

# Preliminary Assessment of Potential Technical Implications of Reactor Refurbishment and New Nuclear Build on Adaptive Phased Management

NWMO TR-2008-10

December 2008

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## ABSTRACT

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**Report No.:** NWMO TR-2008-10  
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### Abstract

Since the Nuclear Waste Management Organization (NWMO) submitted its Final Study in 2005, there have been a number of planned and proposed nuclear refurbishment and new build initiatives which could extend the projected end of nuclear reactor operation in Canada from about 2034 to about 2085 or beyond.

The important technical features of these recent nuclear initiatives include:

- The amount of used nuclear fuel produced in Canada;
- The type of used nuclear fuel produced in Canada; and
- The duration of operation of long-term management facilities in Canada.

The NWMO conducted a preliminary assessment of the potential technical implications of these nuclear initiatives on Adaptive Phased Management and found the following:

1. The amount of used nuclear fuel will determine the design size of the deep geological repository and the requirements for a potentially suitable site. As of January 1, 2008, Canada had about 2 million used CANDU fuel bundles for long-term management and conceptual designs have been developed for a used fuel inventory ranging from 3.6 million to 10 million used fuel bundles. A single deep geological repository could be designed to accommodate a wide range of inventory of used nuclear fuel from existing reactors as well as from proposed new-build reactors.
2. The type of nuclear reactors in Canada will determine the type of used nuclear fuel for long-term management which will impact:
  - i. the physical dimensions of the waste form, for example, small fuel bundles from CANDU reactors and large fuel assemblies from pressurized water reactors or boiling water reactors; and
  - ii. the heat output from used fuel due to the concentration of fission products. Used fuel enriched with uranium-235 will be hotter and thus a smaller amount of enriched uranium fuel can be placed in a container and more repository area is required per container compared to non-enriched fuel.
3. The duration of operation of used fuel transportation, used fuel re-packaging, placement in a deep geological repository and monitoring would be extended by many decades beyond the 30-year operating period associated with a used fuel inventory of 3.6 million bundles. Essentially, each year of continued nuclear reactor operation in Canada would extend the duration of operation of long-term management facilities by about another year.



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## 1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) studied a number of approaches for long-term management of Canada's used nuclear fuel and submitted its Final Study and recommendation of Adaptive Phased Management in November 2005 (NWMO 2005). The recommendation was accepted by the Government of Canada in June 2007.

Adaptive Phased Management emerged from the NWMO's dialogue and engagement with Canadians. The approach is considered to be flexible, adaptable and robust to a number of future used fuel scenarios in Canada ranging from early nuclear phase out to a mixture of continuing nuclear reactor generation over several hundred years. The reference used fuel scenario and other possible used fuel scenarios are described in Appendix 10 of the Final Study (NWMO 2005).

Since the NWMO Final Study was issued in 2005, there have been a number of planned and proposed nuclear reactor refurbishment and new nuclear build initiatives in Canada. Reactor refurbishment activities could extend the projected end of existing CANDU reactor operation in Canada from the previously assumed shut down date of about 2034 to about 2055. New nuclear build activities could introduce a broad range of nuclear reactor designs and fuel types including fuel enriched with uranium-235. New nuclear build would also extend the projected end of nuclear reactor operation in Canada from about 2034 to about 2085 or beyond.

The NWMO has made a commitment to consider the implications of new nuclear initiatives on the implementation of Adaptive Phased Management (NWMO 2008a; 2008b). This report provides a preliminary assessment of the potential technical implications of nuclear reactor refurbishment and new nuclear build on Adaptive Phased Management.

## 2. CANADA'S INVENTORY OF USED NUCLEAR FUEL

Under the *Nuclear Fuel Waste Act* (2002), the NWMO is responsible for long-term management of used nuclear fuel that exists in Canada today and used nuclear fuel that will be produced in Canada in the future.

As of January 1, 2008, Canada had 2,001,738 used CANDU<sup>®</sup> fuel bundles in storage in licensed facilities at the nuclear reactor sites (NWMO 2008a) (See Figures 1 and 2). Currently, the annual production rate of used nuclear fuel ranges from about 85,000 to 95,000 used CANDU fuel bundles per year.

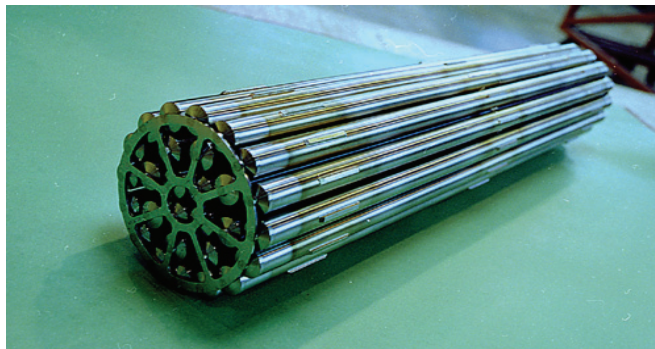


Figure 1: CANDU Fuel Bundle



Figure 2: Example of Wet and Dry Storage of Used Fuel at Nuclear Reactor Sites

### 3. USED FUEL SCENARIOS IN NWMO'S STUDY OF APPROACHES

In 2001, the Joint Waste Owners (Ontario Power Generation Inc., Hydro-Québec, New Brunswick Power and Atomic Energy of Canada Limited) estimated the total projected used fuel bundles from the existing fleet of nuclear reactors in Canada to be about 3.6 million bundles. In 2004, the Joint Waste Owners revised this projected estimate to be about 3.7 million bundles based on a 40-year average nuclear reactor life (NWMO 2005). (Difference is less than 3%).

The 3.6 million used CANDU fuel bundle scenario formed the basis for the NWMO's study of long-term management approaches and its recommendation of Adaptive Phased Management. The ultimate end point of Adaptive Phased Management is placement of used nuclear fuel in a deep geological repository in a suitable host rock formation in Canada. For 3.6 million used CANDU fuel bundles, the underground footprint of a deep geological repository could be about 1.8 km<sup>2</sup> (452 acres) (See Figure 3). During the Study Process, the NWMO also conducted a preliminary examination of other future used fuel scenarios which ranged from early nuclear phase out to a mixture of continuing nuclear reactor generation over several hundred years in Canada (see NWMO 2005; Appendix 10 / Used Fuel Scenarios).

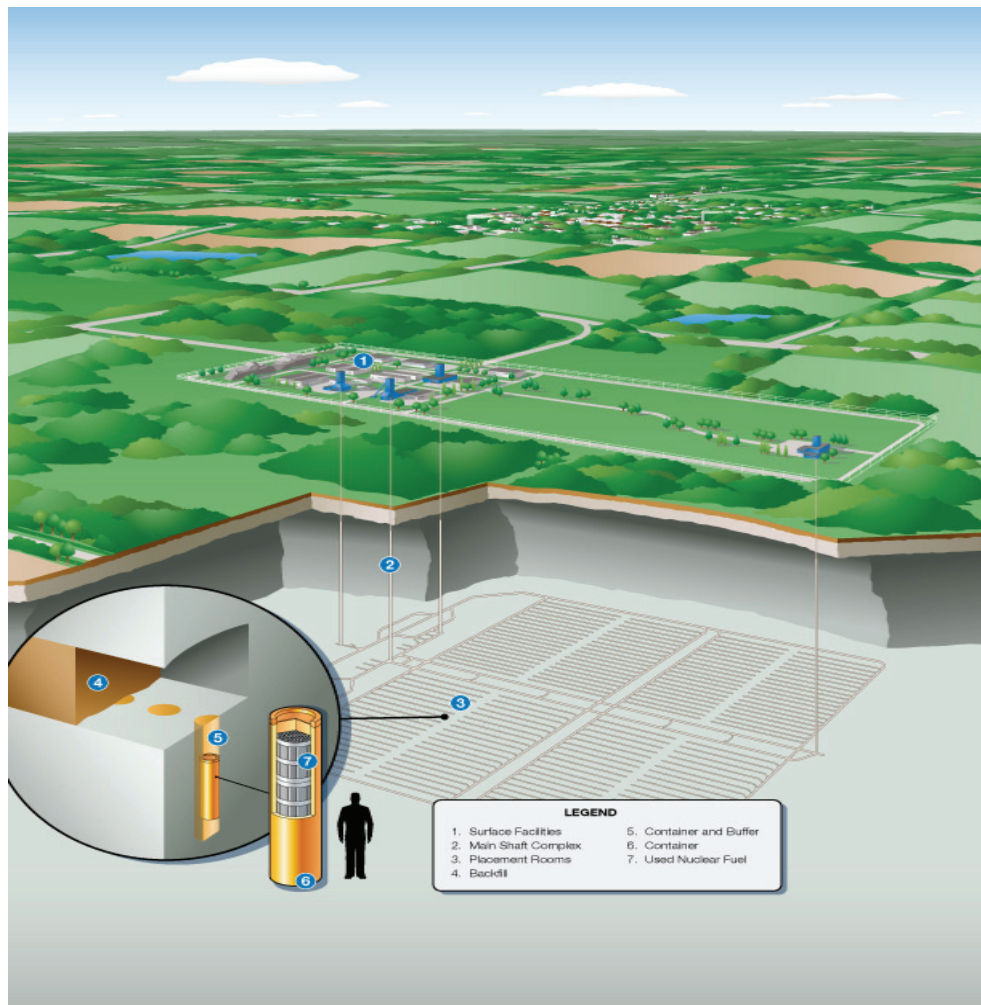


Figure 3: Example Deep Geological Repository in Adaptive Phased Management

#### 4. INITIATIVES WHICH COULD AFFECT INVENTORY OF USED NUCLEAR FUEL

The reference 3.6 million used CANDU fuel bundle scenario, prepared by the Joint Waste Owners in 2001, assumed the existing Canadian nuclear reactors would continue to operate until the end of their design lives (~ 40 years). This used fuel scenario was considered by the NWMO to be reasonable for preparing conceptual designs, estimating costs and comparing long-term management approaches.

There are about 2 million used fuel bundles in storage as of January 1, 2008 and we can reasonably estimate the used fuel production rate over the next few years based on current and predicted reactor operation (~ 85,000 to 95,000 used fuel bundles per year). But estimating Canada's future used fuel inventory over the long term is more uncertain and will depend on the outcome of future energy policy decisions and practical considerations such as the operating performance of each nuclear reactor.

Since the NWMO submitted its Final Study in 2005, there have been a number of planned and proposed nuclear refurbishment and new build initiatives in Canada including, for example:

- **Ontario Power Generation** (see [www.opg.com](http://www.opg.com)):
  - Project Description for Pickering B Units 5 to 8 refurbishment (OPG 2006) to extend Pickering B reactor operation to about 2055;
  - Project Description Darlington B nuclear reactors (OPG 2007) with a start date as early as 2016 and a 60-year full power operating life;
- **Bruce Power** (see [www.brucepower.com](http://www.brucepower.com)):
  - Refurbishment of Bruce A Units 1 and 2 to be completed by 2010 and refurbishment of Bruce A Units 3 and 4 to be completed by 2013 extending Bruce A reactor operation to about 2036;
  - Project Description for New Build at the Bruce site (Bruce Power 2007a) with a start date as early as 2016 and a 60-year full power operating life;
- **New Brunswick Power** (see [www.nbpower.com](http://www.nbpower.com)):
  - Refurbishment of Point Lepreau to be completed by 2009 extending Point Lepreau reactor operation to about 2035;
  - New Brunswick Power and Atomic Energy of Canada Limited (AECL) initiated a feasibility study to build a second reactor at Point Lepreau with a 60-year full power operating life (AECL 2007a); the Government of New Brunswick received the feasibility study in February 2008 (NBG 2008);
- **Alberta Energy / Bruce Power Alberta** (see [www.energyab.com](http://www.energyab.com) and [www.brucepower.com](http://www.brucepower.com)):
  - Alberta Energy submitted a Licence Application for up to two nuclear reactors near Peace River, Alberta with a start date as early as 2017 and a 60-year full power operating life (AECL 2007b).
  - Bruce Power, on behalf of Bruce Power Alberta, signed a letter of intent to buy certain assets of Alberta Energy (Bruce Power 2007b).

The NWMO has conducted a preliminary assessment of the potential technical implications of these proposed nuclear initiatives on implementing Adaptive Phased Management.

## 5. POTENTIAL IMPLICATIONS OF REFURBISHMENT AND NEW NUCLEAR BUILD

Refurbishment of existing CANDU reactors will add to the projected amount of used CANDU fuel bundles and potentially the duration of operation of the NWMO's long-term management facilities (e.g., used fuel transportation facilities, surface handling facilities and the deep geological repository).

The new nuclear build initiatives in Canada could also affect the type of used nuclear fuel generated in Canada since these initiatives are considering a broad range of possible nuclear reactor designs and fuel types including:

- Enhanced CANDU (EC-6);
- Advanced CANDU Reactor® (e.g., AECL ACR-1000®); and
- Pressurized water reactors (e.g., Westinghouse AP1000 PWR).

There are important features of reactor refurbishment and new nuclear build in Canada which have the potential to affect the technical implementation of Adaptive Phased Management:

- a) the amount of used nuclear fuel;
- b) the type of used nuclear fuel; and
- c) the duration of facility operation.

These technical features are interrelated. For example, the amount of used fuel can affect the duration of certain operational activities such as used fuel transportation and repository operation. The schedule of used fuel production can affect the duration of all waste management activities. The type of used fuel can affect the required cooling time for used fuel in storage prior to placement in the deep repository.

The type of used fuel can also affect the NWMO's technical research and development (R&D) program since non-CANDU used fuel could be produced by reactors in Canada for long-term management.

### 5.1 AMOUNT OF USED NUCLEAR FUEL

The primary technical impact from the amount of used fuel on Adaptive Phased Management is the impact on the size of the deep geological repository and the requirements for a potentially suitable site.

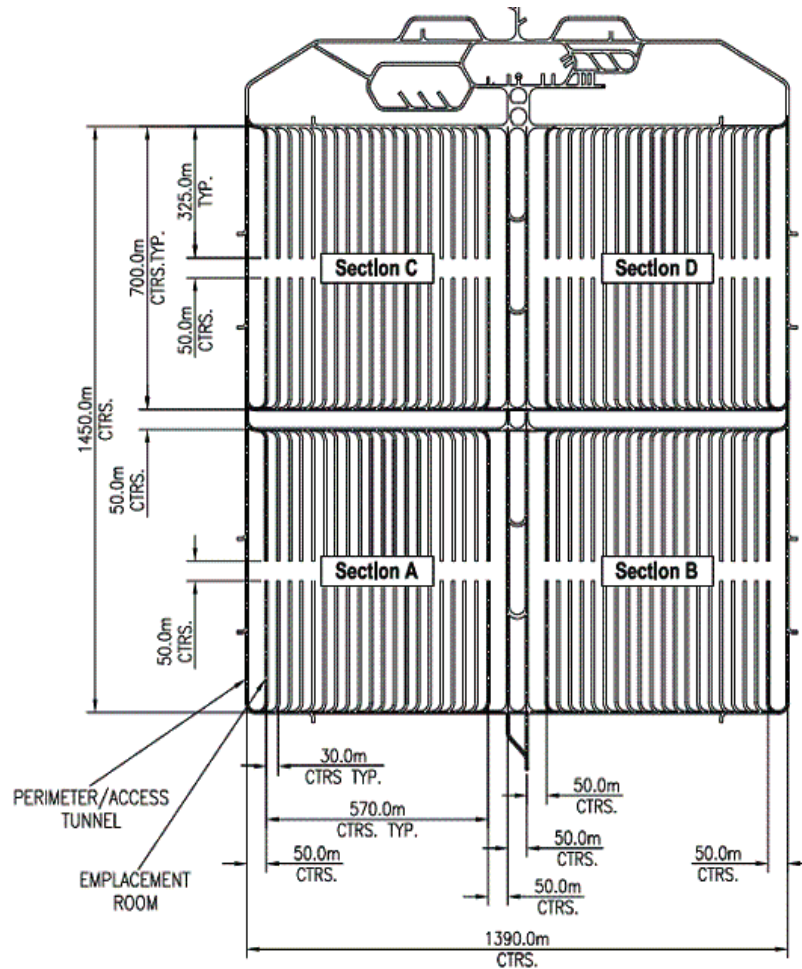
In simple terms, more used nuclear fuel will require a larger deep geological repository; less used nuclear fuel will require a smaller deep geological repository.

Conceptual designs for a deep geological repository have been developed for a wide range of used fuel inventories up to 10 million used CANDU fuel bundles (AECL 1994). Recently, the conceptual design of the deep geological repository in Adaptive Phased Management was based on the 3.6 million used CANDU fuel bundle scenario (for conceptual design and cost estimating purposes). The NWMO has developed conceptual designs for several used fuel

container placement methods and potential rock types. The repository design for the in-floor borehole placement method for used fuel containers in crystalline rock is illustrated in Figure 4.

The layout was designed to ensure the repository would meet thermal and mechanical stability requirements for underground excavations. The 3.6 million used fuel bundles (which have been cooled for a minimum of 30 years) would require a repository layout with 160 placement rooms with 70 used fuel containers per room assuming 324 used fuel bundles per container.

The final design and layout of the repository would depend on a number of factors including the site-specific characteristics of the host rock formation as well as continuing developments and demonstrations of long-lived containment and isolation technology in Canada and abroad.



**Figure 4: A Deep Geological Repository Design for 3.6 million Used Fuel Bundles**

The schedule for transporting the used fuel from the reactor sites to the final site, re-packaging the used fuel into long-lived containers and placing them in the repository is about 30 years (NWMO 2005).

As of January 1, 2008, Canada had about 2 million used CANDU fuel bundles for long-term management. Therefore, the current inventory of used fuel in Canada could be put into 88 placement rooms in the repository over a period of about 17 years. (A little more than half of underground layout for the deep geological repository design shown in Figure 4 would be required for 2 million used fuel bundles).

Each individual nuclear reactor in Canada produces about 4,000 to 5,000 used CANDU fuel bundles per year. The current fleet of nuclear reactors produces about 85,000 to 95,000 used CANDU fuel bundles per year. Reactor refurbishment activities could change the projected used fuel inventory in Canada from 2.8 million to about 5.5 million bundles (Garamszeghy 2008).

Each additional year of operation from the current fleet of nuclear reactors in Canada would require an additional 4 placement rooms in the repository and about another year of repository operation. Therefore, each year of used nuclear fuel production at current levels would increase the design size of the deep geological repository by about 2.5%.

## **5.2 TYPE OF USED NUCLEAR FUEL**

The primary technical impact from the type of used fuel on Adaptive Phased Management is the impact on the content and layout of used fuel containers in the deep geological repository.

The type of used fuel will affect the physical dimensions of the waste form (e.g., small fuel bundles or large fuel assemblies) for storage, transportation and re-packaging into long-lived containers. The range of used fuel types for long-term management would have an impact on the NWMO's technical R&D program since additional studies, safety assessments, facility designs and technology demonstrations would be required for each waste form.

With respect to research, most national waste management organizations are conducting R&D and developing technologies for non-CANDU used fuel or high-level radioactive waste and the NWMO has formal research and information sharing agreements with many of these national organizations (e.g., Posiva (Finland), SKB (Sweden), Nagra (Switzerland) and Andra (France)). The type of used fuel will also affect its required cooling time and heat output, which in turn affects design features such as the packing density of used fuel containers in a deep geological repository.

To understand the impact of used fuel type on Adaptive Phased Management, we will need to review the characteristics of the fuel for different reactor designs associated with the new build initiatives.

Existing CANDU reactors and the Enhanced CANDU are designed to operate with natural uranium which has a uranium-235 content of 0.72%. (Uranium-235 is the main fissile isotope in the fuel). Other reactor designs, such as the Advanced CANDU Reactor being developed by Atomic Energy of Canada Limited (AECL), and the pressurized water reactors (PWR) being developed by Areva, Westinghouse, Mitsubishi and others, have uranium fuel with varying percentages of uranium-235 enrichment up to 4.5%.

The uranium content of typical fuel bundles and fuel assemblies for nuclear reactors is given in Table 1.

**Table 1: Reactor Fuel Types and Uranium Enrichment**

Reactor	Fuel Type	Content	Fuel Mass (kgU)	Uranium-235 (%)
CANDU	CANDU Bundle	Natural Uranium	~ 20	0.72%
ACR	CANFLEX Bundle	Slightly Enriched Uranium	~ 20	up to 2.5%
PWR	Fuel Assembly	Low Enriched Uranium	~ 538	up to 4.5%

The energy produced by a nuclear reactor is related to size and design of the reactor, and to the uranium-235 enrichment of the fuel. An important reactor design parameter is the burn-up of the fuel, often expressed in million-watt hours per kg uranium (MWh/kgU).

Burn-up is important for used fuel management since used fuel with high burn-up will have a higher concentration of heat generating fission products and thus a higher heat output compared with low burn-up fuel. The heat output of used fuel is one of the key parameters in determining the amount of used fuel that can be placed in a used fuel container and the spacing of used fuel containers in the deep geological repository.

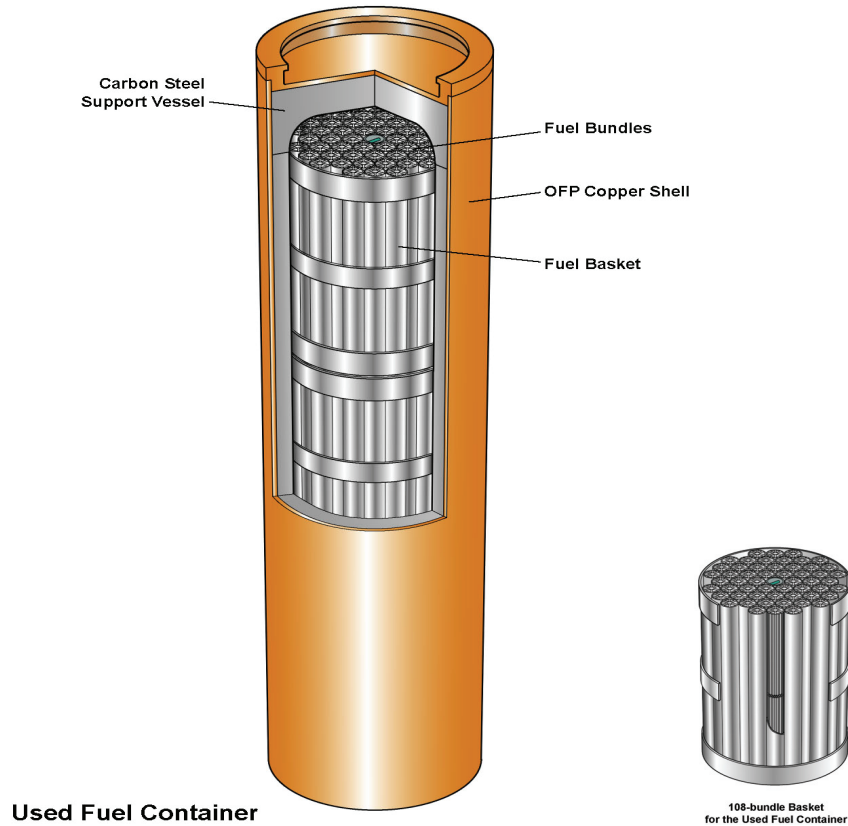
In most cases, the burn-up and the heat output of used fuel correlates directly with the enrichment of uranium-235 in the fuel, as shown in Table 2.

**Table 2: Burn-up of Nuclear Fuel**

Reactor	Fuel Type	Uranium-235 (%)	Typical Burn-up (MWh/kgU)
CANDU	CANDU Bundle	0.7%	220
ACR	CANFLEX Bundle	up to 2.5%	480
PWR	Fuel Assembly	up to 4.5%	1,400

Used fuel containers, and their spacing in a deep geological repository, are designed to meet both the physical dimensions of the fuel and the heat output of the fuel to ensure that the maximum design temperature of the repository, typically 100°C, is never exceeded.

The current Canadian design for a used fuel container for CANDU fuel is illustrated in Figure 5.



**Figure 5: A Canadian Used Fuel Container Design for a Deep Geological Repository**

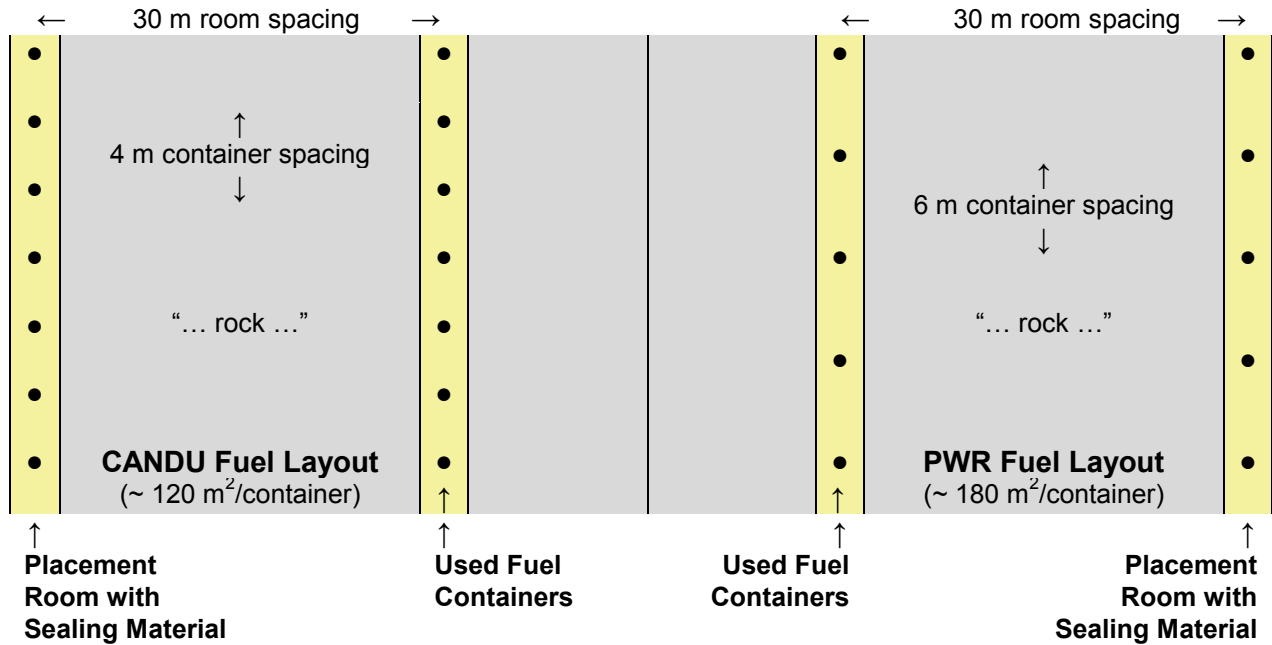
This particular Canadian design for a used fuel container is about 4 m long with a diameter of about 1 m, and would hold 324 used CANDU fuel bundles. If filled with 30-year old CANDU fuel with a burn-up of 220 MWh/kgU, the initial heat output would be about 1,140 watts.

The used fuel container designs being developed by other national waste management organizations typically have a design heat output of about 1,500 to 1,700 watts. Used fuel containers designed for the larger enriched fuel assemblies of PWR reactors are very similar in size to the container designed for the smaller CANDU fuel bundles (e.g., the Swedish used fuel container is about 4.8 m long with a diameter of about 1 m (SKB 2004)).

A typical used fuel container designed for 30-year cooled CANDU fuel bundles holds about 6,480 kg uranium and each container would require about 120 m<sup>2</sup> in the placement room area of the deep repository.

A typical used fuel container designed for 40-year cooled PWR fuel assemblies holds about 1,920 kg uranium and each container would require about 180 m<sup>2</sup> in the placement room area of the deep repository.

An illustration of a possible layout for used fuel containers within the placement rooms of a deep geological repository designed for low burn-up CANDU fuel and for higher burn-up PWR fuel is shown in Figure 6.



**Figure 6: Possible Layout for Used Fuel Containers in a Deep Geological Repository**

In simple terms, enriched uranium fuel with higher burn-up is hotter and thus a smaller amount of enriched used fuel can be placed in a container and more repository area is required for each container compared to low burn-up fuel.

And higher burn-up fuel would require longer cooling times to meet thermal requirements in a repository.

### 5.3 DURATION OF FACILITY OPERATION

Reactor refurbishment and new nuclear build in Canada has the potential to affect the duration of operation of the long-term management facilities during implementation of Adaptive Phased Management. In particular, the duration of operation of the used fuel transportation facilities, surface handling facilities and the deep geological repository could be affected by these initiatives.

The NWMO has examined a number of possible schedules and timetables for implementing Adaptive Phased Management (APM), primarily for the purpose of preparing conceptual designs, cost estimates and evaluating management approaches (NWMO 2005). These timetables have not been optimized nor do they necessarily reflect the most appropriate schedules when technical and social considerations are taken into account. The actual schedule for implementing Adaptive Phased Management will depend on a number of factors including the outcome of future decisions.

### Reference Used Fuel Scenario

For illustrating a possible implementation schedule and one that would be financially conservative, the reference 3.6 million used CANDU fuel bundle scenario assumed that production of used fuel in Canada would be completed around 2034 and transportation of used fuel to the long-term management facility would begin around 2035 (Cogema Logistics 2003a,b).

The earliest possible date for the start of operation of the deep geological repository (DGR) is 2035 and the transportation, re-packaging and placement of 3.6 million used fuel bundles in the deep geological repository would occur over a period of 30 years (CTECH 2003).

This schedule includes a used fuel cooling period of 30 years out-of-reactor prior to placement in a deep geological repository.

An illustrative schedule for the main technical activities associated with implementing Adaptive Phased Management for the 3.6 million used CANDU fuel bundle scenario is given in Figure 7.

Implementing APM <sup>1</sup> – 3.6 million Bundle Scenario										
	Time (years)									
Main Activities	10	20	30	40	50	60	?? <sup>2</sup>	??	??	
Siting & Licensing	█									
Construction (initial)			█							
Demonstration			█							
Transportation				█						
DGR Operation				█						
Monitoring			█							
Extended Monitoring							█			
Closure								█		
Postclosure Monitoring									█	

**Figure 7: Illustrative Schedule for 3.6 million Bundles**

<sup>1</sup> APM is Adaptive Phased Management.

<sup>2</sup> The duration and time period for extended monitoring, and when to close the deep geological repository, and the nature and extent of any postclosure monitoring are decisions to be made by a future society.

## Reactor Refurbishment

The planned and proposed reactor refurbishments in Ontario and New Brunswick could extend the projected end of nuclear reactor operation in Canada from 2034 to about 2055 and could increase the projected used fuel inventory up to about 5.5 million bundles (Garamszeghy 2008).

The planned reactor refurbishments could impact on the duration of the main activities of Adaptive Phased Management in the following manner: used fuel transportation, used fuel re-packaging and placement in the deep geological repository would be extended from 30 years to about 50 years to allow a used fuel cooling period of 30 years out-of-reactor prior to placement in a deep geological repository.

An illustrative schedule for the main technical activities associated with implementing Adaptive Phased Management for 3.6 million used CANDU fuel bundles plus the planned reactor refurbishment is given in Figure 8.

Implementing APM - 3.6 million Bundles + Reactor Refurbishment Scenario												
	Time (years)											
Main Activities	10	20	30	40	50	60	70	80	??	??	??	
Siting & Licensing	█											
Construction (initial)			█									
Demonstration			█									
Transportation				█								
DGR Operation				█								
Monitoring			█									
Extended Monitoring									█			
Closure										█		
Postclosure Monitoring											█	

**Figure 8: Illustrative Schedule for 3.6 million Bundles plus Reactor Refurbishment**

## New Nuclear Build

New nuclear build would extend the projected end of nuclear reactor operation in Canada from 2034 to about 2085 depending on the actual schedule for siting, approval, construction and operation of a new nuclear reactor, regardless of the type of reactor being considered since all of the new reactors have a design operating life of 60 years.

Proposed new-build reactors could increase the projected used fuel inventory by up to 2.3 million CANDU fuel bundles or up to 27,000 PWR fuel assemblies, depending on the type of new reactor technology (Garamszeghy 2008).

New nuclear build could impact on the duration of the main activities of Adaptive Phased Management.

For new nuclear build in Canada, the schedule for used fuel transportation, used fuel re-packaging and placement in the deep geological repository could be extended from 30 years to about 90 years or longer. This schedule includes a used fuel cooling period of 40 years out-of-reactor prior to placement in a deep geological repository to accommodate the hotter fuel associated with nuclear reactors with enriched uranium.

An illustrative schedule for the main technical activities associated with implementing Adaptive Phased Management for 3.6 million used CANDU fuel bundles plus new nuclear build is given in Figure 9.

Implementing APM - 3.6 million Bundles + New Nuclear Build Scenario															
	Time (years)														
Main Activities	10	20	30	40	50	60	70	80	90	100	110	120	??	??	??
Siting & Licensing	█														
Construction (initial)			█												
Demonstration			█												
Transportation				█											
DGR Operation				█											
Monitoring			█												
Extended Monitoring													█		
Closure														█	
Postclosure Monitoring															█

**Figure 9: Illustrative Schedule for 3.6 million Bundles plus New Nuclear Build**

## 6. CONCLUSIONS

The NWMO has conducted a preliminary assessment of the potential technical implications of nuclear reactor refurbishment and new nuclear build on Adaptive Phased Management. The principal technical implications of these nuclear initiatives are:

1. The amount of used nuclear fuel will determine the design size of the deep geological repository. As of January 1, 2008, Canada had about 2 million used CANDU fuel bundles for long-term management and conceptual designs have been developed for a used fuel inventory ranging from 3.6 million to 10 million used fuel bundles. A single deep geological repository could be designed to accommodate a wide range of inventory of used nuclear fuel from existing reactors as well as from proposed new-build reactors.
2. The type of nuclear reactors in Canada will determine the type of used nuclear fuel for long-term management which will impact:
  - i. the physical dimensions of the waste form, for example, small fuel bundles from CANDU reactors and large fuel assemblies from pressurized water reactors or boiling water reactors; and
  - ii. the heat output from used fuel due to the concentration of fission products. Used fuel enriched with uranium-235 will be hotter and thus a smaller amount of enriched uranium fuel can be placed in a container and more repository area is required per container compared to non-enriched fuel.
3. The duration of operation of used fuel transportation, used fuel re-packaging, placement in a deep geological repository and monitoring would be extended by many decades beyond the 30-year operating period associated with a used fuel inventory of 3.6 million bundles. Essentially, each year of continued nuclear reactor operation in Canada would extend the duration of operation of long-term management facilities by about another year.

Additional reactor refurbishment and/or additional new nuclear builds in Canada could extend the duration of operation of long-term management facilities in a fairly linear manner.

The potentially longer time period for used fuel transportation, used fuel re-packaging, placement in the deep geological repository and monitoring could affect the design of these facilities and could also affect the planned implementation schedule and cost of facility maintenance and replacement of operating equipment in Adaptive Phased Management.

The NWMO will give consideration to the potential impact of operating these long-term management facilities over time periods which could extend 80 to 100 years or more.

## REFERENCES

- AECL. 1994. Environmental impact statement on the concept for disposal of Canada's nuclear fuel waste. Atomic Energy of Canada Limited Report AECL-10711, COG-93-1. Chalk River, Ontario.
- AECL. 2007a. AECL 2007 News Release: Team CANDU New Brunswick to Conduct Feasibility Study for Second Nuclear Power Plant at Point Lepreau. Atomic Energy of Canada Limited. (Available at <http://www.aecl.ca/NewsRoom/News/Press-2007/070801.htm>)
- AECL. 2007b. AECL 2007 News Release: Energy Alberta Corporation files an application with the Canadian Nuclear Safety Commission to site its Nuclear Power Plant near Peace River, Alberta. Atomic Energy of Canada Limited. (Available at <http://www.aecl.ca/NewsRoom/News/Press-2007/070827.htm>)
- Bruce Power. 2007a. Bruce Power new build project environmental assessment project description, version 3. Prepared by Golder Associates Limited for Bruce Power, January 19, 2007. (Available at [www.brucepower.com](http://www.brucepower.com))
- Bruce Power. 2007b. Bruce Power News Release: Bruce Power signs letter of intent with Energy Alberta, November 29, 2007. (Available at <http://www.brucepower.com/pagecontent.aspx?navuid=1211&dtuid=83608>)
- Cogema Logistics. 2003a. Conceptual designs for transportation of used fuel to a centralised facility. Cogema Logistics Report 500276-B-005. (Available at <http://www.nwmo.ca/Default.aspx?DN=612,608,237,199,20,1,Documents>)
- Cogema Logistics. 2003b. Logistics of transportation of used fuel to a centralised facility. Cogema Logistics Report 500276-B-009. (Available at <http://www.nwmo.ca/Default.aspx?DN=612,608,237,199,20,1,Documents>)
- CTECH. 2003. Cost estimate for a deep geological repository for used nuclear fuel. Report of a study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. CTECH Report 1106/MD18085/REP/02. (Available at <http://www.nwmo.ca/adx/asp/adxGetMedia.asp?DocID=613,608,237,199,20,1,Documents&MediaID=2791&Filename=DGR+Cost+Estimate+Report.pdf>)
- Garamszeghy, M. 2008. Nuclear fuel waste projections in Canada – 2008 update. Nuclear Waste Management Organization Report NWMO TR-2008-18. Toronto, Canada.
- Heystee, R. 2004. Comparison of conceptual cost estimates for Sweden's deep repository and a Canadian deep geologic repository for used nuclear fuel. Ontario Power Generation Report 06819-REP-00400-10018-R00.

- NBG. 2008. New Brunswick Government received Team CANDU's feasibility study examining the market demand for a second nuclear facility in the province. (Available at <http://www.gnb.ca/cnb/news/ene/2008e0134en.htm>)
- NWMO. 2005. Choosing a way forward. The future management of Canada's used nuclear fuel. Nuclear Waste Management Organization. (Available at [www.nwmo.ca](http://www.nwmo.ca))
- NWMO. 2008a. Moving forward together. Annual report 2007. Nuclear Waste Management Organization. (Available at [www.nwmo.ca](http://www.nwmo.ca))
- NWMO. 2008b. Implementing Adaptive Phased Management 2008 to 2012. Revised June 2008. Nuclear Waste Management Organization. (Available at [www.nwmo.ca](http://www.nwmo.ca))
- OPG. 2006. Project description for the Pickering B refurbishment for continued operation environmental assessment. Ontario Power Generation Inc. Submitted to the Canadian Nuclear Safety Commission, June 2006. (Available at [www.opg.com](http://www.opg.com))
- OPG. 2007. Project description for the site preparation, construction and operation of the Darlington B nuclear generating station environmental assessment. Ontario Power Generation Inc. Submitted to the Canadian Nuclear Safety Commission, April 12, 2007. (Available at [www.opg.com](http://www.opg.com))
- SKB. 2004. RD&D-programme 2004. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste including social science research. Swedish Nuclear Fuel and Waste Management Company, SKB Report TR-04-21. Stockholm, Sweden.