NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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NWMO BACKGROUND PAPERS
6. TECHNICAL METHODS

6-15 ADAPTIVE PHASED MANAGEMENT: DRAFT TECHNICAL DESCRIPTION

Nuclear Waste Management Organization

ADAPTIVE PHASED MANAGEMENT
DRAFT TECHNICAL DESCRIPTION

July 2005

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1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) has evaluated options for the long-term management of Canada's used nuclear fuel. It has examined the three options identified in the *Nuclear Fuel Waste Act (NFWA) (An Act Respecting the Long-Term Management of Nuclear Fuel Waste)* which was brought into force in November 2002:

(1) Deep geological disposal in the Canadian Shield;
(2) Storage at nuclear reactor sites; and
(3) Centralized storage, either above or below ground.

Conceptual designs and cost estimates have been prepared by consultants for the Joint Waste Owners (JWO) (Ontario Power Generation Inc., Hydro-Québec, NB Power Nuclear and Atomic Energy of Canada Limited) for the three options and the associated transportation systems. These reports are available on the NWMO website (www.nwmo.ca/conceptualdesigns). (For example, see Cogema 2003; CTECH 2002; CTECH 2003a; CTECH 2003b).

The three options for long-term management of used fuel have undergone detailed evaluation by the NWMO Assessment Team (Ben Eli et al. 2004) and by Golder/Gartner Lee (2005). The three options were also outlined in the NWMO's Second Discussion Document *Understanding the Choices* (NWMO 2004) and were the subject of extensive cross-country discussion and dialogue with Canadians in the autumn 2004. What we found was each option has strengths, but each option has limitations as well.

From the numerous NWMO's meetings, presentations, dialogue sessions and input to our website, it is becoming clear that the three approaches outlined in the *NFWA* do not capture the necessary features and attributes of a preferred management approach for used nuclear fuel in Canada. There were suggestions that the NWMO should consider a fourth management approach which would select the best features of the three approaches in the *NFWA* and implement them in a staged or phased manner over time (DPRA 2005).

Canadians have told us that the overarching objective for managing used nuclear fuel must be to protect humans and the environment. Therefore, our overall goal is to effectively contain and isolate used nuclear fuel for all time while ensuring that it is managed safely and securely at all times. A long-term management approach which is based on containment and isolation of used fuel is consistent with the draft regulatory guidance provided by the Canadian Nuclear Safety Commission (CNSC) for assessing long-term safety of radioactive waste management (CNSC 2005).

We plan to achieve this overall goal is by implementing an adaptive risk management approach based on centralized containment and isolation of Canada's used nuclear fuel deep underground (NWMO 2005). At all times throughout the three major phases the used fuel would be safe, secure, monitored and retrievable. Containment of used fuel would be achieved through a robust system of engineered barriers and isolation of used fuel would be achieved through a combination of institutional controls and natural barriers.

A staged approach to concept implementation reflects both the complex nature of the task and the very long duration of the activities. It also reflects the desire by many stakeholders to proceed by cautious steps with due regard to technical issues and social acceptance.

The NWMO has developed a high-level description of a **Fourth Option** which can be called **Adaptive Phased Management**. This option has been included in the NWMO's Draft Study Report *Choosing a Way Forward* and forms the basis of the draft recommendation (NWMO 2005). We believe that this approach addresses many of the issues that Canadians have identified during the NWMO study process and provides genuine choice, flexibility and options for long-term care of Canada's used nuclear fuel.

This report outlines a general illustrative technical description of Adaptive Phased Management which can be used for conservative planning and cost estimating purposes. Note that the illustrative description of activities, timetables and outcome of key decisions may appear more definitive than it actually would be given the choice and flexibility of the approach.

2. TECHNICAL DESCRIPTION OF ADAPTIVE PHASED MANAGEMENT

2.1 Three Phases of Implementation

Following a decision by the Government of Canada on the preferred approach for long-term management of Canada's used nuclear fuel, the NWMO would begin implementation of Adaptive Phased Management starting in Year 01.

In Table 1, we provide a high-level description of the activities during three major phases of concept implementation.

2.2 Illustrative Overall Schedule and Key Decisions during Implementation

Each of the three phases of Adaptive Phased Management has many activities and decision points. While we do not know the precise duration of these activities or the outcome of future decisions in the approach, we can provide an indication of a representative schedule for implementation based on the conceptual design work and analyses of the three previous options for used fuel management (Cogema 2003; CTECH 2002; CTECH 2003a; CTECH 2003b) and international experience in radioactive waste management.

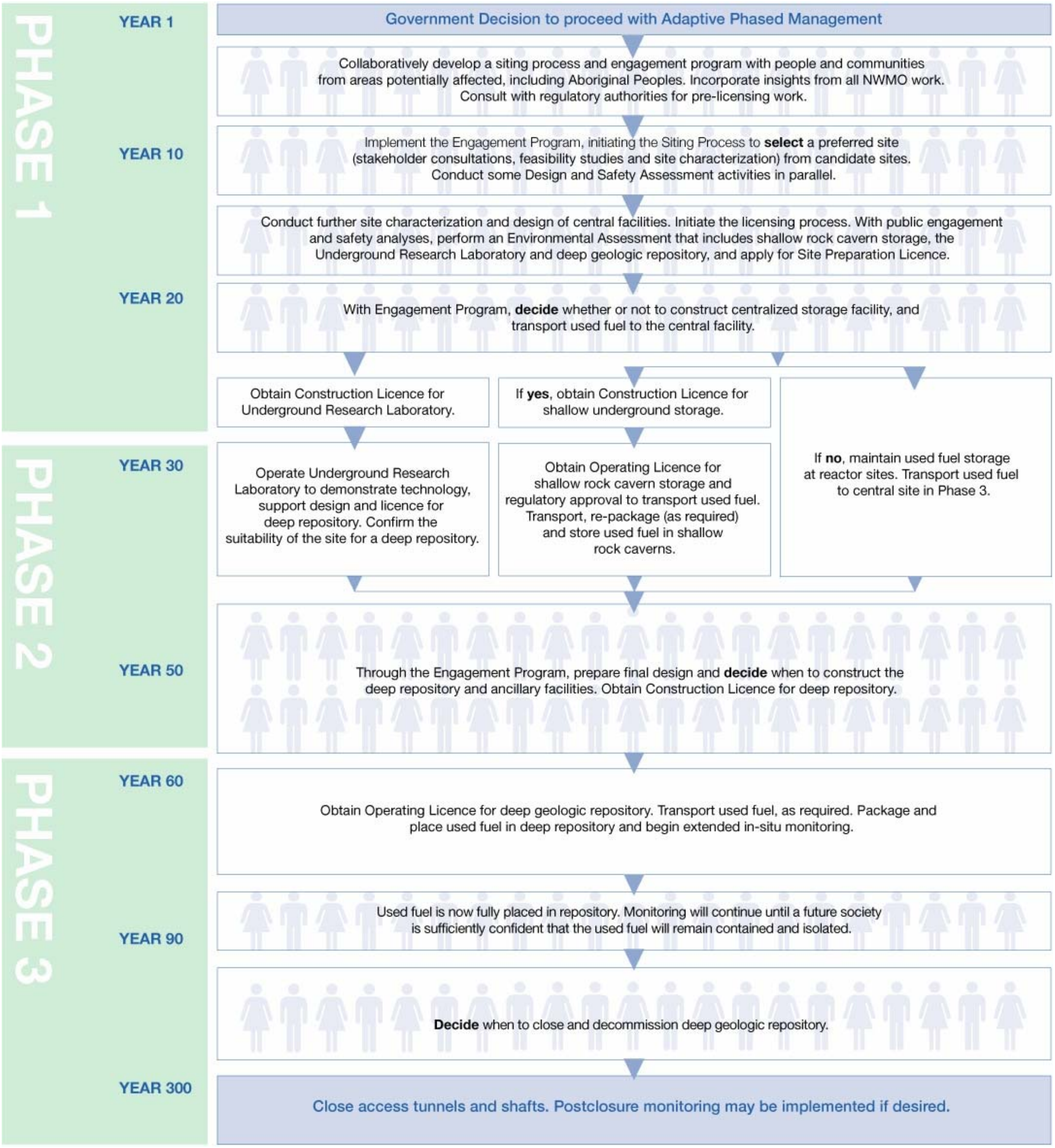
An example of a possible activity flowchart and key decisions during implementation of Adaptive Phased Management is shown in Figure 1. Some of the key decisions which would need to be made over the next several decades and beyond include:

- **Select** a preferred site for central, long-term management of used nuclear fuel.
- **Decide** whether or not to construct an interim underground storage facility at the central site and transport used fuel to the central facility while awaiting development of the deep geologic repository.
- **Decide** when to construct the deep geologic repository and ancillary facilities.
- **Decide** when to close the deep geologic repository and decommission the surface facilities.

Table 1: Three Phases of Adaptive Phased Management

PHASE	
Phase 1: Preparing for Central Used Fuel Management	Maintain storage and monitoring of used fuel at nuclear reactor sites; Develop with citizens an engagement program for activities such as design of the process of choosing a site, development of technology and key decisions during implementation; Continue engagement with regulatory authorities to ensure pre-licencing work will be suitable for the subsequent licencing processes; Select a central site that has rock formations suitable for shallow underground storage, an underground research laboratory and a deep geologic repository; Continue research into technology improvements for used fuel management; Initiate licencing process, which triggers the environmental assessment process under the *Canadian Environmental Assessment Act*; Undertake safety analyses and environmental assessment to obtain the required licences and approvals to construct the shallow underground storage, underground research laboratory and deep geologic repository at the central site, and to transport used fuel from the reactor sites; Develop and certify transportation containers and used fuel handling capabilities; Construct the underground research laboratory at the central site. Decide whether or not to proceed with construction of shallow underground storage facility and to transport used fuel to the central site for storage during Phase 2; and If a decision is made to construct shallow underground storage, obtain an operating licence for the storage facility.
Phase 2: Central Storage and Technology Demonstration	If a decision is made to construct shallow underground storage, begin transport of used fuel from the reactor sites to the central site for extended storage. If a decision is made not to construct shallow underground storage, continue storage of used fuel at reactor sites until the deep repository is available at the central site; Conduct research and testing at the underground research laboratory to demonstrate and confirm the suitability of the site and the deep repository technology; Engage citizens in the process of assessing the site, the technology and the timing for placement of used fuel in the deep repository; Decide when to construct the deep repository at the central site for long-term containment and isolation during Phase 3; and Complete the final design and safety analyses to obtain the required operating licence for the deep repository and associated surface handling facilities.
Phase 3: Long-term Containment, Isolation and Monitoring	If used fuel is stored at a central shallow underground facility, retrieve and repackage used fuel into long-lived containers. If used fuel is stored at reactor sites, transport used fuel to the central facility for repackaging; Place the used fuel containers into the deep geologic repository for final containment and isolation; Continue monitoring and maintain access to the deep repository for an extended period of time to assess the performance of the repository system and to allow retrieval of used fuel, if required; and Engage citizens in on-going monitoring of the facility. A future generation will decide when to close the repository, decommission the facility and the nature of any postclosure monitoring of the system.

Figure 1: Activity Flowchart and Key Decisions for Adaptive Phased Management



*Note, the specific allocation of years for the three major phases of Adaptive Phased Management is for illustrative purposes only.

These decision points in Adaptive Phased Management provide Canadians with genuine choice and the opportunity for the public and other interested stakeholders to participate in concept implementation, including participation in the key decisions which must be made before proceeding to the next step of concept implementation.

The key activities and schedule for Adaptive Phased Management highlight one possible way of proceeding down the path of concept implementation. The precise duration of activities and the outcome of future decisions cannot be known at this time. Nevertheless, the NWMO has prepared an illustrative schedule of activities and conservative decision outcomes for conceptual design, cost estimating and concept analysis purposes. This illustrative schedule of activities is shown in Figure 2.

Note, these example timelines should not be considered as the definitive implementation timetables which would need to be developed following a decision on the preferred management approach by the Government of Canada.

3. Phase 1: Preparing for Central Used Fuel Management

This phase sets the necessary building blocks for establishing the facilities and infrastructure for long-term management of used fuel. While much has been done to advance the technology for used fuel management in Canada, clearly more research and development work needs to be completed. Our approach will enable us to take the time required to gain greater certainty in the performance of used fuel storage, transportation and isolation technologies, and Canadians would have the opportunity to participate in the radioactive waste management programs in other countries with similar concepts and geographical features.

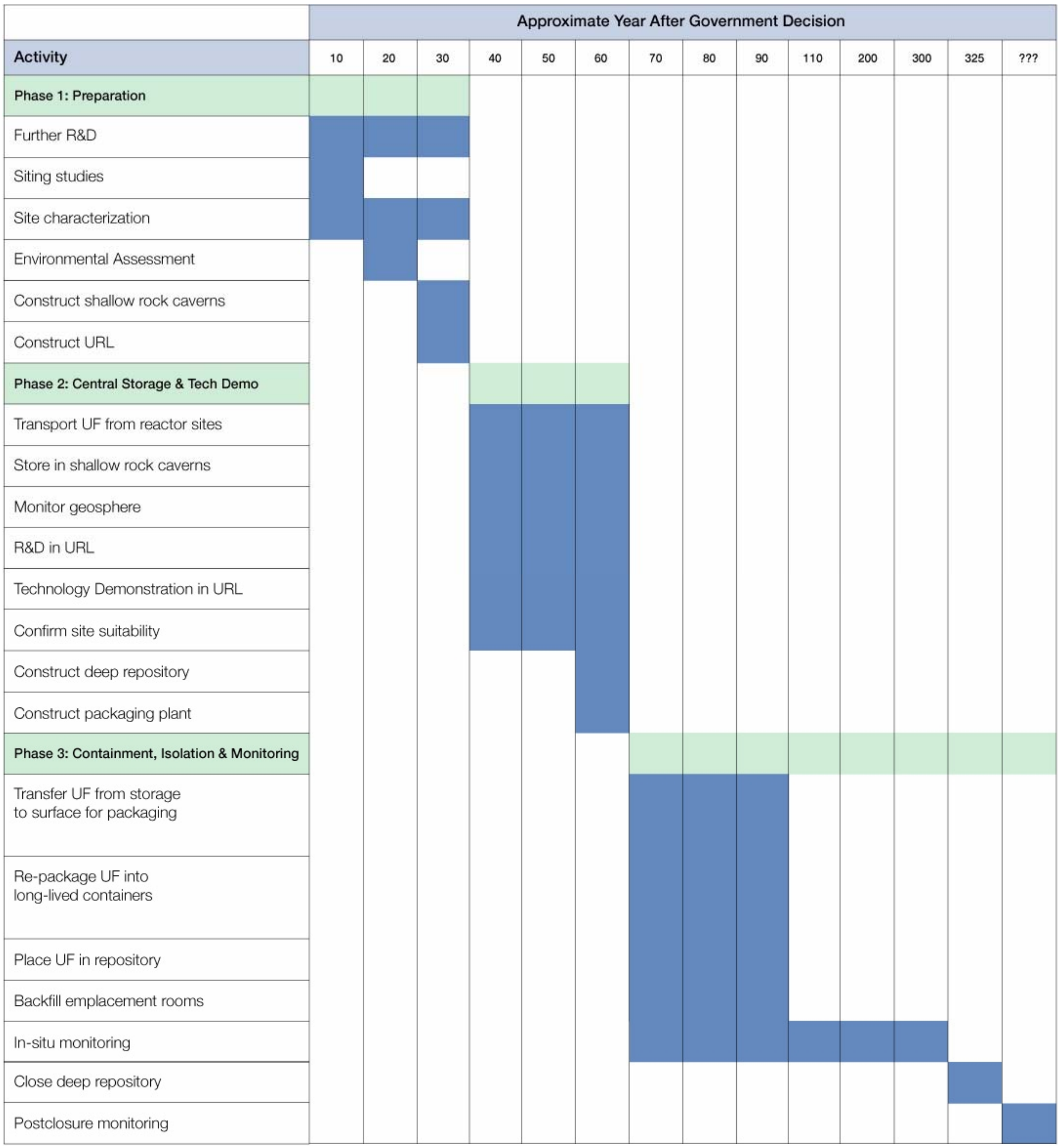
We will put the necessary effort into gaining public confidence in the safety and security of the approach.

3.1 Locating a Central Site for Used Fuel Management

Based on international siting experience in Finland and Sweden, and the conceptual design studies developed for the long-term management options in Canada, we expect that it would take about 10 years to complete the siting feasibility studies and locate a preferred site for long-term management of used fuel. It would then take another 10 years to complete the detailed site characterization, safety analyses, complete the environmental assessment and obtain a Site Preparation Licence for shallow underground rock cavern storage, an underground research laboratory (URL) and a deep geologic repository at the central site. Construction Licences for these facilities would follow at a later time. Public and other stakeholder involvement would be important during the siting process and the environmental assessment and licensing activities.

If a decision is made to build the central storage facility sometime around Year 20, we are planning for 10 years to construct the surface handling facilities and the shallow rock caverns and to construct the underground research laboratory at the central facility. An Operating Licence for shallow rock cavern storage would be obtained by Year 30.

Figure 2: Illustrative Overall Schedule for Adaptive Phased Management



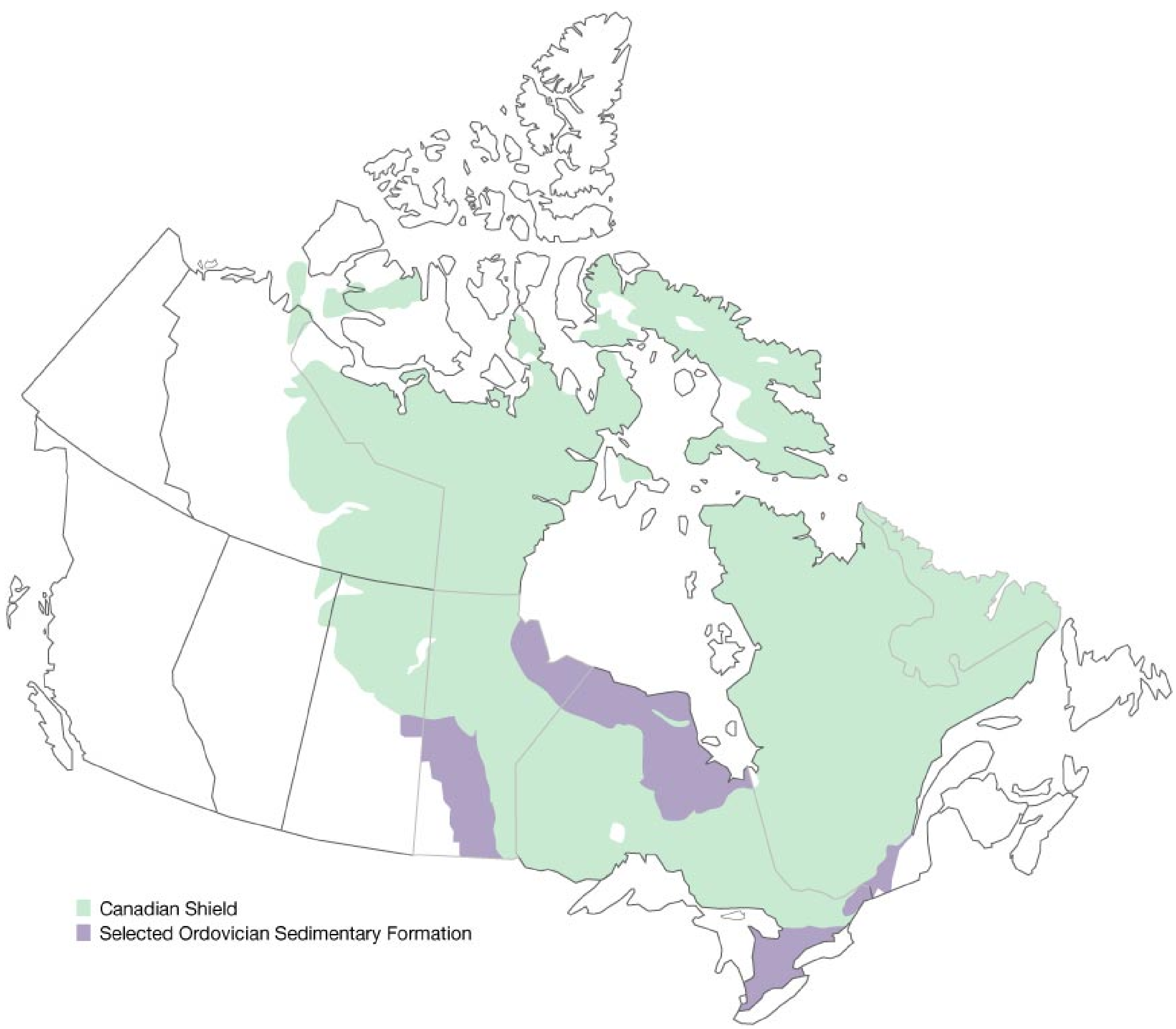
Therefore, for planning and cost estimating purposes, we have indicated about 30 years after Government of Canada decision for locating a central site and building related facilities. It may take longer. It may happen sooner. However, we consider that three decades is a reasonable time period based on international experience.

NWMO intends to seek a willing host community for any facility that may be required, for example, a community with geomedia suitable for shallow underground storage and for a deep geologic repository. Examples of suitable geomedia in Canada may include host rock formations such as the crystalline rock of the Canadian Shield (AECL 1994) and the Ordovician sedimentary rock basins (Mazurek 2004).

The rationale for the selection of these potentially suitable host rock formations is given in Appendix A.

In order for a site to be acceptable, it would need to address scientific and technical factors to ensure that any facility built is capable of protecting us and future generations, other life-forms and the biosphere as a whole into the indefinite future. Potentially suitable siting areas for a central used fuel management facility are illustrated in Figure 3.

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



3.2 Geotechnical and Other Siting Factors

Geotechnical investigations in Canada and elsewhere have confirmed that there are several types of geological formations that possess the features for long-term isolation. The scientific and technical siting factors include:

- Location in suitable rock such as the crystalline rock of the Canadian Shield or in the Ordovician sedimentary rock basins;
- Absence of known potential economic resources at depth;
- Sufficient surface area for receipt facilities and associated infrastructure.
- Seismically stable region with low known or projected frequency of high magnitude earthquakes;
- Low frequency of major groundwater conducting fracture zones, features or faults at repository depth;
- Geotechnically suitable host rock formation near surface for the shallow rock cavern vaults;
- Geotechnically suitable host rock formation at least 200 metres below surface with a preference for a suitable host rock formation between 500 and 1,000 metres below surface for the underground research laboratory and the deep geologic repository;
- Geochemically suitable (e.g., reducing) conditions in groundwater at repository depth;
- Evidence of rock mass homogeneity and stability at repository depth;
- Low hydraulic gradient and low permeability; and
- Diffusion controlled transport of dissolved minerals at repository depth.

Other environmental and social factors may also impact the siting process such as:

- Minimize distances for transporting used fuel and construction resources to the central facility;
- Avoidance of national and provincial parks, environmentally sensitive and protected areas, agricultural land, wetlands, permafrost; and
- Availability of road, rail or water transport options for used nuclear fuel.

The siting process will outline a complete set of siting principles and other factors in site selection.

3.3 Interim Storage of Used Fuel at Reactor Sites

During the siting process, used fuel will continue to be safely stored on an interim basis at each of the reactor sites in Canada, in storage facilities licensed by the Canadian Nuclear Safety Commission. When used fuel is removed it is initially stored under several metres of water in used fuel bays adjacent to the reactors where it cools down for a period of seven to ten years. The fuel bundles are then transferred to dry storage facilities constructed at the reactor sites where they are encased in steel and concrete containers designed to absorb radiation and contain the material from the environment.

The design life of these dry storage facilities is typically about 50 years, although their life expectancy is expected to be 100 years or longer.

An example of wet and dry interim storage facilities is illustrated in Figures 4, 5 and 6.

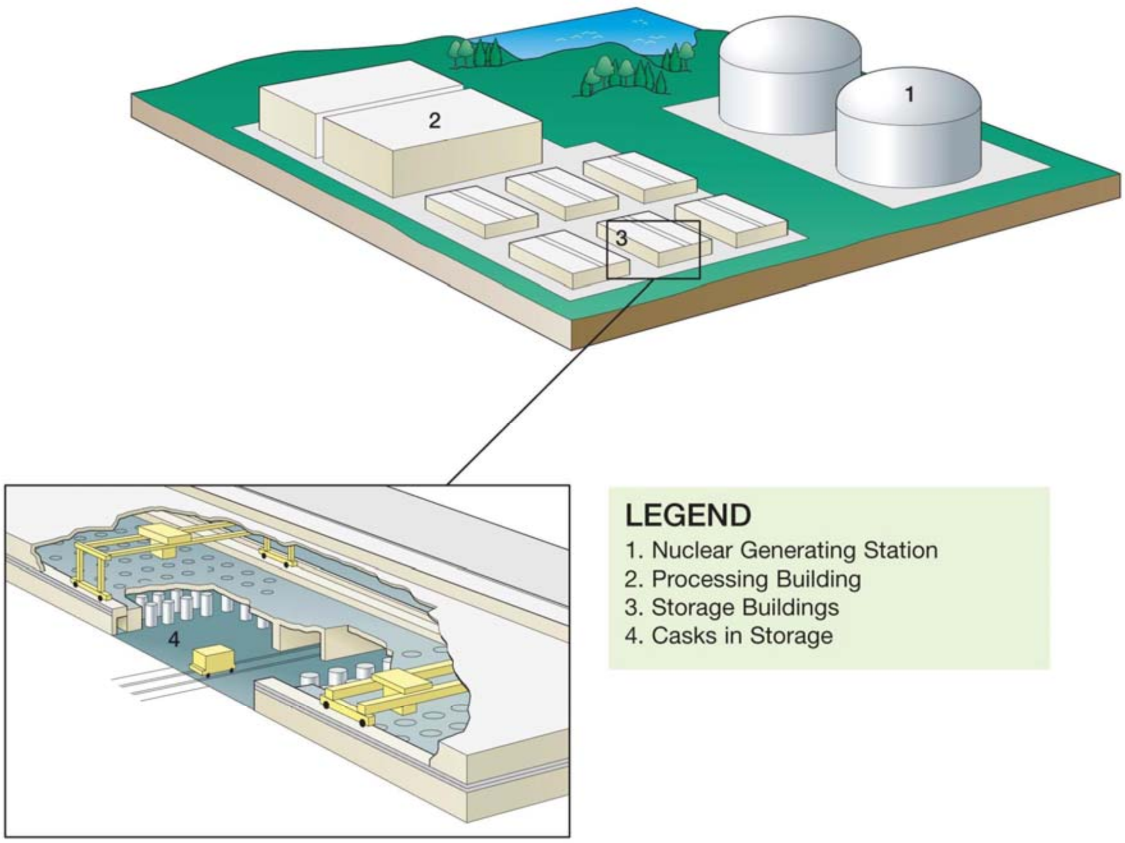
Figure 4: Example of Existing Used Fuel Storage in Wet Fuel Bays at Nuclear Reactor Sites

Figure 5: Example of Existing Used Fuel Storage in Dry Storage at Nuclear Reactor Sites – Surface Storage Building

Figure 6: Example of Existing Used Fuel Storage in Dry Storage at Nuclear Reactor Sites – Dry Storage Container

A generalization of Phase 1 Preparing for Central Used Fuel Management is illustrated in Figure 7.

Figure 7: Phase 1 – Preparing for Central Used Fuel Management



3.4 Continued Research and Technology Development

The siting period will also continue the necessary research and development of the technology for used fuel storage, transportation and isolation. For example, containers and handling systems for interim storage of used nuclear fuel in shallow underground rock caverns may need a design update (CTECH 2003b). Transportation systems for used fuel would need further development, testing and demonstration (Cogema 2003). And the mode of transportation: road, rail or water, may need further optimization to meet the needs of potential host communities for the central facility.

Research and development activities for a deep geologic repository will be required to identify, characterize, engineer, analyze, study, demonstrate and select the appropriate isolation technology and final site during the siting phase. This research and development will address development of site screening criteria and the site selection process, technical and social site characterization, biosphere and geosphere evaluation, computer model development, repository engineering and safety assessment activities conducted to support the feasibility studies in potential host communities, and the selection of a final engineering design and preferred site to support the safety and environmental impact assessment documents and related licensing activities. It would also include development of used fuel monitoring activities at repository depth, demonstration of used fuel container placement and retrieval technology at international underground research laboratories, vault sealing system development, security development work and further development of transportation technology, logistics and implementation schedule.

Initially, the research and development would take place at surface laboratories and at international underground research laboratories at generic sites such as the Äspö Hard Rock Laboratory in Sweden (SKB 2003). (Canadian organizations are currently participating in international research projects at Äspö). Later, the research and development would take place at the underground research laboratory at the preferred site in Canada.

The research and development program follows the step-wise implementation of the adaptive phased management approach with specific information designed to support the decision-making process. Examples of key technical decisions for long-term isolation of used fuel which would be supported by the research and development program include:

- Identification of potentially suitable geomedia at candidate sites for a deep geologic repository (e.g., crystalline rock, sedimentary rock);
- Identification of the site selection process and site screening criteria;
- Selection of candidate sites for a deep geologic repository from preliminary feasibility studies;
- Selection of the preferred host rock and depth for a shallow underground storage facility;
- Selection of the preferred host rock and depth for the deep geologic repository;
- Selection of the preferred site for the underground research facility and the deep geologic repository;
- Selection of long-term isolation design alternative (e.g., in-floor, in-room or long horizontal borehole placement of used fuel containers);
- Selection of the optimal transportation technology, route and logistics (timing);
- Identification of the repository monitoring system during used fuel container placement operations;
- Identification of the nuclear materials safeguards systems for used fuel transportation, storage and placement in a deep geologic repository;
- Identification of the repository monitoring system after used fuel container placement operations;

- Identification of design improvements for a deep geologic repository;
- Identification of the time period for extended monitoring of the deep geologic repository (after container placement operations are complete) and any impacts on the integrity of the used fuel containers within the placement rooms; and
- Support for a decision to decommission and close the facility.

It is expected that the Canadian research and development program would continue its international collaboration and joint R&D program activities with other waste management organizations such as Posiva, SKB and Nagra (Hobbs et al. 2005) and seek opportunities to collaborate with other waste management organizations, as appropriate.

3.5 Construction of Shallow Rock Caverns for Interim Used Fuel Storage

Following the 20-year siting process and obtaining licences to build the central used fuel management facility, Adaptive Phased Management includes the provision for secure underground storage of used fuel in shallow rock caverns constructed at a nominal depth of about 50 metres below surface. There will also be construction of surface buildings and associated facilities to receive used fuel and to provide re-packaging of used fuel for underground storage, as required. Repackaging will depend in part on the eventual mode of used fuel transport from reactor sites: road, rail or water.

As indicated in Figure 1, the decision to construct the shallow rock caverns is assumed to occur in Year 20. This decision is also related to a decision to transport used fuel from the reactor sites to the central facility at about the same time. The need for centralized used fuel storage will depend on a number of social, technical and financial drivers which are not known at this point in time. The Adaptive Phased Management approach provides for this choice and the flexibility to proceed with interim storage at a central facility with used fuel transportation, or continued storage at reactor sites and delayed used fuel transportation until the deep geologic repository is available.

For conceptual design, cost estimating and analysis purposes, the NWMO has conservatively assumed that a central interim used fuel storage facility would be required and that it would take about 10 years to construct the shallow rock caverns and surface support facilities.

3.6 Construction of the Underground Research Facility

The underground research facility is planned to be constructed at a nominal depth between 500 to 1,000 metres below ground at the central facility. This is the depth where we expect the used fuel would eventually be placed for long-term containment, isolation and monitoring.

Since the 1980s, Canada and other countries have conducted many years of research into deep rock repositories for used nuclear fuel and high-level radioactive wastes. Examples of underground research facilities include Atomic Energy of Canada Limited’s (AECL’s) Underground Research Laboratory in Manitoba and SKB’s Äspö Hard Rock Laboratory in Sweden. This particular underground research facility would conduct site-specific research to improve our understanding and confirm the suitability of the site, and demonstrate the safety and feasibility of all aspects of the long-term isolation technology. Canada will also benefit from ongoing studies and demonstrations at international underground research laboratories such as the Äspö Hard Rock Laboratory in Sweden. Following the licensing process, we anticipate that it will take about ten years to construct the shallow underground caverns and the underground research facility.

The next phase of development will build on the progress from the first phase, and will enable transportation of Canada's used nuclear fuel to a central site.

4. Phase 2: Central Storage and Technology Demonstration

4.1 Rock Cavern Storage and Used Fuel Transportation

If a decision is made to provide shallow underground storage of used fuel at the central site, then used fuel transportation would be required to move used bundles from reactor storage sites to a central facility for interim storage in the shallow rock caverns. The mode of transport would depend on the site chosen for the central facility. We anticipate it would take about 30 years to move the estimated 3.7 million used fuel bundles from Canada's seven nuclear reactor sites to the central site (Cogema 2003). This estimated used fuel inventory is based on the assumption that the current fleet of commercial nuclear power reactors in Canada have an average life of 40 years. An example of a shallow rock cavern storage facility is illustrated in Figures 8 and 9 (CTECH 2003b).

Figure 8: Used Fuel Storage in Shallow Rock Caverns at Central Facility – Ramp Access

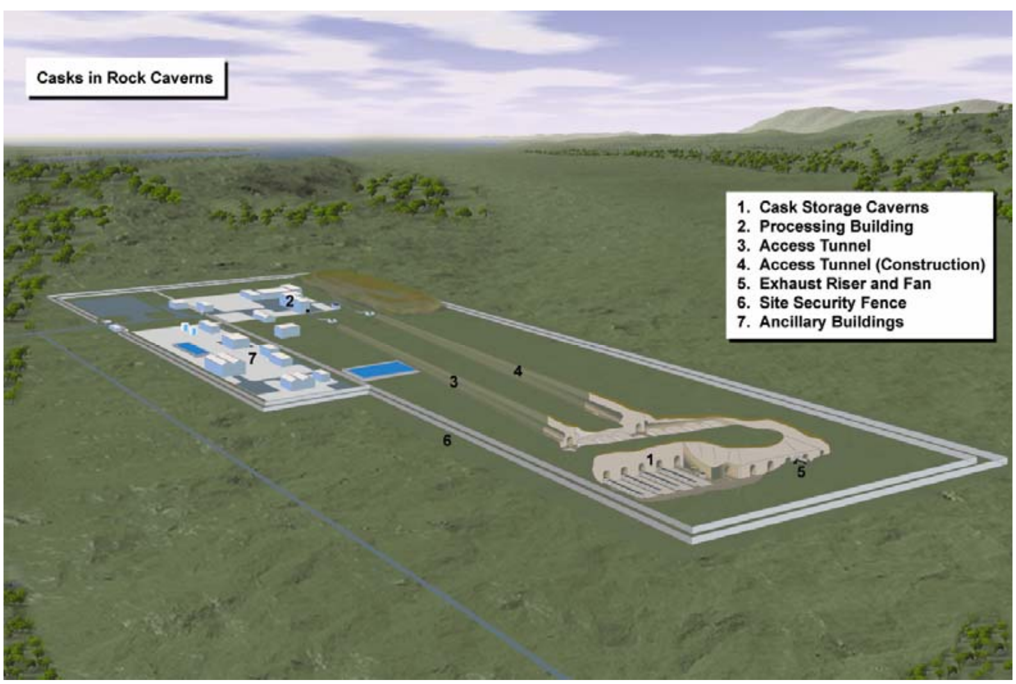
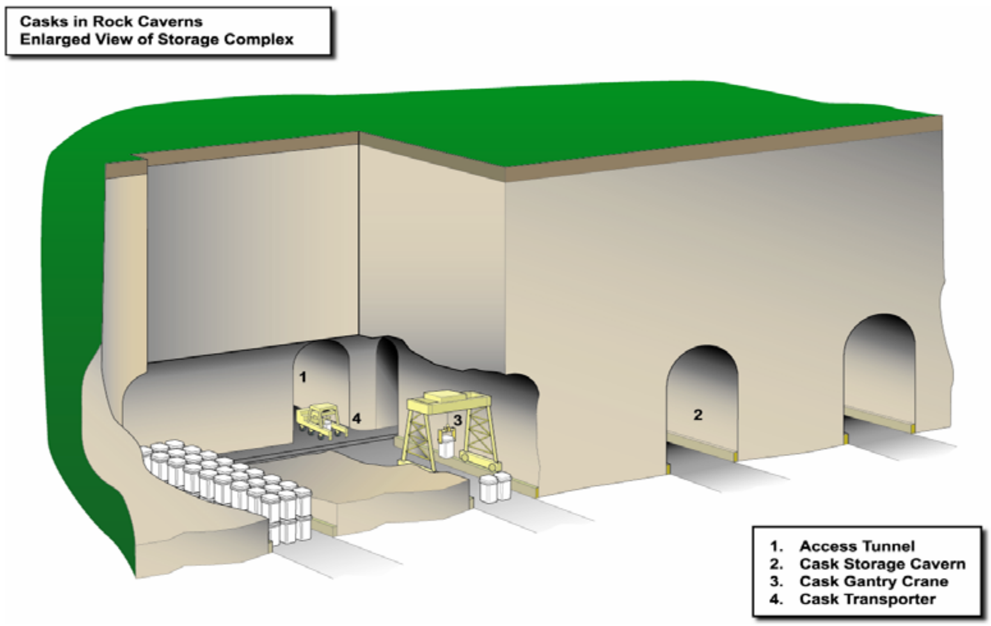


Figure 9: Used Fuel Storage in Shallow Rock Caverns at Central Facility – Underground View



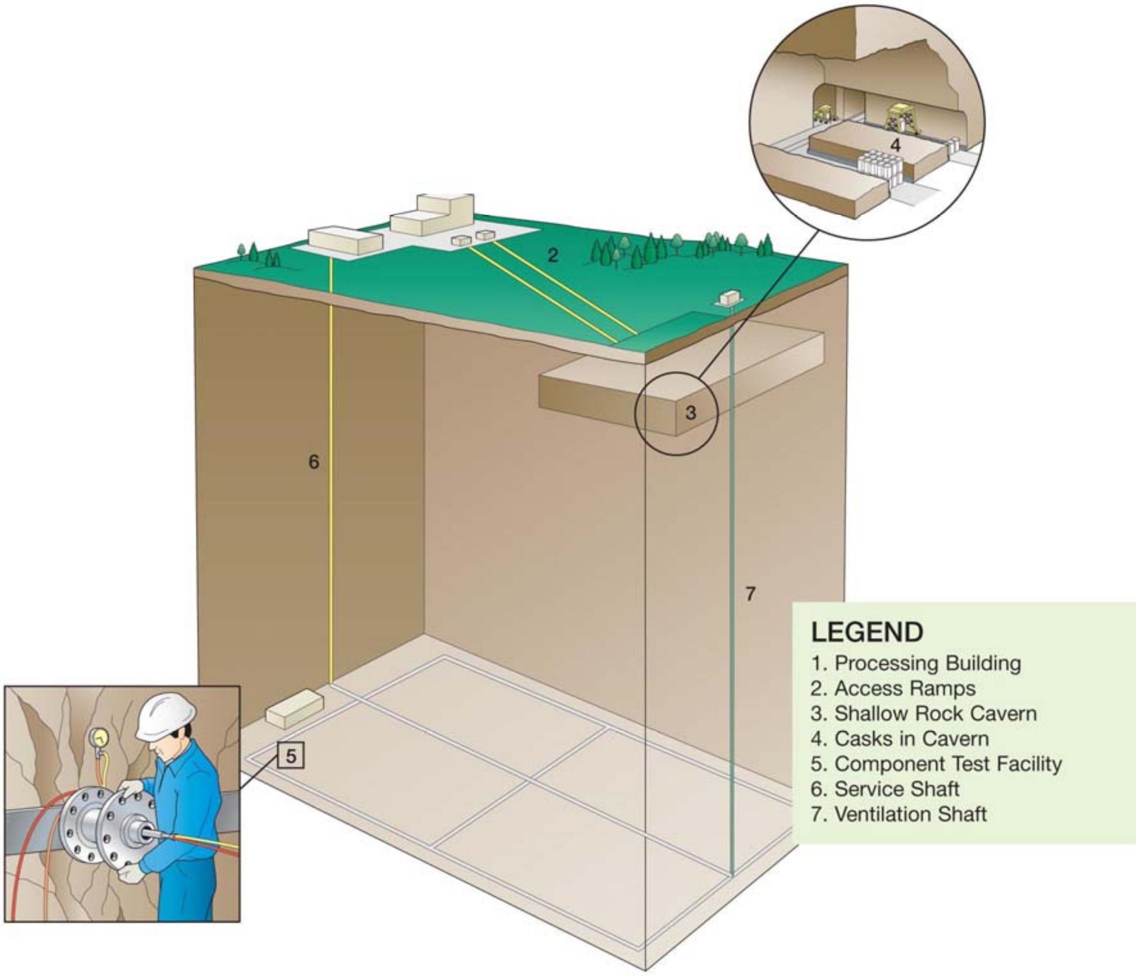
4.2 Demonstration of Used Fuel Containment and Isolation Technology

The concept of containing and isolating used fuel in a deep geologic repository has gained widespread scientific credibility as the preferred long-term approach for dealing with wastes that remain hazardous for hundreds of thousands of years or longer. However, technical uncertainties remain, and further demonstration of the long-term isolation technology is required to build confidence in the safety and long-term reliability of the proposed system.

We conservatively estimate that it would take up to 30 years of research and demonstration at the underground research laboratory to confirm the suitability of the site and to gain sufficient confidence in understand the long-term issues and prove the safety of isolating used fuel in a deep geologic repository. While doing our research and demonstrating the technology in-situ, we will continue to learn from the experiences in other countries with similar waste management programs. Our research will involve studies of the behaviour of the rock mass and groundwater flow at depth, and potential flow paths and long travel times for contaminants that may be released from used fuel containers and repository sealing systems. There will also be tests on engineered barrier materials and sealing systems and demonstration of techniques to retrieve used fuel containers should that be required in the future. There will also be extensive development and demonstration of monitoring equipment and methods.

A generalization of Phase 2 Central Storage and Technology Demonstration is illustrated in Figure 10. The surface processing buildings, the shallow underground used fuel storage facility and the underground research facility are all located at the same central site.

Figure 10: Phase 2 – Central Storage and Technology Demonstration



4.3 Used Fuel – A Future Resource or Waste?

Another issue that we expect will be addressed by the end of Phase 2 is whether or not used nuclear fuel is a potential resource for an advance nuclear fuel cycle or truly a waste. There are on-going international studies on how to reuse nuclear fuel or to treat it to reduce the volume of high-level waste material and potentially its radiotoxicity. These studies include research into reprocessing, partitioning (separation) and transmutation of the radionuclides in used fuel. These technologies are currently difficult to implement and very expensive, and they produce low and intermediate level radioactive wastes which would also require long-term management. There are also social and political concerns associated with reprocessing used nuclear fuel.

Based on current knowledge and understanding, reprocessing used nuclear fuel would add a significant increase to the cost of used fuel management and it would not negate the need for long-term containment and isolation of the residual high-level wastes in a deep repository (Jackson 2005).

The NWMO will maintain a watching brief on this technology as it develops over the next few decades.

4.4 Construction of the Deep Geologic Repository

The final stage of Phase 2 would see the completion of design for long-term isolation of used fuel and the necessary licences for construction and operation of the deep geologic repository. We anticipate a period of about 30 years of investigations and demonstration of technology at the underground research laboratory, along with comments from the public and other interested stakeholders to prepare for the final phase of the approach.

After we have confirmed the suitability of the site and the isolation technology, we will completed the detailed engineering and safety assessments to apply for an Operating Licence for the deep geologic repository along with ancillary surface facilities such as the used fuel packaging plant and the sealing materials compaction plant (CTECH 2002). These facilities would be required to repackage the used fuel from storage containers into long-lived containers for placement in the deep repository.

During this 30-year period of site confirmation and technology demonstration, we have allowed a period of 10 years to complete the design work and construct the required facilities to receive used fuel in the deep repository. If we do not have sufficient information to proceed to the next step of concept implementation, then we have the option to continue further study and analyses to support the decision.

By the end of this phase, we expect to have sufficient knowledge and facilities to begin transfer of used fuel from centralized storage into long-term isolation in a deep geologic repository at the same site.

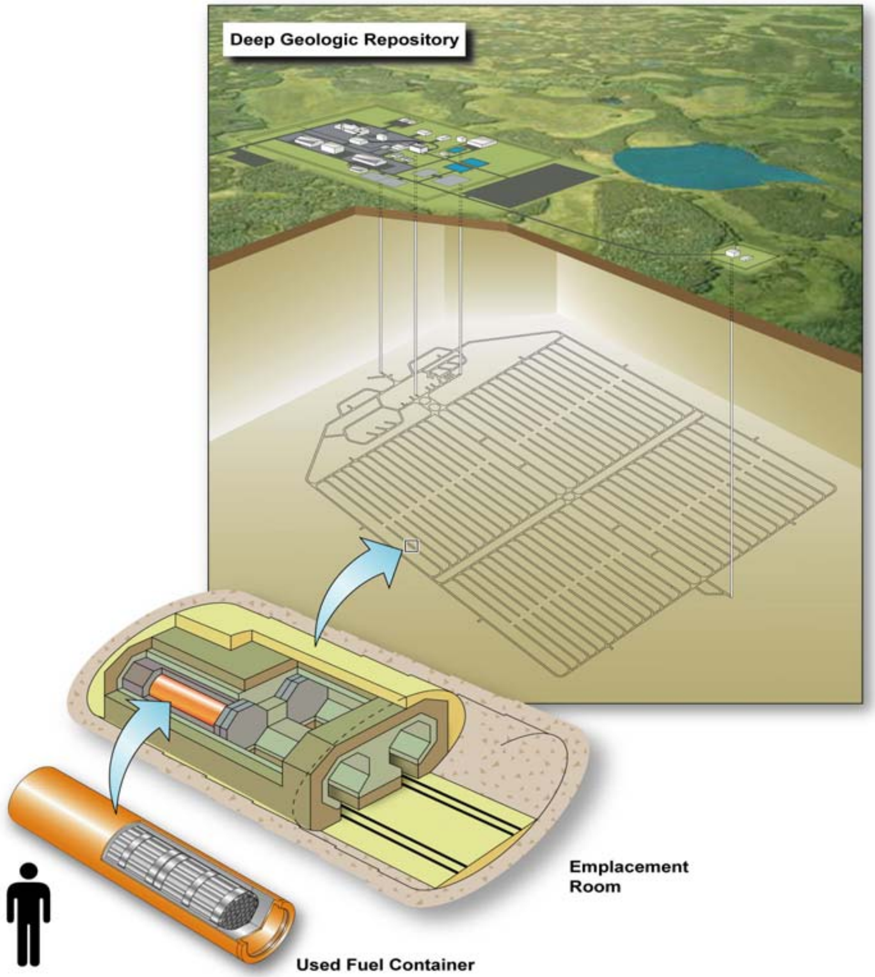
5. Phase 3: Long-term Containment, Isolation and Monitoring

5.1 Deep Geologic Repository

Based on current scientific knowledge, the best way to ensure long-term containment and isolation of used fuel is to put it in engineered systems underground in a deep geologic repository which would keep it isolated from humans and the environment for a very long time. This containment and isolation technology has been studied for many years in Canada and other nations.

An example of a deep geologic repository for used fuel is illustrated in Figure 11.

Figure 11: Cutaway View of a Deep Geologic Repository



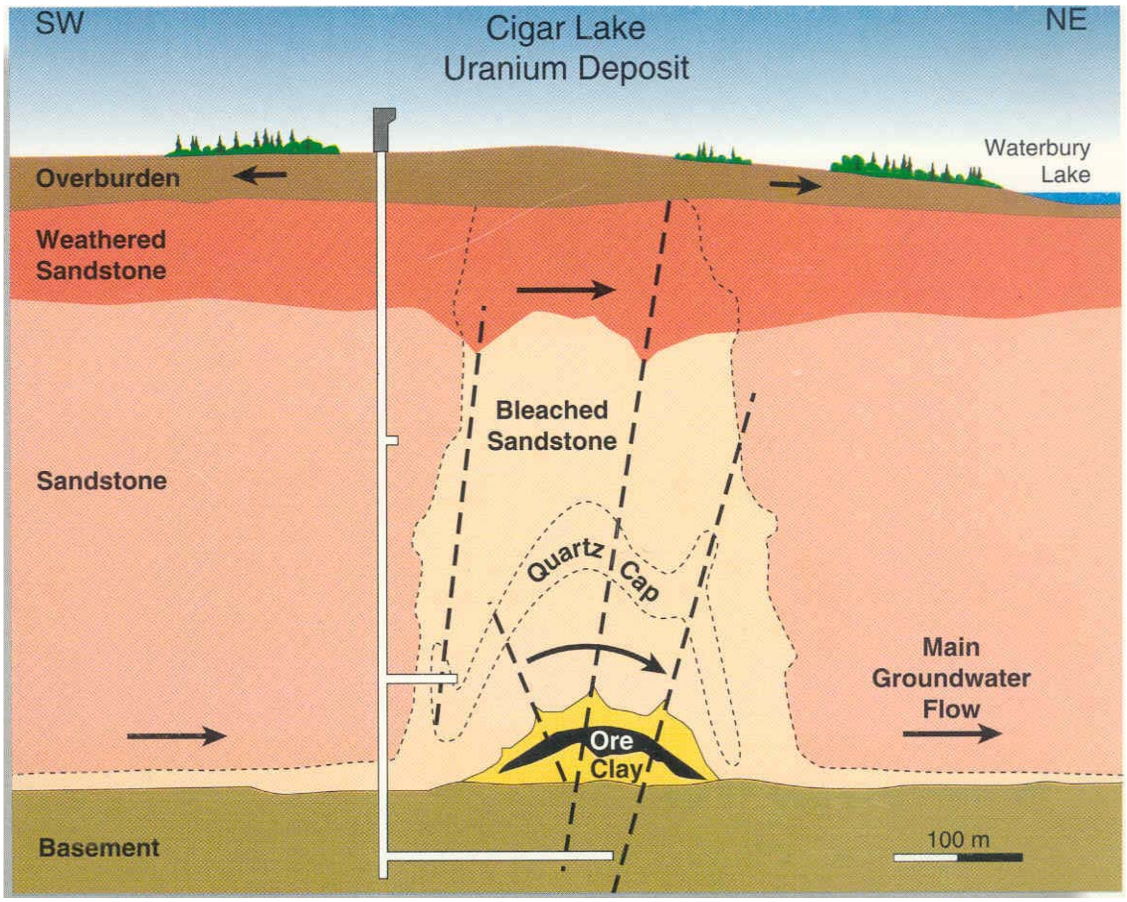
5.2 Natural Analogue for a Deep Geologic Repository

There is geotechnical evidence that suitable host rock formations are stable over hundreds of millions of years. In many respects a deep geologic repository for used nuclear fuel would mimic conditions found in deep uranium ore bodies such as Cigar Lake in northern Saskatchewan. Buried deep underground, the radioactivity in used fuel would slowly decay to that found in the original uranium ore after many hundreds of thousands of years.

A cutaway view of the Cigar Lake uranium ore natural analogue is illustrated in Figure 12. The estimated uranium deposit at Cigar Lake is about 100,000 tonnes which is greater than the reference uranium inventory in 3.7 million used fuel bundles (~ 70,000 tonnes). The basement rock at Cigar Lake is at a depth of about 400 metres below surface.

With the decision to construct a deep geologic repository, a new series of underground excavations would be constructed, likely at a depth of 500 to 1,000 metres below surface. The used fuel bundles would be taken out of the shallow caverns and brought to the surface for repackaging into longer-lived used fuel containers for placement in the the deep repository.

Figure 12: Cutaway View of the Cigar Lake Uranium Ore Natural Analogue



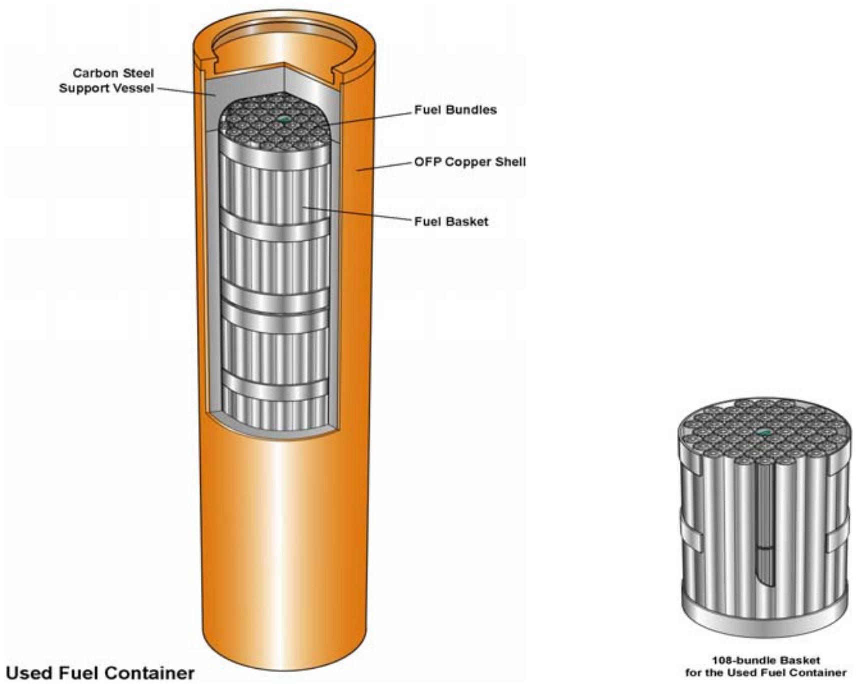
5.3 Used Fuel Container and Sealing Materials

Based on the approaches studied in Canada, Sweden and Finland, we expect containers would consist of a steel structure covered by a corrosion-resistant copper barrier. They would have a design life of at least 100,000 years in a deep repository and they may last longer. The engineered barriers and the natural barrier provided by the host rock at the site would protect the used fuel containers from natural events such as climate change or future glaciations. The design of used fuel containers for long-term isolation in a deep geologic repository will undoubtedly evolve over the next few decades as research and technology demonstration activities progress in Canada and elsewhere.

The current design for a used fuel container is illustrated in Figure 13. Other container designs are also feasible.

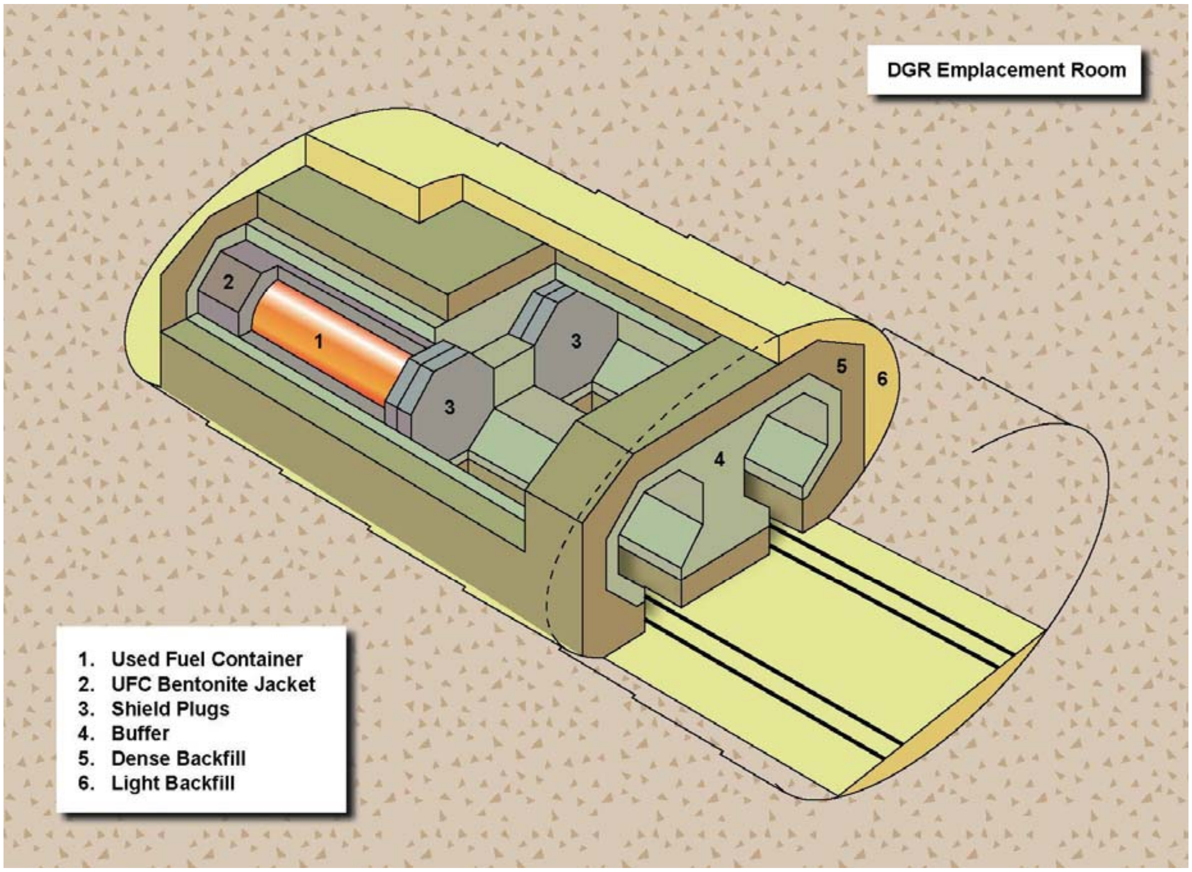
The used fuel containers, each holding 324 used fuel bundles, would be transferred to the placement rooms in the deep repository and surrounded by further engineered barriers, such as clay-based sealing materials. Clay is also an excellent barrier to slow the movement of underground water and the movement of contaminants if a container is breached.

Figure 13: Example of Used Fuel Container and Inner Basket for Deep Geologic Repository



An example of a placement room for used fuel containers is illustrated in Figure 14. In this particular configuration, used fuel containers are placed horizontally within the confines of the room. Other used fuel placement configurations include in-floor borehole and long horizontal tunnels (Hobbs et al. 2005). Decisions on the placement method would depend on site-specific conditions at the central facility and on further engineering studies, analyses and demonstrations of technology.

Figure 14: Example Placement Room for Used Fuel Containers in a Deep Geologic Repository

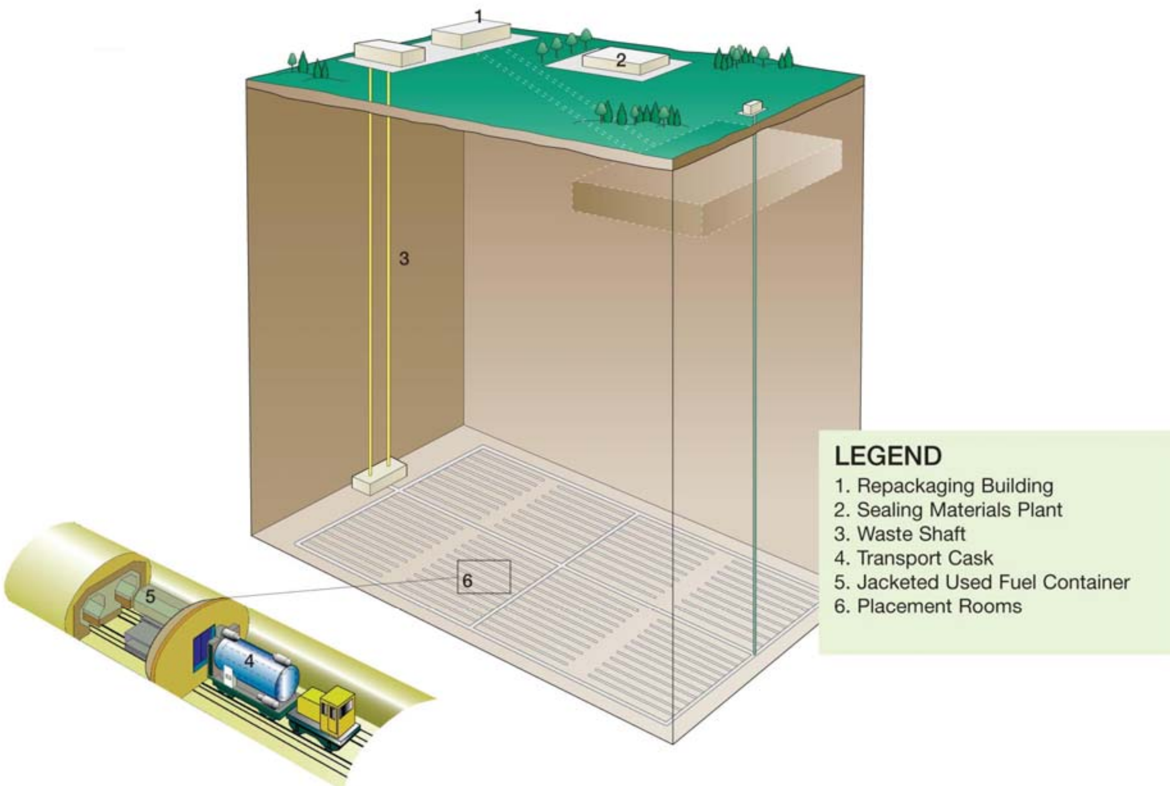


5.4 Used Fuel Transfer from Underground Storage to Deep Repository

Based on previous engineering studies, we estimate it would take about 30 years to transfer the storage containers holding all 3.7 million fuel bundles from the shallow rock caverns to the surface used fuel packaging plant and then down into the deep repository (CTECH 2002). As the used fuel containers are placed in the repository, the remaining void space in the rooms or boreholes holding the isolation containers would be backfilled with clay and concrete-based sealing materials, but the access tunnels and shafts to the surface could remain open for an extended period of time. This would allow in-situ monitoring of the stored fuel and retrieval of the used fuel container, if this was desired. After an additional 20 years, we are assuming that the shallow rock caverns which were used for interim storage would be decommissioned and closed. However, this shallow facility could be re-opened at a later time, if needed for used fuel container retrieval.

A generalization of Phase 3 Long-term Containment, Isolation and Monitoring is illustrated in Figure 15.

Figure 15: Phase 3 – Long-term Containment, Isolation and Monitoring



5.5 Decision to Close the Deep Geologic Repository

We do not know how long a future society would want to maintain in-situ monitoring of used fuel via the open access tunnels and shafts. The decision to backfill and seal the access tunnels and shafts of the deep repository may take some time and we have allowed for this decision to take place after about 300-years. It may happen sooner. Final decommissioning and closure of the deep repository and surface facilities is expected to take about 25 years (CTECH 2002).

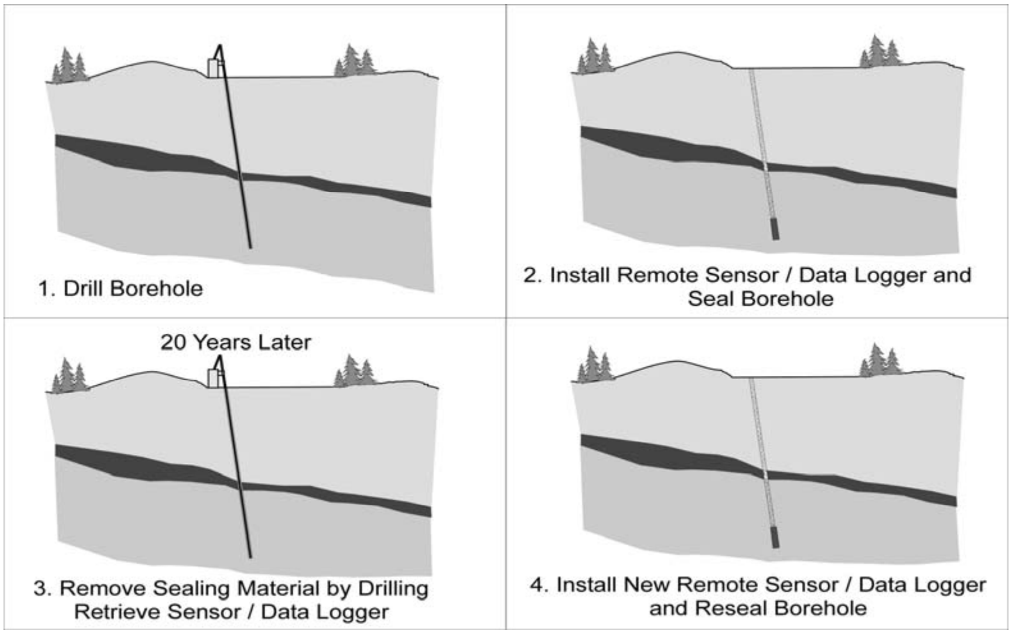
Internationally, there is some precedence for a proposed 300-year monitoring period. For example, the existing low and intermediate level waste facilities at Centre de l'Aube in France, the planned low-level waste facility at Dessel in Belgium and the proposed spent fuel facility at Yucca Mountain, Nevada all have provisions for 300 years of institutional control and monitoring.

5.6 Continued Postclosure Monitoring of the Central Facility

Even after there has been a decision to close the deep facility, we are anticipating a need to provide a future society with the choice to continue monitoring the deep repository during the postclosure period. A concept for a passive system of postclosure monitoring of the deep repository has been proposed and this monitoring could continue indefinitely.

An example of passive postclosure monitoring is illustrated in Figure 16.

Figure 16: System of Passive Postclosure Monitoring of a Deep Geologic Repository



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APPENDIX A:

RATIONALE FOR SELECTION OF POTENTIALLY SUITABLE HOST ROCK FORMATIONS FOR A DEEP GEOLOGIC REPOSITORY IN CANADA

CONTENTS

A.1 INTRODUCTION

In May 2005, the Nuclear Waste Management Organization (NWMO) issued its Draft Study Report *Choosing a Way Forward* (NWMO) for public review and comment prior to submitting the Final Study Report to the Minister of Natural Resources Canada in November 2005. The NWMO has recommended Adaptive Phased Management as the preferred management approach for the long-term care of Canada's used nuclear fuel. One of the technical features of Adaptive Phased Management is that it is based on centralized containment and isolation of used nuclear fuel in a deep geologic repository in a suitable rock formation such as the crystalline rock of the Canadian Shield or Ordovician sedimentary rock (NWMO 2005).

This Appendix provides a brief rationale for why the NWMO considers these two rock formations to be suitable for a deep geologic repository in Canada.

A.2 CANADIAN RESEARCH PROGRAM FOR A DEEP GEOLOGIC REPOSITORY

In 1977, an independent expert group chaired by Kenneth Hare was commissioned by the Department of Energy, Mines and Resources to provide the Government of Canada with a study on the safe long-term management of radioactive waste and describe the options available to Canada for the disposal of these wastes (Aikin et al. 1977). The "Hare Report" identified the important geoscientific characteristics of rock formations for a geologic repository and several potentially suitable rock types which included:

a) rock salt;
b) crystalline rock (intrusive igneous[1] rock of the Canadian Shield);
c) sedimentary rock (shale and limestone); and
d) volcanic tuff.

The study evaluated the available literature on these rock types and noted the advantages and limitations of each. The formations that showed the most promise for Canada in terms of characteristics and general availability were salt, crystalline rock and sedimentary rock. The Hare Report indicated that the Canadian repository research and development (R&D) program should study several different kinds of rock, but Canadian resources should not be spread too thinly (Aikin et al. 1977). The report also suggested that the primary R&D effort should be given to crystalline rock, but that careful attention should be paid to the work being conducted in other countries on other rock types such as sedimentary rock and salt.

In 1978, the governments of Canada and Ontario established the Canadian Nuclear Fuel Waste Management Program to study and advance the technology for storage, transportation and permanent disposal of Canada's nuclear fuel waste (Joint Statement 1978). Since that time, the Canadian R&D program has been primarily directed towards the crystalline rock of the Canadian Shield, including the development of the Underground Research Laboratory by Atomic Energy of Canada Limited (AECL) near Lac du Bonnet, Manitoba.

[1] "Igneous" rocks refer to rocks that have crystallized deep in the earth. The Canadian Shield contains large amounts of igneous rocks.

The potential suitability of the crystalline rock of the Canadian Shield for a deep geologic repository has been extensively documented in AECL's Environmental Impact Statement (EIS) (AECL 1994) and associated geoscientific and safety assessment reports, plus a number of international studies in Sweden, Finland and Switzerland.

AECL's EIS was reviewed by the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel and found to be safe from a technical perspective (CEAA 1998). More recently, the technical feasibility and safety of a deep geologic repository in the crystalline rock of the Canadian Shield has been documented by a conceptual design report (CTECH 2002) and a postclosure safety assessment report (Gierszewski et al. 2004). However, there is less available documentation on other potential suitability of other rock types.

Internationally, salt is being considered as the host rock formation for a deep repository for radioactive waste in countries such as Germany, Romania and the Ukraine (see Witherspoon and Bodvarsson 2001). In the USA, the Waste Isolation Pilot Plant (WIPP) in New Mexico is a licensed repository for non-heat generating transuranic radioactive wastes (see Witherspoon and Bodvarsson 2001 and www.wipp.ws). However, since the Hare Report was issued in 1977, there have been a limited number of Canadian repository studies for used nuclear fuel in rock formations such as salt (e.g., see Meijer Drees 1985) due in part to the fact that salt is a natural resource which may lead to mining activities in the future (Boulton 1978). As well, the presence of natural resources such as salt at depth increases the risk of inadvertent human intrusion into the repository and consequently, countries like Sweden have indicated that these rock types should be avoided during the siting of a long-term facility (SKB 2000). Therefore, the NWMO has decided not to include salt as a suitable host rock formation for a deep geologic repository, particularly as other options are available to us.

Canadian studies on the potential for sedimentary rock as the host rock formation for a deep geologic repository for used fuel include reports by Russell and Gale (1982), Heystee (1989) and Mazurek (2004). The principal findings from these reports are that sedimentary rock formations have favourable geotechnical properties, they are relatively simple, homogeneous and thick, plus there are a large number of potential candidate sites for a deep repository.

In addition to these geoscience studies, the NWMO commissioned a high-level review of the potential changes to the conceptual design and costs of constructing a deep geologic repository for used nuclear fuel in Ordovician sedimentary rock (see NWMO Background Paper 6-13 by NUKEM 2004). The reference rock type for the conceptual design of a deep geologic repository is the crystalline rock of the Canadian Shield (CTECH 2002). The high-level review by NUKEM found that a deep geologic repository could be constructed in sedimentary rock and that the costs would be similar or less than a deep repository constructed in crystalline rock.

The Canadian R&D program for a deep geologic repository for used nuclear fuel has continued.

On behalf of the nuclear fuel waste producers in Canada, Ontario Power Generation (OPG) is conducting R&D activities in used fuel repository engineering, geoscience and safety assessment in collaboration with Canadian universities, consulting companies and through international co-operation initiatives (Hobbs et al. 2005). As part of its R&D program, OPG has prepared a scoping studying for the conceptual design of a deep geologic repository for used nuclear fuel in sedimentary rock based on the Nagra tunnel concept prepared for the Swiss Opalinus Clay study (Nagra 2002) and taking into account the thermal properties of a hypothetical Canadian used fuel repository and surrounding rock mass. The preliminary results indicate that thermally and structurally acceptable repository layouts for used nuclear fuel can be designed in sedimentary rock (Baumgartner 2005).

A.3 INTERNATIONAL RESEARCH PROGRAMS

Over 30 countries have radioactive waste management programs and several (USA, Finland and Sweden) are close to implementing repositories for used nuclear fuel or high level radioactive waste (HLW). The status of the concept for geologic repositories for used nuclear fuel in Canada and abroad has been recently summarized by Witherspoon and Bodvarsson (2001) and McCombie (2003).

Most countries with radioactive waste management programs are focussing their repository programs on either crystalline rock (e.g., Finland and Sweden) or sedimentary rock (e.g., Belgium), while a few countries such as Switzerland, France, Spain and Japan are studying both rock types.

A.4 SUITABILITY OF SEDIMENTARY ROCK

The most recent report on the geoscientific assessment of the suitability of sedimentary rock to host a deep geologic repository for used nuclear fuel in Canada is the study by Mazurek (2004). The geoscientific review included international radioactive waste management programs in sedimentary geomedia and a compilation of existing geoscientific information on the Paleozoic sedimentary sequences in southern Ontario. The suitability of these sedimentary formations was examined in light of the extensive international experience in sedimentary geomedia in Switzerland, France, Belgium, Spain and Japan. This international experience has been derived from comprehensive safety cases (e.g., Nagra 2002) and operation of underground research laboratories in several countries (e.g., Mont Terri, Switzerland; Mol/Dessel, Belgium; Bure, France).

Recently, the Swiss safety case for a used fuel repository in the Opalinus Clay sedimentary rock (Nagra 2002) has also undergone an international peer review by the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD 2004). The properties of the Opalinus Clay in Benken, Switzerland are similar to the Ordovician sedimentary rock formations which are being studied in Canada. The NEA peer review found the sedimentary rock to be a suitable host rock formation since it is a tight, self-sealing material that would provide strong isolation, retention, delay and dispersion of any radionuclides released from a facility located in it. This finding has been corroborated by natural analogue studies, laboratory and field experiments, as well as theoretical studies and analyses (OECD 2004).

From a geoscientific perspective, the general safety-related features of sedimentary rock include (Mazurek 2004):

- sedimentary sequences are horizontally bedded like a “layer cake”, weakly deformed, geometrically simple and straight-forward to conceptualise;

- target rock formations are sufficiently homogeneous, which enhances predictability;

- sedimentary formations have low permeability or low hydraulic conductivity, thus the flow of groundwater through these formations is very slow and transport of contaminants (such as any radionuclides released from a deep geologic repository) is likely dominated by diffusion;

- transport of contaminants through the pore spaces in the sediments is very slow and sorption of contaminants onto the clay minerals will retard the migration of many dissolved contaminants;

- sedimentary formations possess an ability to self-seal fractures and faults;

- multiple lines of geoscientific evidence indicate that the deep sedimentary rock formations are robust to long-term perturbations on geologic time scales (i.e., erosion, glaciation, permafrost); and

- sedimentary formations provide sufficient geomechanical stability for safe repository construction and operation.

With respect to the Paleozoic sedimentary sequences in southern Ontario, the geoscientific review identified the following attributes (Mazurek 2004):

- Ordovician shales and limestones (age 470 to 430 million years ago) have low hydraulic conductivity, and are sufficiently deep (>200 metres below surface) and sufficiently thick (>100 metres) to meet internationally accepted siting preferences;

- degree of vertical and horizontal heterogeneity of geological and hydrogeological attributes in these potential host rock formations is limited and reasonably well known;

- hydrochemical evidence indicates very long underground residence times of formation waters in the Ordovician shales and limestones, and no resolvable cross-formation flow at depth over geological periods of time;

- fresh water flow system near the surface is underlain by a stagnant hydrogeological regime, and given the absence of exfiltration areas for deep groundwaters, flow does not occur or is very limited, thus solute transport is probably by diffusion;

- deep infiltration of surface groundwaters is unlikely due to the high density brines occurring in the deep underground and due to the presence of several low-permeability formations that confine the more permeable units; and

- excavations in deeply buried shales and limestones appears to be feasible in spite of the high horizontal stresses.

A.5 CONCLUSIONS

There are several independent geoscientific arguments suggesting that Ordovician shales and limestones would provide a highly suitable environment to host a deep geologic repository for used nuclear fuel in Canada. There is no evidence that would seriously question the technical feasibility or the long-term safety of a deep repository in these sedimentary formations. Therefore, the prospect of successfully preparing a convincing safety case for a used fuel repository in the Ordovician shales and limestones is substantial.

Based on the information available to the NWMO, both the crystalline rock of the Canadian Shield and Ordovician sedimentary rock are considered to be potentially suitable for a deep geologic repository for Canada's used nuclear fuel. The results from detailed site-specific characterization activities obtained during the site investigation, site selection and licensing phase would be required to confirm the technical suitability of the host rock formation for a deep geologic repository.

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