Nuclear Fuel Waste Projections in Canada – 2010 Update

NWMO TR-2010-17 December 2010

M. Garamszeghy

Nuclear Waste Management Organization

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Nuclear Waste Management Organization
22 St. Clair Avenue East, 6th Floor
Toronto, Ontario
M4T 2S3
Canada

Tel: 416-934-9814
Web: www.nwmo.ca

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ABSTRACT

Title: **Nuclear Fuel Waste Projections in Canada – 2010 Update**
Report No.: **NWMO TR-2010-17**
Author(s): M. Garamszeghy
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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 updates the 2009 report [Garamszeghy, 2009] and summarizes the existing inventory of used nuclear fuel wastes in Canada as of June 30, 2010 and forecasts the potential future arisings from the existing reactor fleet as well as from proposed new-build reactors. The report focuses on power reactors, but also includes prototype, demonstration and research reactor fuel wastes held by AECL.

As of June 30, 2010, a total of approximately 2.2 million used CANDU fuel bundles (44,000 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 5.1 million used CANDU fuel bundles (56,000 t-HM to 102,000 t-HM), depending upon decisions to refurbish current reactors. The lower end is based on an average of 30 calendar years of operation for each reactor (i.e. no refurbishment), while the upper end assumes that reactors are refurbished and life extended for an additional 30 calendar years of operation. The 5.1 million bundles at the upper end of the projection has been reduced from the 2009 report (5.5 million), due to OPG's decision not to refurbish the Pickering B 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 units which are in an advanced state of planning/public discussion or 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 is unchanged from the 2009 report.

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.

For NWMO preliminary planning purposes, a base case of 3.6 million bundles (which represents a point between the lower and upper end forecasts to allow for some reactors being refurbished and some not) and an alternate case of 7.2 million bundles (corresponding to maximum reactor refurbishment along with some new-build CANDU type reactors) has been adopted.

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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 advanced fuel cycles 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, 2010]. This document is the third such annual report and provides an update to the 2009 version [Garamszeghy, 2009].

1.3 SCOPE

This report summarizes the existing inventory of used nuclear fuel wastes in Canada as of June 30, 2010 and forecasts the potential future arisings from the existing reactor fleet as well as from proposed new-build reactors. The report focuses on power reactors, but also includes information on prototype, demonstration and research reactor fuel wastes held by AECL.

1.4 CHANGES SINCE THE 2009 REPORT

The primary changes to the Canadian nuclear landscape since the 2009 report are:

a) Schedule changes in reactor refurbishment projects at Pt Lepreau and Bruce A (note that these changes are not expected to affect the total amount of used fuel produced, just the timing of when it is produced);

b) Decision by OPG not to refurbish Pickering B reactors; and

c) 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 72,999 bundles from June 30, 2009 to June 30, 2010.

	June 30, 2009	June 30, 2010	
Wet storage	1,553,561	1,541,473	bundles
Dry storage	570,051	655,138	bundles
TOTAL	**2,123,612**	**2,196,611**	**bundles**

b) No significant change to the projected future total number of used fuel bundles produced by the existing reactor fleet for the low forecast (2.8 million bundles) and a reduction in the high forecast (from 5.5 to 5.1 million bundles); and

c) No change in the total amount of used fuel forecast from new-build. Note that the new-build projections depend on the selection of reactor type for each project.

Additional changes and considerations include:

a) The Signing of a “letter of intent” between the Province of New Brunswick and AREVA to develop a “clean energy park” near the existing Point Lepreau site, which would consist of one or more mid-sized Generation III+ light water reactors, such as the 1250 MW(e) KERENA boiling water reactor or the 1100 MW(e) ATMEA 1 pressurized water reactor. These are new reactor types which were not previously included in new-build considerations by the various proponents.

b) A renewed commitment in Ontario to refurbish existing reactors at Bruce and Darlington and to build new reactors at Darlington as part of the provincial long-term energy plan.

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, 2010. 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, 2010

Location	Waste Owner	Wet Storage (# bundles)	Dry Storage (# bundles)	TOTAL (# bundles)	Current Status
Bruce A	OPG	364,381	46,464	**410,845**	- 2 units operational, 2 units under refurbishment (expected 2011 return to service)
Bruce B	OPG	375,566	145,912	**521,478**	- 4 units operational
Darlington	OPG	329,198	48,363	**377,561**	- 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	29,833	86,340	**116,173**	- operational
Pickering A	OPG	401,737	214,436	**616,173**	- 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 2012 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**	- mostly fuel from NPD (permanently shut down) and with small amounts from other CANDU reactors
	TOTAL	***1,541,473***	***655,138***	***2,196,611***	Total of: - 17 units in operation - 3 units under refurbishment - 6 units permanently shut down

Notes: data as of June 30, 2010.
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, prototype and test fuel bundles, similar in size and shape to standard CANDU bundles.

Assuming a rounded average of 20 kg heavy metals in a fuel bundle, 2.2 million bundles is equivalent to approximately 44,000 tonnes of heavy metal (t-HM). In addition to the totals shown in Table 1, AECL also has some 21,987 components of research and development fuels such as fuel elements, fuel pellets and fuel debris 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:** most of 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 ~5.1 million bundles (102,000 t-HM). Pickering B reactors will not be refurbished [OPG, 2010].

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

<table>
<tr><th>Location</th><th>Waste Owner</th><th>Total June 2010 (# bundles)</th><th>Typical Annual Production (# bundles)</th><th>Low Scenario (# bundles)</th><th>High Scenario (# bundles)</th></tr>
<tr><td>Bruce A</td><td>OPG</td><td>410,845</td><td>22,500 (1)</td><td>468,000</td><td>1,024,000 (4)</td></tr>
<tr><td>Bruce B</td><td>OPG</td><td>521,478</td><td>23,500 (1)</td><td>639,000</td><td>1,344,000</td></tr>
<tr><td>Darlington</td><td>OPG</td><td>377,561</td><td>23,000 (1)</td><td>643,000</td><td>1,333,000</td></tr>
<tr><td>Douglas Point</td><td>AECL</td><td>22,256</td><td>0 (2)</td><td>22,256</td><td>22,256</td></tr>
<tr><td>Gentilly 1</td><td>AECL</td><td>3,213</td><td>0 (2)</td><td>3,213</td><td>3,213</td></tr>
<tr><td>Gentilly 2</td><td>HQ</td><td>116,173</td><td>4,500</td><td>132,000</td><td>269,000</td></tr>
<tr><td>Pickering A</td><td>OPG</td><td rowspan="2">616,173</td><td>6,800 (3)</td><td rowspan="2">743,000</td><td rowspan="2">833,000 (5)</td></tr>
<tr><td>Pickering B</td><td>OPG</td><td>13,800 (1)</td></tr>
<tr><td>Point Lepreau</td><td>NBPN</td><td>121,758</td><td>4,500</td><td>121,758</td><td>260,000 (7)</td></tr>
<tr><td>AECL Whiteshell</td><td>AECL</td><td>2,268</td><td>0 (2)</td><td>2,268</td><td>2,268</td></tr>
<tr><td>AECL Chalk River</td><td>AECL</td><td>4,886</td><td>0 (6)</td><td>4,886</td><td>4,886</td></tr>
<tr><td colspan="2">TOTAL (bundles)(8)</td><td>2,196,611</td><td>98,600</td><td>2,780,000</td><td>5,096,000</td></tr>
<tr><td colspan="2">(t-HM)</td><td>44,000</td><td>1,980</td><td>56,000</td><td>102,000</td></tr>
</table>

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 (refurbishment currently under way for 2 units).
5) Pickering reactors assumed to be operated until 2021 only.
6) Future forecasts do not include research fuels. AECL Chalk River does not produce any power reactor CANDU used fuel bundles.
7) Point Lepreau is currently shut down for refurbishment and is expected to re-start in 2012.
8) 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. Until such decisions have been made by the proponents, the forecasts regarding types and amounts of fuel resulting from new-build projects is highly speculative. 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 ATMEA1 PWR KERENA BWR	Feasibility study being conducted [MZConsulting, 2008] [AREVA, 2010]
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 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]. In November 2010, the Ontario Government stated that they were still committed to constructing new nuclear units at Darlington. [MEI, 2010]

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 Environmental Impact Statement (EIS), which was submitted in 2009 and is currently undergoing a Joint Panel Review [OPG, 2009], was based on the maximum physical capacity of the site to allow for possible future expansion.

Currently three reactor types are being considered:

a) ***AECL ACR 1000 (Advanced CANDU reactor)***, 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 (Evolutionary Power Reactor)***, 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 (Economic Simplified Boiling Water Reactor)***, 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).

More recently, a “letter of intent” has been signed between the Province of New Brunswick and AREVA to develop a “clean energy park” near the existing Point Lepreau site [AREVA, 2010], which would consist of one or more mid-sized Generation III+ light water reactors, such as the 1250 MW(e) KERENA boiling water reactor (formerly known as the SWR-1000 reactor) or the 1100 MW(e) ATMEA 1 pressurized water reactor. No specific timeline has been announced.

a) ***AECL ACR 1000*** – This would result in a total lifetime production of approximately 192,600 used fuel bundles (3,120 t-HM).

b) ***AREVA KERENA*** – No estimates are currently available for the lifetime fuel production of the KERENA reactor. However, based on the relative power ratings, the total number and mass of fuel assemblies is expected to be less than that for the ESBWR.

c) ***AREVA ATMEA 1*** – No estimates are currently available for the lifetime fuel production of the ATMEA 1 reactor. However, based on the relative power ratings, the total number and mass of fuel assemblies is expected to be similar to the AP1000.

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 had submitted its Environmental Impact Statement (EIS) for new-build at the Bruce Power site in 2008 [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. The data have been extracted from references [Bruce Power, 2008a] and [IAEA, 2004]. Note that various other sources of data may quote different numbers for fuel properties and used fuel production rates. This is generally due to the preliminary nature of some of the designs combined with the various ways some of the reactors can be operated (e.g. enrichment level and burnup, length of operating period between re-fuelling outages for light water reactors, etc).

Details of the fuel used in the ATMEA 1 and KERENA reactors recently proposed for New Brunswick are not currently available. However, the characteristics and quantities are expected to be similar to other PWR (e.g. AP1000) and BWR (e.g. ESBWR) fuels of equivalent power ratings. Further details will be included in future updates of this report.

Table 5 summarizes the total quantity of used fuel that might be produced for the various proposed new-build reactors. 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. As mentioned above, until decisions on reactor types, number of units and operating conditions are taken by the proponents, these forecasts remain highly speculative.

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 projections have not changed from the 2009 forecasts.

TABLE 4: Summary of Fuel Types for Proposed New Reactors

Parameter	ACR 1000	AP1000	EPR	ESBWR	KERENA	ATMEA 1
Reactor Type	Horizontal pressure tube, heavy water moderated, light water cooled	Pressurized light water reactor	Pressurized light water reactor	Boiling light water reactor	Boiling light water reactor	Pressurized light water reactor
Net Power [MW(e)]	1085	1090	1600	1535	1250	1100
Fuel type	CANFLEX ACR fuel bundle	Conventional 17x17 PWR fuel design	Conventional 17x17 PWR fuel design	Conventional 10x10 BWR fuel design	12x12 BWR fuel design	Conventional PWR 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	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	2.47% avg initial core 3.54% avg fo reloads at equilibrium 4.7% max	Up to 5% for equilibrium core
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	3765 mm OL	~4200 mm OL
Fuel assembly U mass [kg initial U]	16.2	538.3	527.5	126.9	~205	n/d
Fuel assembly total mass [kg]	21.5	789	780	~238	~325	n/d
# of fuel assemblies per core	6,240	157	241	1,132	664	157
Fuel load per core [kg initial U]	101,088	84,513	127,128	143,651	137,000	n/d
Annual used fuel production [t-HM/yr per reactor]	52	24	29	28	n/d	n/d
Annual used fuel production [number of fuel assemblies/yr per reactor]	3,210	45	55	225	n/d	n/d
Lifetime used fuel production [t-HM per reactor]	3,120	1,455	1,740	1,692	n/d	n/d
Lifetime used fuel production [number of fuel assemblies per reactor]	192,600	2,700	3,300	13,500	n/d	n/d

Note: Data extracted from references [Bruce Power, 2008a] and [IAEA, 2004]. Annual and lifetime production numbers have been rounded.

n/d = data not available

TABLE 5: Summary of Fuel Forecasts for Potential New Reactors

Reactor	Ontario	Alberta	New Brunswick	Saskatchewan	Potential Total
Expected operating period	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 (# 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 (# 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 (# 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 (# assemblies)		27,000			**27,000**
Tonnes of heavy metals (t-HM)		3,384			**3,384**
KERENA					
# of reactor units	N/A	N/A	??	N/A	**??**
Quantity of fuel (# assemblies)			??		**??**
Tonnes of heavy metals (t-HM)			??		**??**
ATMEA 1					
# of reactor units	N/A	N/A	??	N/A	**??**
Quantity of fuel (# assemblies)			??		**??**
Tonnes of heavy metals (t-HM)			??		**??**

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.

N/A = Not Applicable
?? = unknown at this time

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.

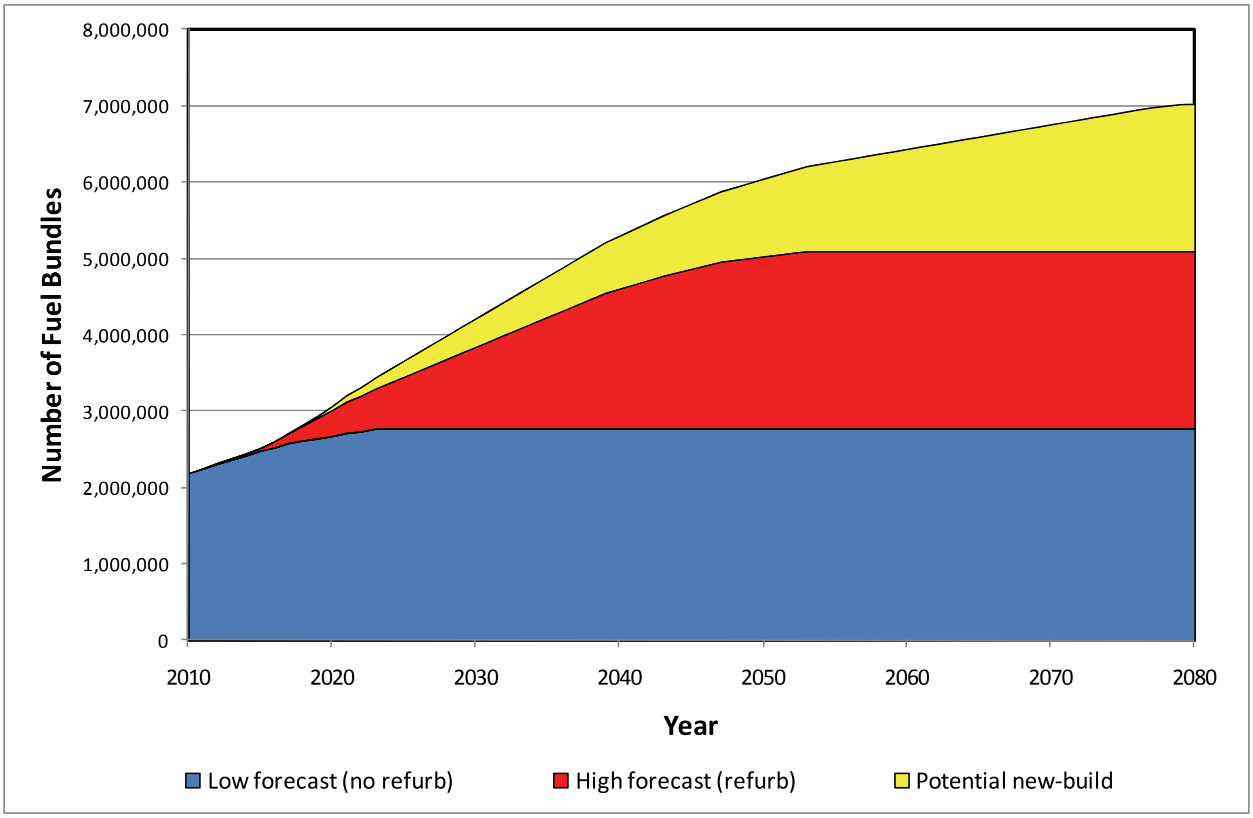

FIGURE 1: Summary of Projected Used Fuel Inventory

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 2.2 million are in existing storage as of June 2010.

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 2.3 million CANDU fuel bundles, for a total of 5.1 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 highly speculative at this time, since decisions regarding potential new reactor numbers, locations, types and timing have not yet been taken.

For NWMO preliminary planning purposes, a base case of 3.6 million bundles (which represents a point between the low and high forecasts for the existing reactor fleet to allow for some reactors being refurbished and some not) and an alternate case of 7.2 million bundles (corresponding to maximum reactor refurbishment along with some new-build CANDU type reactors) has been adopted [Stahmer, 2009].

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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	1985	37 element CANDU bundle; 37 element “long” bundle; (option for 43 element CANFLEX LVRF bundle)	Operating
Bruce B – 6	822	1984		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

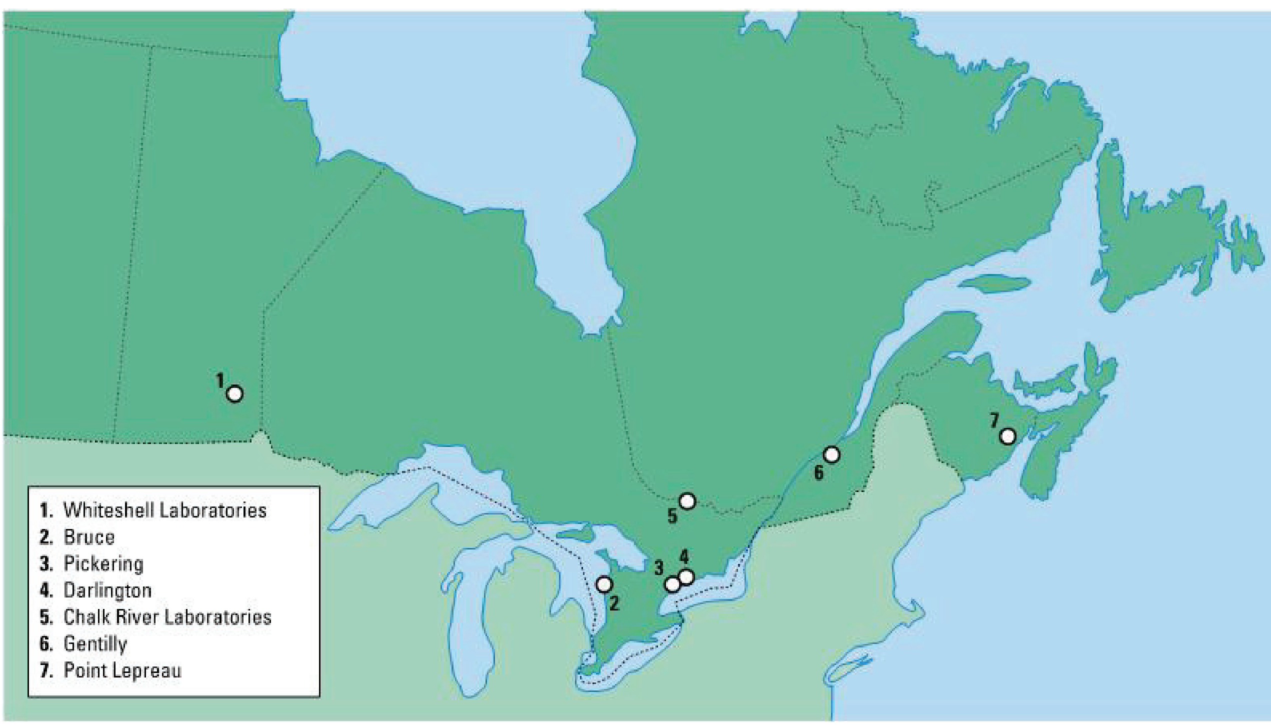


FIGURE A-1: Current Nuclear Fuel Waste Storage Locations in Canada

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 (organic cooled reactor prototype)	60 MW(th)	1965	various research and prototype fuel bundle designs (similar size and shape to standard CANDU bundles)	Permanently shut down in 1985; All fuel currently in dry storage on site
Montreal, Quebec				
Ecole polytechnique	0.02	1976	(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)

Note: the SLOWPOKE reactors use U-235 enriched fuel and can operate on one fuel charge for 20 to 40 years. The total mass of U-235 fuel in a SLOWPOKE reactor core is about one kilogram. Other former research reactors include the 2 MW(th) Slowpoke Demonstration Reactor at Whiteshell, the low power PTR and ZEEP reactors at AECL Chalk River, and several shut down SLOWPOKE reactors at university sites. Used fuel from these shut down research reactors is stored at AECL Chalk River site, AECL Whiteshell site or has been returned to the country of origin (e.g. US).

APPENDIX B: USED FUEL WASTE FORECAST DETAILS FOR EXISTING REACTORS

Forecasts are based on:

Existing stations only (new build not considered).

[(June 2010 actuals) + (number of years from June 2010 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.

Total mass of fuel is based on an assumed rounded bundle mass of 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;
- reactors that have been previously refurbished and are still operating, will operate to the end of their current expected service life only; and
- reactors where a definite decision has been made not to refurbish (e.g. Pickering B), will operate to the end of their current expected service life only.

Note that forecasts are based on the above assumptions for NWMO planning purposes only 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 for Existing Reactors

Location	Unit	Startup	Total to June 2010 (# 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	410,845	22,500	1998	**468,000**	2037	**1,024,000**
	2	1977			1998		2037	
	3	1978			2011		2038	
	4	1979			2015		2039	
Bruce B	5	1985	521,478	23,500	2015	**639,000**	2045	**1,344,000**
	6	1984			2014		2044	
	7	1986			2016		2046	
	8	1987			2017		2047	
Darlington	1	1992	377,561	23,000	2022	**643,000**	2052	**1,333,000**
	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	116,173	4,500	2012	**132,000**	2043	**269,000**
Pickering A	1	1971	616,173	6,800	2021	**743,000**	2021	**833,000**
	2	1971			2005		2005	
	3	1972			2005		2005	
	4	1973			2021		2021	
Pickering B	5	1983		13,800	2013		2021	
	6	1984			2014		2021	
	7	1985			2015		2021	
	8	1986			2016		2021	
Point Lepreau		1983	121,758	4,500	2008	**121,758**	2041	**260,000**
AECL Whiteshell		1965	2,268	0	1985	**2,268**	1985	**2,268**
AECL (NPD/other)			4,886	0		**4,886**		**4,886**
TOTALS (bundles)			**2,196,611**	**98,600**		**2,780,000**		**5,096,000**
(t-HM)			***43,000***	***1,980***		***56,000***		***102,000***

Reactor currently under refurbishment (yellow)

Reactor permanently shut down (red)

Reactor previously refurbished (light blue)

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

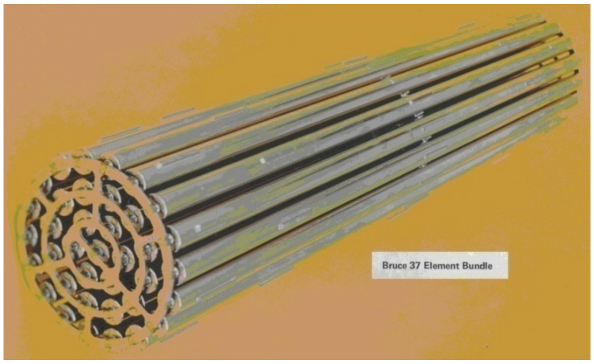
Fissionable material:
Sintered pellets of natural UO_2

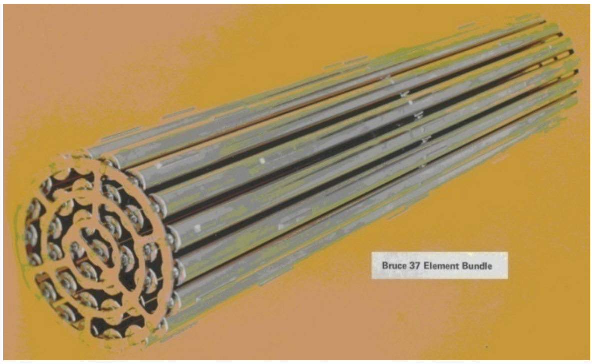
Average burnup:
8,300 MW day / tonne U
(200 MWh/kg U)

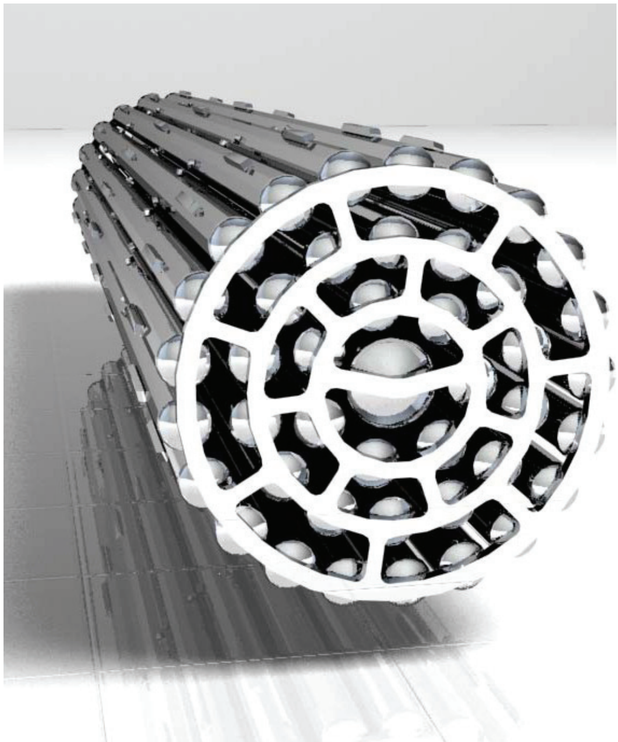
Cladding material:
Zircaloy-4

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

<table>
<tr><th colspan="2">37 element CANDU “standard” bundle</th></tr>
<tr><td rowspan="5">
</td><td>Physical dimensions:
102.5 mm OD x 495 mm OL</td></tr>
<tr><td>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</td></tr>
<tr><td>Fissionable material:
Sintered pellets of natural UO_2</td></tr>
<tr><td>Average burnup:
8,300 MW day / tonne U
(200 MWh/kg U)</td></tr>
<tr><td>Cladding material:
Zircaloy-4</td></tr>
<tr><td colspan="2">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</td></tr>
<tr><td colspan="2">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)</td></tr>
</table>

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: - similar to 37 element “standard” bundle, but is 13 mm longer - 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
- the inner central element uses Dysprosium -(a rare earth element that readily absorbs neutrons and reduces the bundle power maintaining a flat neutronic field profile across the bundle during operation)
- 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

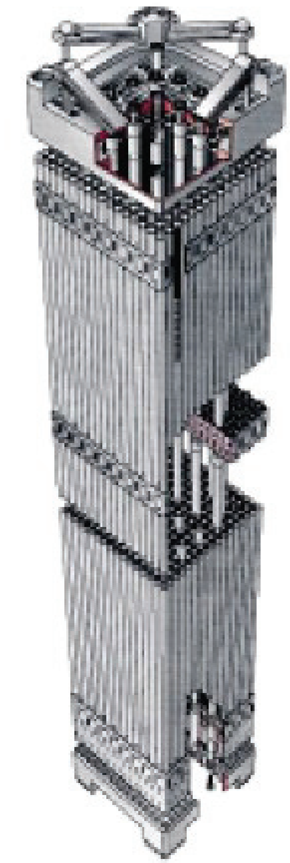
Average burnup:
20,000 MW day/ tonne U

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

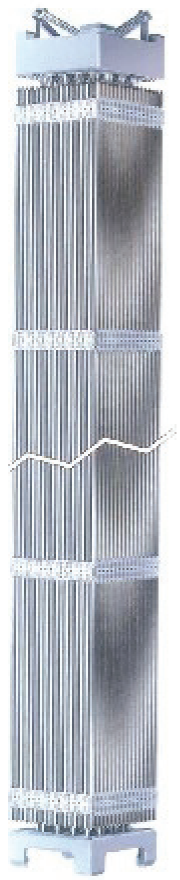
Fissionable material:
Sintered pellets of UO_2
enriched up to 5% U-235

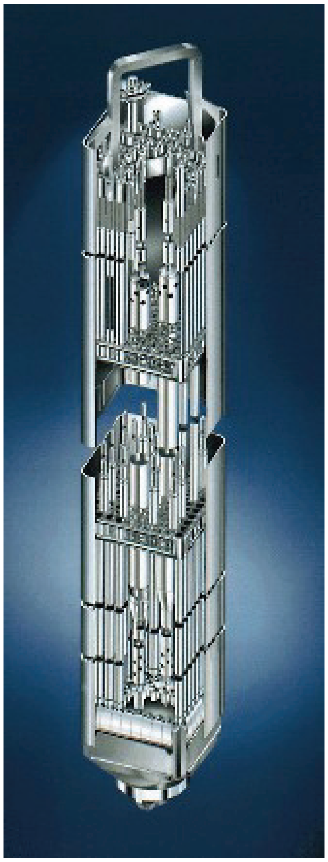
Average burnup:
60,000 MWday/tonne U

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

<table>
<tr><th colspan="2">EPR PWR fuel assembly</th></tr>
<tr><td rowspan="5"></td><td>Physical dimensions:
214 mm square x 4805 mm OL</td></tr>
<tr><td>Mass:
527.5 kg U (598.0 kg as UO_2)
~182 kg other materials in cladding, spacers, etc
780 kg total weight</td></tr>
<tr><td>Fissionable material:
Sintered pellets of UO_2
enriched up to 5% U-235</td></tr>
<tr><td>Average burnup:
62,000 MWday/tonne U</td></tr>
<tr><td>Cladding material:
M5</td></tr>
<tr><td colspan="2">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.</td></tr>
<tr><td colspan="2">Comments:
- used in Areva EPR reactors</td></tr>
</table>

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

<table>
<tr><th colspan="2">KERENA BWR fuel assembly</th></tr>
<tr><td rowspan="5">(picture not available)</td><td>Physical dimensions:
(details not available)

Overall length ~3765 mm</td></tr>
<tr><td>Mass:
~205 kg U (233 kg as UO_2)

~325 kg total weight</td></tr>
<tr><td>Fissionable material:
Sintered pellets of UO_2
enriched up to 4.7% U-235</td></tr>
<tr><td>Average burnup:
Up to 65,000 MWday/tonne U</td></tr>
<tr><td>Cladding material:
Zircaloy-2</td></tr>
<tr><td colspan="2">Construction:
- Details not available, but expected to be similar to AREVA ATRIUM series BWR fuels, with the exception that it uses a larger 12x12 array rather than conventional BWR 10x10 array.
- 128 fuel rods per assembly</td></tr>
<tr><td colspan="2">Comments:
- used in AREVA KERENA (SWR-1000) reactors</td></tr>
</table>

<table>
<tr><th colspan="2">ATMEA-1 PWR fuel assembly</th></tr>
<tr><td rowspan="5">(picture not available)</td><td>Physical dimensions:
(details not available)

Overall length ~4200 mm</td></tr>
<tr><td>Mass:
(details not available)</td></tr>
<tr><td>Fissionable material:
Sintered pellets of UO_2
enriched up to 5% U-235
MOX version also available</td></tr>
<tr><td>Average burnup:
Up to 62,000 MWday/tonne U</td></tr>
<tr><td>Cladding material:
(not available)</td></tr>
<tr><td colspan="2">Construction:
- Details not available, but expected to be similar to conventional AREVA/Mitsubishi PWR fuels</td></tr>
<tr><td colspan="2">Comments:
- used in AREVA ATMEA-1 reactors</td></tr>
</table>