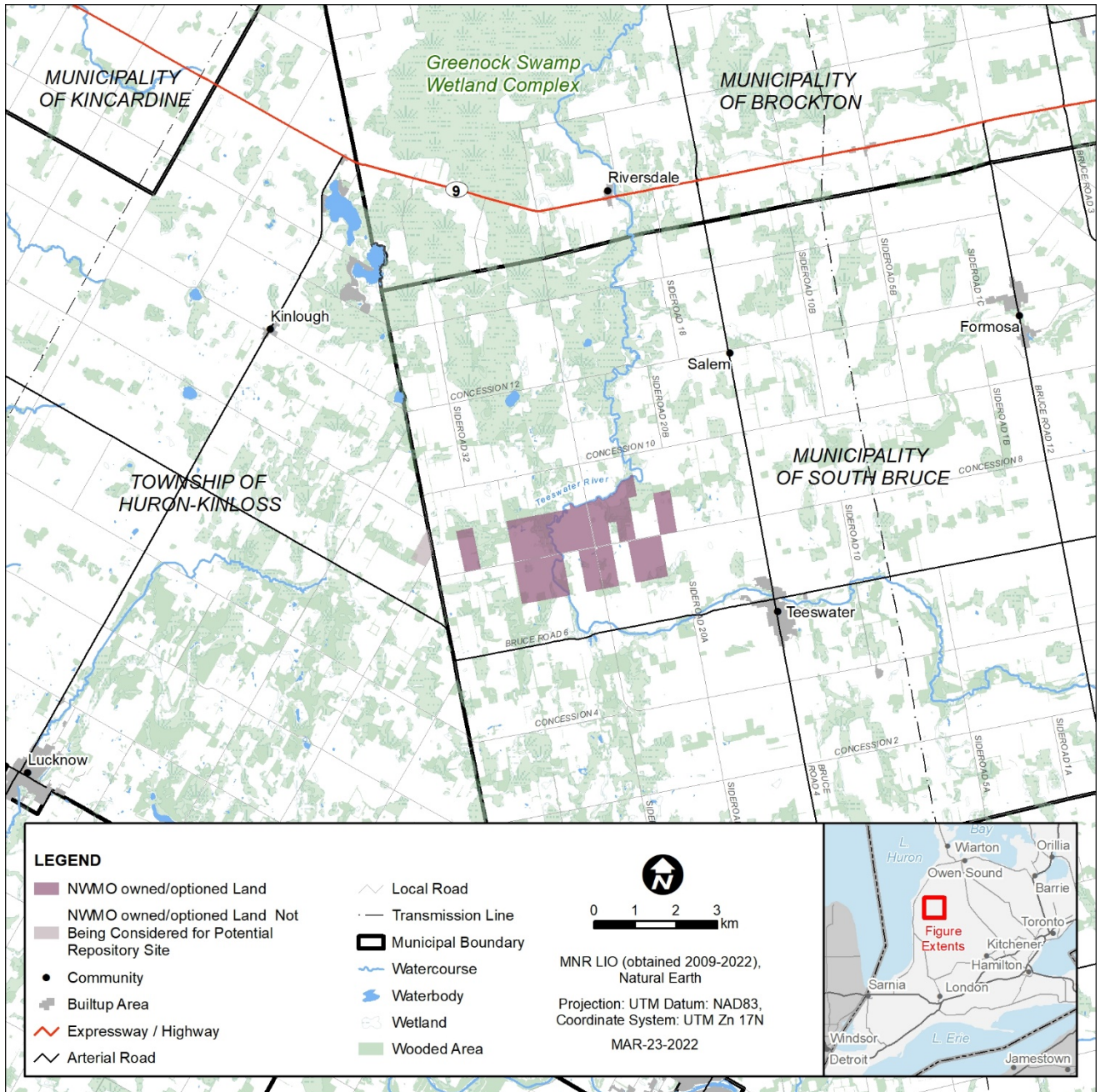


Figure 1.2: General location of the South Bruce Site in southern Ontario. Inset map shows main figure location in Ontario. The repository surface facilities and underground rooms would be located on or under NWMO owned land. Over 1500 acres have been secured by NWMO. This area is sufficient for the repository; however, discussions with interested landowners are ongoing.

1.2 Deep Geological Repository Concept

The fundamental safety objective of the project is to protect humans and the environment, including water, from harmful effects of radioactive or hazardous substances present in the used fuel.

The strategy to achieve this objective is to isolate and contain the radioactive material by placing the used nuclear fuel in a deep stable geological environment, surrounded by multiple barriers. This strategy is referred to here as a **deep geological repository** (also DGR or repository).

The key components of the repository, shown in Figure 1.3, are:

- the waste form (i.e., used nuclear fuel);
- the engineered barrier systems, notably the used fuel container, buffer and sealing materials;
- the host rock;
- the underground repository facilities, notably the shafts, main services area, and the placement rooms connected by access tunnels; and
- the main surface facilities, where fuel is received, packaged, and transferred underground.

The concept also includes the transportation system for moving fuel from interim storage sites to the repository site.

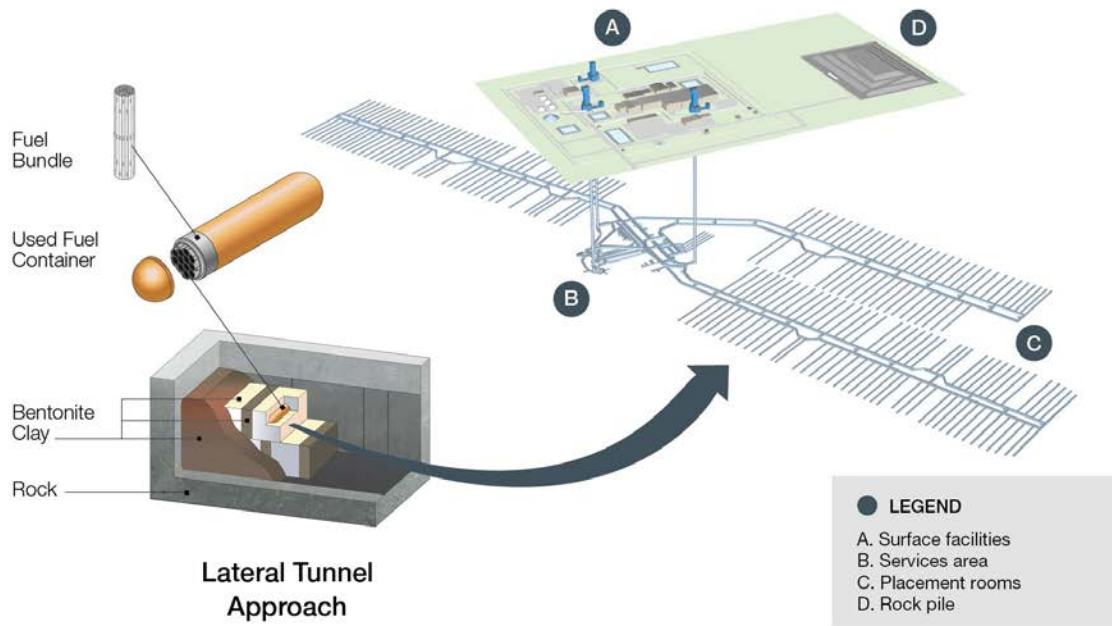


Figure 1.3: Deep Geological Repository concept

1.3 South Bruce Area

The South Bruce Site is in southern Ontario, in the Municipality of South Bruce (Figure 1.1 and Figure 1.2).

This area is located in the western St. Lawrence Lowland, a low relief, gently undulating land surface that occupies much of southwestern Ontario and is covered with glacial sediments. The land surface ranges from a maximum of 249 metres above sea level in the southeast corner of the Municipality of South Bruce to a minimum of 176 metres along the shore of Lake Huron in the Township of Huron-Kinloss. The land surface shows a general slope down towards Lake Huron from southeast to northwest. A flat low-lying area, associated with the Greenock Swamp wetland, is located north of the site downstream along the Teeswater river.

South Bruce and surrounding area is a predominantly agricultural landscape located at the transition of Ontario forest zones. It lies within the Deciduous Forest Region where woodlands consist primarily of American beech and sugar maple, on the northern limit of the Carolinian Forest. In areas where agriculture dominates, terrestrial features and areas are generally associated with valley lands along watercourses and within wetlands.

The most prominent drainage feature in the area is the Teeswater River, which flows from east to west in the Municipality of South Bruce, bending to flow northward and discharging into the Saugeen River at Paisley.

Shallow bedrock is the most important source of drinking water in the area, and is the primary source for municipal water supplies. Shallow bedrock aquifers within the area comprise the upper few metres to over 100 m of bedrock formations. Water quantity and quality within the shallow bedrock aquifer can vary dramatically across the area as a consequence of the different chemical and physical characteristics of the individual bedrock formations.

Further information on the environment is provided in the NWMO Phase 1 Assessment report (NWMO 2014). This information is presently being updated as part of the NWMO site baseline studies and environmental baseline monitoring program.

1.4 Purpose of Report

This document presents the current basis for NWMO's confidence that a deep geological repository could be constructed at the South Bruce Site in a manner that would provide safe long-term management of Canada's used nuclear fuel. This confidence is built on our understanding of the following aspects:

- the characteristics of the geological setting that provide containment and isolation;
- the long-term stability of the geological setting;
- the low risk of future human intrusion into the repository;
- the site is amenable to characterization;
- the robustness of the multiple barrier system;
- the repository can be constructed, operated and closed safely;
- the used fuel can be safely transported to the site; and
- the facility performance will meet regulatory criteria for safety and environmental protection.

This report presents the safety basis and the associated uncertainties as they stand as of early-2022. From a site-specific data perspective, this is based on existing regional information and preliminary observations from the first two boreholes drilled at the site.

In this report, current technical information is provided to support public dialogue and community confidence building for proceeding to the next stage of site selection.

It is not a final safety report, with a comprehensive system understanding and the level of detail needed for obtaining approvals by the regulatory authorities.

This report is part of a step-wise approach. Site characterization, design development and safety analyses are continuing, which will further check and clarify the safety basis. If this site is formally proposed for the repository, these would eventually be documented in a series of reports that support an Impact Assessment and the first licence application, for Site Preparation.

2. NATURE OF THE USED FUEL

Almost all of the used nuclear fuel in Canada (about 99.9%) is produced by CANDU nuclear power reactors in Ontario, Québec and New Brunswick. There are also very small quantities of used fuel from research, demonstration and isotope-producing reactors, largely at the Chalk River Laboratory site in Ontario (NWMO, 2021a). Ontario Power Generation (OPG) is now planning to build a GEH BWRX-300 Boiling Water Reactor (BWR) at its Darlington site.

The fuel for CANDU power reactors is solid uranium dioxide (UO_2) (Figure 2.1), as is the fuel for GEH BWR reactor. This is similar to a common naturally occurring form of uranium, such as found in Canadian uranium ore bodies.

This UO_2 is pressed into a dense ceramic pellet and sealed inside metal tubes made of zirconium alloy. These tubes (called fuel elements) are welded together into a CANDU fuel bundle (Figure 2.1) or a fuel assembly. The bundle characteristics vary slightly between the different CANDU reactors. The Bruce and Darlington 37R fuel bundle, which is the most common to date, contains 37 fuel elements and weighs 23.9 kg, of which 21.7 kg is UO_2 and 2.2 kg is Zircaloy. The GEH BWR fuel assemblies are about 4.5 m long, and weigh about 300 kg.

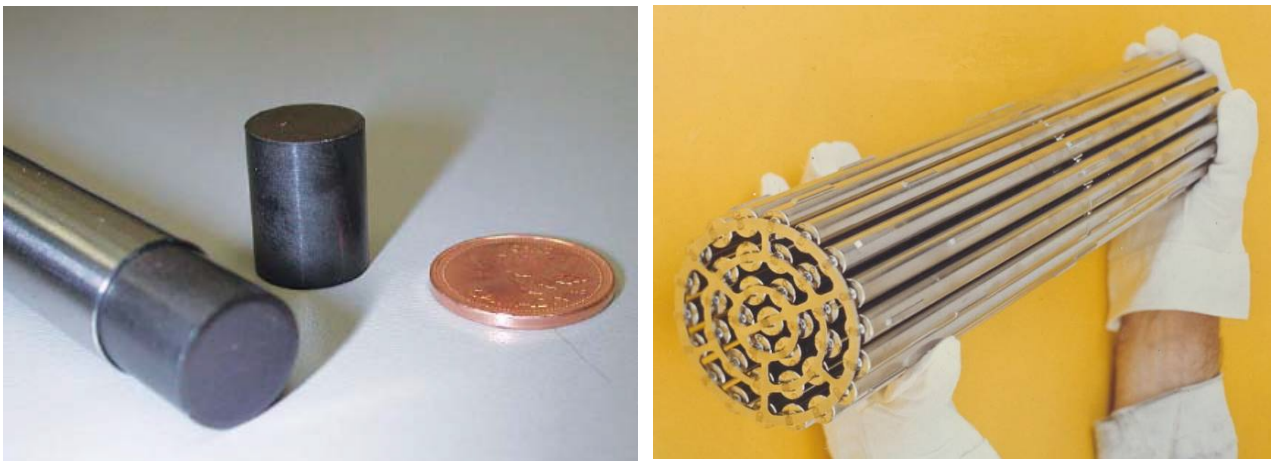


Figure 2.1: (Left) Ceramic UO_2 fuel pellets before irradiation, and pellets fitting inside Zirconium alloy cladding. (Right) Typical CANDU fuel bundle before irradiation

In a reactor, heat is produced by **fission**. Fission occurs within the fuel when a neutron is absorbed by certain heavy atoms (notably U-235) which then split into two smaller atoms (called **fission products**). Neutrons are also released during fission, sustaining the nuclear chain reaction.

New atoms are also generated in the reactor when an existing atom absorbs a neutron, a process called neutron capture or activation. Some new atoms are heavier than uranium, such as plutonium. Collectively, these heavy atoms including uranium are called **actinides**.

Many of the new atoms formed are unstable, i.e., they are **radioactive** atoms or “**radionuclides**”. In this process, the atom spontaneously releases energy, and changes into a different type of atom, a process called **radioactive decay** or **radioactivity**. This decay energy is released as various types of **radiation**, including alpha, beta and gamma radiation.

Eventually, all radioactive atoms decay into stable atoms and do not release further radiation. This radioactive decay is a natural process. It can take anywhere from fractions of a second to occur, to longer than one million years, depending on the particular type of atom. Radioactivity is measured in **Becquerels (Bq)** where 1 Bq is one atom decay per second. Uranium is an example of a naturally occurring radioactive atom.

Before entering the nuclear reactor, the UO_2 fuel consists primarily of uranium and oxygen atoms (inside zirconium alloy metal). On leaving the nuclear reactor, the fuel (now called spent or **used fuel**) still contains mostly uranium and oxygen, but also small amounts of other atoms produced by fission and neutron capture as outlined above. The characteristics of the used fuel depends on the nature of the reactor operation. This operation is often described in part by the **burnup**, which is the cumulative amount of energy released per unit mass of uranium. The burnup range of CANDU fuel is about 120-320 MWh/kg U, with a mean burnup value of 200-220 MWh/kg U. At this burnup, about 2% of the initial uranium has been “burned” and converted into other atoms. GEH BWR fuel is designed for higher burnup of about 1200 MWh/kg U.

Table 2.1 provides a summary of the most abundant atoms in typical CANDU used fuel.

When the used fuel is removed from the reactor, it is highly radioactive and generating radiation. The radioactivity (and radiation) initially decreases very quickly with time. For the first 7-10 years after removal, the used fuel is stored at the reactor site in fuel bays (closed water pools) which provide radiation shielding and cooling. After this time, the used fuel can be stored in air-cooled concrete containers (referred to as dry storage).

The total radioactivity of used fuel decreases with time after the fuel is discharged from the reactor as illustrated in Figure 2.2. The total radioactivity drops by a factor of 1000 over the first 10 years. Over the next 500 years, the fission product radioactivity drops significantly. At this point, the remaining radioactivity is mainly due to the actinides present in the used fuel. The total radioactivity continues to decay slowly. After about 1 million years, the radioactivity in the used fuel is primarily due to the natural radioactivity of uranium. The total mass of uranium and total radioactivity in the repository would be similar to that in large Canadian uranium ore bodies.

**Table 2.1: Composition of fresh and used CANDU UO₂ fuel bundle
(220 MWh/kgU burnup, 30 years since discharge)**

Component *	Fresh (Unirradiated) Bundle	Used Bundle
	Bundle Mass %	Bundle Mass %
Actinides		
U-238	79.41%	78.60%
Pu-239	-	0.22%
U-235	0.58%	0.14%
Pu-240	-	0.10%
U-236	-	0.06%
Th-232	0.04%	0.04%
Am-241	-	0.02%
Pu-242	-	0.01%
Pu-241	-	0.01%
U-234	0.004%	0.003%
Other Actinides	-	0.005%
Other Elements and Fission Products		
O (stable)	10.73%	10.79%
Zr (stable)	8.68%	8.73%
Zr-96	0.25%	0.28%
Sn (stable)	0.16%	0.16%
Xe (stable)	-	0.13%
C (stable)	0.07%	0.07%
Mo (stable)	-	0.05%
Ce (stable)	-	0.05%
Ru (stable)	-	0.05%
Nd (stable)	-	0.05%
Ba (stable)	-	0.04%
Cs (stable)	-	0.03%
Nd-144	-	0.03%
Mo-100	-	0.02%
Tc-99	-	0.02%
Zr-93	-	0.02%
Cs-137	-	0.01%
Other Radionuclides	-	0.04%
Others Stable Isotopes	0.09%	0.24%

*Includes impurities naturally present in fuel

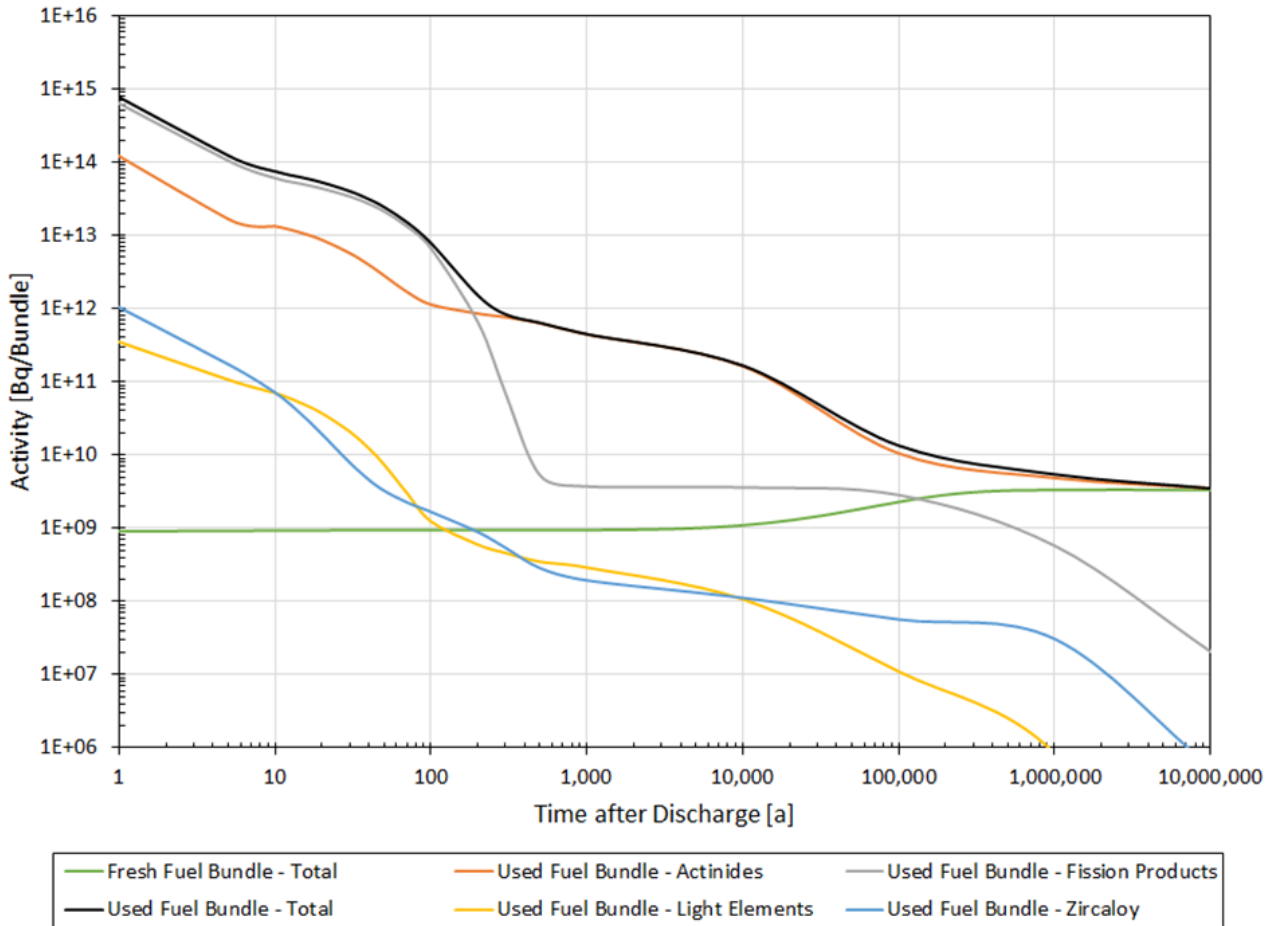


Figure 2.2: Radioactivity of used CANDU fuel decreases with time (fuel burnup of 220 MWh/kgU)

The hazard from used fuel is primarily due to the radiation released by radioactive atoms in the used fuel. Radiation is energy travelling through space. Used fuel releases energy primarily as thermal radiation (heat) and as alpha, beta, gamma and neutron radiation. The latter four are referred to as nuclear radiation or ionizing radiation.

Alpha and beta radiations have small ranges; thin layers of materials or air can easily stop them. In fact, the fuel bundle cladding stops most alphas and betas emitted from the used fuel.

Gamma and neutron radiations can penetrate outside of the used fuel. However, they can be stopped with sufficiently thick layers of dense material referred to as **shielding**. Figure 2.3 shows CANDU used fuel storage in a reactor fuel bay, and in steel-and-concrete canisters (dry storage). These illustrate how several metres of water or tens of centimetres of concrete and steel provide shielding from the radiation from used fuel stored at surface.

In a deep geological repository, used fuel is placed so deep underground that there is no exposure to humans or the environment at surface. The several hundred metres of rock above the repository provide more than sufficient shielding from the gamma and neutron radiation.



Figure 2.3: Photos of workers in CANDU used fuel bay and in dry storage facility.

The radioactive atoms are embedded within the used fuel, which are in turn contained within other engineered and natural barriers. These barriers include the used fuel container, the surrounding clay layer and the several hundred meters of rock above the repository. Exposure of people to these atoms would be highly unlikely as it would require multiple barrier failures, occurring before these atoms had decayed to non-radioactive atoms.

If these radioactive atoms reach the surface environment, they could expose plants, animals and humans through various pathways.

An example of this hazard is the ingestion dose. In particular, it is a measure of the impact from eating food or drinking water that contains radioactive atoms, taking into account how these atoms interact with the body. Analysis indicates that the total internal hazard of the fuel follows the same general shape as the radioactivity in Figure 2.2. It decreases significantly over the first 1000 years, and is due largely to fission products. From 1000 to 100,000 years it is largely due to actinides such as plutonium. After one million years, the remaining hazard is largely due to the decay products of the uranium within the used fuel. After this time, the hazard of a repository is comparable with that of naturally occurring large uranium ore bodies. These ore bodies exist in a variety of locations around the world, and may not be noticeable at surface when the ore bodies are underground (e.g., Cigar Lake, Canada, Cramer and Smellie 1994).

The health effects of radiation on humans are quantified using **sieverts**, a unit of radiation dose that depends on the amount and type of ionizing radiation absorbed and the type of human tissue exposed. One millisievert (mSv) is one-thousandth of a sievert.

People are constantly exposed to naturally occurring radioactivity in the ground and water and air around us, and to natural radiation coming from space. The average Canadian receives a dose of about 1.8 mSv each year from these natural sources (Grasty and LaMarre, 2004).

3. LONG-TERM GEOLOGICAL CONTAINMENT AND ISOLATION

The repository must contain and isolate the used nuclear fuel. To ensure this, the geoscientific conditions (properties and processes) of the South Bruce site should:

- promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances;
- promote long-term containment of used nuclear fuel within the repository; and
- restrict groundwater movement and retard the movement of any released radioactive material.

The ability of the South Bruce Site to safely contain and isolate the used nuclear fuel can be assessed through the following site evaluation factors (NWMO, 2010):

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.
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.
3. The mineralogy of the rock, and 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.
4. The hydrogeological regime within the host rock should exhibit low groundwater velocities.
5. The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement.
6. The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

Each of these factors are discussed in the subsections below and in Sections 4 and 5. They are informed by regional information, and by site characterization studies in the South Bruce area that were initiated in 2012 and are still underway. To date, these include:

- 2012 - Initial Screening desktop study (AECOM, 2012)
- 2012-2014 - Phase I Desktop preliminary assessment (Geofirma, 2014)
- 2020-2021 - Initial Phase 2 preliminary assessment field studies, including borehole drilling, coring and testing, 3D seismic survey, microseismic and shallow groundwater monitoring.

The Phase I Desktop Preliminary Assessment (Geofirma, 2014) provided an initial understanding of the geology at the South Bruce Site and identified the **Cobourg Formation** (named as such because it surfaces near Cobourg, Ontario) as a potentially suitable host rock formation for siting a deep geological repository in South Bruce. The Cobourg Formation is an argillaceous (i.e., clay-containing) limestone that is known to be a strong, low-permeability rock. It is underneath a thick layer of low-permeability shales, the Blue Mountain to Queenston formations (see Figures 3.2 and 3.3). The Cobourg Formation is also underlain by argillaceous limestones of the Kirkfield and Sherman Fall formations. The Cobourg Formation, together with these bounding formations both above and below it, represents the primary natural barrier system for a repository in the South Bruce Site.

Phase I studies were based mostly on available information from historic oil and gas exploration, 2D seismic data, airborne geophysical surveys, and the results of a detailed characterization of the sedimentary rocks beneath the Bruce nuclear site (Intera 2011, NWMO 2011). This site characterization work at the Bruce nuclear site was completed as part of OPG's proposed Deep Geological Repository for Low & Intermediate Level radioactive waste.

Studies carried out after Phase I Preliminary Assessment, including an updated three-dimensional (3D) geological model of the stratigraphy of southern Ontario (Carter et al., 2021) and preliminary results from activities such as the NWMO's borehole drilling activities provide additional insight into the geology at the South Bruce Site, which is discussed in the following subsections.

Importantly, the continuity of the sedimentary formations across southern Ontario in general, and in particular those of Ordovician age, provide a strong basis for the hypothesis that the favourable geoscientific properties of the sedimentary rocks beneath the area, including under the Bruce nuclear site, are transferable to the sedimentary formations underlying the South Bruce Site.

3.1 Geology of the South Bruce Site

The South Bruce Site is located on the eastern flank of the **Michigan Basin**. This basin consists of laterally extensive sedimentary rock formations deposited between approximately 540 and 300 million years ago on the ancient continental margin of eastern North America. As shown in Figure 3.1, the Michigan Basin is centered in Michigan and extends across southern Ontario, where it eventually thins out above the underlying Precambrian (older than 540 million years) basement granitic rock belonging to the Canadian Shield.

The Michigan Basin is about 4.8 km deep at its center (Figure 3.1) and is about 0.9 km deep at the South Bruce Site. It was formed as a series of sedimentary layers. A cross-sectional geological model for southern Ontario, including the South Bruce Site, is illustrated in Figure 3.2 showing the major layers. These layers are labelled first according to when the sediments were deposited on the underlying Precambrian basement rock. Cambrian: about 485-540 million years ago, Ordovician: about 444-485 million years ago, Silurian: about 419-444 million years ago, Devonian: about 360-419 million years ago. The bedrock is overlain with Quaternary sediments, which are basically sand, clays and soil deposited within the past 2.6 million years. Figure 3.3 provides a more detailed breakdown of the typical formations in southern Ontario, including for the South Bruce Site (middle column in Figure 3.3 below), based on the recently updated three-dimensional stratigraphic model (Carter et al., 2021).

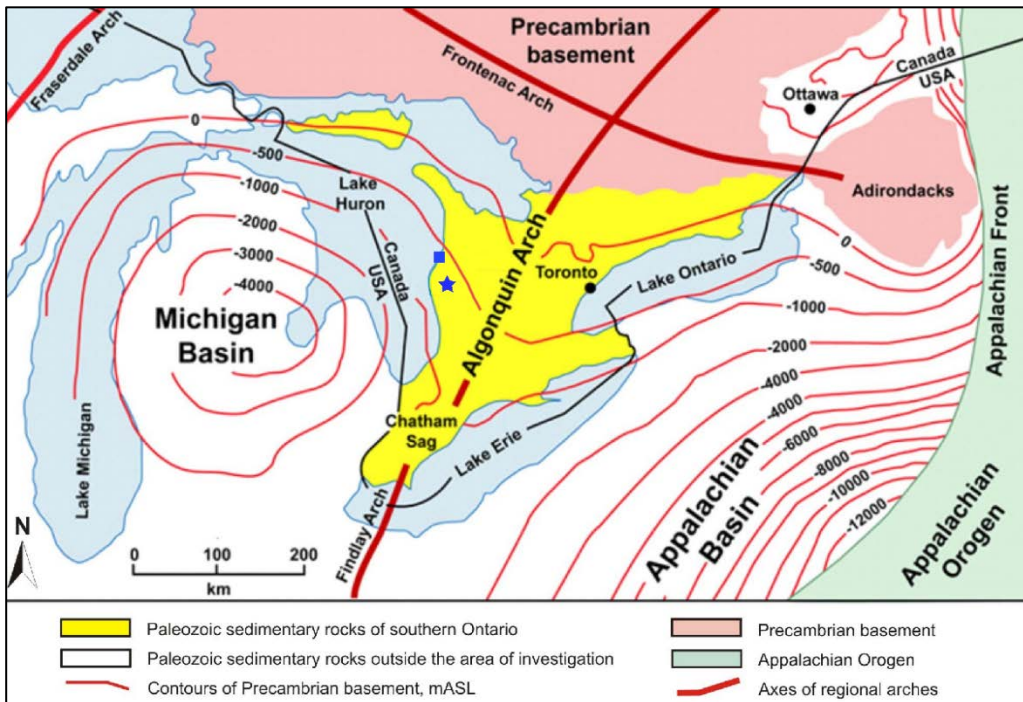


Figure 3.1: Geological features of southern Ontario (modified from Johnson et al., 1992). Blue star indicates location of South Bruce Site and blue square indicates location of the Bruce nuclear site.

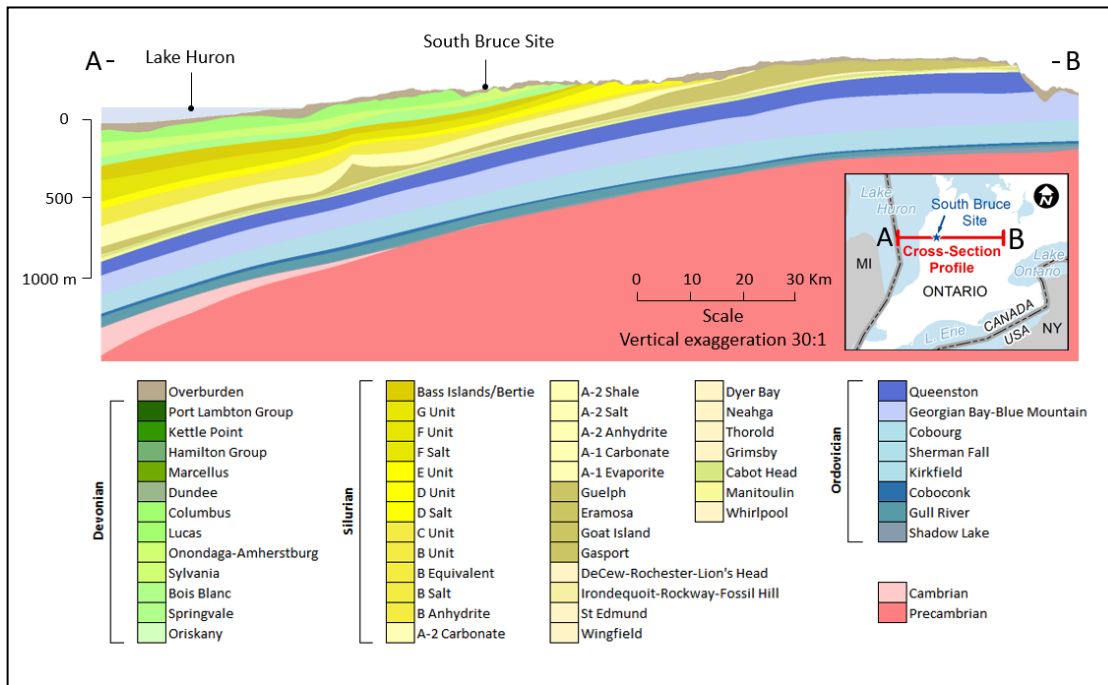


Figure 3.2: Vertical cross-section of the Michigan Basin in southern Ontario showing the main rock formation layers (based on Carter et al., 2021). A 30x vertical exaggeration has been applied to the section in order to illustrate the layering. True formation dips are uniformly < 1° to the southwest.

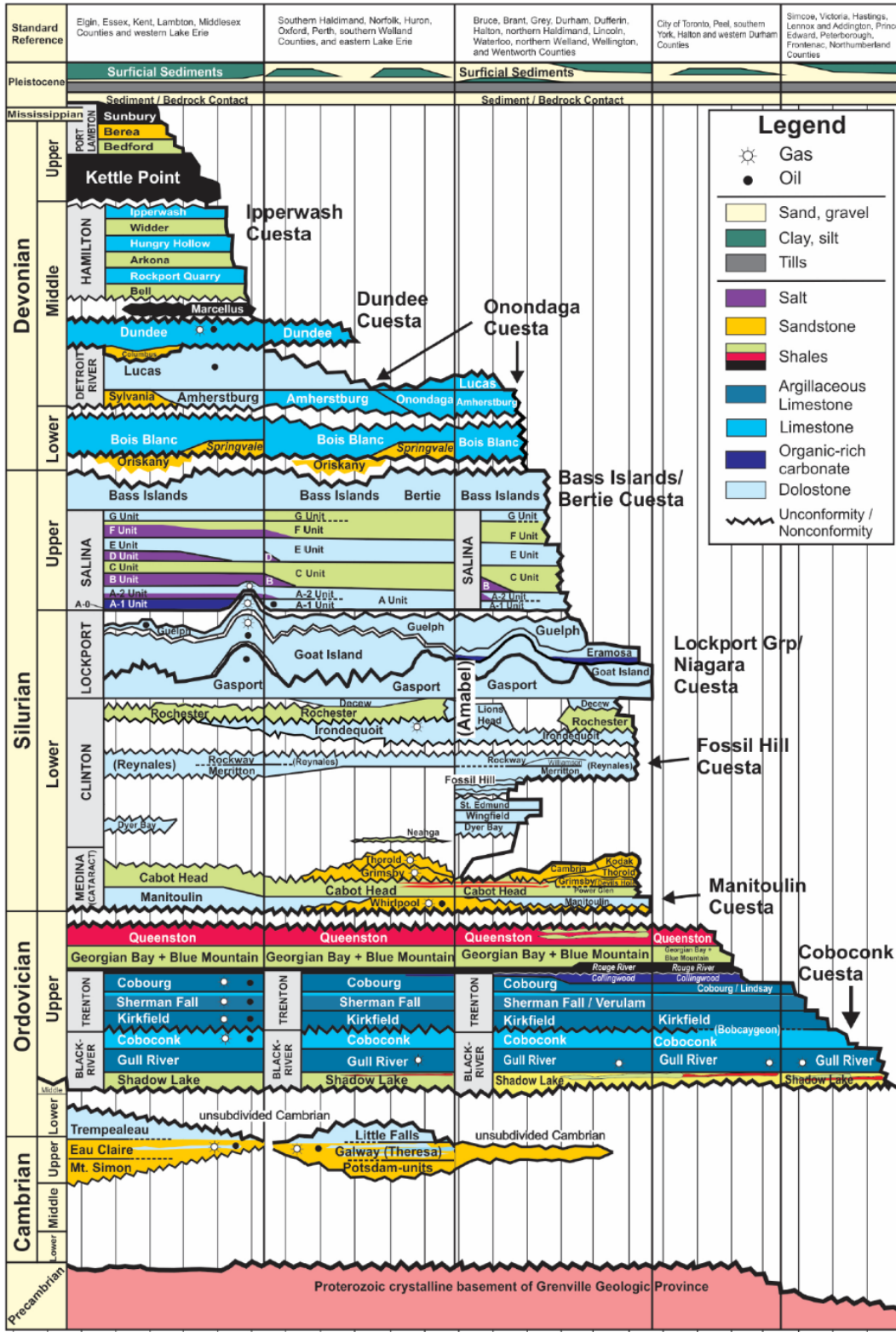


Figure 3.3: Sedimentary rock stratigraphy in southern Ontario, including at the South Bruce Site (middle column) (from Carter et al., 2021).

3.2 Depth of Host Rock

The depth of the South Bruce Site host rock (the Cobourg Formation and overlying shale units) must be sufficient to ensure the safe containment and isolation of the used nuclear fuel from surface disturbances and changes caused by human activities and natural events (e.g. farming, surface construction, climate change, storms). A depth of about 0.5 km, within a nominal range of 0.5 to 0.8 km, is considered sufficient, depending on the geological conditions encountered above and below this depth (NWMO, 2021b).

The NWMO has developed an understanding of the site-specific depth and thickness of the Cobourg Formation based on:

- Phase I Preliminary Assessment studies (Geofirma, 2014), which integrated data from numerous boreholes for oil and gas exploration in the area;
- Preliminary results obtained from drilling of two deep, vertical boreholes extending approximately 0.9 km beneath the South Bruce Site;
- An updated 3D geological model for southern Ontario (Carter et al., 2021).

Geofirma (2014) assessed, based on available oil and gas borehole data within the Municipality of South Bruce, the presence of the Cobourg Formation top at depths ranging from about 433 metres below ground surface in the northeast corner of the Municipality to 717 metres below ground surface towards its southwestern portion. The Phase I Preliminary Assessment also confirmed that the Cobourg Formation is overlain by a more than 200 m thick shale package within the Municipality of South Bruce (i.e., Upper Ordovician shale units). Based on the updated regional geological framework presented in Carter et al. (2021) at the South Bruce Site the top of the Cobourg Formation was predicted to occur at about 660 metres depth. The NWMO initiated the drilling and testing of two deep boreholes at the site in 2021. Preliminary results from the drilling of the first borehole at the South Bruce Site confirmed the presence of the Cobourg Formation top at about 645 metres depth, overlain by more than 200 m of Ordovician shales. The depth of the formation top and the thickness of the Ordovician shales will be further confirmed in the second borehole.

In summary, based on information to date, the host rock (i.e., the Cobourg Formation), overlying Ordovician-aged shale units, and underlying argillaceous limestone formations, are found at sufficient depth beneath the South Bruce Site to ensure the isolation of a deep geological repository from the surface environment.

3.3 Volume of Competent Rock

In addition to having sufficient depth to ensure safe containment and isolation, the host rock at repository depth should have sufficient volume of competent rock at a sufficient distance from major faults and unfavourable heterogeneities, such as regions of high groundwater flow.

The potential deep geological repository site in South Bruce was defined by signed agreements with landowners in South Bruce. The agreements include a combination of option and purchase arrangements that allow the NWMO to conduct studies while allowing landowners to continue using the land. Figure 3.4 shows the over 1,500 acres of land secured by the NWMO that define the potential repository site. This area is sufficient for the repository; however

discussions with interested landowners are ongoing as the NWMO works to further build out the potential repository site and understand and address their comments and concerns.

At the South Bruce Site, based on preliminary results from the first two boreholes, the Cobourg Formation is about 45 m thick. Given the known regional consistency of the thickness of the Cobourg Formation, it is expected that this value is valid for the entire extent of the potential site, and is sufficiently thick to excavate the required tunnels and emplacement rooms for the repository. The Cobourg Formation is a laterally extensive geological formation, extending under much of the Michigan Basin, including beneath the entire South Bruce Site. No active geological features (e.g., faults) or unfavourable heterogeneities have been identified in the Cobourg Formation at the South Bruce Site to date.

In summary, given the thickness and extent of the Cobourg Formation and the extent of land secured by the NWMO, there is sufficient volume of competent rock in the South Bruce Site to host a deep geological repository.

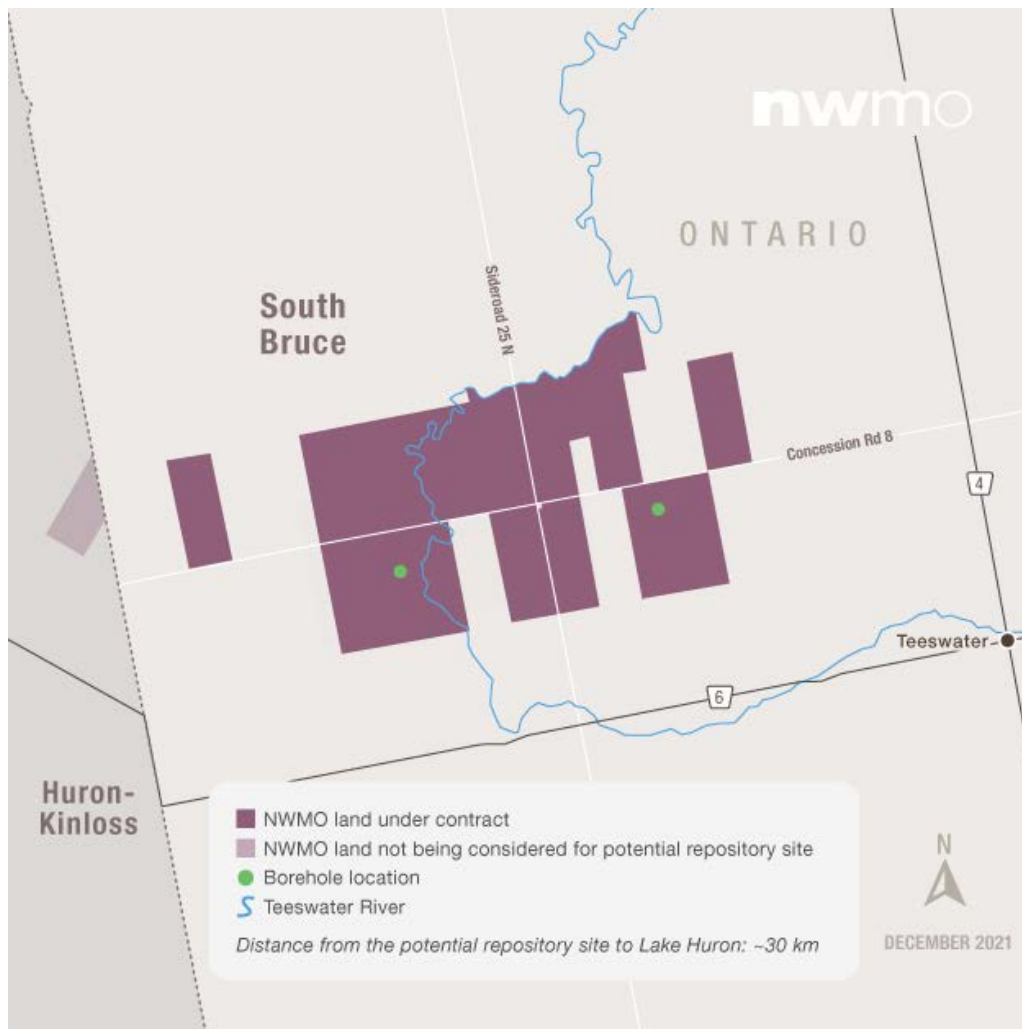


Figure 3.4: Location of the South Bruce potential repository site

3.4 Composition of Rock, Groundwater and Porewater

The mineralogy of the rock, and the geochemical composition of the groundwater and porewater at repository depth should be such that they:

- do not compromise the integrity of the multi-barrier system; and
- promote the retardation of radionuclide movement.

From a groundwater/porewater perspective, ensuring that reducing chemical conditions exist at repository depth is important. This is because oxidizing chemical conditions, which indicate the presence of waters containing dissolved oxygen, and therefore recent contact with the near-surface environment, would suggest that the geological system is not able to retard radionuclide movement. Oxidizing chemical conditions would also have a negative impact (e.g., copper corrosion) on the integrity of the engineered barrier system. Total sulphide concentration in the groundwater should also be low in order to maintain the durability of the engineered barrier system. Highly saline groundwater/porewater at repository depth, although a favourable attribute from the point of view of indicating isolation of the deep groundwater system from fresh water in the shallow subsurface, can have complex effects with respect to the engineered barrier system.

Regarding the mineralogy of the host rock, in order to contribute to maintaining the durability of the engineered barrier system, it should have a low concentration of sulphur-bearing minerals. The mineralogy of the host rock should also have favourable thermal properties in order to ensure good dissipation of residual heat from the used fuel containers. In addition, the rock should have low porosity in order to support the retardation of radionuclide movement. These points are discussed below, except for the thermal properties of the rock which are discussed later in Section 3.6. Overall, the results to date indicate the favourable nature of the mineralogy of the rock, and the geochemical composition of the groundwater and porewater at repository depth, for the South Bruce Site.

Where possible, groundwater samples were collected from different formations in the boreholes and sent to laboratories for geochemical analysis. Information on the geochemical composition of water at depth will also be obtained from the minute amount of porewater extracted from core samples collected at different depths, including from the Cobourg Formation, and overlying and underlying Ordovician formations.

Information on the porewater chemistry from data collected at the Bruce nuclear site can be considered as an analogue for the South Bruce Site, given the proximity and lateral continuity of the sedimentary formations. Analyses of porewater samples from the Ordovician-aged sedimentary formations at the Bruce nuclear site indicated that the fluids (including high salinity brines and gases) had resided within the rock for hundreds of millions of years, consistent with a deep groundwater system has been isolated from the shallow groundwater system for a very long time. At repository depth, conditions were reducing (i.e., dissolved oxygen is not present in any of the Ordovician formations, including the Cobourg Formation). Based on this, oxidizing conditions are not expected at repository depth at the South Bruce Site.

At the Bruce nuclear site, the analysis of a Cambrian groundwater sample was used to understand the sulphide concentration expected at repository depth. The sulphide concentration in that Cambrian groundwater sample was less than 0.5 mg/L (Intera 2011). Similar low sulphide concentrations, which would therefore not likely impact the durability of the copper

within the engineered barrier system, are expected in the deep subsurface at the South Bruce Site.

Site-specific data on the mineralogy (i.e., mineral content) of the Cobourg Formation is being gathered from core samples collected in the boreholes, and results are not yet available. Preliminary core logging data from the boreholes confirmed that the Cobourg Formation is an argillaceous limestone, which is consistent with observations from investigations conducted at the Bruce nuclear site as part of OPG's proposed Deep Geological Repository for Low & Intermediate Level waste. Mineralogical analyses conducted at the Bruce nuclear site showed that the Cobourg Formation is mostly composed of calcite, with subordinate amounts of dolomite, quartz, and illite. Minor to trace amounts of the sulphide-bearing mineral pyrite were identified in the Ordovician-aged sedimentary formations (Intera 2011). Given the lateral consistency of the Ordovician formations in southern Ontario, a similar mineralogy is expected at the South Bruce Site. These low concentrations of sulphur-bearing minerals are not likely to impact the durability of the copper within the engineered barrier system.

At the Bruce nuclear site, the Ordovician shales and argillaceous limestones of the Cobourg Formation exhibit low porosity, which is to be expected in these types of sedimentary rock. The average total porosity of the Ordovician shales is 7.2 volume %. The average total porosity of the Cobourg Formation is 1.5 volume % (Intera, 2011). Overall, these low porosities will contribute to the retardation of radionuclide movement through the rock.

The majority of the rock and water chemistry properties expected to be encountered at repository depth at the South Bruce Site will also not likely adversely impact the repository multi-barrier system. The expected high salinity conditions will require additional analysis regarding its potential effects on the engineered systems. However, it should also be noted that the overall containment and isolation properties of the geosphere are very likely to mitigate this. Based on the transferability of available information from the Bruce nuclear site, it is very likely that the properties of the rock and water chemistry at the South Bruce Site will promote the retardation of radionuclide movement. The discussion of the favourable retardation properties of the rock is also continued in Section 3.5 below.

3.5 Hydrogeological Regime

To retard or slow down the movement of any radionuclide and ensure the isolation of the used fuel from the environment, the hydrogeological regime within the host rock should exhibit low rates of mass transport at repository depth, i.e., the properties of the host rock must be such that if a radionuclide were to be released, its transport through the groundwater would be so slow that radionuclides would have time to decay to insignificant levels before reaching the surface. The ability of water to move through rock is referred to as the rock's **hydraulic conductivity** (or the related property **permeability**). The larger the value of hydraulic conductivity, the more easily water can move through the rock.

During the drilling of the boreholes at the South Bruce Site, groundwater samples were collected when possible. For groundwater samples to be collected while drilling, appreciable groundwater must be able to flow into the borehole, which is an indirect indication of groundwater velocities of the host rock at subsurface. In the two deep boreholes drilled in the South Bruce Site, opportunistic groundwater samples could only be collected from six different formations. These samples were collected from formations that are known to be permeable and are hundreds of metres above the proposed repository host rock formation. The deepest

groundwater sample was collected at approximately 325 m below ground surface. This is more than 300 m above the Cobourg Formation. No appreciable groundwater was able to flow into the borehole from the Cobourg Formation, or the overlying Ordovician shales.

The primary source of information on the host rock's hydraulic conductivity is downhole hydraulic packer testing in the deep boreholes. Packer testing will be conducted in each borehole in intervals at different depths to develop an understanding of the rock's hydraulic conductivity. Additional information on groundwater flow was also obtained from other down hole testing (i.e., geophysical logging) and from long-term pressure monitoring at discrete intervals along some of the deep boreholes. At this stage, given that results from downhole testing are not available for the South Bruce Site yet, understanding of the hydrogeological regime at depth is mostly based on borehole geophysical logging and hydraulic packer testing, as well as Westbay multilevel monitoring system for 10 years, at the deep boreholes at the Bruce nuclear site (Intera, 2011; NWMO, 2011).

Information from the Bruce nuclear site has shown that in the Cobourg Formation, the horizontal hydraulic conductivities have an average value of 10^{-14} m/s. Model results suggest that vertical hydraulic conductivities were equivalent to or less than the horizontal hydraulic conductivities from field and laboratory testing at the Bruce Site (Normani et al. 2017). For comparison, the hydraulic conductivity of pure sand ranges from 10^{-6} to 10^{-2} m/s; the estimated hydraulic conductivities in the Cobourg Formation at the Bruce nuclear site were over 1 million times smaller.

Following the completion of drilling and downhole testing in the first borehole, a Westbay multilevel monitoring system will be installed. This long-term monitoring system is being installed to obtain data on the natural fluid pressures within the different rock formations below the South Bruce Site.

At the Bruce nuclear site, similar measurements indicated in particular that the 200 m of shale just above the Cobourg Formation had a very low formation pressure relative to an assumed hydrostatic level, in other words these shales were determined to be underpressured. Similarly, the argillaceous limestones of the Cobourg, Kirkfield, and Sherman Fall formations are also underpressured at the Bruce nuclear site. The presence of these underpressures provide natural evidence that the Cobourg and its bounding formations have extremely low permeability across the entire Bruce nuclear site and any transport (movement) in these layers will be diffusion-dominated. Preliminary results also indicate similar underpressured conditions within the Cobourg and its bounding formations at the South Bruce Site.

Another geological feature at the Bruce nuclear site was the Cambrian sandstone unit, which was about 200 m below the Cobourg Formation. This rock formation is known to be permeable and also to be under high pressure relative to the hydrostatic level based on results from the Bruce nuclear site. The updated geological model (Carter et al., 2021) predicted that the Cambrian unit pinches out (i.e., becomes very thin to non-existent) beneath the South Bruce Site. Consistent with this prediction, the Cambrian unit was not encountered in the two boreholes drilled at the site. Future field investigations will continue to explore for the presence and hydraulic character of the Cambrian unit beneath the site.

At the Bruce nuclear site, groundwater and porewater was observed to be saline (> 100 g/L total dissolved solids) below 200 m depth, with the exception of one aquifer unit at ~ 325 m depth that had lower salinity. This showed evidence of recharge within that last 10,000 years in that one aquifer. There was no evidence of infiltration of glacial or recent meteoric water into the

underlying Ordovician formations. High salinity can be an indicator of lower rates of mass transport, as a result of the associated increase in fluid density. The presence of high salinity conditions, as shown in Park et al. (2009), can indicate a hydrogeologically stable environment at depth (i.e., low rates of mass transport between the shallow and deep groundwater systems). Site specific salinity information is currently being collected for the South Bruce site.

The very low hydraulic conductivities estimated in preliminary results from hydraulic testing in the first borehole, as well as hydrogeological and hydrogeochemical information from the Bruce nuclear site, provides confidence that the hydrogeological regime at repository depth in South Bruce Site has low rates of mass transport. This is still to be confirmed at the second borehole.

3.6 Geomechanical and Thermal Properties

The Cobourg Formation, which is the identified host rock, must be strong enough to withstand natural stresses as well as stress changes induced by the presence of the repository. This requires measuring the rock mechanical properties and considering both natural stresses in the rock as well as those induced by the repository constructions, and thermal stresses caused by the residual heat from the used fuel containers. These are discussed below.

Site-specific geomechanical and thermal data will be obtained from the current borehole drilling and testing program at the South Bruce Site. While these results are still pending, there is a large volume of geomechanical property data available from detailed drilling and testing investigations at the nearby Bruce nuclear site (NWMO, 2011, Golder Associates Ltd., 2013), and from regional compilations of geomechanical data (NWMO and AECOM Canada Ltd., 2011; Golder Associates Ltd., 2003) and from similar rocks reported in the literature (Clauser and Huenges, 1995; Sass et al., 1984; Cermak and Rybach, 1982).

It is reasonable to assume transferability of the geomechanical and thermal properties from these sources to the South Bruce Site based on the lateral traceability and predictability of the **Paleozoic sequence** (the sedimentary rock formations) in southern Ontario. The geomechanical and thermal properties of the Paleozoic sequence at the South Bruce Site are expected to be similar to those measured at the Bruce nuclear site and elsewhere in southern Ontario. The regional information presented in the subsections below provides confidence that the Cobourg Formation has the favourable geomechanical properties to withstand natural stresses as well as those induced by the presence of the repository.

Rock Mechanical Properties

To date, data on the strength of the Cobourg Formation is mainly based on laboratory testing of intact core samples from the Bruce nuclear site, and limited laboratory testing of rock samples from rock quarries where the Cobourg Formation is exposed at surface.

Based on the available regional data, the Cobourg Formation is sufficiently mechanically strong. Average mechanical properties of the Cobourg Formation at the Bruce nuclear site indicated a uniaxial compressive strength of 113 MPa (NWMO, 2011). Average mechanical properties of the Cobourg Formation from surface samples collected at other locations in southern Ontario indicated a uniaxial compressive strength of 72 MPa (NWMO and AECOM Canada Ltd., 2011). Site specific measurements will be made on core retrieved from the deep boreholes currently being drilled and tested at the South Bruce Site.

Rock Mass Properties

In addition to determining the mechanical properties at the core sample scale it is also important to assess the structural integrity of the rock mass, which refers to a larger scale representation of the bedrock, considering the presence of fractures, weathering, and alteration. A significant presence of these features could have a negative effect on the integrity of the rock mass. Site-specific rock mass properties will be obtained mostly from core logging and downhole testing (i.e., geophysical logging) activities, which are currently underway at the South Bruce site.

Data on rock mass properties of similar sedimentary rocks are available from studies completed at the Bruce nuclear site (NWMO, 2011; NWMO and AECOM Canada Ltd., 2011). Golder Associates Ltd. (2003) estimated rock mass classification ratings in common usage for geomechanics purposes for selected rock formations based on shallow bedrock excavation experience in southern Ontario.

Rock-quality designation (RQD) is a quantitative index of rock quality based on the total cumulative length of core recovered in lengths greater than 10 cm (4 inches), as measured from midpoint to midpoint of natural broken discontinuities (i.e., fractures). 'Good' quality rock has an RQD of more than 75%, and 'excellent' quality rock has an RQD of more than 90%, whereas poor quality rock has an RQD of less than 50%.

At the Bruce nuclear site, the Upper Ordovician shale and limestone units, including the Cobourg Formation, are very sparsely fractured and of excellent quality (NWMO, 2011). The rock mass designation, based on RQD (Deere et al. 1967), for all of the Upper Ordovician shale formations is generally excellent (RQD of 90 to 100%) with occasional local zones of lower quality. Recorded RQD values tend to represent lower bounding values due to the intersection of vertical boreholes with sub-horizontal bedding layers.

The measured fracture frequency in the sedimentary rocks beneath the Bruce nuclear site was similar in all formations and ranges from 0 to 1.7 fractures per metre, with an average value of generally less than 0.3 fractures per metre. The fractures appear to be very tight and well sealed. Similarly, the Trenton Group limestone formations (i.e. Cobourg and Sherman Fall formations) have a rock mass designation of excellent with RQD generally ranging between 90 and 100%. The fracture frequency in all three Trenton Group formations is comparable.

Preliminary results from the first borehole drilled at the South Bruce Site show similar trends with regards to RQD values throughout the sedimentary sequence. RQD values in the Upper Ordovician shale formations and the Trenton Group limestones generally fall between 90-100%. A photographic example of recovered core from the Cobourg Formation at the South Bruce Site is shown in Figure 3.5. Information on rock mass properties from investigations at the Bruce nuclear site provide a good preliminary indication of what can be expected for the South Bruce Site, and indicate that the rock mass properties of the host rock formation at the South Bruce Site are typical of strong sedimentary rocks.



Figure 3.5: Photo of Cobourg Formation core sample from the NWMO's first borehole at the South Bruce Site.

Bedrock Stresses

Bedrock stresses are measured underground, for example in a borehole, and represent the natural forces acting on the bedrock. Understanding the magnitude and direction of stresses in the bedrock is an important input for the design of the repository, specifically when aligning the orientation of the rooms and panels of the repository to optimize stability. At this stage of the site selection process, no direct stress measurements are planned for the South Bruce Site.

There are no direct measurements of stresses for the sedimentary (Paleozoic) rocks at the South Bruce Site; during detailed site characterization site specific stress measurements are planned to be measured to refine the repository layout. However, information on the state of stress expected to exist in the sedimentary rocks beneath the South Bruce Site is indirectly available from regional summaries of measurements made in the surrounding Appalachian and Michigan Basins (NWMO and AECOM Canada Ltd., 2011), from behaviour of borehole core and the borehole walls at the Bruce nuclear site, and from numerical modeling to develop a preliminary stress model for the Bruce nuclear site (NWMO, 2011).

The available regional information on the distribution of principal stresses with depth in the Appalachian and Michigan Basins indicate the presence of relatively high horizontal compressive stresses, characteristic of a thrust fault regime, where both horizontal stresses are greater than vertical stresses. These regional data also indicate that the maximum horizontal in-situ stress is consistently oriented in a northeasterly to east-northeasterly direction (NWMO and AECOM Canada Ltd., 2011). Analysis of borehole ellipticity data from the Bruce nuclear site suggests a similar direction of maximum horizontal stress for Paleozoic rocks (NWMO, 2011).

Thermal Properties

The host rock should be capable of conducting away the residual heat generated from the used fuel containers, and withstanding thermal stresses induced by this heat, without significant structural deformations or fracturing that could compromise the safe containment and isolation functions of the repository.

Thermal testing results of core samples are being obtained from the current borehole drilling and testing program at the South Bruce Site. However, results are still pending.

The literature on thermal conductivities of sedimentary rocks similar to those present beneath South Bruce suggest values of about 2.07 W/(m.K) for shale, 2.29 W/(m.K) for limestone, 2.47-4.5 W/(m.K) for sandstone, 3.62-5.50 W/(m.K) for dolostone, 4.05-5.14 W/(m.K) for anhydrite (Clauser and Huenges, 1995; Sass et al., 1984). A host rock with similar values would be capable of removing the decay heat from the fuel and withstanding thermal stresses induced by the repository (NWMO, 2018).

The geothermal gradient of the South Bruce Site is expected to be similar to that of the Bruce nuclear site. Data from the Bruce nuclear site shows a natural geothermal gradient for the sedimentary sequence of about 14°C/km (NWMO, 2018). This gradient is suitable for repository design.

Host Rock Geomechanical and Thermal Summary

The Paleozoic (sedimentary rock) sequence in southern Ontario is predictable and the formations at the South Bruce Site are not expected to be unusual in their mechanical and thermal behaviour. Based on regional data, including data from the Bruce nuclear site, the South Bruce host rock should be capable of removing the residual heat from the used fuel containers, and withstanding the natural and thermal stresses induced by the repository. On-going site-specific investigations are expected to confirm this.

4. LONG-TERM GEOLOGICAL STABILITY OF THE SITE

The site must provide long-term geological stability for the repository. In particular, the repository should not be unacceptably affected by future geological processes and climate changes, including earthquakes and glacial cycles.

The ability of a site to provide this stability is assessed through the following site evaluation factors:

1. Seismicity: Seismic activity (i.e., earthquakes) at the site should not adversely impact the integrity and safety of the repository during operation and in the very long term.
2. Land uplift, subsidence, and erosion: The expected rates of land uplift, subsidence and erosion at the site should not adversely impact the repository.
3. Future glacial cycles: The evolution of the conditions at repository depth during future climate change such as glacial cycles should not have a detrimental impact on the repository.
4. Distance from geological features: 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.

Each of these are discussed in the subsections below.

4.1 Seismicity

The South Bruce Site is located in a stable, seismically quiet setting overlying the Precambrian rocks of the Canadian Shield at the heart of the North American continent, away from tectonic plate boundaries.

The Canadian government has maintained a network of monitoring stations that record the location and magnitude of seismic events across the country. In southwestern Ontario, these have been supplemented with additional stations by OPG to improve the data coverage and accuracy. Figure 4.1 shows seismic activity for southwestern Ontario as recorded by the Canadian Hazard Information Service between 1985 and 2021. Earthquakes are measured using the Nuttli Scale (m_N), developed for Eastern North America, which represents a modern refinement of the older Richter scale. To date there have not been any earthquakes above magnitude 3 m_N , a magnitude typically felt by most humans, recorded within 50 km from the South Bruce Site. Further discussion regarding the regional faults identified on Figure 4.1 is included in Section 4.4 below.

A Probabilistic Seismic Hazard Assessment was conducted for the Bruce nuclear site in 2010 (AMEC Geomatrix, 2011). Seismic analyses of a hypothetical underground emplacement room in the Cobourg Formation at the Bruce nuclear site using ground motions of 10^{-5} and 10^{-6} annual probability events show that seismic shaking would not induce damage to the host rock, other than potentially dislodging any already fractured rock mass around the excavated openings.

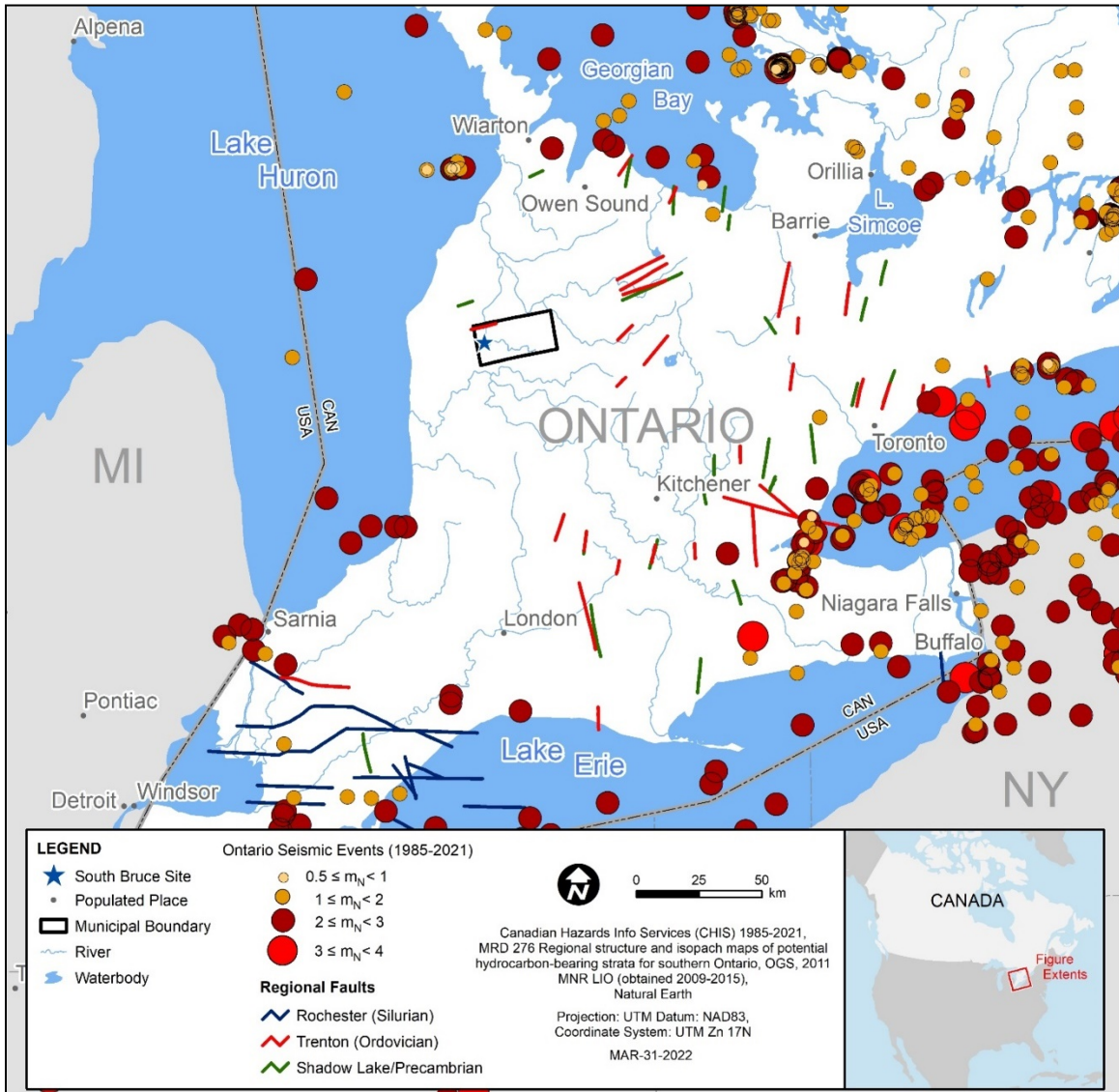


Figure 4.1: Earthquakes recorded in southern Ontario, 1985-2021. Figure also shows location of regional faults in southern Ontario.

A network of microseismic monitoring stations was installed around the South Bruce Site in 2021. These five stations will provide increased ability to identify and locate smaller earthquakes within a 50 km radius of the site. This microseismic network will continuously record seismic events in the long term. Monitoring of earthquakes, even small magnitude events (magnitude $3 m_N$ and lower), will provide information on the overall seismicity and geological structure of the region.

4.2 Land uplift, subsidence and erosion

To ensure the containment and isolation functions of the repository continue in the future, it is important to understand potential changes in land uplift, subsidence and erosion. Land uplift, subsidence and erosion in the Michigan Basin where the South Bruce Site is located are expected to be mostly related to future glacial cycles (Robin et al. 2020). The bedrock in the

South Bruce area is presently uplifting at 1-3 mm per year, as the continental rock slowly recovers from the last ice age (Sella et al. 2007). The rate at which these processes occur in the future will need to be sufficiently slow to ensure that the repository remains isolated from the surface environment over the long term.

Studies by Bell and Laine (1985) estimate an average glacial erosion rate for Canada of 40–70 metres per million years, based on studies of past glacial cycles. Hallet (2011) provides an assessment of glacial erosion rates for southern Ontario, including the South Bruce area. The study by Hallet (2011) concluded that although uncertainties remain in ice sheet reconstructions and estimates of erosion by ice and melt water, all lines of study indicate that, in southern Ontario, glacial erosion would not exceed a few tens of metres in 100,000 years with a conservative estimate of 100 m per 1 million years for the Bruce nuclear site.

There is currently no indication that the South Bruce Site location will experience extreme rates of erosion, uplift, or subsidence that would significantly impact repository safety or perturb the geosphere, over the next million years.

4.3 Future glacial cycles

The climate is expected to change in the future. In the near term, the climate will be influenced by global warming. This is expected to cause changes in weather in southwestern Ontario; the nature of the changes is estimated in Golder (2020). These changes will be important to people and to the surface environment, but are not likely to significantly affect conditions at the repository depth, several hundred metres below surface.

In the future, 50,000 years or more, ice age conditions are expected to return. These conditions have occurred approximately every 100,000 years for the past million years, largely due to the nature of the earth's orbit around the sun. The last ice age started about 100,000 years ago and ended about 10,000 years ago, when the ice retreated out of Ontario towards northern Canada. During an ice age, there can be up to a 2.5 km thick ice sheet over Ontario (Peltier 2011; Stuhne and Peltier 2015, 2016).

In the long-term, one of the key aspects to consider for the stability of the repository is the effect that future glaciations could have on the subsurface. It is specifically important to demonstrate that oxygenated water from future ice sheets will not penetrate to repository depth; the presence of oxygenated water would compromise the integrity of the repository, in part through enhancing corrosion of the used fuel containers, and potentially, erosion of the bentonite buffer. Based on previous analyses, the evolution of the 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 (NWMO, 2018).

Currently, the best indication of the impact of future glaciation on the South Bruce Site is evidence of how the laterally equivalent formations beneath the Bruce nuclear site performed during past glaciations. There was no geochemical evidence found for the infiltration of glacial or recent meteoric recharge water into the host or bounding shale formations beneath the Bruce nuclear site. In addition, numerical simulations indicate: 1) that glacial perturbations do not alter the governing solute transport mechanisms within the deep groundwater system; and 2) that single and multiple glaciation scenarios, when modelled using regional and site-specific parameters, do not result in the infiltration of glacial meltwater into the deep groundwater system (NWMO, 2011). Therefore, based on the understanding that glaciations have had

minimal impact on the rocks at repository depth at the Bruce nuclear site, it is reasonable to also suggest that glaciations will also have minimal impact at the South Bruce Site. This will be confirmed as part of ongoing site characterization activities.

Future ice sheets should also not have a negative impact on the geomechanical stability of the repository. During past glaciations, ice sheets over where the South Bruce Site is located were up to about 2.5 km thick; the weight of the thick ice sheets, and the changing stress conditions and bedrock surface topography during advance and retreat of the ice, need to be taken into consideration in the design of both the repository and the multi-barrier system. For instance, the used fuel containers (Section 7) are designed to withstand the long-term repository loads including future ice sheets over the repository. A key component of the repository design is sealing for decommissioning and the post-closure phase; specifically, all emplacement rooms with containers are filled with bentonite clay to aid in stability under these loads. Similarly, all other underground openings and shafts (e.g., access tunnels, services area, etc.) will be fully backfilled and/or sealed.

Based on information obtained to date, there is no evidence that the evolution of the conditions at repository depth during future climate change scenarios such as glacial cycles will have a detrimental impact on the long-term safety of the repository.

4.4 Distance from geological features

The repository should be located at a sufficient distance from geological features such as zones of large-scale deformation or regional faults that could be potentially reactivated in the future.

Regional faults in southern Ontario are shown on Figure 4.1. As indicated in the legend to this figure, the faults are grouped based on observation of the youngest stratigraphic unit that is offset. The largest faults in southern Ontario are located near the northern edge of Lake Erie, many 10's of kilometres south of the South Bruce Site. The nearest known fault to the site is a fault located approximately five kilometres north of the South Bruce Site. This fault is interpreted to offset rocks as young as the Ordovician limestones. The fault is not sufficiently close to influence the integrity of the repository. Overall, based on all available information, the South Bruce Site is located at a sufficient distance from known geological features such as large-scale deformation zones or major regional faults.

The Cambrian unit is a permeable formation on top of the Precambrian (Canadian Shield) basement in some parts of the Michigan Basin. The Cambrian unit is important because it is known to be permeable, and because it can be under high pressure in places due to its deep confinement. The Cambrian unit was not intersected in the two boreholes drilled at the South Bruce Site. Importantly, there are also low permeability argillaceous limestone layers bounding the Cobourg Formation from below, regardless of whether the Cambrian is present or not. The presence or absence of deep geological features in the subsurface beneath the South Bruce Site, including faults, is continuing to be investigated by analysis of results from a recently completed 3D seismic survey, on-going borehole core logging and hydraulic testing, and on-going microseismic monitoring.

5. FUTURE HUMAN INTRUSION

The site should be selected such that the repository is not likely to be disrupted by future human activities that could compromise the containment and isolation of the fuel. For example, future societies should not have reason to inadvertently drill into the repository.

To minimize the likelihood of inadvertent future human intrusion, the repository:

1. 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.
2. Should not be located within geological formations containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

Each of these are discussed in the subsections below.

5.1 Economically exploitable natural resources

Natural resources assessed for the area broadly include: petroleum resources (conventional and unconventional oil and gas), metallic mineral resources, non-metallic mineral resources (sand and gravel, bedrock resources and salt) and deep potable groundwater resources associated with the Guelph Formation.

There are no known areas of active exploration interest for metallic mineral resources within the area, as evidenced by the lack of active mining claims (MNDM, 2021a) and the lack of metallic mineral occurrences (Figure 5.1; MNDM, 2021b). The Abandoned Mines Information System (MNDM, 2018) and Mineral Deposits Inventory (MNDM, 2021b) show that there are no current or past producing metallic mineral mines within the Municipality of South Bruce.

The South Bruce Site is located within an area that has been identified as a Sand and Gravel Resource Area with a large proportion judged to be of primary significance, and with an average deposit thickness of 5 m (Rowell 2012). There are also a number of discretionary limestone occurrences related to bedrock quarrying for aggregate and building stone use in the central portion of the Municipality; the potential for limestone as a resource for extraction, however, is limited to very shallow depths (typically less than 20 m) and is not considered as a constraint for repository construction.

A potential resource in the area is hydrocarbons. Commercial accumulations of hydrocarbons have been discovered in more than a dozen stratigraphic units throughout the Paleozoic sedimentary sequence of southern Ontario. Figure 5.1 shows the distribution of active and former producing petroleum pools in southern Ontario based on the Oil, Gas and Salt Resources Library (OGSRL, 2019). Most of the current exploration for oil and gas is concentrated within the geographic triangle between London, Sarnia and Chatham-Kent (AECOM Canada Ltd. and Itasca Consulting Canada Inc., 2011) (Figure 5.1). The South Bruce Site is north of this area.

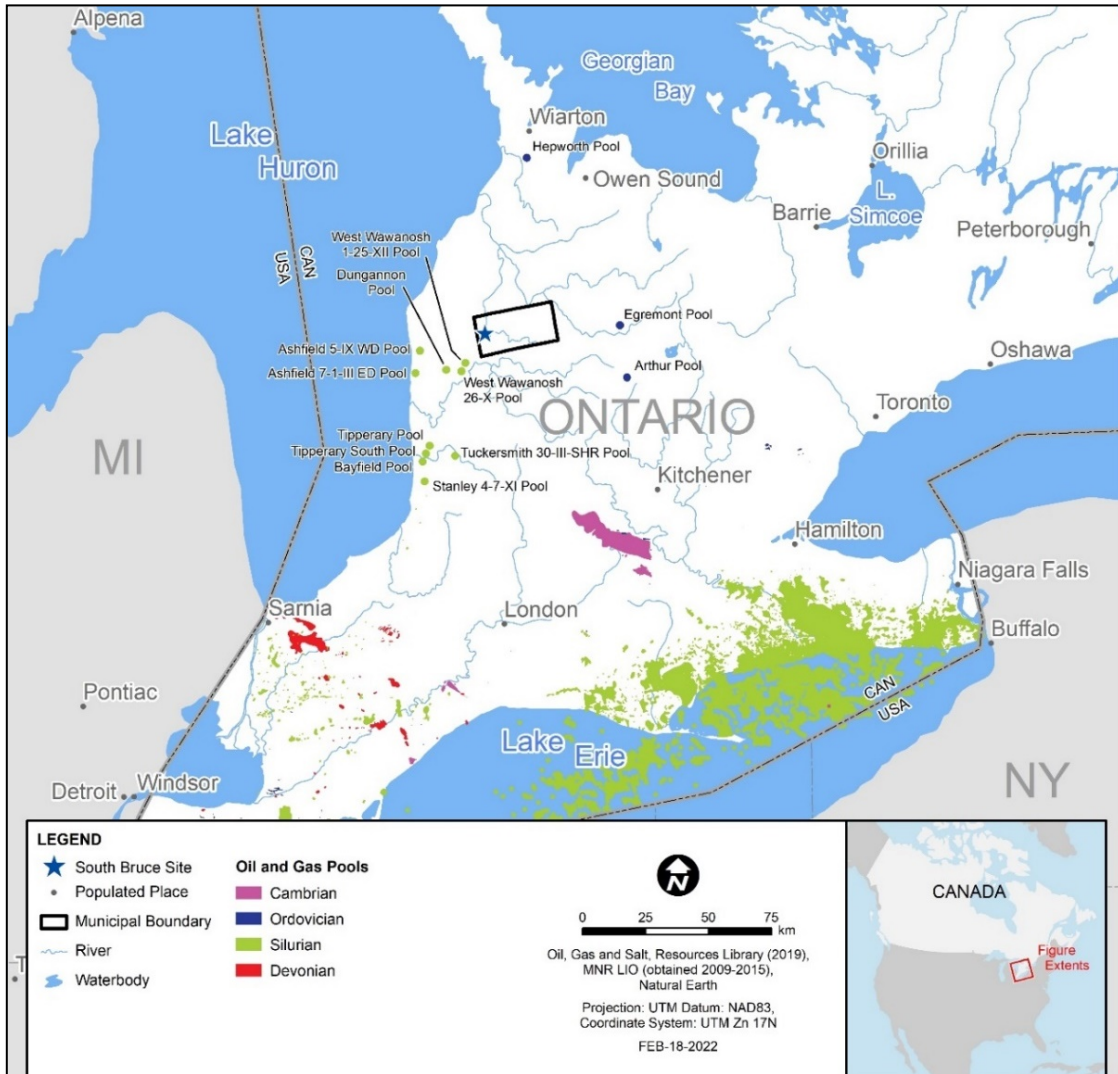


Figure 5.1: Oil and gas producing pools in southern Ontario (OGSRL, 2019)

There are no known oil and gas pools within the Municipality of South Bruce. Prior to the NWMO's work in this area, three previous exploration boreholes were drilled by exploration companies within the Municipality, which resulted in dry holes with no petroleum potential (Geofirma, 2014).

An assessment of potential hydrocarbon resources in the general area (the Huron Domain) was recently completed (Chen et al, 2019). The study focussed on two rock formations within this domain that are anticipated to be the most likely to contain oil or gas – the Collingwood and Rouge River shale rock units. They concluded that there was likely shale oil and gas within the domain, but the amounts were such that “the recovery factor for oil and gas in place resource was exceptionally low.”

Overall, no known economically exploitable mineral resources, hydrocarbon resources, or salt resources, have been previously identified at the potential repository site, and preliminary data

from the two boreholes the NWMO has drilled at the site have not indicated economically significant concentrations of any of these at the site.

Taken together, these findings indicate that while some resource potential may exist around the South Bruce Site, no known economically exploitable mineral resources have been identified at or around the proposed repository volume at the Site.

5.2 Groundwater Resources

Information concerning groundwater use in the Municipality of South Bruce can be obtained principally from the Ontario Ministry of the Environment (MOE) Water Well Information System (WWIS) database (Ontario Ministry of the Environment, 2013a), as well as from regional groundwater studies and source water protection studies based on interpretation of these data. The Municipality of South Bruce has public and municipal water supplies from wells sourcing shallow bedrock aquifers and occasionally overlying overburden aquifers. All known water wells in the Municipality of South Bruce obtain water from overburden or shallow bedrock sources at depths ranging from about 3 to 163 metres below ground surface (mBGS; Geofirma, 2014). Shallow bedrock is the most important source of drinking water in South Bruce, and is the primary source of most of the municipal water supplies located inland from Lake Huron.

The potential for groundwater resources within the host and bounding formations at the South Bruce Site is extremely low. The top of the shallowest bounding formation, the Queenston Formation, is encountered at greater than 400 m below surface at the South Bruce Site. Experience from other areas in southern Ontario, and from the studies completed at the Bruce nuclear site, has shown that there is no active deep groundwater system in the area due to the very low hydraulic conductivities of the Upper Ordovician units. Trenton Group limestones (i.e. Cobourg, Sherman Fall, and Kirkfield formations) at the Bruce nuclear site have average horizontal hydraulic conductivity values ranging from 4×10^{-15} to 1×10^{-14} m/s. Available hydrogeological data from the Bruce nuclear site indicate that the deep groundwater system within the Upper Ordovician units is diffusion-dominated and isolated from the shallow groundwater system. In addition, the Bruce nuclear site exhibits a transition from fresh to non-potable and highly saline groundwater below approximately 200 mBGS.

During the drilling of the boreholes at the site, groundwater samples were collected when possible. For groundwater samples to be collected while drilling, appreciable groundwater must be able to flow into the borehole, which is an indirect indication of groundwater velocities of the host rock at subsurface. In the two deep boreholes in the South Bruce Site, opportunistic groundwater samples could only be collected from six geological formations. These samples were collected from formations that are known to be permeable and are hundreds of metres above the proposed repository host rock formation. The deepest groundwater sample was collected at approximately 325 m below ground surface. This is more than 300 m above the Cobourg Formation. No appreciable groundwater was able to flow into the borehole from the Cobourg Formation, or the overlying Ordovician shales.

In summary, based on the available information, the South Bruce Site does not contain groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

6. AMENABLE TO GEOLOGICAL SITE CHARACTERIZATION

The South Bruce Site must be understood sufficiently so that the repository can be appropriately designed and for there to be sufficient confidence that the site will perform as expected. However, as the host rock is not visible on surface, site characterization will only directly measure a small portion of the site.

Therefore, to ensure confidence that the site is sufficiently understood it is important that the host rock structure and characteristics are relatively predictable from the studies.

Based on all information available to date, the geometry and structure of the Ordovician host rock and bounding formations found at the South Bruce Site and throughout southern Ontario are sufficiently predictable and amenable to site characterization and data interpretation (e.g., Mazurek, 2004).

The lateral traceability of individual, near-horizontally layered and weakly deformed, bedrock formations was demonstrated at the Bruce nuclear site and at the regional scale, especially for the formations of Ordovician age (NWMO, 2011; AECOM and ITASCA CANADA, 2011). The updated 3D geological model for southern Ontario continues to demonstrate the predictable nature of the Ordovician sedimentary formations across southern Ontario (Carter et al., 2021).

Importantly, the site characterization activities at the Bruce nuclear site also indicated a high degree of similarity in geoscientific properties for all Paleozoic (sedimentary) formations between individual boreholes at the Bruce nuclear site (Intera, 2011).

While the site characterization activities at the South Bruce Site are still on-going, an initial assessment of the predictability of the sedimentary rocks beneath the site in the two boreholes, in comparison to the geological conditions encountered at the Bruce nuclear site and throughout the region, indicates that:

- the overall thickness of the Paleozoic formations encountered is broadly consistent with the regional stratigraphic model
- the thickness and character of the Ordovician formations is approximately 435 m based on initial observations from the first boreholes, consistent with expectations
- Cambrian sandstone was not encountered at the base of the boreholes
- the lack of occurrence of significant hydrocarbon indicators is as expected
- the general locations where opportunistic groundwater samples were collected is as expected
- the high fracture frequency encountered in the upper 200 m of the boreholes, and extremely low fracture frequency throughout the Ordovician formations, is as expected

While further analysis is required to confirm if the additional geoscientific properties of the sedimentary rocks beneath the South Bruce Site are consistent with their expected character, all indications to date suggest that they will be, especially with respect to the Ordovician host rock and bounding formations.

These studies provide confidence in the NWMO's ability to characterize and understand the large-scale geometry and structure of the geology in the South Bruce Site.

7. REPOSITORY CONSTRUCTION, OPERATION, AND CLOSURE

The deep geological repository (DGR) can be constructed, operated, and closed safely by:

- incorporating in its design, the best engineering practices and use of known technologies for safe construction, operation, decommissioning, and closure; and
- ensuring the surface and underground characteristics of the site are favourable to the safe construction, operation, decommissioning, and closure and long-term performance of the repository.

For more information on the repository conceptual design including details on the underground and surface facilities, see NWMO's *Deep Geological Repository Conceptual Design Report* (NWMO, 2021b).

The following sections elaborate on the current development status of the key engineered components and considerations for a deep geological repository at the South Bruce Site and ongoing work.

7.1 Engineered Barrier System

7.1.1 Used Fuel Container

The used fuel will be placed inside a long-lived used fuel container (UFC), with the nominal dimensions described in Table 7.1 and illustrated in Figure 7.1. The primary purpose of this container is to contain and isolate the used fuel from the underground environment, preventing water from contacting the used fuel, and so preventing radionuclides in the fuel from escaping into the underground environment.

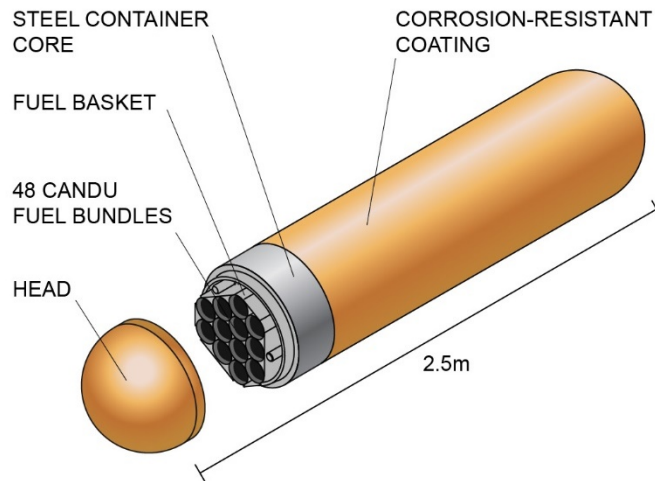
The reference design concept is a copper-coated steel container. The steel provides the structural strength to resist the pressure loads that occur underground, and the copper protects the steel from corrosion. The main reason for the selection of copper is its stability under conditions typically found underground; that is, water-saturated rock and chemically reducing (low oxygen) conditions. There is thermodynamic, experimental, and natural analogue evidence that copper is stable for very long periods under these conditions. A relatively thin layer of copper can last over one million years in the Canadian repository (Hall et al., 2021).

The container is designed to withstand the external pressure loads that would be experienced by the container during its design lifetime in a repository, including the external pressure loads caused by glacier above the repository up to three-km thick during a future ice age.

The container's design is not finalized and will continue to be optimized post-site selection. The design process considers advances in technology and will be informed by site-specific information and safety assessment evaluations. Changes to the container dimensions, material thickness, etc. are possible. For example, the container copper coating process technology has been developed to allow the coating thickness to be tailored to the site-specific requirements (i.e., increased or decreased). At the South Bruce Site, the high salinity in the repository host rock will also need to be considered as part of the design optimization.

Table 7.1: Nominal Used Fuel Container Characteristics

Parameter	Value
Length / Diameter	~ 2500 mm / ~ 600 mm
Steel shell	ASME SA-106 Gr.C / SA-516 Gr.70 Pressure Vessel Carbon Steel ~46 mm thick side shell walls; 30 mm thick head walls
Copper coating	3 mm, high purity copper
Number CANDU bundles	48
Mass (loaded)	~2,800 kg
Initial heat load	~165 W
Design basis (glaciation)	3 km thick icesheet

**Figure 7.1: Illustration of reference copper coated Used Fuel Container**

The reference container is designed for Canada's CANDU fuel bundles and has unique elements to the design, but it shares the key similarities and best practices being investigated and implemented by other leading international waste management organizations. For example, the Swedish (SKB) and Finnish (Posiva) programs have developed a container for light water reactor fuel, with an inner metallic core of cast-iron for structural strength and an outer copper shell for corrosion protection. They are also designing for a future ice age event. More information is provided on international waste management organizations that are pursuing geological disposal in Section 11.

As noted in Section 2, all nuclear generating stations in Canada are CANDU reactors and this fuel type accounts for ~99.9% of all current used fuel. There are plans for new reactors in Canada, which use different technologies and fuel types. In particular, OPG is planning to submit an application to build a GEH BWRX-300 BWR at its Darlington site. The BWRX-300 fuel is similar to the light water reactor fuel that Posiva and SKB manage.

As these plans develop and advance, the NWMO will assess the potential of using the current container design for these other fuels. Fuel characteristics, geometry, and other considerations may require alternative or modified container designs to be developed. NWMO will leverage and build on the reference CANDU fuel container, as well as, international container designs developed for these fuel types.

7.1.2 Buffer Materials and Sealing Systems

A swelling clay-based buffer material will surround each container in order to ensure a low-permeability and chemically benign environment around the containers; specifically, the clay buffer greatly slows the flow of water, creates favourable conditions to minimize corrosion, and mechanically holds and protects the container.

The main component of the buffer is bentonite, a naturally occurring clay. These clays are stable, having typically been formed millions to hundreds of millions of years ago. The main mineral in bentonite is montmorillonite. Montmorillonite is responsible for the most distinctive property of bentonite; it can swell to several times its original volume when placed in water. In the confined space of a repository, this swelling causes the clay to seal fractures and gaps, which makes the saturated clay nearly impermeable.

Bentonite clay buffer is a key component of the multiple-barrier system:

- Bentonite's swelling property greatly reduces the ability for water to flow; increasing the time it takes for water to reach or leave the container;
- Bentonite's chemical and swelling properties help suppresses microbial activity around the container preventing or slowing microbial corrosion of the copper; and
- Bentonite greatly slows radionuclide movement in the unlikely event of container failure; reducing the ability for them to reach the surface and biosphere.

The clay can be compressed into a solid block to allow easier handling and improved performance. The used fuel container will be directly surrounded by this highly compacted bentonite. The bentonite is shaped into two halves of a box with a cut-out for the container to be placed inside. The compacted bentonite is strong enough to support the container inside during the transfer and emplacement activities underground. The upper and lower halves of the bentonite are known as the **buffer box**, as shown in Figure 7.2.

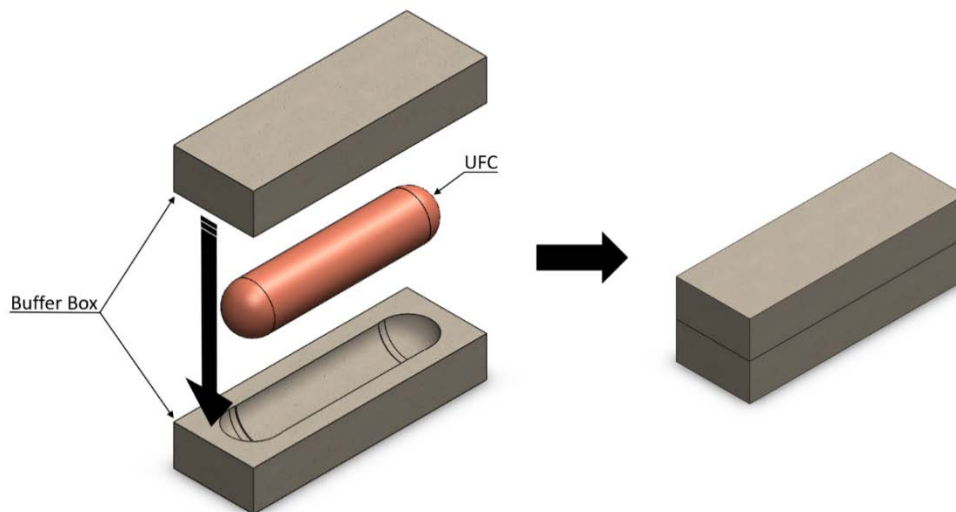


Figure 7.2: Used Fuel Container within a bentonite clay Buffer Box

The buffer boxes are placed in the underground placement rooms as shown in Figure 7.3; stacked two containers high. Bentonite clay blocks are placed between buffer boxes for thermal spacing purposes and to fill small voids used for handling and emplacement. The remaining space between the rock and the buffer box, on the sides and top, is typically less than 30 cm. This space is filled with loose granular bentonite material known as gap fill material.

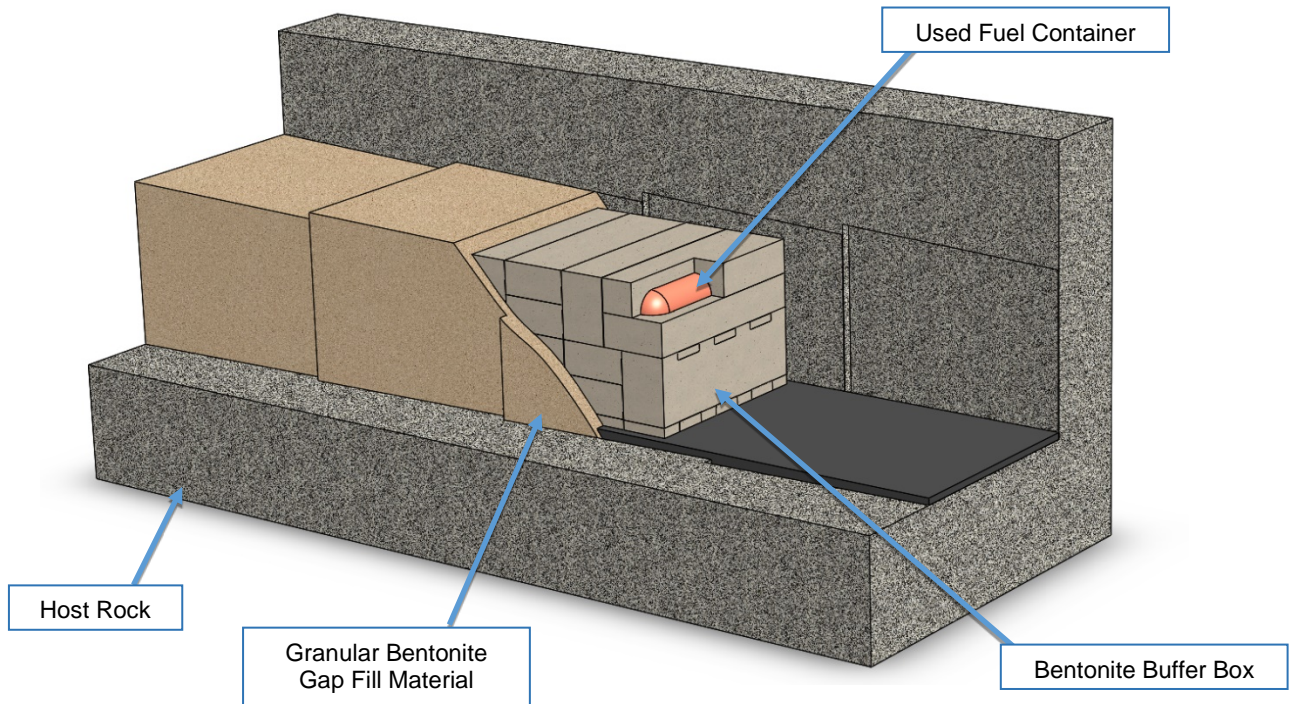


Figure 7.3: Cutaway Illustration of Emplacement Room Concept

The ends of the emplacement rooms, towards the access tunnels, would be sealed with room end plugs made from bentonite clay and a thick concrete bulkhead. These would isolate the filled rooms from the open access tunnels during the operating and extended monitoring phases, and from the closed and back-filled tunnels in the long-term.

The tunnels and other underground openings would be filled with a mixture of crushed-rock and clay based backfill at repository closure, that provides long-term mechanical support to the surrounding rock and reduces the hydraulic conductivity of these openings. The shafts would be sealed with combination of clays, concrete, rock backfill and possibly asphalt.

It is estimated that about 50 years will be needed to complete the container emplacement underground for all of Canada's projected used nuclear fuel (NWMO, 2021a). This will be followed by an extended monitoring period where tunnels will remain open for access underground. For planning purposes, it is assumed that this period will be 70 years, but it could be longer or shorter. It is important to note that monitoring systems will be designed to ensure no impact to long term safety of the repository. Monitoring is discussed further in Section 12. After a suitable monitoring period, and in consultation with stakeholders, all tunnels, shafts and surface boreholes would be backfilled and sealed. There would be no remaining equipment that needed to be maintained to ensure safety. Post-closure monitoring of the facility would, however, continue for some time in order to confirm the repository was operating as expected.

7.1.3 Engineered Barrier Testing

The proposed container, buffer and seals, and emplacement concepts build on established elements of a robust repository approach but represents a novel approach to the overall Engineered Barrier System (EBS) that has been optimized for CANDU fuel. It leverages proven techniques from nuclear/aerospace coating technologies, robotics and automated handling, and mining industries. The use of proven technologies and consistency with international best practices provides confidence that the design will be successful.

To build on that confidence, an experimental and testing program was developed known as the Proof Test Plan. The Proof Test Plan's primary objectives were to develop and demonstrate prototype engineered barrier components and their emplacement.

At the end of 2021, the NWMO has finalized the reference CANDU fuel container and bentonite fabrication and inspection processes including all supporting equipment. These processes have been successfully used to create full-scale container and bentonite buffer box prototypes. This is described further below.

Container Fabrication and Testing

As of early 2022, the NWMO has fabricated six full-scale containers with several partial containers in various stages of manufacturing. A total of 15 containers are planned by the end of 2022. The prototyping process has resulted in improved fabrication methods, full-scale demonstration of inspection methods, and allowed various structural tests to be performed.

The program started with small scale samples subjected to a variety of tests, such as corrosion, mechanical strength, and coating adhesion. For example, copper-coated specimens for materials testing have been placed deep underground in Switzerland as part of international joint projects, and have been placed one km deep in the Pacific Ocean for pressure and saline water corrosion tests.

As the program advanced, larger scale samples and testing were conducted. For example, Figure 7.4 shows a full-scale cross-section of a container being subjected to a beyond design basis loading scenario known as a crush test. The load far exceeds what is expected for the container in the repository, even beyond the bounding loads caused by the next ice age. The testing demonstrated the ability of the steel and weld zone to deform without breaking, and the copper coating remained well bonded under these extreme conditions. The containment boundary remained intact in this test.

Another key test was full-scale container testing at the Applied Research Lab at Penn State University, as shown in Figure 7.5. A container was placed into a test chamber where it was subjected to hydrostatic pressure equivalent to being almost six km underwater. This pressure exceeds the maximum total pressure expected in the repository, including up to a three-km thick ice sheet rock above the repository during the next ice age, by about 20%. This bounding loading condition, well above the container design basis, was selected to confirm that the container initial yield stress and buckling (e.g., crushing) occurred when expected from the computer modeling. The testing confirmed the container can withstand the maximum repository pressure loads without any permanent change and that the modeling was accurate.

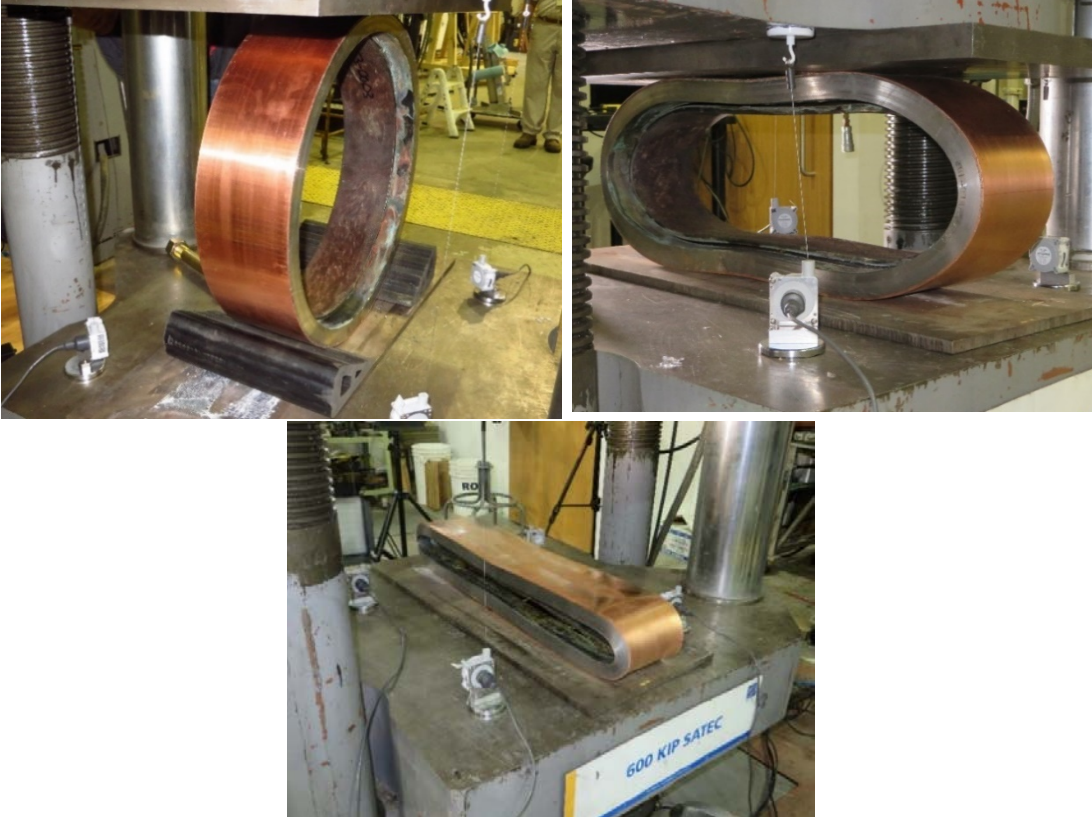


Figure 7.4: Used Fuel Container cross-section undergoing a beyond-design-basis crush test. Copper coating remained bonded to steel.

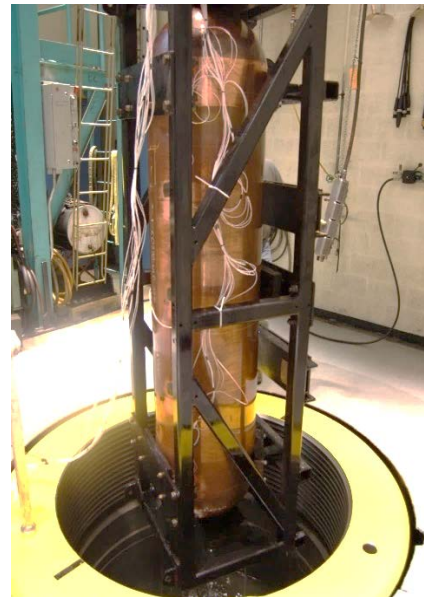


Figure 7.5: Prototype Used Fuel Container subjected to external pressure equivalent to almost 6 km underwater. (Left) Test chamber lid being lowered into place; (Right) Container removed after testing; fully intact – no containment failure.

Buffer Fabrication and Tests

As of early 2022, fabrication of more than 10 buffer boxes have been completed, as shown in Figure 7.6, and various improvements to the design and fabrication methods have been achieved.

For example, initially these buffer boxes were constructed out of smaller bricks that were assembled into a larger box that required a steel frame. Further design work led to the development of a half-buffer box as a single unit that can fully hold the container. This innovation allows for easier handling and assembly of the completed buffer box and eliminates the need for a frame. Testing of different ways to handle the buffer boxes using both a combination of vacuum lift and forklift style technology are shown in Figure 7.7.



Figure 7.6: Prototype Buffer Box and Used Fuel Container

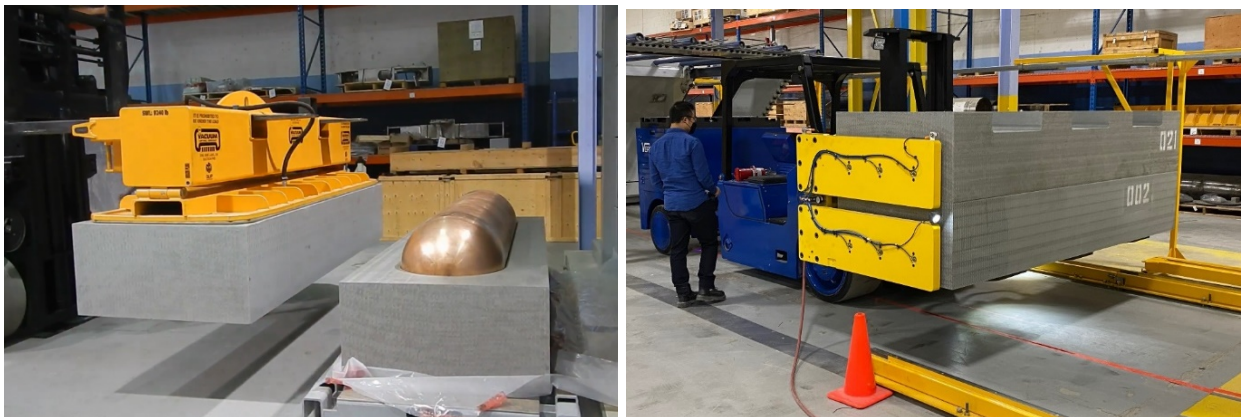


Figure 7.7: Bentonite handling: (Left) Using vacuum lift technology; (Right) Robotic forklift handling of buffer box

Emplacement Test

The NWMO has manufactured a full-scale mock emplacement room, complete with faux-rock walls with simulated drill-and-blast excavation profiles. The program has designed, manufactured, and performed initial testing on all the required emplacement equipment as shown in Figure 7.8.

In 2022, the NWMO will conduct the full-scale emplacement trial using the prototype components and emplacement equipment. The emplacement operational procedures will be tested, and lessons learned documented. The emplacement room will be partially disassembled and inspected to see if the emplacement meets the performance requirements.

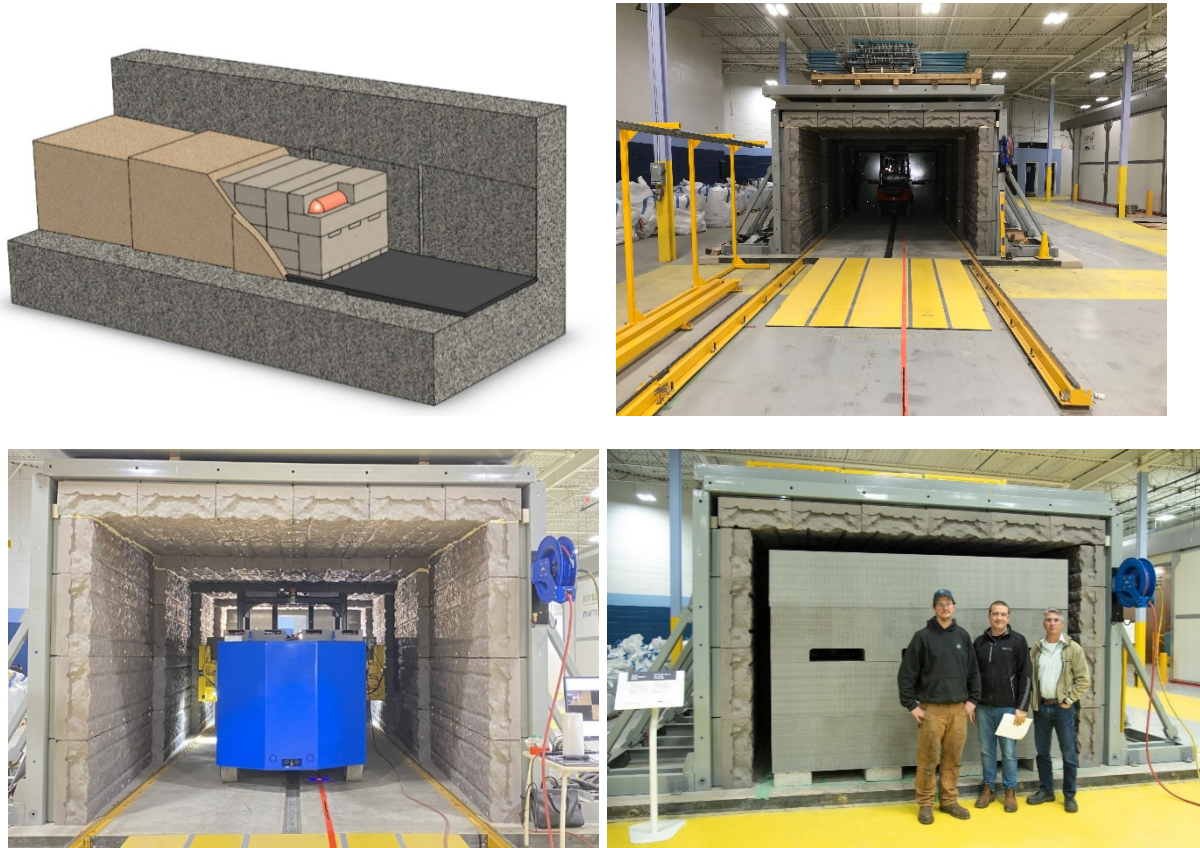


Figure 7.8: (Top Left) Emplacement Room Concept; (Top Right) Full-scale Mock Emplacement Room at NWMO Test Facility; (Bottom Left) Emplacement Machine travelling inside Room; (Bottom Right) Stacked Buffer Boxes

7.2 Underground Facilities

The underground repository is largely a network of access tunnels and placement rooms that will contain the used fuel within the engineered barriers. Placement rooms make up the largest volume of the underground area; however, there are several supporting facilities located within a centralized services area.

Access to the underground is provided via three shafts:

1. Main Shaft Complex: for transfer of the used fuel container in buffer boxes;
2. Service Shaft Complex: for movement of personnel, mining materials, and excavated rock, as well as, main air intake; and
3. Ventilation Shaft Complex: for repository exhaust air; it also provides secondary means of egress for personnel during an underground emergency event.

Underground, the services area acts a central base of underground operations and has the following facilities:

- Main, Service, and Ventilation shaft access;
- Underground Demonstration Facility;
- Refuge stations, offices, lunch area, washrooms;
- Maintenance shop and warehouse;
- Battery charging station;
- Equipment / material storage areas;
- Explosives and detonators magazines;
- Main electrical substation; and
- Truck dump equipped with grizzly and rockbreaker.

From the services area, twin access tunnels branch out forming various “arms” that lead into placement panels. The NWMO has selected this adaptive layout design to accommodate the geology and NWMO owned land, and to provide flexibility during construction and operation. By using these methods, suitable rock for placement rooms will be ensured.

A conceptual repository layout for a hypothetical sedimentary rock site using the adaptive layout design approach is shown in Figure 7.9. This is not the South Bruce site layout; a conceptual repository layout for the South Bruce Site is under development this year based on current available land and field investigation data.

The land currently available to NWMO in the South Bruce Site is shown in Figure 3.4. This area is sufficient for the repository; however, discussions with interested landowners are ongoing as the NWMO works to further build out the potential repository site and understand and address their comments and concerns.

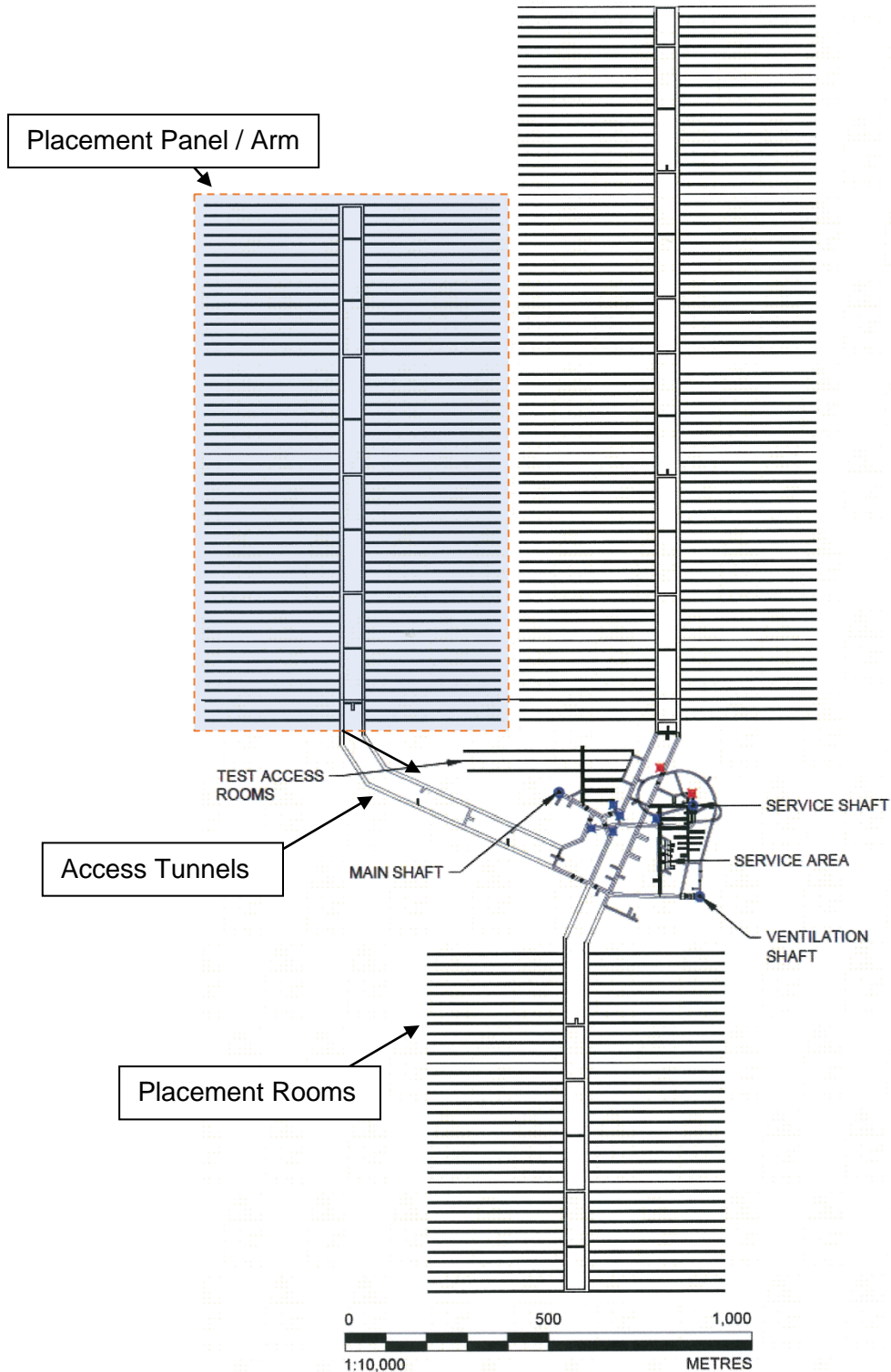


Figure 7.9: Conceptual underground repository layout for a hypothetical sedimentary rock site, showing services area, access tunnels, placement arm panels, and emplacement rooms (NWMO, 2018). Layout is for illustration purposes only and does not reflect the South Bruce Site.

The placement rooms are about 340 m long and about 25 m apart, based on structural and thermal considerations; in particular, to ensure that the temperature at the container surface is limited to 100°C. Containers will be placed in these rooms and surrounded by a clay-based buffer material to ensure low-permeability and chemically favorable conditions. The room ends would be sealed with bentonite clay and a concrete bulkhead plug.

Based on the current nuclear fleet in Canada and planned refurbishments, the repository would contain approximately 5.5 million used fuel bundles within approximately 120,000 containers (NWMO, 2021a). The repository area is about 6 km².

The mechanical properties of the rock are important to the repository design. For the Cobourg Limestone formation rock at the South Bruce Site, excavation of the underground openings at around 650 m depth does not represent a technical problem. There is much experience in this type of engineering in mines in Canada. There will likely be concrete floors, concrete bulkheads and local roof support, for example, rock bolts, grout, and/or shotcrete in the services area and access tunnels. Excavation techniques will be adopted that minimize the extent of the rock excavation damaged zone that typically forms around mined excavations.

The NWMO's current reference plan is that the three shafts will be developed using conventional controlled drill and blast. As the site investigation and the construction plan advances, other shaft excavation techniques (e.g., raise bore excavation) will be considered. The design of the shaft liner and grouting system will be completed after the location of the shaft (and site) is established. The shaft liner will serve two purposes; first it is a measure of ground support, preventing minor ground shifts or loose rock from falling into the shaft, and second it will act as a means to prevent seepage of water in the shaft.

The shaft sinking process in the sedimentary formation will likely require that top 180 to 200 m of bedrock has ground conditioning to limit the amount of groundwater inflow during shaft sinking. Ground conditioning would be achieved using well established techniques such as grouting or ground freezing. The concrete liner in this zone will also be designed to limit ground water into the finished shaft using mining best practice (e.g., hydrostatic concrete liner).

During emergencies, staff will be evacuated to surface or shelter in place following established procedures. Two of the three shafts are equipped to move personnel to/from the surface. The service shaft and the ventilation shaft acting as secondary egress. In cases where evacuation is not immediately possible, a permanent refuge station is included in services area. It will have concrete walls and steel door for fire protection. The refuge station will be equipped with safety and rescue equipment such as a fire extinguisher, eyewash station, first aid kit, emergency food and drink rations. The station can be fully sealed with fresh air supplied via the compressed air system with appropriate backup. Additionally, portable refuge stations will be placed underground in strategic locations in the access tunnels where excavation and emplacement activities are occurring. They are also fully sealable and use compressed air bottles for emergency breathing air. They will be stocked with similar safety equipment and rations as the permanent refuge station.

Another system important for mining safety is underground ventilation. The system uses a series of surface fans, underground booster fans, ventilation doors, and regulators to control airflow distribution and ensure a 'one-pass' ventilation loop into and out of the repository. Most of the exhaust air will be directed out the ventilation shaft with a small amount out through the main shaft. Inflow air will be directed through the service shaft. The exhaust ventilation stack on surface will be equipped with High-Efficiency Particulate Air (HEPA) filtration systems.

During excavation and normal operations, this system would be bypassed as the exhaust air does not need filtration. These systems will be activated in an emergency, such as underground fire or radioactivity being detected in the underground air at above-background concentration levels.

7.3 Surface Facilities

A description of all surface and underground facilities is provided in the 2021 DGR conceptual design report (NWMO, 2021b). A conceptual layout for the surface facilities is shown in Figure 7.10.

The surface facilities will be divided into two types of areas: the Protected Area and the Balance of Site. The Protected Area includes surface facilities that require restricted access, including the Used Fuel Packaging Plant and all shaft complexes providing access to the underground. Security check points and double perimeter fencing will prevent unauthorized access into the Protected Area. Surface facilities located outside the Protected Area, but inside the outer perimeter fence, are considered the Balance of Site. Key facilities in the Balance of Site area will include the Administration Building, Sealing Material Compaction Plant and a Concrete Batch plant. An Excavated Rock Management Area (ERMA) will be established outside of the repository perimeter fence to manage the waste rock from underground operations.

A description of all surface and underground facilities is provided in the 2021 DGR conceptual design report (NWMO, 2021b). The following sections discuss the key facilities with the potential to cause environmental impacts (i.e., water and air emissions) and the technology or processes that will be used to eliminate or mitigate these impacts.



Figure 7.10: Illustration showing conceptual DGR Surface Facility Layout

Site Security

The Protected Area boundaries will consist of a physical protection system, with controlled personnel and vehicle access points consistent with current Nuclear Security Regulations (SOR/2000-209). Additionally, the entire surface facility will be surrounded by a fence in order to provide controlled access to vehicles and persons and to prevent intrusion of wildlife.

The Protected Areas physical protection systems will incorporate a perimeter barrier with unobstructed land of minimum 5 m clear distance on both sides of the barrier. In addition, a system of protective elements will be in place to provide multiple layers of delay, detection and assessment that are controlled through a central command post or security monitoring room. The assessment component will enable security personnel to evaluate detected threats and provide the appropriate response. All of these component layers will further be connected to a back-up uninterrupted power supply, located within the Protected Area.

Nuclear Security Regulation (SOR/2000-209) stipulates that the detection and assessment components must each feature two independent systems. The delay component must have additional capabilities to deny intruders using large vehicles from forcing entry. Consistent with these requirements, the systems established to secure the Protected Areas will include:

- A physical barrier to delay intruders for a sufficient period of time to enable effective interception by response personnel and provide sufficient time delay at all points around the perimeter of the facility. The reference design includes two fences approximately 3 m high and 3 m apart with lighting.
- A detection system to identify intruders immediately and alert security and response personnel. The reference design includes various remote sensors outside and attached to the security fences to alert security of access attempts.
- An assessment system, with a dedicated lighting network, to allow security personnel to clearly identify and quantify any possible intrusion. The reference design includes a network of CCTV cameras throughout the Protected Area including the security fence.

Used Fuel Packaging Plant

The Used Fuel Packaging Plant (UFPP) facility receives the used fuel transport package, opens the transportation package, removes and inspects the used fuel, and transfers the fuel into a used fuel container. There is no reprocessing of the fuel. The container is sealed, inspected, and placed inside a buffer box.

All handling operations that involve used fuel will be completed within heavily shielded enclosures (i.e., hot cells). Fuel handling will use remote tooling and shielded transfer packages. All shielded cells will be environmentally controlled by a filtered ventilation system to prevent the spread of airborne radioactivity.

Specifically, all areas of the UFPP will be zoned and controlled according to external dose rates and the potential for radioactive contamination. Ventilation systems will be designed such that each zone will be under a negative pressure, with the highest potential contamination areas kept at the lowest pressure. This controls the air flow, causing it to move from zones of lower potential contamination to the zone of highest potential contamination. The negative pressures are maintained with an exhaust system that filters the air through High-efficiency Particulate Air (HEPA) filters before releasing it the environment. Radiation monitoring and redundancies would be in place to ensure releases are safe and meet all applicable regulations and standards.

The UFPP will also include the required auxiliary systems, like electrical power systems (regular, emergency and back-up), a central control room, waste management facility, and facilities for personnel. Maintenance on used fuel handling equipment will be performed within the UFPP.

The UFPP will be designed considering upset events, such as earthquakes or fire. The facility will be designed to safely shut down. Emergency power, provided by onsite generators, and additional battery back-up power, ensure critical safety systems are kept functioning in the event of an emergency. Fire protection and suppression systems will follow industry best practices including national standards for facilities that handle nuclear materials.

Water Management Systems

The repository surface and underground facilities need water to facilitate construction and operations. The NWMO's facilities will meet all applicable regulations and requirements for water taking, treatment, monitoring and discharge back to the environment.

At the South Bruce Site, the current reference design assumes conservatively that both water and wastewater systems are independently sourced and located at the site. The water source has not been determined yet. It could be from a nearby surface water body (i.e., Teeswater River) or well. At the South Bruce Site, there may be a possibility to connect to the existing municipal water and wastewater sewage systems. These options will be further examined, should the South Bruce site be selected, through the detailed design phases and in discussions with the community.

If not connected to the existing wastewater sewage systems, sewage collected from all serviced buildings will be piped to an on-site sewage treatment plant for treatment to all applicable regulations prior to recycling or discharge to a local water body. Collected sludge will be taken for disposal off-site following all applicable regulations.

Site stormwater run-off will be collected and diverted to several stormwater management ponds. The current design has one in the protected area and two in the balance of site at opposite ends to facilitate grading flow. All the ponds will be lined, as required, over their base and embankments for protection and to prevent water infiltration back into the ground. Collected water will be monitored and treated, as required, prior to discharge in accordance with all applicable regulatory limits.

Mine water pumped from the underground sumps will be piped to a mine dewatering settling pond. The mine water in the settling pond may contain sediment (rock dust), nitrogen compounds (arising from the explosives used to excavate rock), salt (due to saline ground water inflow into underground repository), possibly particular metallic elements (notably uranium), and hydrocarbons (oils from equipment). If the concentration of these potential chemical contaminants are above acceptable levels, then the water will be treated before being reused as service water or discharged into a receiving water body following all applicable regulatory limits. The design is considering best practices to ensure reuse of mine water for the underground operations (e.g., as service water) where possible.

The design of all stormwater and settling ponds will be in accordance with the Ontario Ministry of the Environment Conservation and Parks manual (MOE, 2003).

Excavated Rock Management Area

An Excavated Rock Management Area (ERMA) is a separate facility that will receive the excavated rock from underground construction. The ERMA location will be within a 5 km distance of the repository shafts, and will be selected to avoid streams and wetlands. The ERMA will occupy an area of approximately 25 hectares (~500 m x 500 m) with a reference rock pile height of 15 m, and have a capacity of approximately 2.5 million cubic metres of rock required for all underground excavation over the life-cycle of the facility. The ERMA will be fenced during construction and operations.

A key component of the ERMA is water management. This includes storm water management to collect run-off flows via perimeter ditching, consolidation of run-off into a settling pond, and monitoring water quality (e.g., suspended solids, chemical contaminants, etc.) to ensure compliance prior to discharge. If required, the storm water would be treated according to all applicable regulations prior to discharge to the environment.

A key design consideration for a mining rock pile is whether the stormwater that falls on and percolates through the rock pile becomes contaminated. In particular, whether this water become acidic or has a high concentration of metals or salt. This is determined in advance through standard laboratory leachate tests. Leachate tests characterize soluble parts of the rock and are used to predict migration and associated risk; for example, these types of tests can determine if the excavated rock is potentially acid generating (PAG).

Leachate tests have not yet been conducted on the core from the South Bruce area; however, there is some test data for the Cobourg Formation from Bruce County. Tests performed on core from the nearby Bruce nuclear site in Kincardine determined the rock to be non-PAG. A comprehensive leachate testing program during the detailed site characterization phase will be conducted. This testing is to confirm the rock is non-PAG and determine leachate concentrations to inform the excavated rock management area design.

The previous regional testing provides confidence that PAG will not be a concern at the South Bruce Site; nonetheless, the NWMO is advancing ERMA designs that take this concern into consideration. If the rock is found to be acid-generating or have concentrations of concern, then the ERMA will be designed to limit the amount of leachate that could seep into underlying soil and rock. This is achieved by developing the ERMA with a composite or multiple-layer liner system including the main rock pile area, the perimeter ditches, and the stormwater management pond. The storm water would then be treated according to all applicable regulations prior to discharge to the environment.

The rock pile will be rehabilitated after excavated rock placement has ended. The pile can be shaped and restored by vegetating the surface with native plant species and in manner capable of supporting a self-sustaining ecosystem.

The ERMA has been conservatively sized for all excavated rock and assumes no use of the rock for other purposes (e.g., granular grade for road base, etc.). This will be investigated as part of detailed site characterization.

7.4 Site Specific Characteristics for Construction, Operations, and Closure

Site specific factors important to the safe construction, operation, and closure include:

- The surface area should be sufficient to accommodate surface facilities and associated infrastructure;
- The soil depth over the host rock should not adversely impact repository construction; and
- The strength of the host rock and bedrock stress at repository depth should allow the repository to be safely excavated, operated and closed.

7.4.1 Surface Area and Infrastructure

A key evaluation factor for site selection confidence is that the surface area is sufficient to accommodate surface facilities and associated infrastructure.

Figure 1.1 showed the vicinity around the South Bruce Site. The area is relatively flat and agricultural.

The site has suitable surface area for the construction and operation of DGR surface facilities and excavated rock management area.

An on-site construction camp is not planned.

In terms of existing infrastructure, the proposed site is within 5 km of Teeswater and is approximately 10 km south of Ontario Highway 9. The Goderich-Exeter Railway (GEXR) rail line is approximately 50 km to the south. Electrical transmission and natural gas distribution are available in the region.

Based on information to date, there is high confidence that the surface area and infrastructure can support the construction, operations, and closure of the repository.

7.4.2 Overburden

Geological mapping in the South Bruce Site area indicates that the bedrock is mostly covered by overburden (soil cover) deposits. Average overburden thickness is approximately 20 m and varies from 0 to 73 m within the Municipality of South Bruce. The thinnest overburden deposits are found in the valleys of the Teeswater River and Formosa Creek – the latter cuts down into limestone bedrock. Borehole 1 at the South Bruce Site encountered 19.6 m of overburden.

Based on site investigations information to date, there is high confidence that the overburden conditions will not adversely impact construction of the repository. Additional geotechnical work during detailed site characterization will inform the level of effort regarding site grading, cut and fill, and aggregate requirements; however, these are all conventional construction challenges with solutions that do not affect overall safety and performance of the facilities.

7.4.3 Host Rock Strength and Bedrock Stresses

As noted in Section 3.6, while there are no direct bedrock stress measurements at this time, analysis shows the orientations of the maximum horizontal stresses follow the general trend in southern Ontario. The underground layout will align the room and panel orientations taking this into account to optimize room stability.

As noted in Section 3.6, based on the regional characteristics of the host rock, plus Canadian and international mining experience, there is high technical confidence that both the strength of the rock and bedrock stresses would allow the safe excavation, construction, operation, and closure of the deep geological repository.

8. TRANSPORTATION

The repository site needs to allow the safe and secure transportation of used fuel from storage sites. The NWMO will need to demonstrate that this repository is located in an area that:

1. is amenable to the safe transportation of used nuclear fuel.
2. allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

The following sections elaborate on these key considerations for confidence in the transportation system.

For more information on the conceptual transportation system and plan, see NWMO's *Transportation System Conceptual Design Report* (NWMO, 2021c) and *Preliminary Transportation Plan* (NWMO, 2021d).

8.1 Developing a Safe Transportation System

8.1.1 Transportation System Overview

Used fuel is presently stored in interim facilities at or near reactor sites. This fuel will be transferred on-site from interim storage into certified transportation packages, and then brought to the repository site. Once at the repository site, the transport packages will be unloaded, checked, and then returned to pick up more used fuel.

The reference transportation system will operate for approximately 50 years. On an annual basis there will be around 650 shipments, which is about 2 to 3 packages per day on average. The number of daily shipments vary as the transportation system is designed to accommodate schedule variance due to weather, temporary road traffic and closures, unplanned maintenance, etc. The NWMO will not transport used fuel if conditions are not suitable.

8.1.2 Transportation Packages

Safety of transporting used nuclear fuel begins with transportation package design.

Transportation of used nuclear fuel will occur in a transportation package that adheres to stringent Canadian regulations and international standards. Used nuclear fuel transportation packages are designed and tested to ensure protection of people and the environment during normal operations, as well as during accident conditions.

The Canadian Nuclear Safety Commission (CNSC) is responsible for evaluating transportation packages and certifying designs. Before a transportation package can be used in Canada, the design must be certified by the CNSC to meet regulatory requirements, which incorporate international safety standards. The requirements include tests designed to demonstrate the ability of the package to withstand severe impact, fire, and water immersion. These are extreme tests to demonstrate the durability of the packages.

The specific tests include:

1. 9-m free drop test onto a flat, unyielding surface;
2. 1-m free drop puncture test onto a rigid spike of 15 cm diameter and 20 cm length;
3. Thermal test of a fully engulfing fire for 30 minutes at approximately 800°C; and
4. Immersion tests of 8 hours at 15 metres and 1 hour at 200 m.

Also, the certification requires that the drop tests be completed in sequence followed by the fire test on the same package. This is to emulate real world vehicle accidents.

The 9-metre free-drop test is a severe test compared to real world accidents. Although the speed of the package at impact can be much higher in real world accidents, the peak loads on the package during this test are many times higher than those experienced when a train travelling at 160 kilometres an hour collides with a transportation package. This is predominantly due to the use of rigid, unyielding target in the free-drop; a detailed analysis and explanation is provided in the NWMO technical report (Easton, 2014).

In order to meet these tests, the transportation package designs typically feature thick steel body and lids, which are attached with several large lid bolts. The lid and bolts are further protected by an impact limiter, which effectively acts as a shock absorber in the event of impact and heat shield in the event of fire. An example certified package for CANDU used fuel, the Used Fuel Transportation Package (UFTP), is illustrated in Figure 8.1 and its characteristics are noted in Table 8.1.

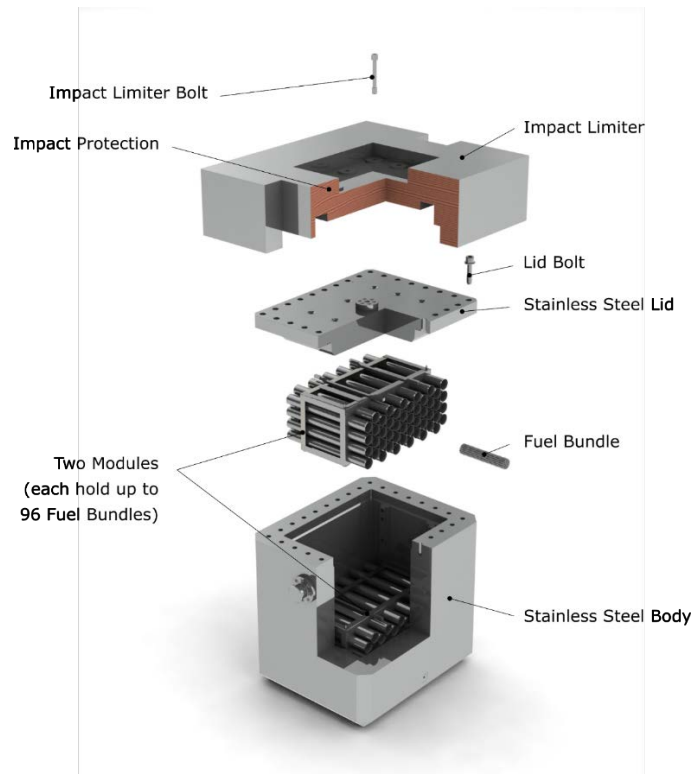


Figure 8.1: Illustration of Used Fuel Transportation Package (UFTP). A stainless-steel package with walls nearly 30 centimetres thick.

Table 8.1: Used Fuel Transportation Package Characteristics

	Used Fuel Transportation Package (UFTP)	Basket Transportation Package (BTP)¹	Dry Storage Container Transportation Package (DSC-TP)²
Contents	192 used fuel bundles (2 rectangular modules, each holding 96 bundles)	120 used fuel bundles (2 cylindrical fuel baskets, each holding 60 bundles)	384 used fuel bundles (4 rectangular modules, each holding 96 bundles)
Approximate Assembled Dimensions	Length = 2.4m Width = 2.0m Height = 2.2m	Length = 2.3m Width = 2.3m Height = 2.5m	Length = 3.7m Width = 3.4m Height = 6.0m
Approximate Loaded Weight	35 tonnes	28 tonnes	100 tonnes

1: The BTP is a package for transporting cylinder fuel baskets used at Gentilly-2 (Quebec) and Point Lepreau (New Brunswick) nuclear generating stations.

2: The DSC-TP is the transportation package configuration of the OPG Dry Storage Container (DSC). This package is part of the road/rail combination mode used fuel transportation system; on roadways it would be considered a superload. It is not used in the proposed reference transportation system.

* See references (NWMO, 2021c and 2021d) for more information on these packages.

Package certification can be done via physical testing of scaled prototypes and/or computer modeling. The Used Fuel Transportation Package was designed and tested in the 1980s using a half-scale model as shown in Figure 8.2. The package passed all testing and is currently certified for use.

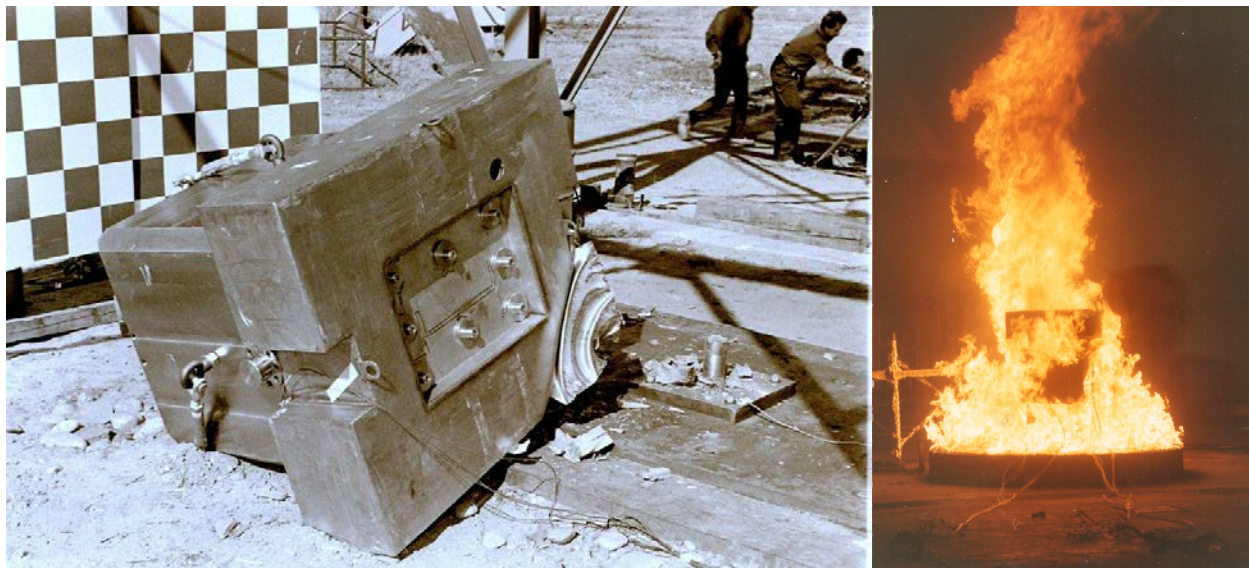


Figure 8.2: Half-Scale Used Fuel Transportation Package: (Left) after drop test; and (Right) during fire testing



Figure 8.3: Photos from "Operation Smash Hit". A used fuel transportation package in direct collision with train traveling at 160 km/h with no release of contents. (Clockwise) Depicts train just before collision, after collision, and dented but intact package among wreckage.

Several countries have conducted additional testing to demonstrate the robustness of used fuel transportation packages. In the United Kingdom, a test known as “operation smash hit” had a locomotive and three train cars travelling at approximately 160 km/h purposely collide into a used fuel transportation package as shown in Figure 8.3. The package did not breach nor release its contents. Videos of this test and other transportation package testing are readily available online (Cooperail, 2015).

8.1.3 Transportation Modes

The NWMO is currently investigating two potential transportation system designs using road and rail, as shown graphically in Figure 8.4:

1. All road transportation system
2. Road/rail combination transportation system

The all-road transportation system makes use of transportation packages that are of a size and weight suitable for transport over existing highway networks using tractor-trailers satisfying provincial road restrictions (i.e., not requiring oversize / overwidth permits, “conventional” road transport). Road transportation provides more flexibility in terms of scheduling and routing. The specific routes will be selected for each shipment based on conditions at that time, such as road construction, weather and security.

An all-rail option is not viable. Some of the existing interim storage sites (i.e., nuclear generating stations) no longer have functioning rail lines within a suitable distance or sufficient used fuel quantities to make rail logistically advantageous. A road/rail combination system is possible depending on the interim storage site. Some interim storage sites will require an intermodal facility to transfer transportation packages from a train to tractor-trailer; additionally, some packaging options would classify as a superload shipment. Superloads are heavy haul shipments that require special permits to transport because of their weight and/or size; for example, the dry storage container transportation package (DSC-TP) described in Table 8.1.

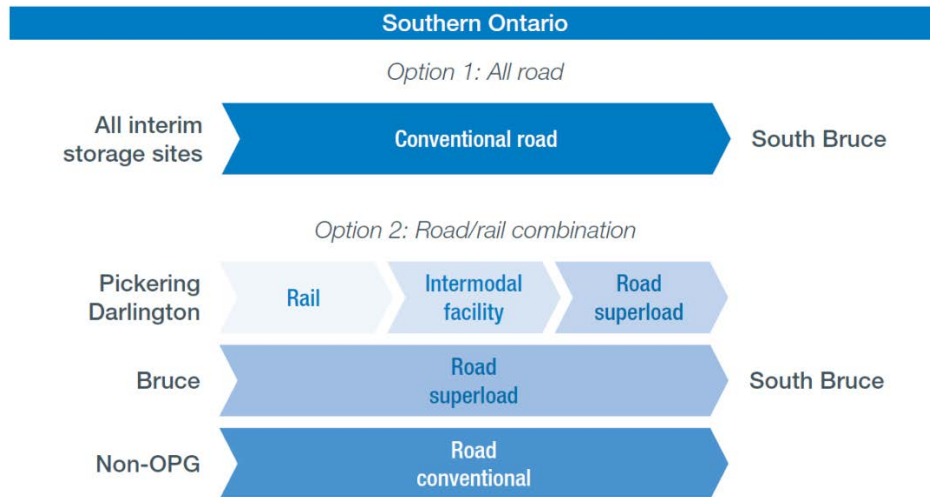


Figure 8.4: Transportation systems under consideration for the South Bruce Site

The potential repository area at the South Bruce Site is located close to existing roads and highways such as Ontario Highway 9; however, the nearest rail line is the Goderich-Exeter Railway (GEXR) approximately 50 km to the south.

For the road transportation system, some local road upgrades and/or development of new road connections from existing highway routes will be required. The NWMO and the Municipality of South Bruce are working with other regional communities to understand the changes that may need to be made to the road network and how the traffic to and from the site can be managed. Safety for all users - horse and buggy, bicycle, foot traffic, farm vehicle, cars and trucks - is being taken into consideration.

For the road/rail transportation system, an intermodal facility would be required near the existing GEXR rail line, as well as, additional spur lines at the OPG interim storage facilities. The intermodal facility would transfer the used fuel transportation packages to/from rail to road transportation modes (e.g., train to/from trucks). A conceptual intermodal facility is shown in Figure 8.5.

The NWMO has confirmed the technical feasibility of both of these transportation systems; however, the road/rail combination system requires more infrastructure, facilities, and package handling operations. At this time, the NWMO's reference Used Fuel Transportation System (UFTS) for the South Bruce Site is the all-road system. The all-road transportation system uses

existing highway networks for the journey, provides more flexibility in terms of scheduling and routing, avoids the need for intermodal facilities and superload shipments.

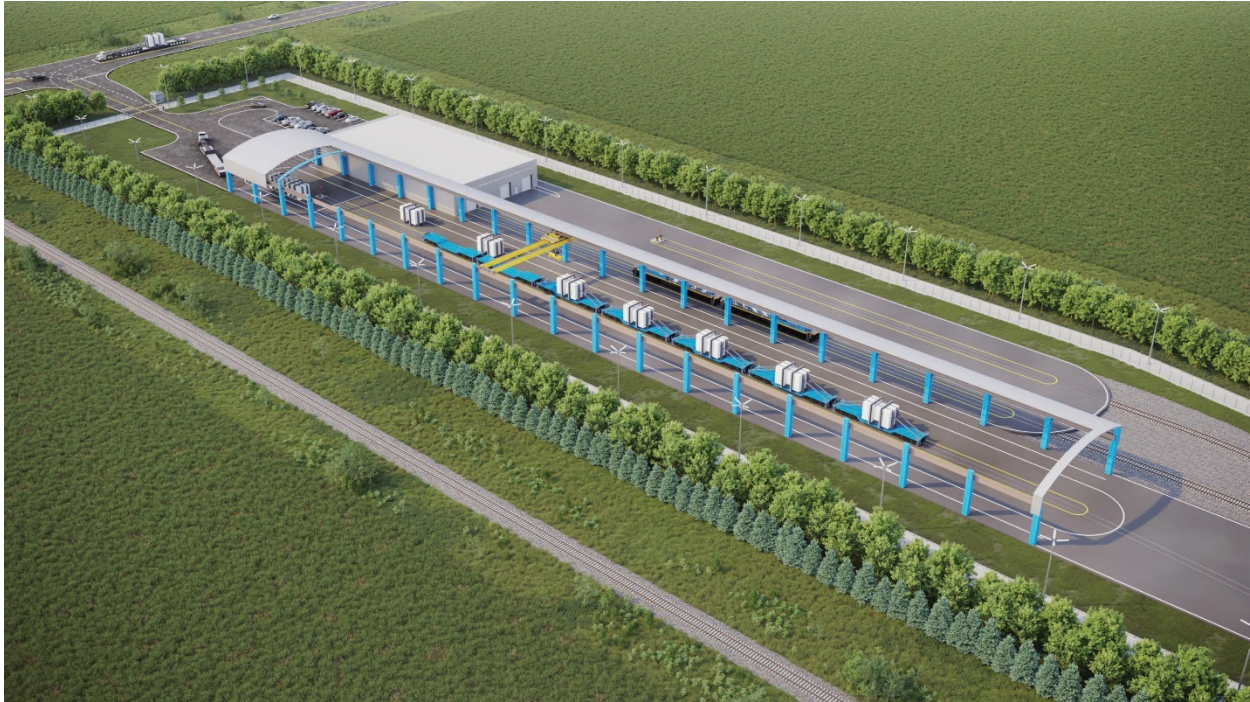


Figure 8.5: Conceptual Used Fuel Transportation System Intermodal Facility to transfer packages from rail to road modes.

8.2 Safety, Security, and Emergency Response

The NWMO's transportation program will need to meet the CNSC's and Transport Canada's regulatory requirements. These regulations cover the transportation package certification, operational and radiological safety, security provisions, and emergency response.

The following sections describe the security and emergency response aspects of the transportation program.

Based on the information to date, the South Bruce Site location does not present any barriers that prevent security and emergency response planning and protocols for the operational phase from being implemented effectively. For example, in Bruce county there has been ongoing transportation of low and immediate level radioactive waste shipment for 45 years in support of the Bruce nuclear site operations using such plans. Similar plans have been applied nationally and internationally on used fuel shipments successfully for over 50 years. As a result, there is high confidence that a safe and secure transportation system can be designed and operated.

8.2.1 Security

A license from the CNSC is required to transport used nuclear fuel. As part of the license application, a Transportation Security Plan must be developed that includes:

- Threat assessment that looks at the nature, likelihood and consequences of acts or events that may place prescribed information or the used fuel bundles at risk, along with corresponding mitigation measures, including emergency response;
- Communication arrangements;
- Proposed security measures;
- Arrangements with response forces; including provisions for advanced notification of shipment and contacting the appropriate response force during shipment;
- Provisions for the support of response forces along the transport route;
- Planned and alternate routes;
- Contingency arrangements to address such events as a mechanical breakdown of a transport or escort vehicle, or failure of a shipment to arrive at its destination at the expected time; and
- Procedures to be followed during an unscheduled stop or unscheduled delay during transport.

To protect the safety and security of the shipments the regulations mandate that the Transportation Security Plan is prescribed information and cannot be made publicly accessible.

In addition to the security plan, the shipments will be accompanied by one or more escorts. Their responsibilities would involve:

- Conducting searches of persons, materials, vehicles, as needed;
- Remaining in frequent contact with the shipper, receiver, local authorities, and response forces along the transport route;
- Inspecting for security breaches and vulnerabilities, and ensuring the secure storage of any transport equipment; and
- Responding to and assessing incidents and events.

Finally, communication, tracking, and other security technology are used to ensure the shipments are completed safely and securely. Drivers and escorts will communicate with a central Transportation Communication and Control Centre, which monitors and tracks all shipments and acts a single point of contact for all agencies involved. The technologies involved include:

- Communication equipment including combination of encrypted satellite telephone/communications, encrypted cellular telephone, and privately licensed CB radio frequencies.
- GPS tracking systems to monitor the location of the tractor-trailers, transportation packages, and escorts during the shipments.
- Anti-theft electronic immobilizer systems installed on the tractor-trailers, which allow remote disabling of the vehicle and may include biometric scanners for operation (e.g., handprint).

8.2.2 Emergency Response

In Canada, the emergency management community has adopted a standard approach for responding to incidents. Federal, provincial and local governments use a comprehensive approach to emergency management, which includes having in place measures for prevention, mitigation, preparedness, and response and restoration activities for all modes of transportation.

The NWMO will develop and provide a Transportation Emergency Response Plan to the Canadian regulatory agencies to demonstrate that appropriate emergency measures are in place. The plan will ensure co-ordination among the NWMO, provincial and local first responders, as well as federal agencies.

The emergency response plan may include, but is not limited to the following:

- Description of the emergency response organization and external agencies, as well as their roles, responsibilities, capabilities, and duties, and how they will work together;
- Agreements on assistance with other facilities and/or other organizations;
- Plans for mobilizing and deploying resources for response;
- Description of roles and responsibilities (e.g., driver, escort, NWMO transportation command centre staff, first on the scene team, response team, recovery team);
- Training and qualification requirements, as well as drills and joint exercises; and
- Communication protocols, as well as procedures for alerting and notifying key organizations and personnel, as well as the public.

As an additional support, Transport Canada operates Canadian Transport Emergency Centre (CANUTEC) – a national advisory service that assists emergency response personnel in handling dangerous goods emergencies on a 24/7 basis. The emergency centre is staffed by bilingual scientists specializing in chemistry or a related field and trained in emergency response.

9. NATURAL ANALOGUES

The repository will need to be effective for very long times. In addition to the stability of the geosphere, the long-term stability of the engineered barrier materials is important. These materials have been selected based in part on the known durability of similar natural materials under deep geological conditions.

In particular, the Cigar Lake uranium ore body in Saskatchewan is a natural analogue for the repository (see Figure 9.1). Geological evidence from Cigar Lake indicates that the uraninite ore, a natural uranium oxide, remained stable underground for over 1.3 billion years. The combination of uranium oxide ore, surrounded by natural clay, in a deep geological setting was effective in containing the uranium such that there was no indication of the ore deposit at the surface (Cramer and Smellie 1994). In a repository, the similar stability of the uranium oxide used fuel will also ensure long-term containment of the radionuclides in the used fuel.

Similarly, the stability of copper can be inferred from the existence of natural copper deposits. Notable examples are the natural copper plates found in the Keweenaw Peninsula, northern Michigan (Figure 9.2) and in the Permian Littleham Mudstone in southwest England. The existence of these long-lived deposits shows that copper and bentonite clay can remain stable for long periods under conditions not very different to those expected in a repository.

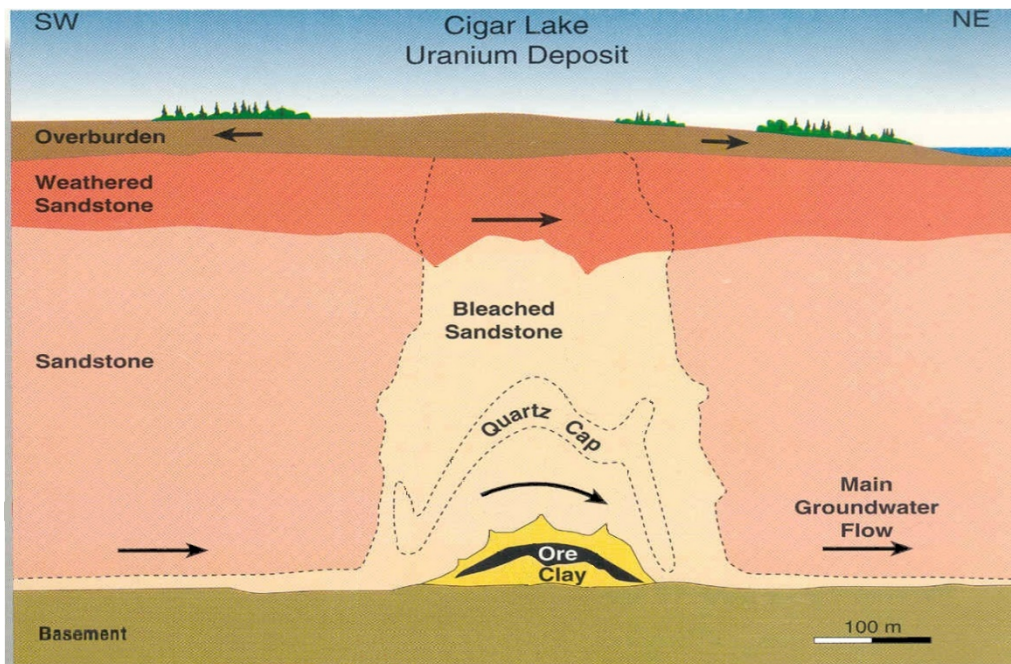


Figure 9.1: Cross-section of the Cigar Lake uranium ore body in Saskatchewan (adapted from Cramer and Smellie 1994). The uranium ore, surrounded by a clay layer at 430 m depth, has remained isolated from the surface environment for over 1.3 billion years.

There are numerous other natural analogues that provide evidence for the long-term behavior of the materials in the repository. Table 9.1 summarizes several useful analogs.

Table 9.1: Selected natural analogue studies

NATURAL ANALOGUE	PHENOMENA/PROCESSES
<i>Uranium dioxide (fuel) behaviour</i>	
Cigar Lake uranium ore body, Saskatchewan, Canada	Stability of uranium oxide over 1.3 billion years underground (Cramer and Smellie 1994).
Oklo natural reactor, Gabon, Africa	Natural nuclear reactor that operated underground for a few hundred thousand years about 2 billion years ago. Illustrates slow transport of some radionuclides in a geological setting.
<i>Copper and copper-iron behaviour</i>	
Natural copper, Keweenaw Peninsula, Lake Superior, USA	Natural copper ore formed 1 billion years ago and remained stable, illustrating durability of copper under underground conditions.
Natural copper, Littleham Cove, England	Natural copper plates formed about 200 million years ago, and preserved in compacted clay. Illustrates durability of copper in clays (SKB 2000).
Kronan cannon, Sweden	Bronze (copper alloy) cannon buried under sea mud for 300 years. Illustrates durability of copper under anoxic conditions.
Inchtuthill nails, Scotland	Buried iron nails from Romans. Illustrates slow iron corrosion in anoxic conditions.
<i>Clay behaviour</i>	
Wyoming bentonite, USA	Large deposits of bentonite clay formed from volcanic ash from 95 million years ago, illustrating durability of bentonite clay.
Dunnarobba forest, Italy	Wood tree stumps preserved in clay 2 million years ago. Illustrates bentonite clay ability to preserve materials, in part through suppressing microbial activity.
Avonlea bentonite, Saskatchewan	Chemical and mineralogical stability of bentonite over 75 million years.
<i>Cement and concrete behaviour</i>	
Hadrian's Wall, Great Britain	A simple form of cement was used in the walls 1900 years ago. Illustrates cement durability
Maqarin, Jordan	Interaction of 2 million year old natural cements with surrounding rock. Illustrates scientific understanding of the long-term effects is consistent with real site behaviour.



Figure 9.2: Natural copper sheet from White Pine Mine, Keweenaw Peninsula, Michigan, USA (on display at Royal Ontario Museum). This copper shape is because it was extracted by blasting in the mine. The copper sheet is about 1 billion years old.

10. SAFETY ASSESSMENT

A safety assessment is performed to demonstrate that the deep geological repository will meet regulatory safety criteria, taking uncertainties into account. That is, it will show that the system is robust. The safety assessment does this in part through demonstrating that under many scenarios, both likely and unlikely, the potential maximum dose to a future family living on or near the repository, using local well water and growing their own food, would not exceed the regulatory limit.

The safety assessment is a systematic quantitative analysis of the performance of the repository and comparison of this performance against criteria. The basis for the assessment is described in Canadian regulatory documents (notably REGDOC-2.11.1, CNSC 2021a,b), which are informed by international guidance (e.g., IAEA, 2011a,b). The safety assessment is ultimately evaluated by the Canadian nuclear regulator during the federal Impact Assessment and licensing processes.

Prior to the present evaluation of a repository on the South Bruce Site, seven post-closure safety assessment studies were carried out in Canada for hypothetical sites. Two of these assessments (AECL 1994, Wikjord et al. 1996) were assessed as part of the federal 1998 Environmental Assessment on the concept of deep geological disposal of nuclear fuel waste (CEAA 1998). The most recent Canadian study for a sedimentary rock site was called the Seventh Case Study (NWMO 2018).

Safety assessments of other sites have also been published in other countries, including United Kingdom (RWM 2016) and Switzerland (Nagra 2002). Safety assessments have been presented as part of the licencing process for proposed repositories in Finland (Posiva 2007), Sweden (SKB 2011) and France (Andra 2005).

Although the geological environment and details of the repository concept varied from study to study, these studies found that geological disposal of used nuclear fuel in a suitable rock and site could protect humans and the environment from the long-term hazards of used nuclear fuel. These and similar studies have supported the plans by countries with major nuclear power programs to manage their used fuel or high-level radioactive wastes in a deep geological repository (see Section 11). The NWMO is now building on these studies to develop an assessment specific to the South Bruce Site.

For the South Bruce Site, the process starts with the understanding of the site developed through the site characterization and environmental baseline programs, and the development of the engineering design for the site. This information is used in the safety assessment. As more information becomes available, and as part of the licencing process, the safety assessment is progressively iterated to provide a more detailed assessment.

At the present time, the initial NWMO assessment for the South Bruce Site has assumed that the rock formation properties are consistent with those identified in the same formations at the Bruce nuclear site. These assumptions will be revised as more site-specific information is collected.

The safety assessment evaluates the performance of the repository before and after its closure for various scenarios. During the pre-closure period, these include normal operations and

accident scenarios. During the post-closure period, these scenarios consider the likely or expected future behavior of the site, as well as unlikely or what-if scenarios. In particular, for understanding the potential impacts, the post-closure safety assessment estimates the consequences of container failure, considering anywhere from a small number to all containers failing. The potential peak dose impacts are assessed assuming a future family living at or near the repository. (Potential impacts on people living further away would be less.)

As noted in Section 2, the effects of nuclear radiation are described as the radiation dose. The results of the safety assessment are based on this concept, and for humans, radiation dose is reported here in units of millisieverts (mSv).

People are constantly exposed to nuclear radiation from naturally occurring sources in the ground and water and air around us, and to natural radiation coming from space. The average Canadian receives a dose of about 1.8 mSv each year from these natural sources (Grasty and LaMarre 2004). This natural background radiation varies by location; for example it is about 1.5 mSv in Toronto and about 4.0 mSv in Winnipeg. Around South Bruce, the natural background radiation dose is estimated as about 1.6 mSv per year (Arcadis 2022).

In Canada, the nuclear regulator CNSC has set the dose limits for members of the public at 1 mSv per year above background, and for nuclear energy workers at 20 mSv per year (CNSC 2000). In practice, the regulators and facility operators follow the principle of As Low As Reasonably Achievable (ALARA), and actual doses are much less than these regulatory limits.

The initial safety assessment makes the unlikely assumption that multiple containers have failed and that a future family is living at or near the site where they would be at highest exposure. This analysis indicates that the potential peak dose rate would be below regulatory limit and the natural background dose rate. There would be no health effects to this assumed future family.

This assessment will be revised using more site specific information.

11. INTERNATIONAL CONSENSUS

Deep geological disposal is proposed internationally as the preferred long-term management approach for used nuclear fuel and other high-level radioactive waste. It has been adopted as the national plan in most countries with substantial nuclear power programs.

Geological disposal is backed by decades of worldwide research and development, including crystalline, sedimentary and salt rocks. There have been a wide range of studies from laboratory experiments to major underground demonstration projects. Canada in particular conducted several major experiments at the AECL Underground Research Laboratory in Pinawa, Manitoba (Chandler, 2003). Collectively, this worldwide experience provides assurance that this approach is supported by good scientific understanding (OECD 2020).

There are currently no operating underground repositories for used fuel and high-level wastes, but one is under construction and two are in licencing. Table 11.1 summarizes the status in various countries for used fuel disposal.

There are several operating underground facilities for low and intermediate-level radioactive wastes in other countries, including the US WIPP facility for transuranic wastes. There are also several near-surface disposal facilities in other countries for low-level radioactive wastes.

In Canada the NWMO facility would be the only deep geological repository for used fuel. However, for clarity, the following other projects have or are being considered for nuclear wastes in Canada:

- A deep geological repository for Ontario Power Generation's (OPG) low and intermediate level radioactive waste was proposed at the Bruce nuclear site in the Municipality of Kincardine, Ontario. Environmental assessment hearings were completed in 2015, but the project was cancelled by OPG as it did not have the support of the local First Nation.
- A deep underground research laboratory was constructed near Pinawa, Manitoba, and operated from about 1980 to 2010 (Chandler, 2003). Although the site information was used to support a federal environmental assessment review (AECL 1994), it was never intended as a repository. No wastes were placed in this site, and it has since been closed and decommissioned.
- A proposed near-surface disposal facility for low-level radioactive wastes at the Chalk River nuclear site is currently being evaluated through the Impact Assessment process (CNL 2021). www.cnl.ca/environmental-stewardship/near-surface-disposal-facility-nsdf/
- A surface disposal facility for historic low-level radioactive waste was completed in 2021 at Port Granby in Ontario. A similar facility is under construction at Port Hope in Ontario. (www.phai.ca)

Table 11.1: Repository plans for used fuel and high level waste in several countries

COUNTRY	FORM OF WASTE	ROCK TYPE	DEPTH	CONTAINER CONCEPT	LOCATION	SCHEDULE
Finland	Used fuel	Crystalline rock (granite)	~450 m	Copper shell; cast iron structure; surrounded by bentonite clay	Olkiluoto reactor site on southwest coast	Construction in progress. Operating licence application in 2021.
Sweden	Used fuel	Crystalline rock (granite)	470 m	Copper shell; cast iron structure; surrounded by bentonite clay	Forsmark reactor site on east coast	Construction licence approval in 2022 (method and site)
France	Vitrified HLW, used fuel, long-lived ILW	Clay rock	~500 m	Steel containers; placed within concrete tunnels	Meuse/Haute-Marne area in east-central France	Preliminary construction licence application in 2019.
Switzerland	Vitrified HLW and used fuel	Clay rock	400 – 1000 m	Steel canister (copper coating under evaluation)	Siting process under way in three siting regions in Northern Switzerland	Site selection in late 2022
China	Vitrified HLW, used fuel	TBD	TBD	TBD	Three candidate sites in Gansu province	Constructing underground research lab at one site. Site selection in 2020s.
Russia	HLW	Crystalline rock	TBD	TBD	Zheleznogorsk in Krasnoyarsk Territory, Siberia	Site approved in 2016; constructing underground research lab at site
UK	Vitrified HLW, used fuel	TBD	TBD	TBD	TBD	Siting process underway; several communities under consideration
Germany	Vitrified HLW, used fuel	Clay, crystalline and salt rock options	TBD	TBD	TBD	Starting siting process
Japan	Vitrified HLW	TBD	TBD	TBD	TBD	Siting process underway
USA	Used fuel from power reactors and navy program, vitrified HLW	TBD	TBD	TBD	TBD	TBD. Licence application filed 2008 for Yucca Mtn but subsequently suspended

*TBD – To be decided, HLW – High-level waste, ILW – Intermediate-level waste

12. MONITORING

The site will be monitored for decades during site characterization, preparation, construction and operation, so there will be a substantial amount of information on the repository before a decision is made to close the repository.

General monitoring expectations are laid out in the International Atomic Energy Agency (IAEA) site-specific safety guide, “*Monitoring and surveillance of radioactive waste disposal facilities*” (IAEA 2014). International practice in repository monitoring is illustrated in reports from the Finnish repository site (e.g., Posiva 2012) and the Swedish repository site (e.g., Berglund and Lindborg 2017). The Canadian regulatory system also defines monitoring expectations for nuclear and other industrial facilities, for example, CSA (2015) and CNSC (2017). In particular, environmental monitoring is standard practice at all nuclear facilities including uranium mines.

Site Selection and Site Characterization Phase

At the South Bruce Site, instrumentation to monitor pressures will be installed in the first borehole, which will build on the 10 years of data obtained from similar instruments that had been installed in deep boreholes at the Bruce nuclear site. Five microseismic stations have been installed within a 50 km radius of the site, allowing for the ongoing monitoring of seismicity (i.e., earthquakes) down to magnitude one. In addition, a shallow groundwater monitoring network is being installed around the siting area and baseline environmental monitoring is underway. If this site is selected for detailed site characterization, additional monitoring installations would be completed at that time.

Site Preparation and Construction Phase

Monitoring of the environmental, geotechnical and geoscientific conditions during the shaft and repository level excavations will be used to confirm expectations from prior surface-based measurements, including directly informing the construction program (i.e., confirmation of room locations and orientations).

Tests on engineered barrier and repository operation topics will be conducted in the Underground Demonstration Facility (UDF), which would be constructed early in the excavation stage. Figure 12.1 is an illustration of the repository concept showing the underground demonstration areas.

The tests during this phase will include short-term tests that would inform the application for a licence to operate the facility, as well as installation of longer-term tests that could be used to inform future closure decisions, such as installing sealing material compatibility tests in boreholes, or container tests in a trial emplacement room. Monitoring equipment would be installed as part of these tests located within the central services area.

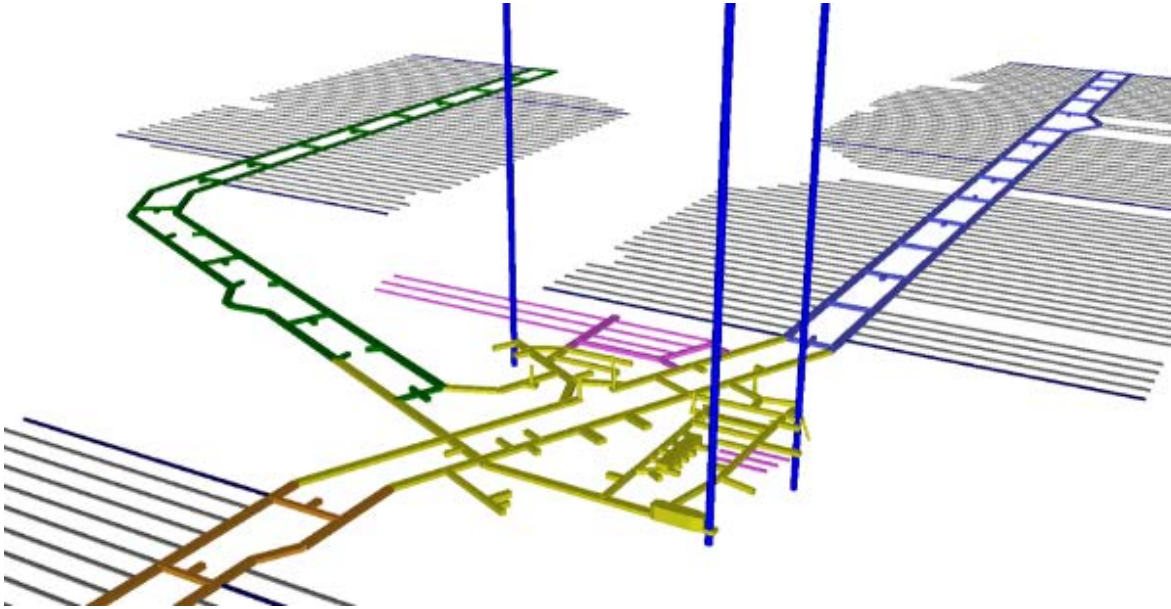


Figure 12.1: Illustration of centralized service area of repository showing the underground demonstration areas (highlighted in purple). (For illustration purposes only; does not reflect site specific layout for South Bruce Site.)

Operations, Monitoring and Closure Phase

The operations, monitoring and closure phase will extend over a period of 100+ years. During this time, monitoring of the environmental and geological conditions would continue.

Ongoing environmental monitoring will support the repository construction and operations, as well as confirm that the repository is not causing unanticipated effects on people or the environment, including water.

There are three general categories of underground monitoring that would occur during this time:

- Geological monitoring;
- Underground Demonstration Facility (UDF) tests; and
- Specialty borehole tests and monitoring.

The first category would include the continued monitoring of geological conditions including:

- Stress fields in the rock, and changes caused by excavation and heating;
- Groundwater pressure and chemistry, and changes caused by excavation and heating;
- Rock temperature, and changes caused by excavation, ventilation and heating; and
- Initiation, propagation and dilation of fractures, displacement of rock around openings.

This monitoring would be achieved by several methods including remote monitoring (e.g., acoustic emission), tunnel monitoring (e.g., groundwater chemistry, temperature) and borehole monitoring (e.g., chemistry, radioactivity, porewater pressure, temperature). It will be used to verify that, at least at distances of tens of metres from the containers, conditions are as expected. All monitoring systems will be designed to ensure no impact to the functionality of the engineered barrier system and long-term safety of the repository.

The second category would include dedicated tests conducted within the UDF (or other niche areas). The first is the early UDF area where tests are installed soon after repository excavation has connected two shafts to allow an air flow and underground working area to be established. The second is a larger area for trial emplacement room tests.

In the demonstration tests, containers could be installed in a well-monitored environment similar to a repository emplacement, monitored continuously and decommissioned for examination at various times. If the containers have used fuel, and if they are installed with close-by monitoring, there may be an expectation that they would be retrieved and re-emplaced without the monitoring hardware as part of the final repository closure.

The third category of monitoring covers specialty tests that may occur across the repository and check aspects of performance of the as-emplaced containers. Important factors in planning for this monitoring are the longevity of the sensors and whether they could affect the system that they are monitoring. For example, large scale experiments to date have embedded sensors within buffer elements, and have often observed that the power or signal cables can affect the test as they penetrate through the otherwise self-sealing clay buffer. Also, many of these instruments have a lifetime measured in years under in-situ conditions, which is short relative to the potential time frame of interest. Together, this puts an emphasis on monitoring that is remote, such that the instruments can be maintained if necessary and such that they do not interfere with the controlled conditions in the engineered barriers.

These constraints generally limit the testing to that conducted through boreholes around an emplacement room, with enough standoff distance to minimize risk of interference with the rooms, and to remote sensors such as acoustic emission monitoring.

Post-closure Monitoring

After closure, the site is essentially fully returned to its intended end-state. The level of monitoring will be reduced but is expected to include continued environmental monitoring of surface and shallow groundwaters. Other monitoring that could be undertaken would focus on parameters that are indicative of the conditions near or within the repository. Options include monitoring through deep boreholes in the vicinity of the repository (e.g., groundwater chemistry, radionuclides, pressure, temperature), remote sensing such as acoustic emission or microseismics arrays from surface or near-surface, and satellite monitoring of surface temperature and elevation change.

These will monitor the evolution of the site from the repository operations state to the post-closure state. Once future generations are comfortable that the repository is performing as designed, post-closure monitoring is expected to cease.

Knowledge Preservation

A related aspect to monitoring the repository, is preserving information on the repository over the long timescales required to, in part, prevent inadvertent intrusion, but also to keep future generations informed to support their planning and decisions. This is a topic of global interest, and Canada participates in these discussions (Pescatore et al. 2019).

The NWMO anticipates this would be done in different forms. In particular, there would be land use controls imposed. And key information files would be preserved widely and in various formats. It is anticipated that some type of marker would be provided at the site itself.

13. REGULATORY FRAMEWORK

The NWMO facility is defined as a Class IB nuclear facility under the federal *Nuclear Safety and Control Act* and regulations.

Canada has a well-developed regulatory framework for evaluation of safety of nuclear facilities. This framework is consistent with international best practice (e.g., IAEA 2011a, 2011b), and requires the proponent to complete a series of licensing decision steps, with progressively more information.

The first formal step is an assessment in accordance with the federal *Impact Assessment Act*. Subsequently licences are required from the Canadian regulator, the Canadian Nuclear Safety Commission (CNSC), to prepare the site, to construct the repository, to operate the facility, to decommission the facility, and eventually to abandon the site (release it from regulatory licencing).

In evaluating any proposed repository, CNSC would consider the extent to which the proposal addresses the principles set out in their regulatory document REGDOC-2.11 (CNSC 2021a):

- a) generation of radioactive waste is minimized to the extent practicable by the implementation of design measures, operating procedures and decommissioning practices;
- b) the management of radioactive waste is commensurate with its radiological, chemical and biological hazard to the health and safety of persons and the environment and to national security;
- c) the assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time when the maximum impact is predicted to occur;
- d) predicted impacts on the health and safety of persons and the environment from the management of radioactive waste are no greater than the impacts that are permissible in Canada at the time of the regulatory decision;
- e) measures needed to prevent unreasonable risk to present and to future generations from the hazards of radioactive waste are developed, funded and implemented as soon as reasonably practicable; and
- f) trans-border effects on the health and safety of persons and the environment that could result from the management of radioactive waste in Canada are not greater than the effects experienced in Canada.

14. UNCERTAINTIES AND FUTURE WORK

A variety of studies are ongoing in site characterization, environmental baseline, engineering and safety assessment, which will improve our understanding of the site and its safety basis (see, for example, Figure 14.1).

One site specific uncertainty is the geometry of a sediment-filled valley located along the west side of the South Bruce Site, just west of the Teeswater River. The valley is about 50-m deep and trends southwesterly at surface. This is expected to be a shallow feature, which will not impact repository containment and isolation functions, but will need to be characterized in order to accurately model surface and shallow groundwater movement.

To date, where the potential host rock has been encountered at depth, it has been tight (i.e., cannot transmit sufficient groundwater for fluid geochemical analyses). The tightness of the rock is a favourable property in the context of containment and isolation functions of a repository but also requires additional methods to understand the water chemistry deep in the subsurface. Given this limited availability of groundwater samples in the Cobourg Formation (and the overlying Ordovician shales), an emphasis is instead placed on measuring the porewater chemistry in order to define hydrogeochemical trends with depth and the overall understanding of system evolution. Together, the groundwater and porewater chemistry are important datasets used to develop an understanding of the relative ages of fluids within the shallow to deep groundwater systems, and to allow assessments to be made of potential interactions with engineered barrier materials should the site be selected to host a repository.

In order to reduce these uncertainties additional studies are planned, including more fieldwork and drilling of additional boreholes as part of the detailed site characterization program should the South Bruce Site be selected. Further information will also be obtained during repository construction by characterisation of tunnel walls, drilling of pilot holes, and other techniques to confirm the nature of the geology. Also, the wide range of measurements that are currently underway will be integrated into a conceptual model that will serve to improve the overall site understanding across all geoscientific disciplines, and on-going activities such as seismic monitoring and long-term pressure monitoring of boreholes are continually adding to a regional database of geoscientific information.

It should also be noted that the simple geometry and laterally continuous nature of the sedimentary formations suggest that the overall geological character of the bedrock beneath the South Bruce Site is already relatively well understood.

Numerical modelling will soon be underway to integrate the results into a consistent site model. Formally, the information on the current site characteristics will be documented in a Descriptive Site Geosphere Model, and the past and projected future conditions (e.g., future ice ages) will be documented in a Geosynthesis report.

In addition to the ongoing geological and environmental site characterization work, there is work underway to improve the engineered barriers and the design, and to conduct a safety assessment.



Figure 14.1: Photo of one of five microseismic monitoring stations installed around the area in order to obtain more detailed information on site seismicity.

A site-specific engineering design is being developed, as well as continued optimization of the engineered barriers, fuel handling, and emplacement systems. In 2022, for example, full-scale non-nuclear trials at NWMO's test facility are planned to demonstrate prototype emplacement equipment. Important areas of work include the underground layout and the specific repository depth.

The high salinity of the porewater at repository depth is an important feature of this site. It is generally favourable for repository performance as it is consistent with long-term geological stability and low groundwater flow. High salinity however has a range of effects on the engineered barriers that need to be considered. For example, it reduces the extent of bentonite clay swelling, but is intrinsically favourable for suppressing microbial activity which is one of the function of the swelling clay. Work to date has been conducted using regional chemistry and salinity information. As the specific chemistry at this site is measured in the site characterization program, work will be needed to establish properties and optimized design for these specific chemistry conditions.

For safety assessment, work is underway to develop site-specific models, including the interface between the underground geology and the surface environment. Important topics in the near term include incorporating the developing understanding of the geology and groundwater chemistry into the safety assessment.

15. CONCLUSIONS

The Nuclear Waste Management Organization (NWMO) is presently in a multi-year process of identifying a safe site for a deep geological repository for Canada's used nuclear fuel in an area with informed and willing hosts. This is similar to plans in other countries with nuclear power programs, including in particular Finland and Sweden which have approved sites for their planned deep geological repositories.

The fundamental safety objective of the project is to protect humans and the environment, including water, from harmful effects of radioactive or hazardous substances present in the used fuel.

The used fuel is initially very radioactive and hazardous. However, its radioactivity naturally decreases with time. The deep geological repository, including engineered and natural barriers, provides containment and isolation while this natural process occurs.

Previous discussions and studies have identified the Revell Site in northwestern Ontario and the South Bruce Site in southern Ontario as candidate repository sites. Neither of the two sites have yet been identified as the preferred site.

This report focuses on the South Bruce Site. It summarizes the results to date with respect to why this site would be suitable from a technical perspective for hosting a repository. It is intended to support public discussion around site selection, and is focussed on those aspects that are likely of most interest to that discussion.

Based on the assessment results to date, the NWMO is confident that a deep geological repository could be constructed at the South Bruce Site in a manner that would provide safe long-term management for Canada's used nuclear fuel.

This report is part of a larger and ongoing site assessment process. Ongoing and future technical work will include further site studies, design development and safety analyses to further check and clarify the safety basis. If the site is formally proposed for a repository, this work would ultimately be presented to Canadian federal regulators for an Impact Assessment and then for a series of licence applications. This is a process that will take years before approval to construct could be received. And even after construction and then operations begins, there will be continued monitoring to ensure that the site is and remains suitable.

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