

Nuclear Fuel Waste Projections in Canada – 2009 Update

NWMO TR-2009-30

December 2009

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Nuclear Waste Management Organization

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MANAGEMENT
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ABSTRACT

Title: Nuclear Fuel Waste Projections in Canada – 2009 Update
Report No.: NWMO TR-2009-30
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Company: Nuclear Waste Management Organization
Date: December 2009

Abstract

Since the Nuclear Waste Management Organization 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; and
- The type of used nuclear fuel produced in Canada;

This report updates the 2008 report [Garamszeghy, 2008] and summarizes the existing inventory of used CANDU nuclear fuel wastes in Canada as of June 30, 2009 and forecasts the potential future arisings from the existing reactor fleet as well as from proposed new-build reactors.

As of June 30, 2009, a total of approximately 2.1 million used CANDU fuel bundles (42,000 tonnes of heavy metal (t-HM)) were in storage at the reactor sites. For the existing reactor fleet, the total used fuel produced to end of life of the reactors ranges from about 2.8 to 5.5 million used CANDU fuel bundles (56,000 t-HM to 110,000 t-HM), depending upon decisions to refurbish current reactors. This total projection has not changed since the 2008 report. The lower number is based on an average of 30 calendar years of operation for each reactor (i.e. no refurbishment), while the higher number assumes that reactors are refurbished and life extended for an additional 30 calendar years of operation.

Used fuel produced by potential new-build reactors will depend on the type of reactor and number of units deployed. New-build plans are at various stages of development and the decisions about reactor technology and number of units have not yet been made. If all of the units where a formal licence application has already been submitted are constructed, the total additional quantity of used fuel from these reactors could be up to 1.9 million CANDU fuel bundles (31,200 t-HM), or 21,600 PWR fuel assemblies (11,640 t-HM), or 27,000 BWR fuel assemblies (3,384 t-HM), or some combination thereof. This total has been reduced from the 2008 report due to cancellation of some new-build plans in Ontario.

As decisions on new nuclear build and reactor refurbishment are made by the nuclear utilities in Canada, the forecasted inventory of nuclear fuel waste will be incorporated into future updates of this report.

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1. INTRODUCTION

1.1 BACKGROUND

The Nuclear Waste Management Organization (NWMO) has a legal obligation to manage all of Canada's used nuclear fuel – that which exists now and that which will be produced in the future. We must continually monitor new developments and be prepared to assume our legal responsibilities to manage used nuclear fuel in light of evolving energy policy.

In recent years, Canada's energy policy landscape has evolved. New Brunswick, Ontario, Saskatchewan, and even Alberta (heretofore a non-nuclear province) are engaged in discussions about adding to Canada's existing number of nuclear reactors. In Ontario, the debate extends further. Consideration is being given to introducing light water reactors, a technology used elsewhere in the world that produces used nuclear fuel with characteristics different from those which Canadian nuclear operators now manage.

Decisions on new nuclear reactors, recycling or other changes in energy choices will not be made by the NWMO. They will be taken by nuclear operators in conjunction with government and the regulators. It is important that we recognize uncertainties in our operating environment and put in place an active process for ongoing monitoring and review of new developments so that we can plan for the long-term management of used fuel arising from such decisions.

As energy policy decisions are taken that substantially affect the volumes or types of used fuel NWMO must manage, we must provide for the ongoing engagement of Canadians on the social, ethical and technical appropriateness of the long-term management plans for these materials. As part of our continuing engagement of Canadians, the NWMO will be discussing with interested individuals and organizations how changing conditions, such as new-build, different fuel types or reprocessing should be addressed. And, we will continually review, adjust and validate our implementation plans as appropriate against the changing external environment.

1.2 PURPOSE

The NWMO has made a commitment to publish information on current and future potential inventories of used fuel volumes and types on an annual basis [NWMO, 2008]. This document is the second such annual report and provides an update to the 2008 version [Garamszeghy, 2008].

1.3 SCOPE

This report summarizes the existing inventory of used nuclear fuel wastes in Canada as of June 30, 2009 and forecasts the potential future arisings from the existing reactor fleet as well as from proposed new-build reactors.

1.4 CHANGES SINCE THE 2008 REPORT

The primary changes to the Canadian nuclear landscape since the 2008 report are:

- a) the withdrawal of licence application by Bruce Power for new-build reactors in Ontario [Bruce Power, 2009]; and
- b) the suspension of the reactor type selection for new-build in Ontario. [Infrastructure Ontario, 2009]

The first change results in a reduction in the number of potential new-build units, while the second change results in on-going uncertainty over the new reactor types and subsequently the type and quantity of used fuel they will produce.

Additional changes include:

- a) Delay in reactor refurbishment projects at Pt Lepreau and Bruce A (note that these delays are not expected to reduce the total amount of used fuel produced, just the timing of when it is produced); and
- b) An increase in the amount of used fuel currently in wet and dry storage, due to another year of reactor operation.

The overall effects of these changes on the projected used fuel inventory are:

- a) An increase in the total amount of used fuel currently in storage of 77,392 bundles from June 2008 to June 2009.

	June 2008	June 2009	
Wet storage	1,548,399	1,553,561	bundles
Dry storage	497,821	570,051	bundles
TOTAL	2,046,220	2,123,612	bundles

- b) No significant change to the projected future total number of used fuel bundles produced by the existing reactor fleet for either the low forecast or high forecast (2.8 million to 5.5 million bundles, respectively); and
- c) A decrease in the total amount of used fuel forecast from new-build:

	2008 Forecast	2009 Forecast
CANDU fuel bundles	2.3 million	1.9 million
PWR fuel assemblies	27,000	21,600
BWR fuel assemblies	27,000	27,000

Note that the new-build projections depend on the selection of reactor type for each project and may be some combination of the above (i.e. not the total of all of the above).

2. INVENTORY FROM EXISTING REACTORS

2.1 CURRENT INVENTORIES

Table 1 summarizes the current inventory of nuclear fuel waste in Canada as of June 30, 2009. The inventory is expressed in terms of number of CANDU used fuel bundles and does not include fuel which is currently in the reactors, which is not considered to be “nuclear fuel waste” until it has been discharged from the reactors.

TABLE 1: Summary of Nuclear Fuel Waste in Canada as of June 30, 2009

Location	Waste Owner	Wet Storage (# bundles)	Dry Storage (# bundles)	TOTAL (# bundles)	Current Status
Bruce A	OPG	370,232	33,024	403,256	- 2 units operational, 2 units under refurbishment (expected 2011 return to service)
Bruce B	OPG	383,911	114,428	498,339	- 4 units operational
Darlington	OPG	326,552	29,952	356,504	- 4 units operational
Douglas Point	AECL	0	22,256	22,256	- permanently shut down
Gentilly 1	AECL	0	3,213	3,213	- permanently shut down
Gentilly 2	HQ	39,245	73,200	112,445	- operational
Pickering A	OPG	392,863	205,824	598,687	- 2 units operational, 2 units permanently shut down
Pickering B	OPG				- 4 units operational
Point Lepreau	NBPN	40,758	81,000	121,758	- currently undergoing refurbishment (expected 2010 return to service)
AECL Whiteshell	AECL	0	2,268	2,268	- permanently shut down. See Note (1)
AECL Chalk River	AECL	0	4,886	4,886	-includes fuel from NPD (permanently shut down) and other CANDU reactors
TOTAL		1,553,561	570,051	2,123,612	Total of: - 17 units in operation - 3 units under refurbishment - 6 units permanently shut down

Notes: data as of June 30, 2009.

AECL = Atomic Energy of Canada Limited

HQ = Hydro-Québec

NBPN = New Brunswick Power Nuclear

OPG = Ontario Power Generation Inc

(1) 360 bundles of Whiteshell fuel are standard CANDU bundles. The remaining bundles are various research fuel bundles, similar in size and shape to standard CANDU bundles.

Assuming an average of 20 kg heavy metals in a fuel bundle, 2.1 million bundles is equivalent to 42,000 tonnes of heavy metal (t-HM). In addition to the totals shown in Table 1, AECL also has some 21,987 items of research reactor fuels, experimental fuels and partial fuel elements in storage at Chalk River.

Further details on the existing reactors can be found in Appendix A.

2.2 FUTURE FORECASTS

Forecasts of future nuclear fuel waste arisings are given in Table 2. Two scenarios are provided in the forecasts:

- a) **Low:** the reactors are shut down at the end of the projected life of the fuel channels (i.e. nominal 30 calendar years (equivalent to about 25 effective full power years) of operation), resulting in a total of ~2.8 million bundles (56,000 t-HM);
- b) **High:** the reactors are refurbished with a new set of pressure tubes and other major components, then operated for a further 30 calendar years (25 effective full power years) to a total of 60 calendar years, resulting in a total of ~5.5 million bundles (110,000 t-HM).

Note that these scenarios are constructed for NWMO planning purposes only to provide a range of possible fuel arisings and may differ from the official business plans of the reactor operators. Operation of the reactors, including whether or not to refurbish, are subject to future business planning decisions of the individual reactor operators. Forecasts are expressed in terms of number of used CANDU fuel bundles and are rounded to nearest thousand bundles. Details are provided in Appendix B.

TABLE 2: Summary of Projected Nuclear Fuel Waste from Existing Reactors

Location	Waste Owner	Total June 2009 (# bundles)	Typical Annual Production (# bundles)	Low Scenario (# bundles)	High Scenario (# bundles)
Bruce A	OPG	403,256	22,500 ⁽¹⁾	483,000	1,039,000 ⁽⁴⁾
Bruce B	OPG	498,339	23,500 ⁽¹⁾	640,000	1,345,000
Darlington	OPG	356,504	23,000 ⁽¹⁾	645,000	1,335,000
Douglas Point	AECL	22,256	0 ⁽²⁾	22,256	22,256
Gentilly 1	AECL	3,213	0 ⁽²⁾	3,213	3,213
Gentilly 2	HQ	112,445	4,800	120,000	274,000
Pickering A	OPG	598,687	6,800 ⁽³⁾	746,000	1,181,000
Pickering B	OPG		13,800 ⁽¹⁾		
Point Lepreau	NBPN	121,758	4,800	121,758	283,000 ⁽⁵⁾
AECL Whiteshell	AECL	2,268	0 ⁽²⁾	2,268	2,268
AECL Chalk River	AECL	4,886	0 ⁽⁶⁾	4,886	4,886
TOTAL (bundles)⁽⁷⁾		2,123,612	99,200	2,789,000	5,490,000
(t-HM)		42,000	1,990	56,000	110,000

Notes:

- 1) Based on 4 reactors operating
- 2) Reactor is permanently shut down and not producing any more fuel
- 3) Based on 2 reactors operating
- 4) All units at Bruce A are assumed to be refurbished and life extended (refurbishment currently under way for 2 units)
- 5) Point Lepreau is currently shut down for refurbishment and is expected to re-start in 2010
- 6) Future forecasts do not include research fuels. AECL Chalk River does not produce any CANDU fuel bundles.
- 7) Totals may not add exactly due to rounding to nearest 1,000 bundles for future forecasts.

3. INVENTORY FROM POTENTIAL NEW-BUILD REACTORS

There are two categories of proposed new reactor projects:

- a) projects which are currently undergoing an environmental assessment; and
- b) projects which are in the preliminary discussion or consideration phase

This report does not assess the probability of any one these projects proceeding. Execution of the projects rests entirely with the proponent. In addition, the technologies for each project have not yet been selected. The NWMO will continue to monitor the situation and will evaluate the implications and options for the different fuel types as part of the review of the Adaptive Phased Management approach.

TABLE 3: Summary of Proposed New Reactors

Proponent	Location	In-service timing	Reactor Type(s)	Status
OPG	Darlington, Ontario	First unit 2018 (see note 1)	4 x ACR 1000 or 4 x AP1000 or 3 x EPR (see note 1)	Selected as site for first 2 reactors by Ontario Government EIS report & updated application for a site preparation licence was submitted Sept 30, 2009. [OPG 2009]
Bruce Power / Energy Alberta	Northern Lights, Alberta	First unit 2017	4 x ACR 1000 or 3 x AP1000 or 2 x EPR or 2 x ESBWR	Site preparation licence application submitted to CNSC March 2008 [Bruce Power Alberta, 2008]
Province of New Brunswick	Point Lepreau, New Brunswick	(not publicly announced)	ACR 1000	Feasibility study being conducted [MZConsulting, 2008]
Bruce Power Saskatchewan	Saskatchewan (no specific site selected yet)	First unit 2020	ACR 1000 or AP1000 or EPR	Feasibility study conducted by Bruce Power [Bruce Power, 2008b]
Bruce Power	Bruce Nuclear Power Development, Ontario	First unit 2016	4 x ACR 1000 or 3 x AP1000 or 2 x EPR (see note 1)	EIS report submitted September 2008 [Bruce Power, 2008a] Application withdrawn, July 2009 [Bruce Power 2009]
Bruce Power	Nanticoke, Ontario	First unit after 2020	2 x ACR 1000 or 2 x AP1000 or 2 x EPR	Bruce Power announced intent to start EA, Oct 31, 2008. Application withdrawn, July 2009 [Bruce Power 2009]

Notes:

- 1) Selection of reactor type for new-build in Ontario was to be made by Ontario Government (Infrastructure Ontario) in 2009. However, although the procurement process was suspended in June 2009 until further notice [Infrastructure Ontario, 2009], OPG is still proceeding with the EA and site preparation licence application process [OPG, 2009].

3.1 PROJECTS CURRENTLY UNDERGOING ENVIRONMENTAL ASSESSMENT

3.1.1 ONTARIO POWER GENERATION

OPG is currently undertaking an environmental assessment (EA) for building up to 4 new reactors at its Darlington site, in Clarington just east of Toronto [OPG, 2007]. The Darlington site has been selected by the Government of Ontario to host the first two new-build reactors in the province, with an expected in service date of 2018. The EA is being conducted for the maximum physical capacity of the site to allow for possible future expansion.

Currently three reactor types are being considered:

- a) **AECL Advanced CANDU 1000 (ACR 1000)**, which is a 1085 MW(e) net heavy water moderated, light water cooled pressure tube reactor. Up to 4 ACR 1000 reactors would be built on the site in two twin unit pairs. This would result in a total lifetime production of approximately 770,400 used fuel bundles (12,480 t-HM).
- b) **Westinghouse AP1000**, which is a 1090 MW(e) net pressurized light water reactor. Up to 4 AP1000 reactors would be built on the site, which would result in a total lifetime production of approximately 10,800 PWR fuel assemblies (5,820 t-HM).
- c) **AREVA EPR**, which is a 1600 MW(e) net pressurized light water reactor. Up to 3 EPR reactors would be built on the site, which would result in a total lifetime production of approximately 9,900 PWR fuel assemblies (5,220 t-HM).

All three reactor designs are considered to be “Generation III+”, and are designed to operate for 60 years. The Province, through its Infrastructure Ontario program, will be selecting the preferred vendor. However, the selection process was suspended in June 2009 [Infrastructure Ontario 2009].

As described below in Section 3.3 (with further details in Appendix C), all three reactor types operate with enriched uranium fuel. The ACR 1000 fuel is similar in size and shape to existing CANDU fuel bundles. The AP1000 and EPR fuel assembly is considerably different from the CANDU fuels in terms of size and mass, but is very similar to conventional pressurized light water reactor fuels used in many other countries around the world.

3.2 ADDITIONAL PROJECTS UNDER CONSIDERATION

3.2.1 ALBERTA

Bruce Power Alberta submitted a site preparation licence application to the CNSC in March 2008 to construct up to 4 power reactors in the municipal district of Northern Lights, Alberta, with the first unit being in-service as early as 2017 [Bruce Power Alberta, 2008]. A preferred reactor type was not specified in the licence application, however, four reactor types were included:

- a) **AECL ACR 1000** – up to 4 ACR 1000 reactors would be built on the site in two twin unit pairs. This would result in a total lifetime production of approximately 770,400 used fuel bundles (12,480 t-HM).
- b) **Westinghouse AP1000** – up to 3 AP1000 reactors would be built on the site, which would result in a total lifetime production of approximately 8,100 PWR fuel assemblies (4,365 t-HM).

- c) **AREVA EPR** – up to 2 EPR reactors would be built on the site, which would result in a total lifetime production of approximately 6,600 PWR fuel assemblies (3,480 t-HM).
- d) **GE ESBWR**, which is a 1535 MW(e) net boiling light water reactor. Up to 2 ESBWR reactors would be built on the site, which would result in a total lifetime production of approximately 27,000 BWR fuel assemblies (3,384 t-HM).

3.2.2 NEW BRUNSWICK

The Province of New Brunswick is currently conducting a feasibility study to construct a second reactor at the Point Lepreau site, based on an ACR 1000 reactor type [MZConsulting, 2008]. No in-service date has been publicly announced yet. The ACR 1000 would result in a total lifetime production of approximately 192,600 used fuel bundles (3,120 t-HM).

3.2.3 SASKATCHEWAN

Bruce Power Saskatchewan is currently conducting feasibility studies for constructing one or more power reactors in the Province of Saskatchewan. No specific site has been selected. The earliest potential in-service date is in the 2020 timeframe. The facility would likely be a single unit and three reactor technologies are being considered [Bruce Power, 2008b]:

- a) **AECL ACR 1000** – This would result in a total lifetime production of approximately 192,600 used fuel bundles (3,120 t-HM).
- b) **Westinghouse AP1000** – This would result in a total lifetime production of approximately 2,700 PWR fuel assemblies (1,455 t-HM).
- c) **AREVA EPR** – This would result in a total lifetime production of approximately 3,300 PWR fuel assemblies (1,740 tonnes of uranium).

3.2.4 ONTARIO

Bruce Power has submitted its Environmental Impact Statement (EIS) for new-build at the Bruce Power site [Bruce Power, 2008a]. Bruce Power also announced on October 31, 2008 that they would be starting an environmental assessment to construct 2 reactors near the Nanticoke site in Ontario. In July 2009, Bruce Power subsequently announced that they had withdrawn their applications for these two projects [Bruce Power, 2009]

3.3 SUMMARY OF NUCLEAR FUEL CHARACTERISTICS FROM NEW-BUILD REACTORS

Table 4 presents a summary of the major characteristics and quantities of nuclear fuels that are used in the proposed new-build reactor types. Further details can be found in Appendix C.

Table 5 summarizes the total quantity of used fuel that might be produced if all of the reactors where a formal licence application has already been submitted are constructed. Note that the totals correspond to the case where all of the new-build reactors are of the same type. In reality, different reactor types might be built in the different locations. The total additional quantity of used fuel from these reactors could be up to 1.9 million CANDU fuel bundles (31,200 t-HM), or 21,600 PWR fuel assemblies (11,640 t-HM), or 27,000 BWR fuel assemblies (3,384 t-HM), or some combination thereof. The total CANDU and PWR projections have decreased from the 2008 forecasts due to the reduction in the number of potential new reactor units.

TABLE 4: Summary of Fuel Types for Proposed New Reactors

Parameter	ACR 1000	AP1000	EPR	ESBWR
Reactor Type	Horizontal pressure tube, heavy water moderated, light water cooled	Pressurized light water reactor	Pressurized light water reactor	Boiling light water reactor
Net Power [MW(e)]	1085	1090	1600	1535
Fuel type	CANFLEX ACR fuel bundle	Conventional 17x17 PWR fuel design	Conventional 17x17 PWR fuel design	Conventional 10x10 BWR fuel design
Fueling method	On power	Refueling shutdown every 12 to 24 months and replace portion of the core	Refueling shutdown every 12 to 24 months and replace portion of the core	Refueling shutdown every 12 to 24 months and replace portion of the core
Fuel enrichment	Up to 2.5% for equilibrium core	2.4-4.5% avg initial core 4.8% avg for reloads	Up to 5% for equilibrium core	1.7-3.2% avg initial core 4.5% avg for reloads
Fuel dimensions	102.49 mm OD x 495.3 mm OL	214 mm square x 4795 mm OL	214 mm square x 4805 mm OL	140 mm square x 4470 mm OL
Fuel assembly U mass [kg initial U]	16.2	538.3	527.5	126.9
Fuel assembly total mass [kg]	21.5	789	780	~238
Number of fuel assemblies per core	6,240	157	241	1,132
Fuel load per core [kg initial U]	101,088	84,513	127,128	143,651
Annual used fuel production [t-HM/yr per reactor]	52	24	29	28
Annual used fuel production [number of fuel assemblies/yr per reactor]	3,210	45	55	225
Lifetime used fuel production [t-HM per reactor]	3,120	1,455	1,740	1,692
Lifetime used fuel production [number of fuel assemblies per reactor]	192,600	2,700	3,300	13,500

Note: Data extracted from reference [Bruce Power, 2008a]. Annual and lifetime production numbers have been rounded.

TABLE 5: Summary of Fuel Forecasts for Potential New Reactors

Reactor	Ontario	Alberta	New Brunswick	Saskatchewan	Potential Total
Expected operating period (start of first unit to end of last unit)	2018 to 2085	2017 to 2085	??	~2020 to 2080	~2017 to ~2085
ACR 1000					
# of reactor units	4	4	1	1	10
Quantity of fuel (CANDU bundles)	770,400	770,400	192,600	192,600	1,926,000
Tonnes of heavy metals (t-HM)*	12,480	12,480	3,120	3,120	31,200
AP 1000					
# of reactor units	4	3	N/A	1	8
Quantity of fuel (number of assemblies)	10,800	8,100		2,700	21,600
Tonnes of heavy metals (t-HM)	5,820	4,365		1,455	11,640
EPR					
# of reactor units	3	2	N/A	1	6
Quantity of fuel (number of assemblies)	9,900	6,600		3,300	19,800
Tonnes of heavy metals (t-HM)	5,220	3,480		1,740	10,440
ESBWR					
# of reactor units	N/A	2	N/A	N/A	2
Quantity of fuel (number of assemblies)		27,000			27,000
Tonnes of heavy metals (t-HM)		3,384			3,384

Note:

* "tonnes of heavy metals" (t-HM) includes uranium and all of the transuranics isotopes produced in the reactor as part of the nuclear reactions via various neutron activation and decay processes.

4. SUMMARY OF PROJECTED USED FUEL INVENTORY

The projected inventory from current reactor operations, reactor refurbishment, and potential new reactors, developed in Sections 2 and 3, is summarized in Figure 1.

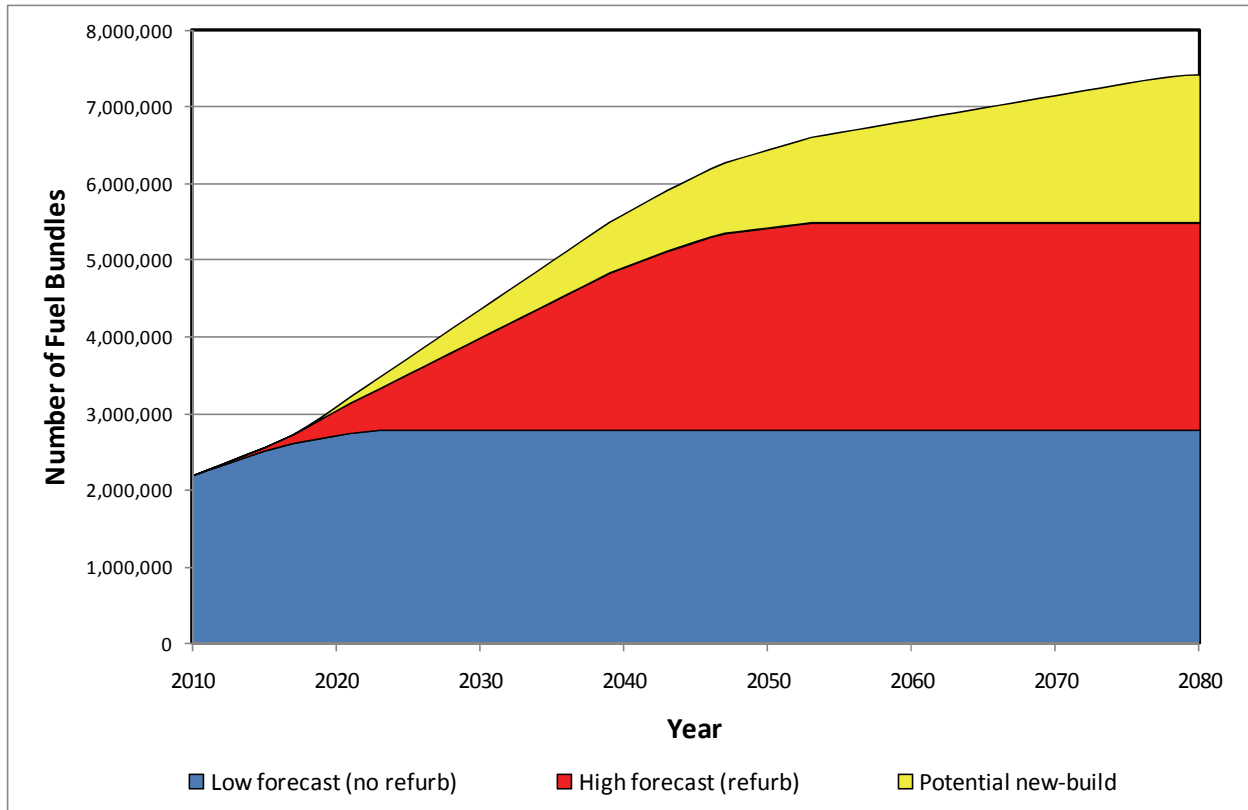


FIGURE 1: Summary of Projected Used Fuel Inventory

The “low forecast” (blue shaded area) represents the inventory from the existing Canadian fleet of reactors, up to the end of their initial operating period (approx calendar 30 years), prior to refurbishment. This amounts to a total of approximately 2.8 million CANDU fuel bundles, of which 2.1 million are in existing storage as of June 2009.

The “high forecast” (red shaded area) represents the additional used fuel bundles that would be generated if all of the existing Canadian reactor fleet is refurbished and life extended for another 30 calendar years of operation. This amounts to an additional approximately 2.7 million CANDU fuel bundles. Note that not all of the existing reactors may be refurbished and the decisions over whether or not to refurbish reactors will be taken by their owner/operators on a case-by-case basis over the next few years.

The “potential new-build” (yellow shaded area) represents the additional used fuel bundles that could be generated if 10 new CANDU ACR-1000 reactors are constructed, amounting to approximately 1.9 million bundles of their projected 60 year operating life. This quantity is speculative at this time, since decisions regarding potential new reactor numbers, locations, types and timing have not yet been finalized.

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APPENDIX A: SUMMARY OF EXISTING CANADIAN REACTORS

TABLE A1: Nuclear Power Reactors

Location	Rating (MW(e) net)	Year In- service	Fuel Type*	Current Status
Bruce Nuclear Power Development, Ontario				
Bruce A – 1	750	1977	37 element CANDU bundle	Undergoing refurbishment
Bruce A – 2	750	1977		Undergoing refurbishment
Bruce A – 3	750	1978		Operating
Bruce A – 4	750	1979		Operating
Bruce B – 5	795	1984	37 element CANDU bundle; 37 element “long” bundle; (option for 43 element CANFLEX LVRF bundle)	Operating
Bruce B – 6	822	1985		Operating
Bruce B – 7	822	1986		Operating
Bruce B – 8	795	1987		Operating
Darlington, Ontario				
Darlington 1	881	1992	37 element CANDU bundle; 37 element “long” bundle	Operating
Darlington 2	881	1990		Operating
Darlington 3	881	1993		Operating
Darlington 4	881	1993		Operating
Gentilly, Quebec				
Gentilly 2	635	1983	37 element CANDU bundle	Operating
Pickering, Ontario				
Pickering A – 1	515	1971	28 element CANDU bundle	Operating
Pickering A – 2	515	1971		Permanently shutdown in 2005
Pickering A – 3	515	1972		Permanently shutdown in 2005
Pickering A – 4	515	1973		Operating
Pickering B – 5	516	1983		Operating
Pickering B – 6	516	1984		Operating
Pickering B – 7	516	1985		Operating
Pickering B – 8	516	1986		Operating
Point Lepreau, New Brunswick				
Point Lepreau	635	1983	37 element CANDU bundle	Undergoing refurbishment

Note: refer to Appendix C for description of fuel types

TABLE A2: Prototype and Demonstration Power Reactors

Location	Rating (MW(e) net)	Year In- service	Fuel Type	Current Status
Bruce Nuclear Power Development, Ontario				
Douglas Point (CANDU PHWR prototype)	206	1968	19 element CANDU bundle	Permanently shut down in 1984; All fuel currently in dry storage on site
Gentilly, Quebec				
Gentilly 1 (CANDU-BLW boiling water reactor prototype)	250	1972	18 element CANDU-BLW bundle	Permanently shut down in 1978; All fuel currently in dry storage on site
Rolphton, Ontario				
NPD (CANDU PHWR prototype)	22	1962	19 element CANDU bundle; various prototype fuel designs (e.g. 7 element bundle)	Permanently shut down in 1987; All fuel currently in dry storage at AECL Chalk River

**FIGURE A-1: Current Nuclear Fuel Waste Storage Locations in Canada**

TABLE A3: Research Reactors

Location	Rating (MW(th))	Year In-service	Fuel Type	Comments
Hamilton, Ontario				
McMaster University	5	1959	(research)	MTR Pool type reactor
Kingston, Ontario				
Royal Military College	0.02	1985	(research)	(20 kW(th) SLOWPOKE 2)
Chalk River, Ontario				
NRU	135	1957	(research)	Operating
NRX	42	1947	(research)	Permanently shut down in 1992
MAPLE 1	10		-	Never fully commissioned
MAPLE 2	10		-	
ZED-2	250 W(th)	1960	(research)	Operating
Whiteshell, Manitoba				
WR-1 (CANDU-OCR organic cooled reactor prototype)	60 MW(th)	1965	36 element CANDU-OCR bundle	Permanently shut down in 1985; All fuel currently in dry storage on site
Montreal, Quebec				
Ecole polytechnique	0.02	1974	(research)	(20 kW(th) SLOWPOKE 2)
Halifax, Nova Scotia				
Dalhousie University	0.02	1976	(research)	(20 kW(th) SLOWPOKE 2)
Edmonton, Alberta				
University of Alberta	0.02	1977	(research)	(20 kW(th) SLOWPOKE 2)
Saskatoon, Saskatchewan				
Saskatchewan Research Council	0.02	1981	(research)	(20 kW(th) SLOWPOKE 2)

APPENDIX B: USED FUEL WASTE FORECAST DETAILS

Forecasts are based on:

$[(\text{June 2009 actuals}) + (\text{number of years from June 2009 to end-of-life}) * (\text{typical annual production of fuel bundles})]$ rounded to nearest 1000 bundles.

For multi-unit stations, the station total forecast is the sum of the above calculated on a unit-by-unit basis.

Total mass of fuel is based on average bundle containing 20 kg of heavy metals (e.g. uranium).

End-of-life (EOL) dates are determined from the following scenario details:

a) **“Low” scenario:**

- the reactors are shut down at the end of the projected life of the fuel channels (i.e. nominal 25 effective full power years (equivalent to 30 calendar years) of operation);
- reactors that have been permanently shut down do not restart;
- reactors that have been previously refurbished and are still operating, will operate to the end of their current expected service life; and
- reactors which are currently undergoing refurbishment do not restart.

b) **“High” scenario:**

- all reactors (except those mentioned below) are refurbished with a new set of pressure tubes and other major components, then operated for a further 25 effective full power years (30 calendar years) to a total of 60 calendar years;
- reactors that have been permanently shut down do not restart; and
- reactors that have been previously refurbished and are still operating, will operate to the end of their current expected service life.

Note that forecasts are based on conservative NWMO planning assumptions and may differ from the business planning assumptions used by the reactor operators. In addition, as decisions on refurbishment are taken by the reactor operators, the two scenarios will merge in the future.

TABLE B1: Detailed Used Fuel Forecasts

Location	Unit	Startup	Total to June 2009 (# bundles)	Typical Annual Production (# bundles)	Low Scenario (~30 yrs)		High Scenario (~60 yrs)	
					End-of-life	(# bundles)	End-of-life	(# bundles)
Bruce A	1	1977	403,256	22,500	1998	483,000	2037	1,039,000
	2	1977			1998		2037	
	3	1978			2011		2038	
	4	1979			2015		2039	
Bruce B	5	1984	498,339	23,500	2014	640,000	2044	1,345,000
	6	1985			2015		2045	
	7	1986			2016		2046	
	8	1987			2017		2047	
Darlington	1	1992	356,504	23,000	2022	645,000	2052	1,335,000
	2	1990			2020		2050	
	3	1993			2023		2053	
	4	1993			2023		2053	
Douglas Point		1968	22,256	0	1984	22,256	1984	22,256
Gentilly 1		1972	3,213	0	1978	3,213	1978	3,213
Gentilly 2		1983	112,445	4,800	2011	120,000	2043	274,000
Pickering A	1	1971	598,687	6,800	2021	746,000	2021	1,181,000
	2	1971			2005		2005	
	3	1972			2005		2005	
	4	1973			2021		2027	
Pickering B	5	1983		13,800	2013		2043	
	6	1984			2014		2044	
	7	1985			2015		2045	
	8	1986			2016		2046	
Point Lepreau		1983	121,758	4,800	2008	121,758	2043	283,000
AECL Whiteshell		1965	2,268	0	1985	2,268	1985	2,268
AECL (NPD/other)			4,886	0		4,886		4,886
TOTALS (bundles)			2,123,612	99,200		2,789,000		5,490,000
(t-HM)			42,000	1,990		56,000		110,000

Reactor currently under refurbishment

Reactor permanently shut down

Reactor previously refurbished

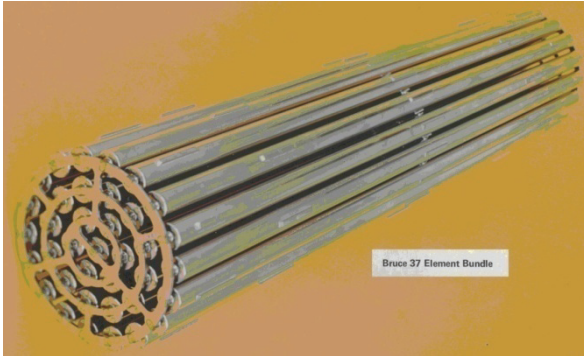
Note: forecasts are rounded to nearest 1,000 bundles
or 1,000 t-HM

APPENDIX C: DESCRIPTION OF FUEL TYPES

C.1 FUELS FROM EXISTING REACTORS

28 element CANDU bundle	
	Physical dimensions: 102.5 mm OD x 497.1 mm OL
	Mass: 20.1 kg U (22.8 kg as UO_2) 2.0 kg Zircaloy in cladding, spacers, etc 24.8 kg total bundle weight
	Fissionable material: Sintered pellets of natural UO_2
	Average burnup: 8,300 MW day / tonne U (200 MWh/kg U)
	Cladding material: Zircaloy-4
Construction: - bundle is composed of 28 elements (fuel pins), arranged in 3 concentric rings with 4 elements in the inner most ring, 8 elements in the second ring and 16 elements in the outer ring - construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity	
Comments: - used in Pickering A and B reactors	

37 element CANDU “standard” bundle


Physical dimensions:

102.5 mm OD x 495 mm OL

Mass:

19.2 kg U (21.7 kg as UO_2)

2.2 kg Zircaloy in cladding, spacers, etc

24.0 kg total bundle weight

Fissionable material:

Sintered pellets of natural UO_2

Average burnup:

8,300 MW day / tonne U

(200 MWh/kg U)

Cladding material:

Zircaloy-4

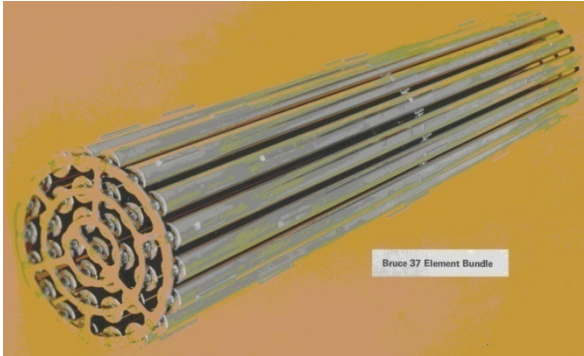
Construction:

- bundle is composed of 37 elements (fuel pins), arranged in 4 concentric rings with 1 element in the inner most central ring, 6 elements in the second ring, 12 elements in the third ring and 18 elements in the outer ring
- construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity

Comments:

- used in Bruce A and B, Darlington, Gentilly-2 and Point Lepreau reactors (Gentilly-2 and Point Lepreau have minor construction differences on the end plates and spacers compared to the Bruce and Darlington designs)

37 element CANDU “long” bundle


Physical dimensions:

102.5 mm OD x 508 mm OL

Mass:

19.7 kg U (22.3 kg as UO_2)

2.24 kg Zircaloy in cladding, spacers, etc

24.6 kg total bundle weight

Fissionable material:

Sintered pellets of natural UO_2

Average burnup:

8,300 MW day / tonne U

(200 MWh/kg U)

Cladding material:

Zircaloy-4

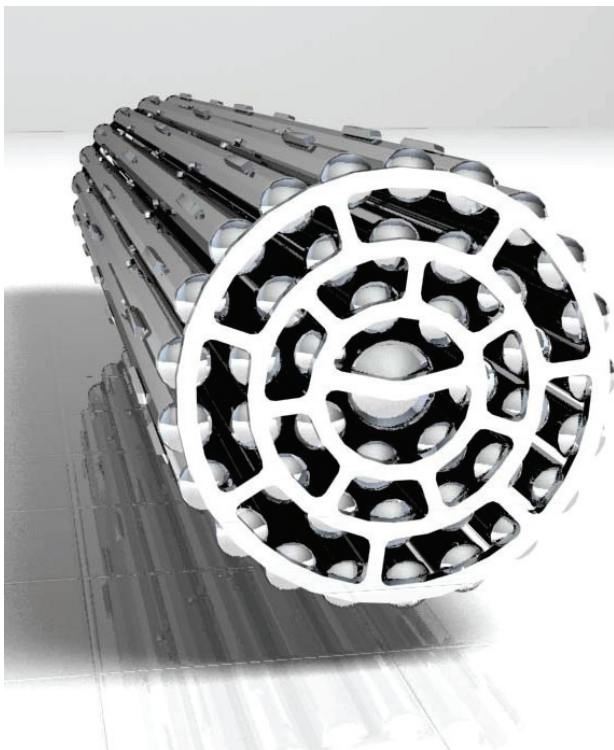
Construction:

- bundle is composed of 37 elements (fuel pins), arranged in 4 concentric rings with 1 element in the inner most central ring, 6 elements in the second ring, 12 elements in the third ring and 18 elements in the outer ring
- construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity

Comments:

- used in Bruce B, and Darlington reactors

43 element CANFLEX LVRF bundle


Physical dimensions:

102.5 mm OD x 495.3 mm OL

Mass:

18.5 kg U (21.0 kg as UO_2)
 2.1 kg Zircaloy in cladding, spacers, etc
 23.1 kg total bundle weight

Fissionable material:

Sintered pellets of UO_2
 slightly enriched to 1.0% U-235

Average burnup:

8,300 MW day / tonne U
 (200 MWh/kg U)

Cladding material:

Zircaloy-4

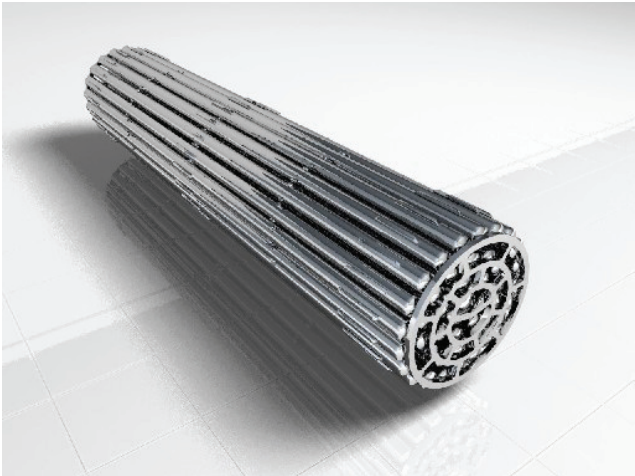
Construction:

- bundle is composed of 43 elements (fuel pins), arranged in 4 concentric rings with 1 element in the inner most central ring, 7 elements in the second ring, 14 elements in the third ring and 21 elements in the outer ring
- diameter and composition of fuel pins varies by ring
- construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity

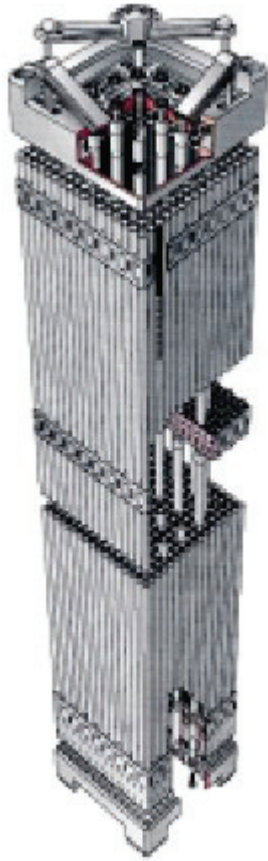
Comments:

- used in Bruce B reactors

C.2 FUELS FROM POTENTIAL NEW-BUILD REACTORS

43 element CANFLEX ACR bundle	
	Physical dimensions: 102.5 mm OD x 495.3 mm OL
	Mass: 16.2 kg U (18.4 kg as UO_2) 3.1 kg Zircaloy and other materials in cladding, spacers, etc 21.5 kg total bundle weight
	Fissionable material: Sintered pellets of UO_2 enriched to 2.5% U-235
	Average burnup: 20,000 MW day/ tonne U
	Cladding material: Zircaloy-4
Construction: - bundle is composed of 43 elements (fuel pins), arranged in 4 concentric rings with 1 element in the inner most central ring, 7 elements in the second ring, 14 elements in the third ring and 21 elements in the outer ring - diameter and composition of fuel pins varies by ring - construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity	
Comments: - used in AECL ACR-1000 reactors	

AP1000 PWR fuel assembly


Physical dimensions:

214 mm square x 4795 mm OL

Mass:

538.3 kg U (613 kg as UO_2)
 ~176 kg ZIRLO and other materials in
 cladding, spacers, etc
 789 kg total weight

Fissionable material:

Sintered pellets of UO_2
 enriched up to 5% U-235

Average burnup:

60,000 MWday/tonne U

Cladding material:

ZIRLO

Construction:

- Each fuel assembly consists of 264 fuel rods, 24 guide thimbles, and 1 instrumentation tube arranged within a 17 x 17 matrix supporting structure. The instrumentation thimble is located in the center position and provides a channel for insertion of an in-core neutron detector, if the fuel assembly is located in an instrumented core position. The guide thimbles provide channels for insertion of either a rod cluster control assembly, a gray rod cluster assembly, a neutron source assembly, a burnable absorber assembly, or a thimble plug, depending on the position of the particular fuel assembly in the core.

Comments:

- used in Westinghouse AP1000 reactors

EPR PWR fuel assembly


Physical dimensions:

214 mm square x 4805 mm OL

Mass:

527.5 kg U (598.0 kg as UO_2)

~182 kg other materials in cladding, spacers, etc

780 kg total weight

Fissionable material:

Sintered pellets of UO_2

enriched up to 5% U-235

Average burnup:

62,000 MWday/tonne U

Cladding material:

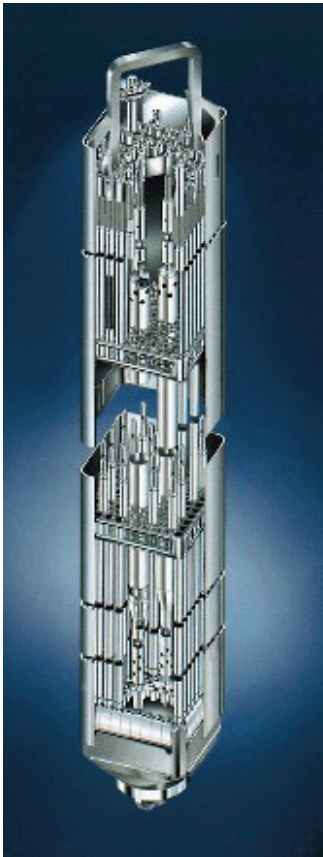
M5

Construction:

- Each fuel assembly consists of 265 fuel rods and 24 guide thimbles which can either be used for control rods or for core instrumentation arranged within a 17 x 17 matrix supporting structure. The guide thimbles provide channels for insertion of either a rod cluster control assembly, a gray rod cluster assembly, a neutron source assembly, a burnable absorber assembly, a thimble plug or core instrumentation, depending on the position of the particular fuel assembly in the core.

Comments:

- used in Areva EPR reactors

ESBWR fuel assembly	
	Physical dimensions: 140 mm square x 4470 mm OL
	Mass: 126.9 kg U (143.9 kg as UO_2) 94.1 kg Zircaloy and other materials in cladding, spacers, etc 238 kg total weight
	Fissionable material: Sintered pellets of UO_2 enriched up to 5% U-235
	Average burnup: 50,000 MWday/tonne U
	Cladding material: Zircaloy-4
Construction: - The BWR fuel assembly consists of a fuel bundle and a channel. The fuel bundle contains the fuel rods and the hardware necessary to support and maintain the proper spacing between the fuel rods. The channel is a Zircaloy box which surrounds the fuel bundle to direct the core coolant flow through the bundle and also serves to guide the movable control rods. - Each fuel bundle consists of a 10x10 array of 78 full length fuel rods, 14 part length rods (which span roughly two-thirds of the active core), two large central water rods and 8 tie rods.	
Comments: - used in GE ESBWR reactors	