Joint Waste Owner Conceptual Designs

Conceptual Designs for Four Centralized Extended Storage Facility Alternatives for Used Nuclear Fuel

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

Centralized Extended Storage Facility 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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1.0 Introduction

The Nuclear Fuel Waste Act (NFWA) requires the Nuclear Waste Management Organization 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 NWFA to develop conceptual designs for the approaches and associated engineering cost estimates.

This document provides the lifecycle cost estimates for a Centralized Extended Storage (CES) facility 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 the centralized extended storage facility,
- retrieval of used fuel from storage and transport to the facility, and
- siting, initial construction and operation, extended operation and monitoring, two major refurbishments, and one fuel repackaging event.

This report summarizes the assumptions used and results of the cost estimating work for the centralized extended storage facility approach. The cost estimates are based on 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 of interim storage, transportation and centralized extended storage. Similar reports have been prepared for the other two approaches: Deep Geological Repository (DGR) and Reactor-Site Extended Storage (RES). Lifecycle costs, expressed as present value costs, allow the cost of approaches 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 (Ref 1 for OPG).

The estimate for transportation of the nuclear fuel waste to the central storage facility, 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, and refurbishment of the central storage facility was provided by CTECH (Ref 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 central storage facility
- Cost of maintaining wet bays after stations have shut-down until all the used fuel is transferred to either the central storage facility or on-site dry storage is 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
- The central storage facility will be located at a remote location in Ontario
- Four centralized storage alternatives were considered for the centralized extended storage approach including Casks and Vaults in Storage Buildings (CVSB), Surface Modular Vaults (SMV), Casks and Vaults in Shallow Trenches (CVST), and Casks in Rock Caverns (CRC)
- Used fuel will be stored in the central storage facility consisting of a single design selected from the four alternate approaches studied by CTECH
- Central storage facility in-service will be 2023 assuming a government decision is made in 2006
- The central storage facility will have a capacity to process approximately 120,000 fuel bundles per year and be operational for nominally 30 years
- The CES facility is intended to operate in cycles of approximately 300 years which would continue indefinitely. The CES cost estimates address the first such cycle.

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 presents the projected number of fuel bundles for various scenarios resulting from all existing plants achieving from 30 to 50 years of production. 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 are retired after 25 or 30 years.

Waste Owner	Bundles as of Dec-03 (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**

5.0 Cost Estimates

The following sections detail the cost of interim storage, retrieval, transportation and centralized extended storage 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 a CES long-term storage 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 central storage facility
- 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 central storage facility in-service date of 2023, some used fuel is transferred directly from the wet bays to the central storage facility. 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 central storage facility.

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			
	CVSB, CRC, and CVST		SMV	
	2002M$	PV Jan 2004 M$	2002M$	PV Jan 2004 M$
Interim Storage	1,481	1,047	1,481	1,047
Retrieval	152	71	483	225
Total	**1,633**	**1,118**	**1,964**	**1,272**

CVSB, CRC, and CVST retrieval costs are lower than SMV since SMV will require the removal of fuel from DSCs prior to shipment in the case of road transportation, or post shipment in the case of rail transportation.

5.2 Transportation

The total cost of transportation of used fuel from the owner facilities to the centralized extended storage facility was estimated to be 1,162 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	7
Safety Assessment	4
Public Affairs	12
Project Management	38
Transporters	37
Maintenance Facility	96
Casks	48
UFTS Auxiliary Equipment	87
Transfer Facilities	56
Nuclear Facility Loading	49
Transportation System Operations	534
Operational Systems	123
Environmental Management System	4
Decommissioning	18
Program Management	48
Total 2002M$	**1,162**
Total PV Jan 2004 M$	**573**

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 mostly rail option. This option was chosen as a basis for the CES estimate because it would allow transportation of the loaded DSCs to the centralized site for storage (Reference 2).

5.3 Centralized Extended Storage (CES)

In this study it has been assumed that the centralized extended storage facilities would need to operate indefinitely. In order to do so, the CES facilities would be refurbished on a regular basis and the fuel would need to be periodically repackaged when containers reach the end of their service lives. These refurbishment and repackaging events would be carried out indefinitely.

The CES estimates are based on 347 years of operations. The last 300 years of this time period represents a compete cycle of facility refurbishment and repackaging for all alternatives. Should it be necessary to estimate costs beyond 347 years, then the costs for this 300 year period can be repeated as required to generate costs (e.g. for 647, 947 years etc). The table below includes only the first cycle, up to 347 years. The calculation of costs far in the future requires the use of long-term economic forecasting with its inherent uncertainties. The present value impact of the first repeat cycle for CVSB is approximately 4M$ (PV Jan 2004) using current long-term economic factors.

Four alternatives were conceptualized and estimated for the centralized extended storage approach namely:

1. Casks and Vaults in Storage Buildings (CVSB)
2. Surface Modular Vaults (SMV)
3. Casks and Vaults in Shallow Trenches (CVST)
4. Casks in Rock Caverns (CRC)

The cost of siting, construction, operations, extended monitoring, refurbishment, and repackaging for each alternative was estimated by CTECH. It is shown below in total and segregated by WBS.

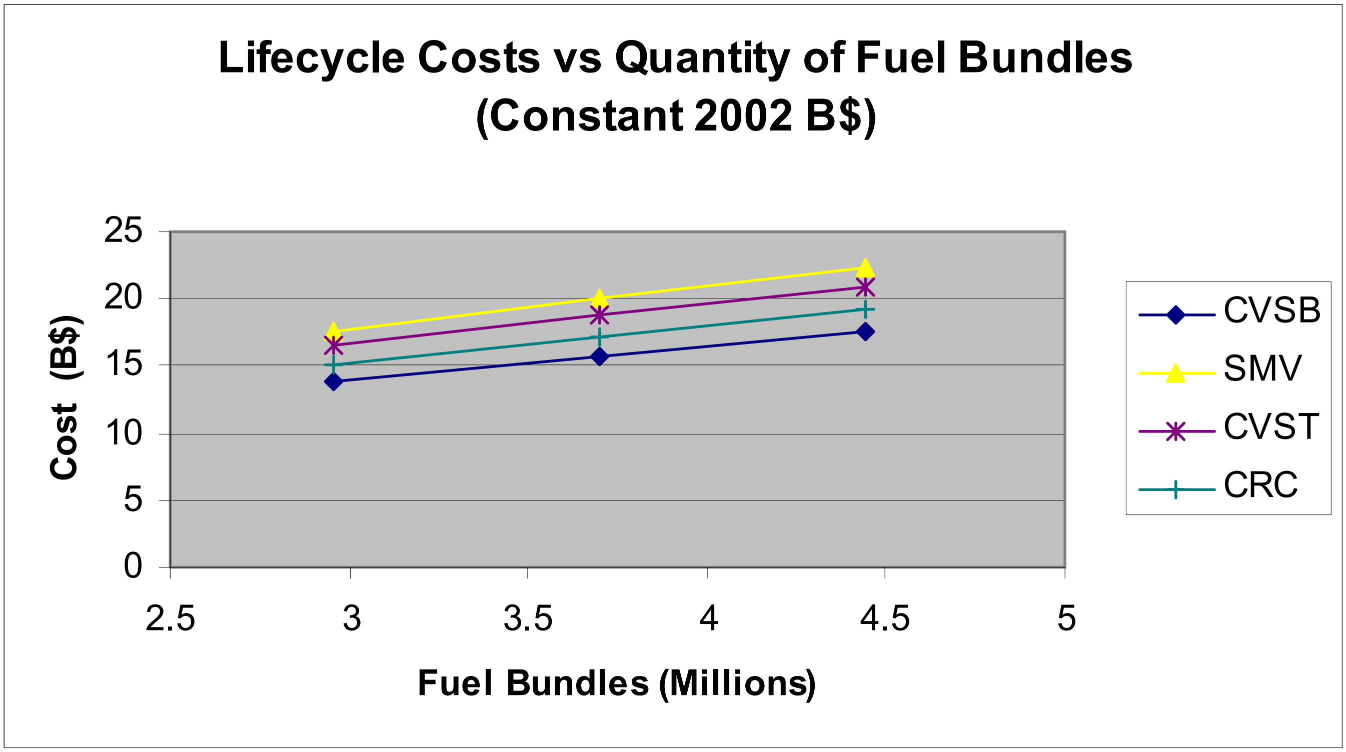
Centralized Extended Storage WBS	Alternative Approaches: Estimated Cost 2002M$			
	CVSB	SMV	CVST	CRC
Siting	44	44	46	48
Facility Development	64	94	79	89
Safety Assessment	37	37	37	37
Licensing & Approval	157	159	159	206
Public affairs	64	64	64	64
Facility Design & Construction	360	539	593	546
Facility Operations	11,516	15,242	14,236	12,656
Env Assessment & Monitoring	530	530	530	530
Program Management	131	150	146	138
Total 2002 M$	**12,903**	**16,860**	**15,890**	**14,314**
Total PV Jan 2004 M$	**1,449**	**1,958**	**1,893**	**1,736**

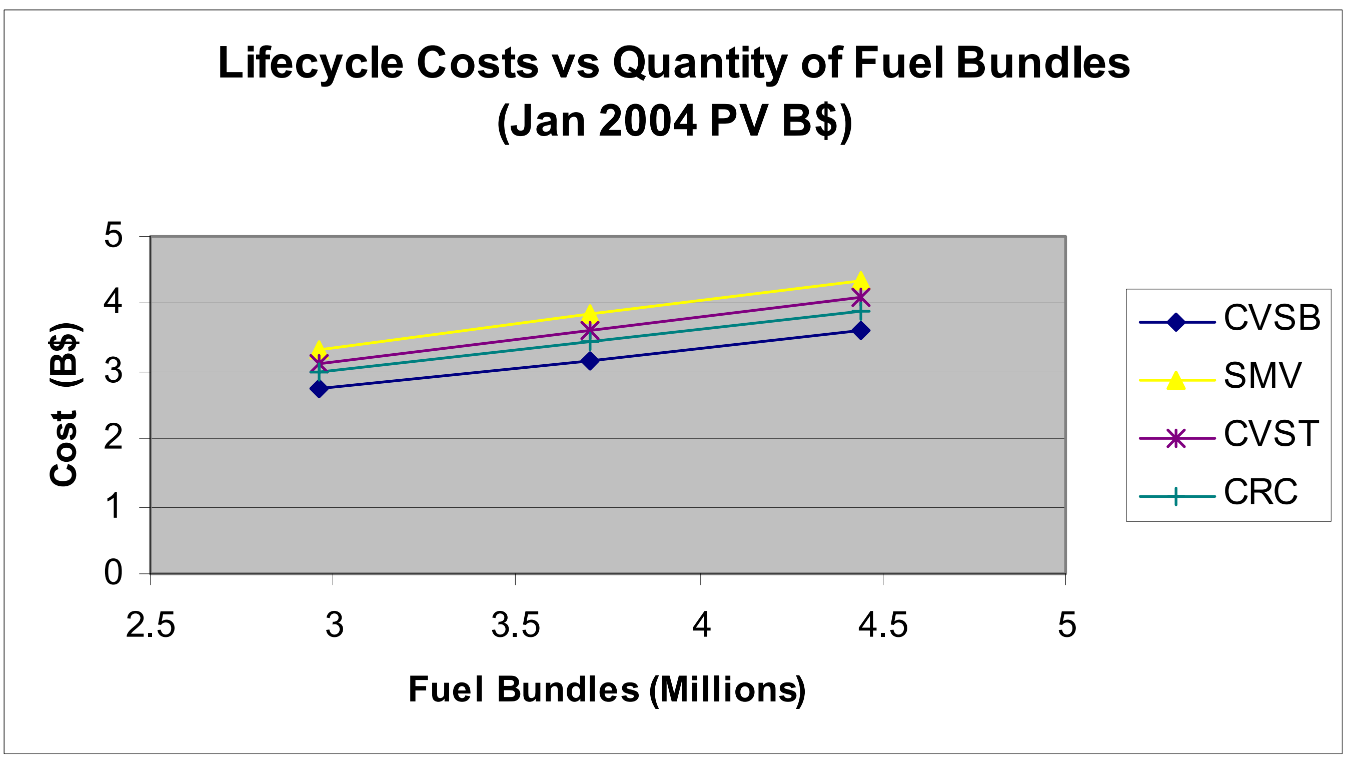
5.4 Overall Lifecycle Costs Based on Quantity of Fuel Bundles (Post July 1, 2006)

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

Alternative	Fuel Bundles (Millions)/Station Life (Years)	Estimated Cost				
		Interim Storage and Retrieval 2002 M$	Rail Transportation 2002 M$	Central Storage 2002 M$	Total 2002 M$	Total PV Jan 2004 M$
CVSB (Casks & Vaults in Storage Buildings)	3.0/30	1,398	997	11,448	13,843	2,761
	3.7/40	1,633	1,162	12,903	15,698	3,140
	4.4/50	1,868	1,322	14,248	17,438	3,507
SMV (Surface Modular Vaults)	3.0/30	1,667	997	14,930	17,594	3,337
	3.7/40	1,964	1,162	16,860	19,986	3,803
	4.4/50	2,262	1,322	18,645	22,229	4,252
CVST (Casks & Vaults in Shallow Trenches)	3.0/30	1,398	997	14,076	16,471	3,154
	3.7/40	1,633	1,162	15,890	18,685	3,584
	4.4/50	1,868	1,322	17,568	20,758	3,999
CRC (Casks in Rock Caverns)	3.0/30	1,398	997	12,698	15,093	3,017
	3.7/40	1,633	1,162	14,314	17,109	3,427
	4.4/50	1,868	1,322	15,809	18,999	3,823

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


Lifecycle Costs vs Quantity of Fuel Bundles
(Constant 2002 B$)
Cost (B$)
25
20
15
10
5
0
2.5
3
3.5
4
4.5
5
Fuel Bundles (Millions)
CVSB
SMV
CVST
CRC


Lifecycle Costs vs Quantity of Fuel Bundles
(Jan 2004 PV B$)
Cost (B$)
5
4
3
2
1
0
2.5
3
3.5
4
4.5
5
Fuel Bundles (Millions)
CVSB
SMV
CVST
CRC

6.0 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 Centralized Extended Storage Facility 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.

Centralized Extended Storage

Centralized extended storage 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. 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.