Joint Waste Owner Conceptual Designs

Conceptual Design for a Deep Geological Repository for Used Nuclear Fuel

Costs of Alternative Approaches for the Long-Term Management of Canada's Nuclear Fuel Waste

Deep Geologic Disposal Approach

A Submission to the Nuclear Waste Management Organization by Ontario Power Generation, Hydro-Québec, New Brunswick Power and Atomic Energy of Canada Ltd.

The cost estimates presented in this report were prepared by engineering consultants based on typical concept designs. The concept designs are considered feasible but are not recommendations.

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Appendix 1 - Life Cycle Cost Scenarios

1.0 Introduction

The Nuclear Fuel Waste Act requires the Nuclear Waste Management Organization (NWMO) to submit a report to Government which includes a comparison of costs, risks and benefits of three approaches for managing Canada's nuclear fuel waste.

In advance of the NWMO being established, the Joint Waste Owners (JWO), consisting of Ontario Power Generation (OPG), Hydro-Quebec (HQ), New Brunswick Power (NBP) and Atomic Energy of Canada (AECL), commissioned a study in 2001 based on requirements in the then draft Act to develop conceptual designs for the alternatives and associated engineering cost estimates.

This document provides the lifecycle cost estimate for a deep geologic disposal approach. The lifecycle cost of this approach includes the costs involved in:

- interim storage of nuclear fuel waste at reactor sites until all used fuel is transferred to a deep geologic repository,
- retrieval of used fuel from storage and transport to the repository, and
- siting, construction, operation, extended monitoring, closure and decommissioning of the repository.

This report summarizes the assumptions used and results of the cost estimating work for the deep geological disposal approach. The basis for the cost estimates is the AECL deep geological concept adapted to take account of recommendations from the Nuclear Fuel Waste Management and Disposal Concept Report (Seaborn Report) issued in 1988 by the Canadian Environmental Assessment Agency. The cost estimates include typical concepts proposed by consultants. While the concepts are considered feasible, they are <u>not</u> recommendations of the Joint Waste Owners.

Lifecycle costs, as presented in this report, include costs for fuel waste including storage, transportation and deep geological disposal. Similar reports have been prepared for the other two approaches: Centralized Extended Storage (CES) and Reactor-Site Extended Storage (RES). Lifecycle costs, expressed as present value costs, allow the cost of alternatives to be compared by the Nuclear Waste Management Organization (NWMO).

2.0 Source of Estimates

The estimates for interim storage of used nuclear fuel at reactor sites have been calculated using waste volumes provided by the respective owners currently storing the material and the application of OPG full unit interim storage costs to these volumes (Reference 1 for OPG).

The estimate for transportation of the nuclear fuel waste to the repository has been provided by Cogema Logistics (Reference 2). Cogema Logistics is a French company with extensive experience in transporting nuclear fuel waste in Europe.

The estimated cost of siting, construction, operation, extended monitoring, closure and decommissioning of the repository was provided by CTECH (Reference 3). At the time the contract was let, CTECH was a joint venture of CANATOM (SNC-LAVALIN, AECON) and AEA Technologies (UK) (now RWE Nukem).

3.0 Key Estimating Assumptions

For the purpose of the cost estimates presented in this report, the following key assumptions have been made:

- A total of 3.7 million fuel bundles are produced. The basis of this assumption is discussed in Section 4. This assumption is not a definitive prediction of the fuel bundles to be produced. In addition, the cost estimates do not address the small quantities of AECL non-CANDU used fuel
- Interim dry storage activities at reactor sites include construction of new facilities or expansion of existing facilities, operating and maintaining the facilities including container requirements, and the decommissioning of the facilities once all the fuel is transferred to the repository
- Cost of maintaining wet bays after stations have shut-down until all the used fuel is transferred to either the repository or dry storage are included in interim storage cost estimates
- Used fuel bundles from a reactor will be placed in interim wet storage for a minimum cooling period of seven years (ten years for OPG fuel) before transfer to dry storage or disposal
- The repository will be located at a remote location on the Canadian Shield in Ontario
- Repository in-service will be 2035 assuming a government decision is made in 2006
- Used fuel will be emplaced at a depth of 1,000 m in plutonic rock
- The repository will have a capacity to process approximately 120,000 fuel bundles per year and be operational for nominally 30 years

4.0 Used Fuel Inventory & Projections

The amount of nuclear fuel waste that is required to be managed is a major assumption in the development of the estimate. The following table includes the estimated number of fuel bundles produced by waste owners as of December 2003. There is significant uncertainty regarding the number of fuel bundles which will eventually be produced in Canada. The actual production will depend on decisions by waste producers on the refurbishment of power plants. It will also depend on whether new plants are built. The table below represents the projected number of fuel bundles for various scenarios resulting from all existing plants achieving from 30 to 50 years of production.

Waste Owner	Bundles as of December 2003 (Estimated)	Bundles Estimate – Average Station Life		
		30 years	40 Years	50 Years
OPG	1,592,946	2,654,682	3,274,412	3,894,142
HQ	94,160	135,000	180,000	225,000
NBP	103,489	135,000	180,000	225,000
AECL	30,682	30,682	30,682	30,682
T o t a l	**1,821,277**	**2,955,364**	**3,665,094**	**4,374,824**

For the remainder of this analysis, the quantity of fuel bundles assumed is 3.7 million. This quantity is representative of all plants achieving an average 40-year life. This could also be achieved by several plants being refurbished and achieving a 50 or 60 year life while others are not refurbished and retired after 25 or 30 years.

5.0 Cost Estimates

The following sections detail the cost of interim storage, retrieval, transportation and geological disposal of used fuel for the 3.7 million fuel bundle scenario. The total life cycle cost estimates for the 3.0 million and the 4.4 million fuel bundle scenarios are also summarized in Section 5.4. Appendix 1 of this document describes the scaling process used to derive the 3.0 and 4.4 million fuel bundle costs.

Cost estimates are shown in year 2002 constant dollars and also in January 2004 present value (PV) dollars. The present value calculation is based on a discount rate of 5.75% which assumes a 3.25% real rate of return over a projected long-term average increase in the Ontario Consumer Price Index of 2.5%.

5.1 Interim Storage and Retrieval of Used Fuel at Reactor sites

In this report interim storage means the continued storage of used fuel at waste owner locations until the used fuel is moved to the DGR disposal facility. Reference 1 provides the cost of interim storage of used fuel at OPG. These costs include:

- storing used fuel in dry storage at reactor sites from July 1, 2006 until the fuel is assumed to be shipped to the repository
- decommissioning of dry storage facilities and dry storage containers
- wet bay operational costs once stations have been shut-down until the wet bays containing the used fuel are emptied
- full dry storage facility costs (i.e. operations and maintenance, licensing, engineering support, and design and construction costs) are included for all storage activities.

The estimate for OPG assumes 3.3 million fuel bundles. The baseline interim storage cost estimate produced in 2001 has been adjusted slightly to account for escalation, changes to used fuel arising projections and cost incurred. The original design life of the wet bays is 50 years. It has been assumed that not all used fuel will be transferred to dry storage containers. Within the constraints of the wet bay design life and a repository in-service date of 2035, some used fuel is transferred directly from the wet bays to the repository. The costs to operate the wet bays during station life are accounted for in the cost of operating the stations. All used fuel must remain in the wet bays for a minimum cooling period. The interim storage costs are dependant on when fuel will be shipped to the repository.

The HQ and NBP method for storing used fuel in dry storage differs from that used by OPG. Following water pool storage, HQ store used fuel in vaults, and NBP store used fuel in silos. Information is available on the cost of constructing HQ and NBP dry storage systems but is not readily available on water pool storage or the operations and licensing costs for dry storage or retrieval. Information is also not readily available for AECL. For this reason, this report assumes the same unit cost for interim storage for HQ, NBP and AECL fuel as for OPG. Based on the information available for HQ and NBP this is expected to be conservative. However, this should not distort any comparison because on a Canada-wide basis the HQ, NBP, and AECL fuel quantity represents only 11% of the total used fuel (based on 40 year projections).

The following table shows the estimated costs for interim storage and retrieval of 3.7 million fuel bundles.

Storage Program	Estimated Cost	
	2002 M$	Jan 2004 PV M$
Interim Storage	1,795	1,187
Retrieval	585	232
Total	**2,380**	**1,418**

5.2 Transportation

The total cost of transportation of used fuel from the owner facilities to the disposal facility was estimated to be $ 954 M$ (2002$) based on estimates prepared by Cogema Logistics. The cost to load used fuel at the storage facilities is specific to each waste owner. In cases where there is a common geographic location of used fuel storage between waste owners [e.g. Douglas Point and Bruce Nuclear Power Development (AECL/OPG); G1 and G2 (AECL/HQ)], the cost of commonly located facilities is shared.

The Transportation program work breakdown structure (WBS) and associated cost estimate in constant and present value (PV) terms is as follows:

Transportation WBS	Estimated Cost 2002 M$
Mode & Route Development	1
System Development	4
Safety Assessment	4
Public Affairs	12
Project Management	38
Transporters	13
Maintenance Facility	78
Casks	50
UFTS Auxiliary Equipment	116
Nuclear Facility Loading	77
Transportation System Operations	334
Operational Systems	153
Environmental Management System	4
Decommissioning	22
Program Management	48
Total 2002M$	**954**
Total PV Jan 2004 M$	**390**

Three options were conceptualized and estimated by Cogema for the transportation system including all-road, mostly rail, and mostly water. The above costs represent the estimate for the all-road only option (Reference 2); the most flexible of the options.

5.3 Deep Geologic Repository (DGR)

The cost of siting, construction, operations, extended monitoring, closure and eventual decommissioning of the repository was estimated by CTECH. It is shown below in total and segregated by WBS.

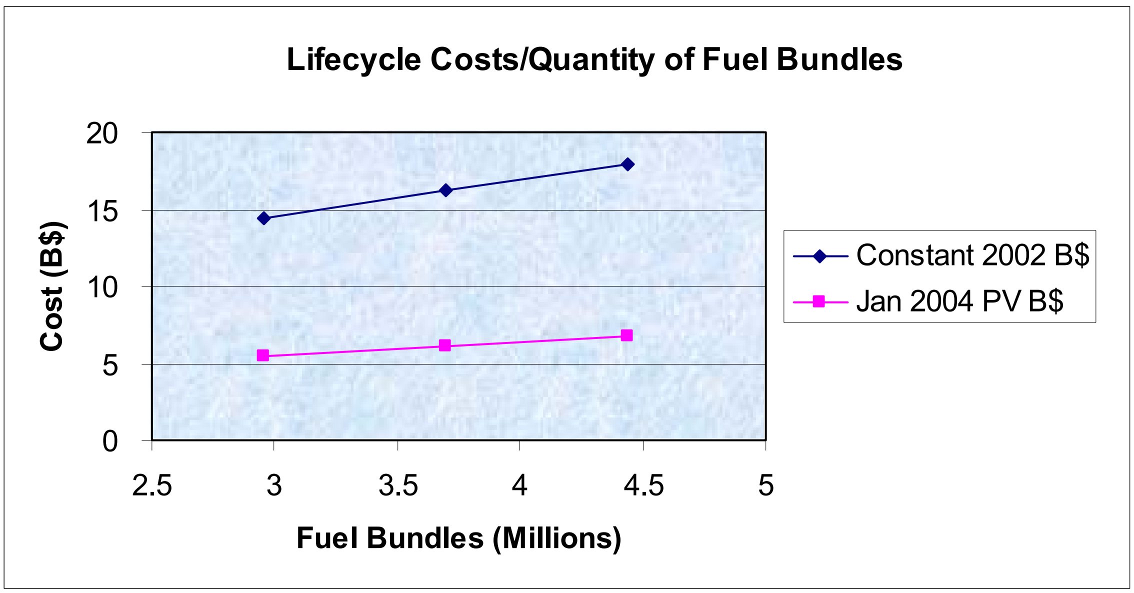
Deep Geologic Repository WBS	Estimated Cost 2002 M$
Siting	397
Repository Development	411
Safety Assessment	687
Licensing & Approval	120
Public affairs	107
Facility D&C	2,416
Facility Op	7,368
Environmental Assessment & Monitoring	236
Decommissioning & Closure	854
Program Management	285
Total 2002M$	**12,881**
Total PV Jan 2004 M$	**4,349**

5.4 Overall Lifecycle Costs Based on Quantity of Fuel Bundles (Post July 1, 2006)

The overall lifecycle costs for various numbers of fuel bundles/station lives is summarized as follows in constant 2002M$ and January 2004 PV M$:

Fuel Bundles (millions)/Station Life (Years)	Estimated Cost				
	Interim Storage and Retrieval 2002 M$	Road Transportation 2002 M$	Disposal 2002 M$	Total 2002 M$	Total PV Jan 2004 M$
3.0/30	2,054	815	11,487	14,356	5,529
3.7/40	2,380	954	12,882	16,216	6,157
4.4/50	2,706	1,091	14,208	18,005	6,763

In constant dollar and present value terms, the above table is shown graphically in the following illustration.



6.0 Comparison of Cost Estimates

In 2002 and 2003, a study was carried out to update the conceptual design and cost estimate for a Deep Geologic Repository for used nuclear fuel owned by Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited (Reference 3). The cost estimate for a Deep Geologic Repository was prepared by CTECH and documented in a draft report submitted in June 2003.

On July 3 and 4, 2003, meetings were held with SKB to compare costs in the June 2003 draft cost estimate report with equivalent cost estimates prepared by SKB for their Deep Geologic Repository. Items that were compared during the meeting included: unit costs for selected activities, equipment and materials; staffing assumptions; overall costs for a siting program, and selected research, development and demonstration (RD&D) programs; and overall costs for the packaging plant, auxiliary surface facilities and the deep geologic repository.

In most cases costs were similar and if there were differences, they could be explained mostly by the fact that the Canadian repository is designed to accommodate a larger used fuel inventory. For example, the unit costs for labour, bentonite, copper and the total annual operating cost-per-container were similar. Assumptions about staffing levels were generally similar or if there were large differences they could be explained. Cost estimates for siting and RD&D programmes and various repository facilities were similar and, if different, could be rationalized in all cases.

Adjustments to the CTECH estimate were made based on the cost comparison exercise with SKB and the final DGR cost estimate report was issued in September 2003.

7.0 References

1. Used Fuel Storage Life Cycle Cost Estimate Report. OPG Report No. 06819-REP-00400-10005-R0, May 14, 2001.

2. Cost Estimate for Transportation of Used Fuel to a Centralized Facility , Cogema Logistics Report, September 2003.

3. Cost Estimate for a Deep Geologic Repository for Used Nuclear Fuel. CTECH Report, September 2003.

4. American Association of Cost Engineers (AACE) publication “Skills & Knowledge of Cost Engineering” Third Edition, 1987 revised 1994, Section 2 “Order of Magnitude Estimating.”

Appendix 1
Life Cycle Cost Scenarios

This appendix describes how the raw data produced by OPG, HQ, NBP, AECL, CTECH, and COGEMA Logistics was used in producing the cost estimates in this report.

Interim Storage and Retrieval

OPG interim storage and retrieval costs are obtained from operating data for water pool storage, dry storage, and retrieval. Full unit costs and incremental unit costs are calculated from this data. Costs for the 40-year OPG scenario are derived directly from operating data; 30 and 50-year OPG scenarios are based on incremental unit costs on a bundle basis.

AECL, HQ, and NBP costs for the 30, 40, and 50 year scenarios are calculated using OPG full unit costs for interim storage and retrieval on a bundle basis. AECL, HQ, and NBP bundle totals for the 30/40/50 year scenarios are based on information provided by the waste owners.

Transportation

Transportation costs for the three scenarios are calculated by scaling the variable cost elements provided by COGEMA according to the bundle projections described above.

Disposal

Disposal costs are calculated by scaling the CTECH cost estimate according to the total bundle projections for the 3.0, 3.7 and 4.4 million bundles scenarios. Fixed-type cost components are not scaled. Variable-type cost components are scaled in direct proportion to the total bundle projections. Step-Fixed type cost elements are scaled according to the "Six-Tenths" method widely used and validated in the Process Plant Industry (Reference 4).

The 'Six-Tenths" method states that if the cost of a given unit is known at one capacity (C_1), and a cost is required at another similar unit of new capacity (C_2), the known cost multiplied by "C_2/C_1 exp 0.6" will estimate the cost of the new capacity.

$$\$_2 = \$_1 \times (C_2 / C_1)^{exp}$$

Where $\$_2$ = the estimated cost of the new unit
$\$_1$ = the known cost of the old unit
C_2 = the capacity of the new unit
C_1 = the capacity of the old unit
Exp = the exponent (power factor) 0.6.

The mathematical relationship reflects the non-linear increase (or decrease) in cost with size and shows economy of scale where the cost per unit of capacity decreases (increases) as the project size increases (decreases) and vice versa.