Nuclear Fuel Waste Projections in Canada – 2008 Update

NWMO TR-2008-18

December 2008

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Nuclear Waste Management Organization

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ABSTRACT

Title: **Nuclear Fuel Waste Projections in Canada – 2008 Update**
Report No.: **NWMO TR-2008-18**
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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 summarizes the existing inventory of used CANDU nuclear fuel wastes in Canada as of June 30, 2008 and forecasts the potential future arisings from the existing reactor fleet as well as from proposed new-build reactors.

As of June 30, 2008, a total of 2.0 million used CANDU fuel bundles 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 2.8 to 5.5 million used CANDU fuel bundles (56,000 tonnes of heavy metal (t-HM) to 110,000 t-HM), depending upon decisions taken to refurbish current reactors.

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 potential 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 2.3 million CANDU fuel bundles (37,440 t-HM), or 27,000 PWR fuel assemblies (14,550 t-HM), or 27,000 BWR fuel assemblies (3,384 t-HM).

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.

A fundamental tenet of Adaptive Phased Management (APM) is the ongoing incorporation of new learning and knowledge to guide decision making. We must continually monitor new developments and be prepared to adjust our implementation plans as required in light of changes to our operating environment.

APM was proposed in 2005 following an extensive three-year dialogue with Canadian citizens, specialists and Aboriginal people. Since then Canada's energy policy landscape has evolved. New Brunswick, Ontario 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 adjust our implementation path as may be required.

From a technical perspective APM is flexible. However, from a social perspective it requires the ongoing engagement of Canadians to determine how it is implemented. It will be important that we test the applicability of our existing plans for their social, ethical and technical appropriateness in light of new projections of used fuel types and volumes to be managed. 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 incorporated into our approach. And, we will continually review, adjust and validate our implementation plans 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 first such annual report.

1.3 SCOPE

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

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, 2008. 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, 2008

Location	Waste Owner	Wet Storage (# bundles)	Dry Storage (# bundles)	TOTAL (# bundles)	Current Status
Bruce A	OPG	370,389	23,040	**393,429**	- 2 units operational, 2 units under refurbishment
Bruce B	OPG	371,911	102,908	**474,819**	- 4 units operational
Darlington	OPG	331,576	2,304	**333,880**	- 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	38,381	70,200	**108,581**	- operational
Pickering A	OPG	395,384	185,746	**581,130**	- 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
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 and other CANDU reactors)
	TOTAL	**1,548,399**	**497,821**	**2,046,220**	Total of: - 17 units in operation - 3 units under refurbishment - 5 units permanently shut down

Notes: data as of June 30, 2008.

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.

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 25 effective full power years (equivalent to about 30 calendar years) of operation);

b) **High:** the reactors 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.

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 2008 (# bundles)	Typical Annual Production (# bundles)	Low Scenario (# bundles)	High Scenario (# bundles)
Bruce A	OPG	393,429	22,500 (1)	**484,000**	**1,041,000 (4)**
Bruce B	OPG	474,819	23,500 (1)	**628,000**	**1,333,000**
Darlington	OPG	333,880	23,000 (1)	**633,000**	**1,323,000**
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	108,581	4,800	**119,000**	**272,000**
Pickering A	OPG	581,130	6,800 (3)	**739,000**	**1,174,000**
Pickering B	OPG		13,800 (1)		
Point Lepreau	NBPN	121,758	4,800	**121,758**	**285,000 (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 (7)		**2,046,220**	**99,200**	**2,758,000**	**5,461,000**

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 October 2009
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	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 EA underway, EIS report expected to be submitted Q2 2009 [OPG, 2007]
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]
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]
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.
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]

Notes:

1) Selection of reactor type for new-build in Ontario to be made by Ontario Government (Infrastructure Ontario) in 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 (5,076 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 in early 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.

3.1.2 BRUCE POWER

Bruce Power has submitted its Environmental Impact Statement (EIS) for new-build at the Bruce Power site [Bruce Power, 2008a]. According to their schedule, the first reactor could be in-service as early as 2016. Similar to the OPG case, three reactor types are being considered (up to 4 x ACR 1000, 3 x AP1000, or 2 x EPR), with the final choice of reactor type being made by the Province of Ontario. (It is expected that the same reactor vendor would be chosen for both Bruce Power and OPG.)

The 4 ACR 1000 units would result in a total lifetime production of approximately 770,400 used fuel bundles (12,480 t-HM). The 3 AP1000 units would result in a total lifetime production of approximately 8,100 PWR fuel assemblies (4,365 t-HM). The 2 EPR units would result in a total lifetime production of approximately 6,600 PWR fuel assemblies (3,384 t-HM).

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 (3,384 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 (1,692 tonnes of uranium).

3.2.4 ONTARIO

Bruce Power announced on October 31, 2008 that they would be starting an environmental assessment to construct 2 reactors near the Nanticoke site in Ontario. The earliest in-service date for the first reactor is 2018. Three reactor types are being considered:

a) ***AECL ACR 1000*** – 2 ACR 1000 reactors would be built on the site in a twin unit pair. This would result in a total lifetime production of approximately 385,200 used fuel bundles (6,240 t-HM).

b) ***Westinghouse AP1000*** – 2 AP1000 reactors would be built on the site, which would result in a total lifetime production of approximately 5,400 PWR fuel assemblies (2,910 t-HM).

c) ***AREVA EPR*** – 2 EPR reactors would be built on the site, which would result in a total lifetime production of approximately 6,600 PWR fuel assemblies (3,384 tonnes of uranium).

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 2.3 million CANDU fuel bundles (37,440 t-HM), or 27,000 PWR fuel assemblies (14,550 t-HM), or 27,000 BWR fuel assemblies (3,384 t-HM).

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	784.7	784.0	~238
Number of fuel assemblies per core	6,240	157	241	1,132
Fuel load per core [kg initial U]	101,088	84,599	127,128	143,651
Annual used fuel production [t-HM/yr per reactor]	52	24	28.2	28.2
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	1,692	1,692
Lifetime used fuel production [number of fuel assemblies per reactor]	192,600	2,700	3,300	13,500

Notes:

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

TABLE 5: Summary of Fuel Forecasts for Proposed New Reactors

Reactor	Darlington, Ontario	Bruce Nuclear Power Development, Ontario	Northern Lights, Alberta	Potential Total
Expected operating period (start of first unit to end of last unit)	2018 to 2085	2016 to 2085	2017 to 2085	2016 to 2085
ACR 1000				
# of reactor units	4	4	4	12
Quantity of fuel (CANDU bundles)	770,400	770,400	770,400	2,311,200
Tonnes of heavy metals (t-HM)*	12,480	12,480	12,480	37,440
AP 1000				
# of reactor units	4	3	3	10
Quantity of fuel (number of assemblies)	10,800	8,100	8,100	27,000
Tonnes of heavy metals (t-HM)	5,820	4,365	4,365	14,550
EPR				
# of reactor units	3	2	2	7
Quantity of fuel (number of assemblies)	9,900	6,600	6,600	23,100
Tonnes of heavy metals (t-HM)	5,076	3,384	3,384	11,844
ESBWR				
# of reactor units	N/A	N/A	2	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.

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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; 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

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:

[(June 2008 actuals) + (number of years from June 2008 to end-of-life) * (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.

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;
- 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;
- 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.

TABLE B1: Detailed Used Fuel Forecasts

Location	Unit	Startup	Total to June 2008 (# bundles)	Typical Annual Production (# bundles)	Low Scenario (~30 yrs) End-of-life	Low Scenario (~30 yrs) (# bundles)	High Scenario (~60 yrs) End-of-life	High Scenario (~60 yrs) (# bundles)
Bruce A	1	1977	393,429	22,500	1998	**484,000**	2037	**1,041,000**
	2	1977			1998		2037	
	3	1978			2011		2038	
	4	1979			2015		2039	
Bruce B	5	1984	474,819	23,500	2014	**628,000**	2044	**1,333,000**
	6	1985			2015		2045	
	7	1986			2016		2046	
	8	1987			2017		2047	
Darlington	1	1992	333,880	23,000	2022	**633,000**	2052	**1,323,000**
	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	108,581	4,800	2011	**119,000**	2043	**272,000**
Pickering A	1	1971	581,130	6,800	2021	**739,000**	2021	**1,174,000**
	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	**285,000**
AECL Whiteshell		1965	2,268	0	1985	**2,268**	1985	**2,268**
AECL Chalk River			4,886	0		**4,886**		**4,886**
		TOTALS	**2,046,220**	**99,200**		**2,758,000**		**5,461,000**

Reactor currently under refurbishment

Reactor permanently shut down

Reactor previously refurbished

Note: forecasts are rounded to nearest 1,000 bundles

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

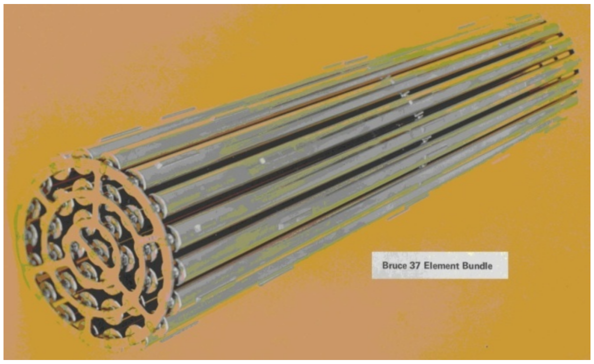
Average burnup:
8,300 MW day / tonne U
(200 MWh/kg U)

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

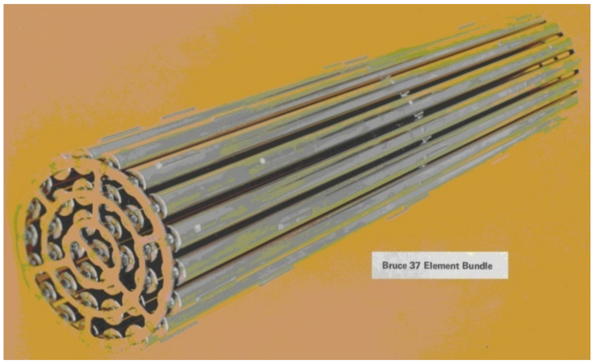
Construction:

- 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 - 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 - 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 (611.3 kg as UO_2) 173.4 kg ZIRLO and other materials in cladding, spacers, etc 784.7 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

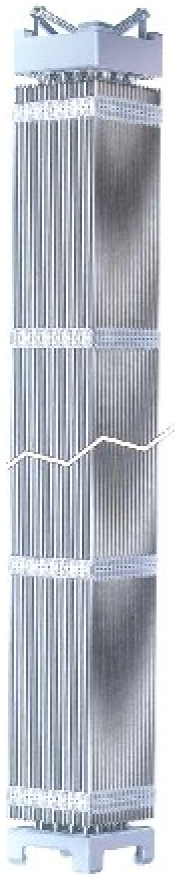
Construction:

- 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)

186 kg other materials in cladding, spacers, etc

784 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

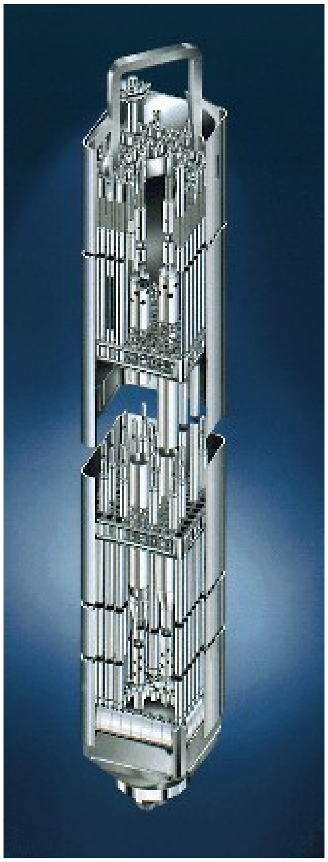
Construction:

- 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