Joint Waste Owner Conceptual Designs

Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel

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

Reactor-Site Extended Storage 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, 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 Reactor-Site Extended Storage (RES) approach. The lifecycle cost of this approach includes the costs involved in:

- interim storage of nuclear fuel waste at reactor sites until fuel is transferred to extended storage,
- retrieval of used fuel from interim storage, and
- construction and operation, monitoring, major refurbishments, and repackaging events for reactor-site extended storage.

This report summarizes the assumptions used and results of the cost estimating work for the reactor-site extended storage 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 and reactor-site extended storage. Similar reports have been prepared for the other two approaches: Deep Geological Repository (DGR) and Centralized Extended Storage (CES). 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 estimated cost of construction, operation, and refurbishment of the reactor-site facilities was provided by CTECH (Ref 2). 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,
- Cost of maintaining wet bays after stations have shut-down until all the used fuel is transferred to either the on-site dry storage or extended 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 disposal
- The CTECH reactor-site cost estimates include twenty-one separate estimates on a reactor-site (waste owner) basis. For the purpose of this report the twenty-one cost estimates are logically grouped into 3 design alternatives as either current technology, new above ground technology, or new below ground technology.
- Used fuel will be stored in the reactor-site extended storage facilities consisting of a single design alternative selected from one of the three alternatives mentioned above
- Reactor-site facility in-service dates will vary from 2006 to 2020 dependent on the alternative selected and assuming a government decision is made in 2006
- The RES facilities are intended to operate in cycles of approximately 300 years which would continue indefinitely. The RES 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 represents 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 a 40-year life or 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, and reactor-site 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 5.3. Appendix 1 of this document describes the scaling process used to derive the 3.0, 3.7, 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 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 as necessary to a RES long-term storage facility. The necessity will vary with the RES long-term alternative selected as detailed in Section 5.2. Reference 1 provides the baseline cost estimate for interim storage of used fuel at OPG reactor sites. These costs include:

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

The estimate for OPG assumes 3.3 million fuel bundles from a 40 year generation program. 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 the reactor-site extended storage facility in-service dates, some used fuel is transferred directly from the wet bays to the reactor-site extended 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 reactor-site extended storage facilities.

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 of 3.7 million fuel bundles for each estimate alternative.

Alternative	2002M$	PV Jan 2004 M$
Current Technology	1,994	1,400
New Above Ground Technology	1,304	934
New Below Ground Technology	1,297	933

Interim storage costs vary for alternatives due to the longer interim storage period associated with the current technology alternative versus that required for new technology programs.

5.2 Reactor-Site Extended Storage (RES)

In this study it has been assumed that the reactor-site extended storage facilities would need to operate indefinitely. In order to do so, the RES 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.

Twenty-one reactor-site extended storage scenarios were conceptualized and estimated specific to waste owner sites. For the purposes of this report, the twenty-one scenarios were logically grouped into three alternatives for each of 7 sites as follows:

1. Current technology - including Casks in Storage Buildings (CSB), Silos (SILO), and Vaults (VLTS)

2. New above ground technology – including Surface Modular Vaults (SMV) and Silos in Storage Buildings (SSB)

3. New below ground technology – including Casks in Shallow Trenches (CST), Silos in Shallow Trenches (SST), and Vaults in Shallow Trenches (VST).

The following table shows the twenty-one scenarios including their respective alternative grouping and in-service dates.

Owner	Extended Storage Scenario	Alternative Grouping	Station	Description	In-Service date
OPG	**CSB**	**1**	Pickering	Casks in Storage Buildings	2006*
	CSB	**1**	Bruce	Casks in Storage Buildings	2006*
	CSB	**1**	Darlington	Casks in Storage Buildings	2006*
	SMV	**2**	Pickering	Surface Modular Vaults	2016
	SMV	**2**	Bruce	Surface Modular Vaults	2018
	SMV	**2**	Darlington	Surface Modular Vaults	2020
	CST	**3**	Pickering	Casks in Shallow Trenches	2016
	CST	**3**	Bruce	Casks in Shallow Trenches	2018
	CST	**3**	Darlington	Casks in Shallow Trenches	2020
NBP	**SILO**	**1**	Pt. Lepreau	Silos	2006*
	SMV	**2**	Pt. Lepreau	Surface Modular Vaults	2016
	VST	**3**	Pt. Lepreau	Vaults in Shallow Trenches	2016
HQ	**VLTS**	**1**	Gentilly	Vaults	2006*
	SMV	**2**	Gentilly	Surface Modular Vaults	2020
	VST	**3**	Gentilly	Vaults in Shallow Trenches	2020
AECL Chalk River	**SILO**	**1**	Chalk River	Silos	2006*
	SSB	**2**	Chalk River	Silos in Storage Buildings	2016
	SST	**3**	Chalk River	Silos in Shallow Trenches	2016
AECL Whiteshell	**SILO**	**1**	Whiteshell	Silos	2006*
	SSB	**2**	Whiteshell	Silos in Storage Buildings	2018
	SST	**3**	Whiteshell	Silos in Shallow Trenches	2018

* = Current technology In-Service dates are shown as 2006 to align with the earliest possible date for a Government decision in 2006. Actual In-Service dates are earlier.

The cost of siting, construction, operations, extended monitoring, refurbishment, and repackaging for each alternative was summarized from costs estimated by CTECH. They are shown below in total and segregated by WBS.

WBS	Alternative Grouping		
	Current Technology (1)	New Above Ground Technology (2)	New Below Ground Technology (3)
Siting	6	6	8
System Development	54	152	86
Safety Assessment	27	30	32
Licensing and Approvals	218	232	225
Public Affairs	18	18	18
Facility Design & Construction	148	1,171	842
Facility Operation	14,651	22,197	18,485
EA and Monitoring	516	576	586
Program Management	6	21	21
Total 2002 M$	**15,643**	**24,404**	**20,302**
Total PV 2004 M$	**925**	**3,488**	**2,628**

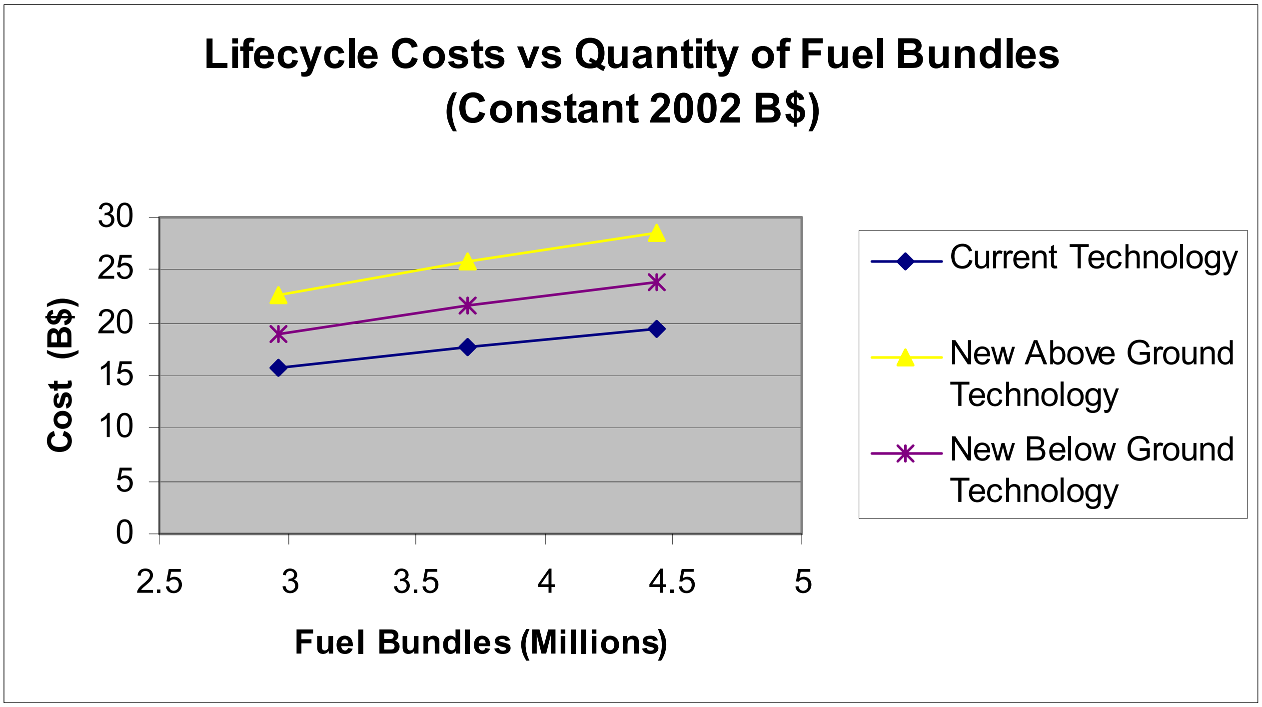
The RES estimates are based on a nominal 300 years of operation representing a complete cycle of facility refurbishment and repackaging for all alternatives. Should it be necessary to estimate costs beyond 300 years, then the costs for this period can be repeated as required to generate costs (e.g. for 600, 900 years ..etc). The table above includes only the first cycle up to 300 years. The calculation of costs far in the future require the use of long-term economic forecasting with its inherent uncertainties. The present value impact of the first repeat cycle is approximately 5M$ (PV Jan 2004) using current long-term economic factors.

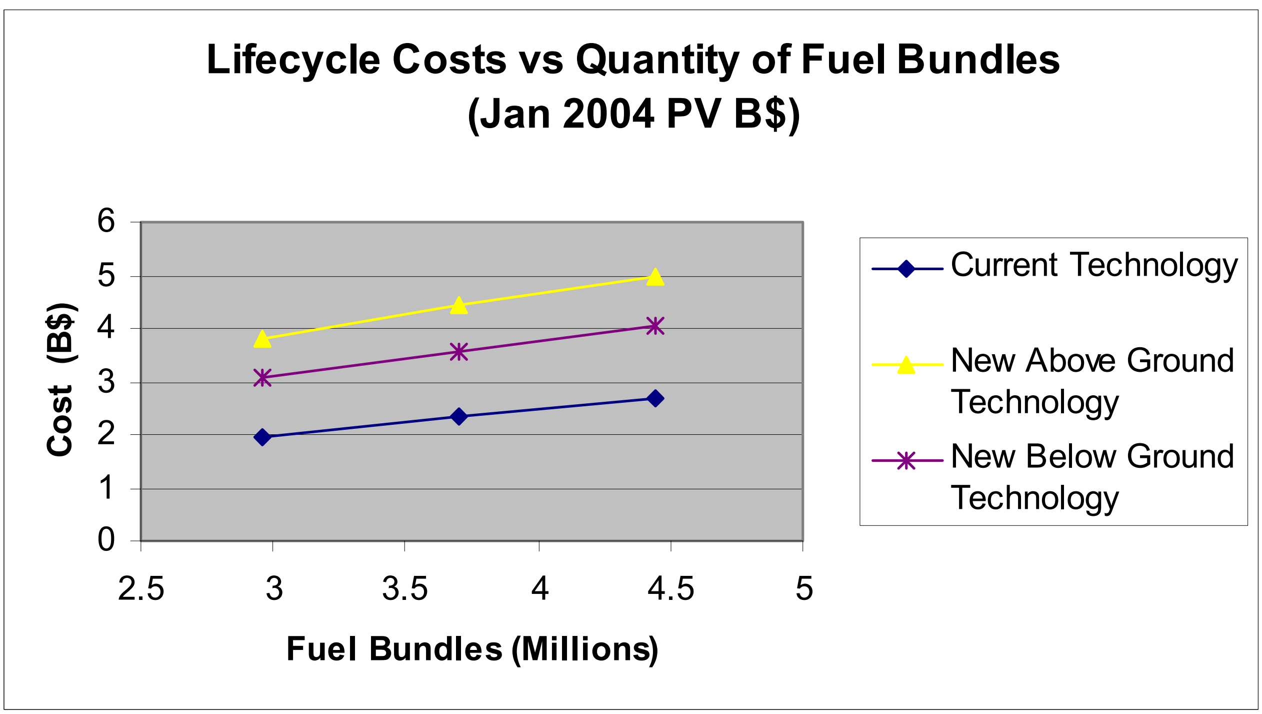
5.3 Overall Lifecycle Costs Based on Quantity of Fuel Bundles (Post July 1, 2006)

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

Alternative Grouping	Fuel Bundles (Millions)/ Station Life (Years)	Estimated Cost			
		Interim Storage 2002 M$	Reactor-Site Storage 2002 M$	Total 2002 M$	Total PV Jan 2004 M$
Current Technology (1)	3.0/30	1,782	13,880	15,662	1,958
	3.7/40	1,994	15,643	17,637	2,324
	4.4/50	2,207	17,269	19,476	2,682
New Above Ground Technology (2)	3.0/30	1,091	21,491	22,582	3,809
	3.7/40	1,304	24,404	25,708	4,422
	4.4/50	1,517	27,084	28,601	4,999
New Below Ground Technology (3)	3.0/30	1,085	17,957	19,042	3,071
	3.7/40	1,297	20,302	21,599	3,561
	4.4/50	1,510	22,463	23,973	4,026

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$)
Cost (B$)
30
25
20
15
10
5
0
2.5
3
3.5
4
4.5
5
Fuel Bundles (Millions)
Current Technology
New Above Ground Technology
New Below Ground Technology


Lifecycle Costs vs Quantity of Fuel Bundles
(Jan 2004 PV B$)
Cost (B$)
6
5
4
3
2
1
0
2.5
3
3.5
4
4.5
5
Fuel Bundles (Millions)
Current Technology
New Above Ground Technology
New Below Ground Technology

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 Reactor-Site Extended Storage for Used Nuclear Fuel. CTECH Report, September 2003.

3. 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, and CTECH was used in producing the cost estimates in this report.

Interim Storage

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 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.

Reactor-Site Extended Storage

Reactor-Site 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 3).

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.