Nuclear Fuel Waste Projections in Canada – 2024 Update

NWMO-TR-2024-09 **November 2024**

T. Reilly

Nuclear Waste Management Organization

Nuclear Waste Management Organization
22 St. Clair Avenue East, 4th Floor
Toronto, Ontario
M4T 2S3
Canada

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

Nuclear Fuel Waste Projections in Canada – 2024 Update

NWMO-TR-2024-09

November 2024

T. Reilly
Nuclear Waste Management Organization

Document History

Title:	Nuclear Fuel Waste Projections in Canada – 2024 Update		
Report Number:	NWMO-TR-2024-09		
Revision:	R000	Date:	November 2024
Nuclear Waste Management Organization			
Authored by:	T. Reilly		
Verified by:	K. Liberda and R. Ajaz		
Reviewed by:	M. Ion, P. Gierszewski and S. Dolatshahi		
Approved by:	C. Boyle		

ABSTRACT

Title: **Nuclear Fuel Waste Projections in Canada – 2024 Update**
Report No.: **NWMO-TR-2024-09**
Author(s): T. Reilly
Company: Nuclear Waste Management Organization
Date: November 2024

Abstract

This report summarizes the existing inventory of used nuclear fuel wastes in Canada as of June 30, 2024 and forecasts the potential future nuclear fuel waste from the existing reactor fleet as well as from proposed new-build reactors. While the report focuses on power reactors, it also includes prototype, demonstration and research reactor fuel wastes held by AECL, which are included in the NWMO mandate.

As of June 30, 2024, a total of approximately 3.3 million used CANDU fuel bundles (about 64,260 tonnes of heavy metal (t-HM)) were in storage at the reactor sites, an increase of about 74,550 bundles since the 2023 NWMO Nuclear Fuel Waste Projections report.

For the existing reactor fleet, the total projected number of used fuel bundles produced to the end of life of the reactors is approximately 5.9 million used CANDU fuel bundles (approximately 112,750 t-HM). This projection is based on published plans as of September 2024 and NWMO planning assumptions regarding the refurbishment and life extension of Darlington and Bruce reactors, as well as continued operation of Pickering A until 2024 and Pickering B until the end of 2026. Additional scenarios included in this year's estimates provide a range of forecasts (5.7 to 6.4 million bundles) to reflect uncertainties in future life extension plans of the existing reactor fleet.

Used fuel produced by potential new-build reactors, including small modular reactors (SMRs) will depend on the size and type of reactor and number of units deployed. New-build plans are at various stages of development. Decisions on future reactor refurbishment, new nuclear build or advanced fuel cycle technologies will be made by the nuclear utilities in Canada. The impacts of these decisions on projected inventory of nuclear fuel waste are discussed and will be incorporated into future updates of this report when there is reasonable certainty in the amount and timing of the additional nuclear fuel waste.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

1. INTRODUCTION

1.1 BACKGROUND

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's nuclear fuel waste (Canada 2002).

The NWMO continually reviews and adjusts its implementation plans as appropriate consistent with the external environment. As part of this process, the NWMO annually publishes the current and future potential inventories of used fuel amounts and types from existing and future reactors (Reilly 2023). This document provides an update of the current inventories from existing operating stations as of June 2024 and the projected inventories using available information as of September 2024.

Decisions on new nuclear reactors, advanced fuel cycles or other changes in energy choices will not be made by the NWMO. They will be made by the utilities in conjunction with government and regulators. However, it is important that the NWMO is prepared for these potential changes so that the NWMO can plan for the long-term management of used fuel arising from such decisions. As part of this, the NWMO maintains a watching brief on alternative technologies (NWMO 2024).

1.2 SCOPE

This report summarizes the existing inventory of used nuclear fuel wastes in Canada as of June 30, 2024 and forecasts the potential future nuclear fuel waste from the existing reactor fleet. The report focuses on power reactors and includes information on prototype, demonstration and research reactor fuel wastes held by Atomic Energy of Canada Limited (AECL).

The report also discusses used fuel that would result from operation of potential new reactors in Canada, including small modular reactors (SMRs). Note that the information included in this report reflects the SMR fresh fuel characteristics; the SMR fuel wasteforms may be different.

1.3 CHANGES SINCE THE 2023 REPORT

The primary changes to the Canadian nuclear landscape since the 2023 report are:

a) An increase in the total amount of used fuel currently in storage, due to another year of reactor operation.

b) Refurbishments of reactor units continue as planned, with Bruce A Unit 3, Bruce B Unit 6, Darlington Units 1 and 4 all being offline in the last year.

c) Bruce B Unit 6 completed refurbishment in September 2023 (Bruce Power 2023a).

d) Darlington Unit 3 completed refurbishment in July 2023 (OPG 2023a).

e) In October 2024 the Canadian Nuclear Safety Commission (CNSC) announced a decision to amend the licence held by OPG for Pickering Nuclear Generating Station. The decision authorizes OPG to operate Units 5-8 until December 31, 2026 (CNSC 2024a).

f) OPG is conducting a feasibility assessment on the potential for refurbishing Pickering B Units 5-8. OPG completed the assessment stage in August 2023 (Ontario 2022 and

OPG 2023b). In January 2024 the Ontario government stated support for OPG's plan to refurbish and further operate the Pickering B Units 5-8 (Ontario 2024).

g) Bruce Power has submitted to the Impact Assessment Agency of Canada (IAAC) an Initial Project Description for expansion of the Bruce Power site for up to 4,800 MWe. (Bruce Power 2024).

The combined effects of these changes on the current and projected used fuel inventory are:

a) An increase in the total amount of used fuel currently in storage from June 30, 2023 to June 30, 2024.

	June 30, 2023	**June 30, 2024**	**Net change**	
Wet storage	1,395,152	1,372,766	-22,386	bundles*
Dry storage	1,872,140	1,969,076	96,936	bundles
TOTAL	**3,267,292**	**3,341,842**	**74,550**	**bundles**

** Note: A negative number means more used fuel was transferred from wet to dry storage than was produced during the year.*

b) Small increases in the total fuel waste projections (5.7-6.4 million bundles), assuming refurbishment plans published as of September 2024 and various scenarios of operation after refurbishment for Bruce, Darlington, and Pickering B units. These projections are detailed in Section 2.

Note that these projections do not include any potential fuel waste resulting from operation of new reactors, including SMRs. Projections from potential fuel waste resulting from operation of new reactors are detailed in Section 3.

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, 2024. 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).

As of June 30, 2024, there are approximately 3.3 million bundles in wet or dry storage. This is equivalent to approximately 64,260 tonnes of heavy metal (t-HM). Figure 1 summarizes the history of wet and dry storage of used fuel in Canada to the end of June 2024. Initially, all fuel was wet-stored in the station used fuel storage bays. Dry storage was initiated in the 1970s at shutdown AECL prototype reactors. Starting in the 1990s, older fuel in the wet bays at the operating power reactors has been transferred to dry storage on an ongoing basis. In the future, the inventory in wet storage will remain relatively constant (since wet bay space is fixed), while the inventory in dry storage will continue to grow over time.

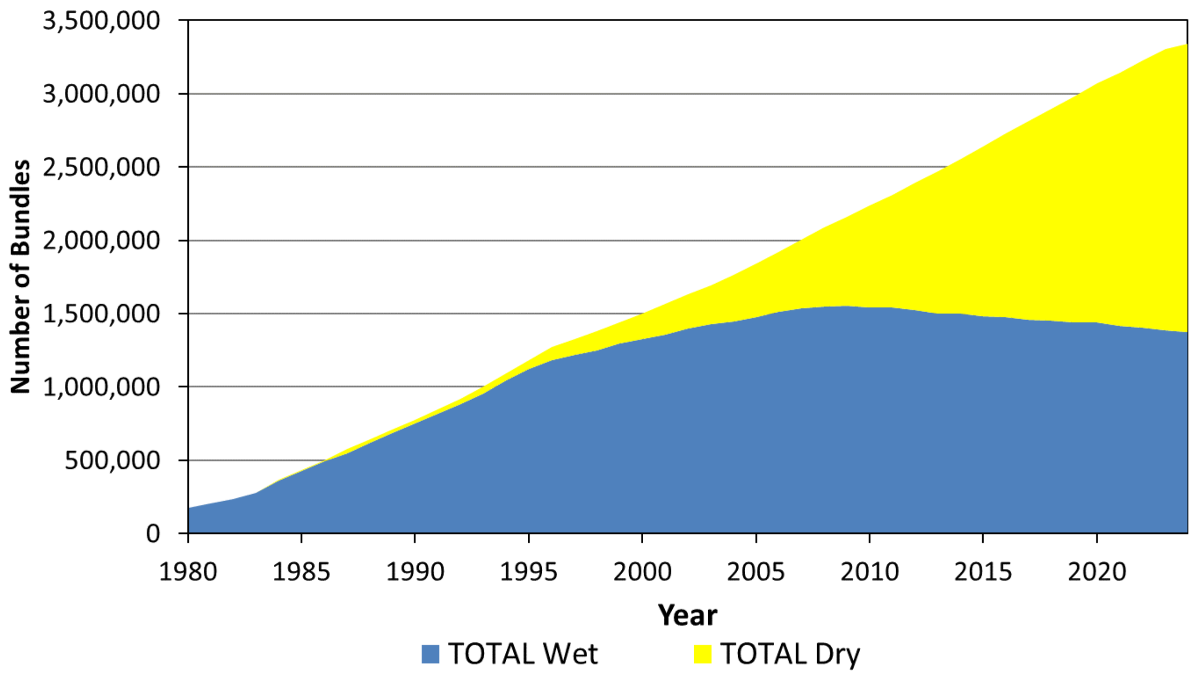


Figure 1: Summary of Used Fuel Wet and Dry Storage History

Table 1: Summary of Nuclear Fuel Waste in Canada as of June 30, 2024

Location	Waste Owner	Wet Storage (# bundles)	Dry Storage (# bundles)	TOTAL (# bundles)	Current Status
Bruce A	OPG[1]	330,062	319,872	649,934	- 3 units operational - 1 unit undergoing refurbishment See Note (2)
Bruce B	OPG[1]	339,608	491,126	830,734	- 4 units operational See Note (2)
Darlington	OPG	295,119	360,485	655,604	- 2 units operational - 2 units undergoing refurbishment See Note (3)
Douglas Point	AECL	0	22,256	22,256	- permanently shut down 1984
Gentilly 1	AECL	0	3,213	3,213	- permanently shut down 1977
Gentilly 2	HQ	0	129,925	129,925	- permanently shut down 2012
Pickering A	OPG	367,552	496,615	864,167	- 2 units operational - 2 units non-operational since 1997 (permanently shut down 2005)
Pickering B	OPG				- 4 units operational
Point Lepreau	NBPN	40,425	134,997	175,422	- 1 unit operational
Whiteshell	AECL	0	2,301	2,301	- permanently shut down 1985 See Note (4)
Chalk River	AECL	0	4,886	4,886	- predominately fuel bundles from the NPD reactor (permanently shut down 1987) and natural UO_2 fuel from other reactors
		0	~3,400	~3,400	- research fuels; see Note (5)
	Total	**1,372,766**	**1,969,076**	**3,341,842**	

Notes:

AECL = Atomic Energy of Canada Limited
HQ = Hydro-Québec
NBPN = New Brunswick Power Nuclear
OPG = Ontario Power Generation Inc.

1) OPG is responsible for the used fuel that is produced. Bruce reactors are leased to Bruce Power for operation.

2) Bruce Units 3-8 are currently undergoing refurbishment, unit-by-unit. The Bruce A Unit 3 was shut down in March 2023 and is expected to be completed in 2026. Bruce B Unit 6 was shut down in Jan 2020 and refurbishment completed in September 2023.

3) Refurbishment of Darlington Unit 1 started in Feb 2022 and is expected to be complete by June 2025. Refurbishment of the Darlington Unit 2 was completed in June 2020. Refurbishment of Darlington Unit 3 started in Sep 2020 and was completed early in July 2023. Refurbishment of Darlington Unit 4 started in July 2023 and is expected to be completed in 2026.

4) This value includes UO_2 and uranium carbide bundles from the WR-1 reactor, 360 natural UO_2 bundles from the Douglas Point reactor, miscellaneous CANDU bundles, and various experimental fuel types, commercial fuel pieces, and hot cell remnants in CANDU-bundle sized cans.

5) This estimate is the mass-based estimate of the number of bundle equivalents in the AECL inventory and includes the majority of the research reactor and experimental fuel in the AECL fuel inventory. The remaining inventory items will be assessed with respect to their suitability for disposal in the APM DGR and have therefore been excluded at this time.

2.2 PROJECTED NUCLEAR FUEL WASTE

Forecasts of future nuclear fuel waste are summarized in Table 2. The forecasts are based on the NWMO's assumptions used for planning purposes only and may differ from the business planning and operational assumptions of the reactor operators.

Three scenarios are provided in the estimates of this year's projections. These estimates are based on published plans as of September 2024, for refurbishment and life extension for the current reactor fleet, use conservative assumptions, and include a number of uncertainties, as described below.

a) Reference Scenario

1) This scenario includes only existing CANDU stations, with the following assumptions regarding refurbishment (IESO 2024a and 2024b, Ontario 2022, OPG 2021a, NB Power 2019):

   - Reactors that have been permanently shut down do not restart (Gentilly-2, Pickering A Units 2 and 3).
   - Reactors that have been refurbished (Bruce A Units 1 and 2, Bruce B Unit 6, Darlington Units 2 and 3, and Point Lepreau) and reactors that will be refurbished (Darlington Units 1 and 4, Bruce A Units 3 and 4 and Bruce B Units 5, 7 and 8) with new sets of pressure tubes and other major components will operate for 35 effective full power years (EFPY).
   - Pickering A Units 1 and 4 will operate until the end of 2024 and Pickering B Units 5–8 will operate until the end of 2026[1].

2) Fuel in reactor core is removed prior to a refurbishment and not re-used. No fuel is generated during the refurbishment period. End-of-life total includes final reactor core fuel.

3) The forecast for each station is calculated as *[(June 2024 actuals) + (number of years from June 2024 to end-of-life) * (typical annual production of fuel bundles)]*, rounded to nearest 1,000 bundles.

   The forecast annual production of fuel bundles is a conservative estimate for each station, resulting in a conservative projection of the overall total. The annual production values assumed in the projection are reviewed each year for accuracy with the projections against fuel produced in the year. This year the values have been revised, to the extent possible, to further align with reactor operators' planning assumptions.

4) Units are assumed to operate until December 31 of the shutdown year.

   The forecast conservatively assumes operation to end of year of shutdown. If an earlier (mid-year) shutdown were assumed for all stations, the total would be reduced by about 47,000 bundles.

5) Units operate to current end of life dates.

---

[1] In October 2024, the CNSC granted an amendment to the licence held by OPG, authorizing operation of Pickering B Units 5-8 until the end of December 2026 (CNSC 2024a).

Changes to the estimated end-of-life dates for refurbished reactors would result in changes to the overall forecast. For example, a potential 3-year extension or reduction of operation of all stations relative to current plans, assuming the highest typical annual bundle production, would affect the total bundle count by +/- about 93,000 bundles per year. Assuming a future 3-year extension/reduction for all units would affect the bundle count by about +/- 280,000 bundles.

6) Total mass of heavy metals (e.g., uranium) in fuel is based on an average bundle mass of heavy metal specific to each reactor type.

b) Low Scenario

1) The low scenario projection is calculated using the same method as the reference scenario, but with different assumptions for the operating lifetime of existing CANDU stations, including:
   - Reactors that have been refurbished (Bruce A Units 1 and 2, Bruce B Unit 6, Darlington Units 2 and 3, and Point Lepreau) and reactors that will be refurbished (Darlington Units 1 and 4, Bruce A Units 3 and 4 and Bruce B Units 5, 7 and 8) will operate for about 30 EFPY. This assumption is based on previous published operation plans.
   - Pickering A Units 1 and 4 will operate until the end of 2024 and Pickering B Units 5–8 will operate until the end of 2026.

2) All other assumptions remain the same as those used for the reference scenario.

c) High Scenario

1) The high scenario projection is calculated using the same method as the reference scenario, but with different assumptions for the operating lifetime of existing CANDU stations, including:
   - All reactors that have been refurbished (Bruce A Units 1 and 2, Bruce B Unit 6, Darlington Units 2 and 3, and Point Lepreau) and reactors that will be refurbished (Darlington Units 1 and 4, Bruce A Units 3 and 4 and Bruce B Units 5, 7 and 8) will operate for about 35 EFPY.
   - Pickering B Units 5–8 will operate until the end of 2026, be refurbished and also operate for about 35 EFPY.

2) All other assumptions remain the same as those used for the reference scenario.

In summary, 5.7-6.4 million used fuel bundles existing and forecasted represents the best estimate range based on published plans for the existing CANDU stations as of September 2024.

The associated uncertainty for the reference, low, and high scenarios could include +/- 0.28 million bundles (based on 3-year early or delayed shutdown of all current units) and about -0.05 million bundles (for mid-year end-of-life shutdown vs assumed end-of-year shutdown).

The forecast is subject to potential changes on annual basis, to account for reactor operators' updated plans for refurbishment and life extension, as well as for adjustments in calculations to reflect the most up-to-date numbers of bundles in storage versus previous year's projections.

Further information is provided in Appendix A including detailed assumptions for the refurbishment schedule, annual fuel production and reactor lifetimes for each unit. Details on the existing reactors can be found in Appendix B and fuel types in Appendix C.

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

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">Waste Owner</th><th>Total June 2024</th><th>Typical Annual Production</th><th>Low Scenario (7)</th><th>Reference Scenario (7)</th><th>High Scenario (7)</th></tr>
<tr><th>(# bundles)</th><th>(# bundles)</th><th>(# bundles)</th><th>(# bundles)</th><th>(# bundles)</th></tr>
<tr><td>Bruce A</td><td>OPG</td><td>649,934</td><td>21,700 (1)</td><td>1,270,000</td><td>1,275,000</td><td>1,275,000</td></tr>
<tr><td>Bruce B</td><td>OPG</td><td>830,734</td><td>24,600 (1)</td><td>1,733,000</td><td>1,801,000</td><td>1,801,000</td></tr>
<tr><td>Darlington</td><td>OPG</td><td>655,604</td><td>22,600 (1)</td><td>1,339,000</td><td>1,452,000</td><td>1,452,000</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><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><td>3,213</td></tr>
<tr><td>Gentilly 2</td><td>HQ</td><td>129,925</td><td>0 (2)</td><td>129,925</td><td>129,925</td><td>129,925</td></tr>
<tr><td>Pickering A</td><td>OPG</td><td rowspan="2">846,167</td><td>5,950 (3)</td><td rowspan="2">929,000</td><td rowspan="2">929,000</td><td rowspan="2">1,409,000</td></tr>
<tr><td>Pickering B</td><td>OPG</td><td>13,700 (1)</td></tr>
<tr><td>Point Lepreau</td><td>NBP</td><td>175,422</td><td>4,800</td><td>259,000</td><td>259,000</td><td>259,000</td></tr>
<tr><td>Whiteshell</td><td>AECL</td><td>2,301</td><td>0 (2)</td><td>2,301</td><td>2,301</td><td>2,301</td></tr>
<tr><td>Chalk River</td><td>AECL</td><td>~8,286</td><td>0 (4)</td><td>~8,286</td><td>~8,286</td><td>~8,286</td></tr>
<tr><td colspan="2">TOTAL (bundles) (5)</td><td>3,341,842</td><td>93,350</td><td>5,696,000</td><td>5,882,000</td><td>6,362,000</td></tr>
<tr><td colspan="2">(t-HM)(6)</td><td>64,260</td><td>1,800</td><td>109,190</td><td>112,750</td><td>122,280</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) Future forecasts do not include research fuels. Chalk River does not produce any CANDU power reactor used fuel bundles. However, it may receive bundles from power reactor sites from time to time for testing. This will not affect overall total numbers of bundles, since they will be subtracted from the reactor site.
5) Totals may not add exactly due to rounding to nearest 1,000 bundles for future forecasts.
6) "tonnes of heavy metals" (t-HM) based on an average of bundle mass specific for each reactor type.
7) Assumes units operate until December 31 of the shutdown year and the core is defueled in the following year.

3. INVENTORY FROM POTENTIAL NEW REACTORS

There are two categories of proposed new reactor projects:

- projects which have received or are currently undergoing regulatory approvals; and
- potential projects which have been discussed by various implementing organizations (proponents), but which do not have any regulatory approvals underway.

This report focuses on the first category. However, it does not assess the probability of any of these projects proceeding. Execution of each project rests entirely with the proponent.

At this time, some proposed new projects are not CANDU reactors and do not produce used CANDU fuel bundles. They are also higher burnup than used CANDU fuel, so typically produce less mass of used fuel for a given amount of electric power. However, these other used fuel wastes are not directly comparable to used CANDU fuel on a mass basis as they would generally be producing more decay heat and contain more radioactivity per unit fuel mass. These are characteristics that are important for repository design, in addition to fuel mass (or volume).

In order to better visualize the characteristics of this potential future inventory with respect to disposal, the inventory is presented here on an equivalent thermal power basis. That is, how many used CANDU bundles would be generated in producing an equivalent amount of thermal power? This number of CANDU bundles would have experienced a similar amount of fission, and therefore have a roughly similar amount of decay heat and radioactivity as the new types of used fuel. In this report, this equivalency is used to illustrate the potential impacts of these new reactors on the inventory of fuel wastes requiring long-term management.

Decisions on new nuclear reactors, advanced fuel cycles or other changes in energy choices will not be made by the NWMO. They will be made by the utilities in conjunction with government and regulators. The NWMO will continue to monitor these developments and the implications of new reactors as part of its Adaptive Phased Management approach.

3.1 PROJECTS WHICH HAVE RECEIVED OR CURRENTLY UNDERGOING REGULATORY APPROVALS

There are four new reactor projects undergoing regulatory reviews. These projects total approximately 6,115 MWe of new reactors operating for 40 to 100 years, which could approximately result in an additional fuel waste amount equivalent to 3,086,000 CANDU bundles, based on a simple correlation of electric power to CANDU bundles on a thermal power basis. The details of these projects are summarized below.

3.1.1 Ontario Power Generation

Ontario Power Generation (OPG) holds a Nuclear Power Reactor Site Preparation Licence that allows preparation of the Darlington nuclear site for future construction and operation of up to 4 new reactors, with a maximum combined net electrical output of 4,800 MWe (OPG 2021b).

In December 2021 OPG announced a partnership with GE Hitachi Nuclear Energy (GEH). OPG has selected GEH to further develop the BWRX-300 SMR design to be constructed at the Darlington nuclear site by 2030 (OPG 2022a). In September 2022, OPG began non-nuclear site preparation activities for an SMR at Darlington and submitted an application to the CNSC for the Licence to Construct in October 2022 (OPG 2022b). In July 2023, the Ontario government announced it will work with OPG to commence planning and licensing for three additional SMRs, for a total of four SMRs at the Darlington nuclear site (Ontario 2023a).

In April 2024 the CNSC determined that the existing environmental assessment for the Darlington New Nuclear Project is applicable to the GEH BWRX-300 SMR (CNSC 2024b). In July 2024 OPG applied to the CNSC to request to amend the current Nuclear Power Reactor Site Preparation Licence to allow for non-nuclear site preparation work to continue while awaiting a Licence to Construct decision from the CNSC (OPG 2024).

The BWRX-300 is a light water reactor (LWR), specifically a boiling water reactor (BWR), utilising low enriched fuel, the reactor has a power rating of 870 MWth (300 MWe) (GEH 2023). The fuel is proposed to be based on Global Nuclear Fuel's (GNF) GNF2 product line and is described in Appendix C.3. It is estimated that over the reactor's expected 60-year lifetime it could result in about 2,400 GNF2 used fuel assemblies (roughly 440 t-HM initial). Based on a simple correlation to CANDU bundles on a thermal power basis, it is estimated that this used fuel would be equivalent to about 117,000 CANDU used fuel bundles per reactor, totalling approximately 470,000 equivalent CANDU fuel bundles for four proposed BWRX-300s at the Darlington nuclear site.

GNF2 BWR fuel is the same type of fuel that is being planned for handling and disposal in Sweden, Finland, and Switzerland, as all three of these countries have BWR reactors discharging BWR fuel (GEH 2023).

3.1.2 Global First Power

Global First Power (GFP), a partnership between Ultra Safe Nuclear Corporation (USNC) and OPG, propose to construct and operate a Micro Modular Reactor (MMR) plant on AECL property at the Chalk River site. Canadian Nuclear Laboratories (CNL) and GFP signed a hosting agreement formalizing the framework under which CNL and GFP will cooperate with respect to licensing, design, siting, and other matters with respect to advancement of the SMR project (CNL 2020a).

In April 2019, GFP submitted to the CNSC an initial application for a Licence to Prepare Site for a SMR at the Chalk River site (GFP 2019a) and followed up with the submission of Part 1 of the full application in July 2023 (GFP 2023). In October 2024, USNC announced that it is seeking to run a sale process pursuant to Section 363 of Chapter 11 of the U.S. Bankruptcy Code. During this process, USNC will maintain operational continuity across its projects, including the deployment of its MMR systems in the U.S. and Canada (USNC 2024). At the time of writing this report, the CNSC review of GFP's application was still in progress.

The MMR is a high temperature gas-cooled reactor (HTGR). The original proposal was a 5 MWe (15 MWth) reactor with an anticipated operational life of 20 years and a single fuel loading at reactor start-up (GFP 2019b). In 2023, the concept was revised to 15 MWe (45 MWth) and 40 years operation with refueling approximately every three years (GFP 2024).

At this stage there is limited technical information about the MMR fuel and its fuel waste characteristics. The fuel contains low-enriched uranium of a potential range 9.9-19.75% U-235 (USNC 2023) and is manufactured with TRI-structural ISOtropic (TRISO) fuel particles. The TRISO fuel particles are assembled into a Fully Ceramic Micro-encapsulated (FCM™) fuel pellet. The fuel pellet design was updated in December 2023 with an annular hole through the centre of the pellet to improve cooling (GFP 2024). The fuel pellets are proposed to be stacked in vertical channels within hexagonal graphite blocks, comprising an MMR fuel element (GFP 2019b). The MMR fuel is described in Appendix C.3.

The MMR fuel is substantially different than CANDU fuel and the quantities and characteristics of potential fuel wastes have not been published at this time. It is estimated that one 15 MWe (45 MWth) MMR at the Chalk River site operating for 40 years would produce used fuel equivalent to about 4,300 CANDU used fuel bundles based on a simple correlation to CANDU bundles on a thermal power basis.

The NWMO will continue to monitor the progress of this project.

3.1.3 New Brunswick Power

New Brunswick Power (NB Power) in partnership with ARC Clean Technology Canada is proceeding with work to deploy a SMR. Planning and project development are underway to deploy one ARC-100 reactor at the Point Lepreau nuclear site.

On June 30, 2023, NB Power submitted an Environmental Impact Assessment (EIA) registration document to the Department of Environment and Local Government (DELG) (New Brunswick 2023), and a Licence to Prepare Site application to the CNSC (NB Power 2023).

The ARC-100 is a 100 MWe sodium-cooled, fast flux, pool-type reactor that builds on the 30-year operation of the EBR-II reactor, which was built and operated by the Argonne National Laboratory in the U.S. from 1964-1994 (ARC Clean Technology 2023). The fuel is metallic with an average enrichment of 13.1% U-235; details of the fuel are described in Appendix C.3.

It is estimated that over the reactor’s expected 60-year lifetime it could result in 297 ARC-100 metallic fuel assemblies (ARC Clean Technology 2023). Based on a simple correlation to CANDU bundles on a thermal power basis, it is estimated that this used fuel would be equivalent to about 40,000 CANDU used fuel bundles for one ARC-100 reactor at the Point Lepreau nuclear site.

The NWMO continues to monitor the progress of the regulatory approval process of this project. As more information becomes available, additional details on ARC-100 metallic fuel assemblies and potential fuel waste inventories from the proposed SMR will be included in future versions of this report.

3.1.4 Bruce Power

In July 2023, the Ontario government announced it is starting pre-development work with Bruce Power to site a new large reactor project (Ontario 2023b). Bruce Power is planning to start community engagement and conduct the environmental assessment for federal approval to determine the feasibility of siting up to 4,800 MWe of new nuclear generation on its current site (Bruce Power 2023b).

At this time, no decision has been made on the specific reactor design that would be considered by Bruce Power. The initial project description uses a technology neutral approach through use of a Plant Parameter Envelope (PPE) and currently considers information from the designs of the following reactor models (Bruce Power 2024b):

- Atkins Réalis – MONARK
- Électricité de France – European Pressurized Water Reactor (EPR)
- Hitachi-GE Nuclear Energy – Advanced Boiling Water Reactor (ABWR)
- GE Hitachi Nuclear Energy – BWRX-300
- Westinghouse – AP1000 Pressurized Water Reactor

All these reactor designs utilise CANDU fuel (MONARK) or LWR fuel with known wasteforms that have been studied and planned for handling and disposal in Canada or internationally.

The project has a proposed capacity of up to 4,800 MWe or 13,600 MWth and would be located on the Bruce Power site. Bruce Power assume a 60 – 100 year operational lifespan depending on the technology selected, with a potential start of operations in 2045. For illustrative purposes, it is estimated that 13,600 MWth nuclear power operating for 80 years could result in an amount of used fuel equivalent to up to 2.6 million CANDU used fuel bundles. This estimate is based upon a simple correlation to typical CANDU used fuel bundle energy and maximum operating efficiency.

3.2 Potential Projects and Developments

In 2020, the Government of Canada launched Canada's SMR Action Plan in 2020 (NRCan 2020), and in 2022, four provinces identified three streams to support SMR technology readiness (Ontario, New Brunswick, Alberta and Saskatchewan 2022). For illustrative purposes, an estimate of the fuel waste that could result from the operation of the SMRs considered in these projects is provided below, using a simple correlation to CANDU bundles on a thermal power basis. However, it is noted that there are various degrees of uncertainty with respect to the future implementation of these projects, including the number of reactors that could be considered for operation under each stream.

- The Stream 1 Darlington project is discussed in Section 3.1.1 and could produce used fuel equivalent to about 117,000 CANDU used fuel bundles per BWRX-300 reactor. Assuming four such reactors operating for 60 years at the Darlington site could result in approximately 470,000 equivalent CANDU used fuel bundles. Assuming four reactors at Darlington and four similar reactors operating in Saskatchewan for 60 years, could result in approximately 940,000 equivalent CANDU used fuel bundles in total.
- The Stream 2 has two projects:
    - The ARC-100 project is discussed in Section 3.1.3 and could produce used fuel equivalent to about 40,000 CANDU used fuel bundles, assuming one reactor operating for 60 years.
    - Moltex Energy's proposed Stable Salt Reactor - Wasteburner (SSR-W) 300 MWe fast reactor at Point Lepreau is designed to utilise molten salt fuel produced by reprocessing CANDU used fuel (IAEA 2022). Details of the residual salt fuel wasteform are not available at the time of writing this report. For illustrative purposes based on a simple correlation to CANDU bundles on a thermal power basis, it is estimated that one SSR-W operating for 60 years could produce used fuel equivalent to about 106,000 CANDU used fuel bundles, while also

consuming some of the wastes (actinides) from existing CANDU used fuel bundles.

- The Stream 3 micro-SMR project at Chalk River is discussed in Section 3.1.2 and it is estimated that one MMR operating for 40 years could produce used fuel equivalent to approximately 4,300 CANDU used fuel bundles. Additionally, in November 2023 the Government of Saskatchewan announced $80 million for the Saskatchewan Research Council to pursue the deployment of an eVinci microreactor, which will be built by Westinghouse Electric Company and expected to be operational by 2029 (Saskatchewan 2023). A 13 MWth eVinci microreactor operating for 40 years could produce used fuel equivalent to approximately 1,300 CANDU used fuel bundles.

The CNSC continues the pre-licensing reviews for a variety of SMR designs (CNSC 2024c).

CNL looks to establish partnerships with vendors of SMR technology to develop, promote and demonstrate the technology in Canada, and continues annual calls for proposals of its Canadian Nuclear Research Initiative program (CNRI), the 4th call for proposals was announced in October 2024 (CNL 2024). CNL has agreements with SMR technology vendors including GFP, StarCore Nuclear (CNL 2019), Moltex Energy (CNL 2020b), USNC (CNL 2020c), NB Power (CNL 2020d), Terrestrial Energy (CNL 2020e), and ARC Canada (CNL 2022).

X-energy announced in April 2024 that it is working with TransAlta to conduct an initial feasibility study regarding the potential benefits of deploying a SMR at a repurposed fossil fuel power plant site in Alberta (X-energy 2024). In December 2023, X-energy completed Phases 1 and 2 of the CNSC’s vendor design review for the Xe-100 SMR (CNSC 2023).

4. SUMMARY OF PROJECTED USED FUEL INVENTORY

As of June 30, 2024 there are approximately 3.3 million used fuel bundles in wet or dry storage.

Based on currently announced and potential refurbishment and life extension plans for the existing nuclear reactor fleet in Canada, three scenarios are considered this year (see Section 2.2 for details):

- A reference scenario forecast projects a total of approximately 5.9 million bundles.
- A low scenario forecast projects a total of approximately 5.7 million bundles.
- A high scenario forecast projects a total of approximately 6.4 million bundles.

Its associated uncertainty could include: +/- 0.28 million bundles (based on 3-year early or delayed shutdown of all current units) and -0.05 million bundles (for mid-year end-of-life shutdown vs assumed end-of-year shutdown).

In addition, there are a number of new projects that are in various stages of planning. The SMRs that are in early licensing could add approximately +0.51 million equivalent CANDU used fuel bundles from four BWRX-300 units at Darlington site, one GFP MMR at Chalk River site, and one ARC-100 reactor at Point Lepreau site. The Bruce C project could also add approximately +2.6 million equivalent CANDU used fuel bundles to the total projections; there is however significant uncertainty on this estimate as a reactor technology and operating lifetime have not been selected by Bruce Power at this time.

The existing and projected inventory from current CANDU reactor operations, CANDU reactors approved and potential refurbishment, and proposed new nuclear projects currently undergoing regulatory review described in Section 3.1, is summarized in Figure 2.

In summary, the approximate 5.7-6.4 million used fuel bundles forecasted represents the best estimate range based on utility published plans, as of September 2024 for the existing nuclear fleet.

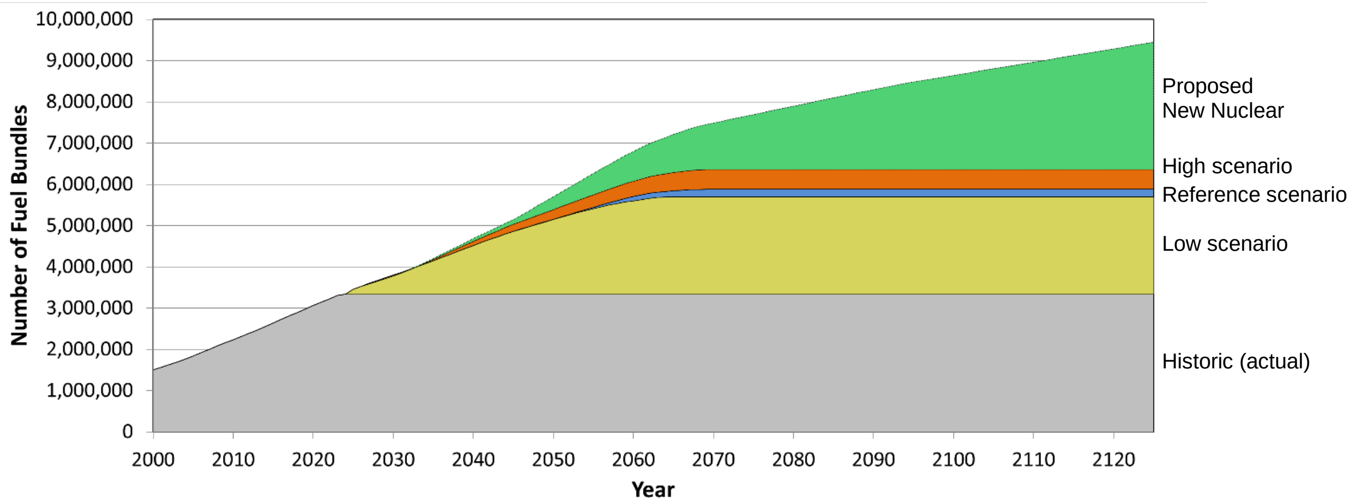


Figure 2: Summary of Projected Used Fuel Inventory

REFERENCES

ARC Clean Technology. 2023. Fuel cycle for ARC-100 commercial demonstration at the Point Lepreau Nuclear Site in New Brunswick. ARC Clean Technology Technical Document. Available at: https://www.arc-cleantech.com/uploads/Fuel%20Cycle%20for%20ARC-100%20Commercial%20Demonstration%20at%20the%20Point%20Lepreau%20Nuclear%20Site.pdf

Bruce Power. 2023a. Bruce Power's renewed Unit 6 declared commercially operational on 39th anniversary of first in-service date. Bruce Power news release, September 14, 2023. Available at www.brucepower.com

Bruce Power. 2023b. "Bruce Power provides formal notice of intent to begin early community engagement, Impact Assessment for Bruce C", Bruce Power news release, October 20, 2023. Available at www.brucepower.com

Bruce Power. 2024. Bruce C Project Initial Project Description Plain Language Summary. August 2024.

Canada. 2002. Nuclear Fuel Waste Act, S.C. 2002, c. 23.

CNL. 2019. "Update on CNL's SMR invitation process". Chalk River Nuclear Laboratories news release, February 15, 2019. Available at www.cnl.ca

CNL. 2020a. "CNL reaches Project Host Agreement with Global First Power", Chalk River Nuclear Laboratories news release, November 18, 2020. Available at www.cnl.ca

CNL. 2020b. "CNL & Moltex Energy partner on SMR fuel research", Chalk River Nuclear Laboratories news release, April 23, 2020. Available at www.cnl.ca

CNL. 2020c. "CNL & USNC partner on SMR fuel research", Chalk River Nuclear Laboratories news release, February 26, 2020. Available at www.cnl.ca

CNL. 2020d. "Canadian Nuclear Laboratories and NB Power sign collaboration agreement to advance small modular reactors", Chalk River Nuclear Laboratories news release, February 27, 2020. Available at www.cnl.ca

CNL. 2020e. "CNL and Terrestrial Energy partner on SMR fuel research", Chalk River Nuclear Laboratories news release, September 15, 2020. Available at www.cnl.ca

CNL. 2022. "CNL Partners with ARC Canada to advance fuel development", Chalk River Nuclear Laboratories news release, July 27, 2022. Available at www.cnl.ca

CNL. 2024. "CNL expands highly successful CNRI program to include fusion technologies in annual call for proposals". Chalk River Nuclear Laboratories news release, October 04, 204. Available at https://www.cnl.ca/cnl-expands-highly-successful-cnri-program-to-include-fusion-technologies-in-annual-call-for-proposals/

CNSC. 2023. Executive summary: Combined phases 1 and 2 pre-licensing vendor design review - X-energy. Available at: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/x-energy-executive-summary/

CNSC. 2024a. “Pickering Nuclear Generating Station Units 5 to 8 until December 31, 2026”. Canadian Nuclear Safety Commission News release. October 11, 2024. Available at: https://www.canada.ca/en/nuclear-safety-commission/news/2024/10/commission-authorizes-ontario-power-generation-inc-to-operate-pickering-nuclear-generating-station-units-5-to-8-until-december-31-2026.html

CNSC. 2024b. “Independent Commission determines environmental assessment for Ontario Power Generation’s Darlington New Nuclear Project is applicable to the selected reactor technology” CNSC News release. April 22, 2024. Available at https://www.canada.ca/en/nuclear-safety-commission/news/2024/04/independent-commission-determines-environmental-assessment-for-ontario-power-generations-darlington-new-nuclear-project-is-applicable-to-the-select.html

CNSC. 2024c. Pre-Licensing Vendor Design Review. Canadian Nuclear Safety Commission. Available at http://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm

GEH. 2023. BWRX-300 General Description. GE Hitachi Nuclear Energy Technical Document 005N9751 Revision F. December 2023.

GFP. 2019a. Licence to Prepare Site Initial Application: MMR Nuclear Plant at Chalk River. Global First Energy Report CRP-LIC-01-002. Available at www.globalfirstpower.com.

GFP. 2019b. Project Description for the Micro Modular Reactor™ Project at Chalk River. Global First Energy Report CRP-LIC-01-001. Available at www.globalfirstpower.com.

GFP. 2023. “Chalk River Project Update”, GFP news release, July 14, 2023. Available at www.globalfirstpower.com.

GFP. 2024. Global First Power Project Update Newsletter, February 2024. Available at www.globalfirstpower.com.

IAEA. 2022. Advances in Small Modular Reactor Technology Developments A Supplement to: IAEA Advanced Reactor Information System (ARIS) 2022 Edition. September 2022. Vienna, Austria.

IESO. 2024a. Annual Planning Outlook Ontario’s electricity system needs: 2025-2050. Independent Electricity System Operator Report. March 2024. Toronto, Canada.

IESO. 2024b. 2024 Annual Planning Outlook: Ontario Generation Resources Database. Independent Electricity System Operator file. March 2024. Available at Annual Planning Outlook (ieso.ca)

NB Power. 2019. New Brunswick Power’s 10-Year Plan. Fiscal Years 2021 to 2030. Available at www.nbpower.com.

NB Power. 2023. License to Prepare Site Application. Énergie NB Power report 0930-00581-0001-001-LPA-A-00. June 30, 2023.

New Brunswick. 2023. NB Power - ARC Clean Technology Advanced Small Modular Reactor - Commercial Demonstration Unit. Government of New Brunswick. Available at https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/environmental_impactassessment/comprehensive_reviews/arc-clean-technology.html

NRCan. 2020. “Canada’s Small Modular Reactor Action Plan”. Natural Resources Canada. Available at Canada’s Small Modular Reactor Action Plan.

NWMO. 2024. Watching Brief on Advanced Fuel Cycles and Alternative Waste Management Technology - 2023 Update, Nuclear Waste Management Organization. March 2024. Available at www.nwmo.ca.

Ontario. 2022. “Ontario Supports Plan to Safely Continue Operating the Pickering Nuclear Generating Station” Government of Ontario News Release, September 29, 2022. Available at https://news.ontario.ca/en/release/1002338/ontario-supports-plan-to-safely-continue-operating-the-pickering-nuclear-generating-station

Ontario. 2023a. “Ontario Building More Small Modular Reactors to Power Province’s Growth”, Government of Ontario news release, July 07, 2023. Available at https://news.ontario.ca/en/release/1003248/ontario-building-more-small-modular-reactors-to-power-provinces-growth

Ontario. 2023b. “Province Starts Pre-Development Work for New Nuclear Generation to Power Ontario’s Growth”, Government of Ontario news release, July 05, 2023. Available at https://news.ontario.ca/en/release/1003240/province-starts-pre-development-work-for-new-nuclear-generation-to-power-ontarios-growth

Ontario. 2024. “Ontario Supporting Plan to Refurbish Pickering Nuclear Generating Station”, Government of Ontario news release, January 30, 2024. Available at https://news.ontario.ca/en/release/1004128/ontario-supporting-plan-to-refurbish-pickering-nuclear-generating-station

Ontario, New Brunswick, Alberta and Saskatchewan. 2022. A Strategic Plan for the Deployment of Small Modular Reactors. October 2022.

OPG. 2021a. “Darlington Refurbishment Performance Update Q1 2021”, Ontario Power Generation news release, May 20, 2021. Available at www.opg.com.

OPG. 2021b. CNSC Record of Decision - Application to Renew the Power Reactor Site Preparation Licence for the Darlington New Nuclear Project. Available at www.opg.com.

OPG. 2022a. “Darlington New Nuclear Project Update”, Ontario Power Generation news release, January 2022. Available at www.opg.com.

OPG. 2022b. “OPG applies to Canadian Nuclear Safety Commission for Licence to Construct”, Ontario Power Generation news release, October 2022. Available at www.opg.com.

OPG. 2023a. "OPG celebrates the early completion of Darlington Unit 3", Ontario Power Generation news release, July 18, 2023. Available at www.opg.com.

OPG. 2023b. Pickering Nuclear Generating Station: Mid Term Update. Written submission from Ontario Power Generation to the Canadian Nuclear Safety Commission. August 31, 2023. Available at: www.opg.com.

OPG. 2024. Darlington New Nuclear Project – Application for Amendment to Power Reactor Site Preparation Licence PRSL 18.00/2031. Ontario Power Generation letter to the CNSC CD# NK054-CORR-00531-11035. July 15, 2024.

Reilly, T. 2023. Nuclear Fuel Waste Projections in Canada – 2023 Update. Nuclear Waste Management Organization Technical Report NWMO-TR-2023-09. December 2023. Toronto, Canada.

Saskatchewan. 2023. "Government of Saskatchewan Funds Microreactor Research" Government of Saskatchewan news release, November 27, 2023. Available at www.saskatchewan.ca.

SaskPower, NB Power, Bruce Power, and Ontario Power Generation. 2021. Feasibility of Small Modular Reactor Development and Deployment in Canada. Available at https://www.opg.com/innovating-for-tomorrow/small-modular-nuclear-reactors/

USNC. 2023. "USNC Boosts MMR Power, Flexibility, and Value". USNC news release. August 01, 2023. Available at www.usnc.com.

USNC. 2024. "Ultra Safe Nuclear Corporation ("USNC") Files Chapter 11 Petition to Facilitate Sale". USNC news release. October 29, 2024. Available at www.usnc.com.

X-energy. 2024. "X-energy, TransAlta Partner to Study Deployment of Advanced Small Modular Nuclear Reactors in Alberta through Emissions Reduction Alberta Award". X-energy news release. April 2, 2024. Available at: https://x-energy.com/media/news-releases/x-energy-transalta-partner-to-study-deployment-of-advanced-small-modular-nuclear-reactors-in-alberta-through-emissions-reduction-alberta-award

APPENDIX A: USED FUEL FORECAST DETAILS

Three scenarios are provided in the estimates of this year's projections. These estimates are based on published plans, as of September 2024 for refurbishment and life extension for the current reactor fleet, use conservative assumptions, and include a number of uncertainties.

Table A1 provides details for the assumed dates of refurbishment and shutdown of each reactor used to calculate the projections. Refurbishments yet to be completed are rounded to either the mid-point or end-point of the year for purposes of estimating the used fuel projections.

Table A2 provides details on the used fuel forecasts from existing reactors.

Table A1: Refurbishment Schedule for Existing Reactors

Location	Unit	Refurbishment Schedule (Start-End)	
		Reference & Low Scenarios	High Scenario
Bruce A	1	Complete	
	2	Complete	
	3	03/2023 – 06/2026	
	4	01/2025 – 12/2027	
Bruce B	5	07/2026 – 06/2029	
	6	Complete	
	7	07/2028 – 06/2031	
	8	07/2030 – 06/2033	
Darlington	1	02/2022 – 06/2025	
	2	Complete	
	3	Complete	
	4	07/2023 – 12/2026	
Douglas Point	-	-	
Gentilly 1	-	-	
Gentilly 2	-	-	
Pickering A	1	Complete	
	2	-	
	3	-	
	4	Complete	
Pickering B	5	-	01/2027 – 12/2030
	6	-	01/2027 – 12/2031
	7	-	01/2027 – 12/2032
	8	-	01/2027 – 12/2033
Point Lepreau	1	Complete	
Whiteshell	-	-	
Chalk River/ NPD/other	-	-	

Table A2: Detailed Used Fuel Forecasts from Existing Reactors

Location	Unit	Start up	Total to June 2024	Typical Annual Production	Low Scenario		Reference Scenario		High Scenario	
			(# bundles)	(# bundles)	End-of-life	(# bundles)	End-of-life	(# bundles)	End-of-life	(# bundles)
Bruce A	1	1977	649,934	21,700	2043	1,270,000	2044	1,275,000	2044	1,275,000
	2	1977			2043		2043		2043	
	3	1978			2061		2061		2061	
	4	1979			2062		2062		2062	
Bruce B	5	1985	830,734	24,600	2062	1,733,000	2064	1,801,000	2064	1,801,000
	6	1984			2058		2059		2059	
	7	1986			2063		2066		2066	
	8	1987			2063		2068		2068	
Darlington	1	1992	655,604	22,600	2055	1,339,000	2060	1,452,000	2060	1,452,000
	2	1990			2050		2055		2055	
	3	1993			2053		2058		2058	
	4	1993			2056		2061		2061	
Douglas Point		1968	22,256	0	1984	22,256	1984	22,256	1984	22,256
Gentilly 1		1972	3,213	0	1977	3,213	1977	3,213	1977	3,213
Gentilly 2		1983	129,925	0	2012	129,925	2012	129,925	2012	129,925
Pickering A	1	1971	864,167	5,950	2024	929,000	2024	929,000	2024	1,409,000
	2	1971			2005		2005		2005	
	3	1972			2005		2005		2005	
	4	1973			2024		2024		2024	
Pickering B	5	1983		13,700	2026		2026		2065	
	6	1984			2026		2026		2066	
	7	1985			2026		2026		2067	
	8	1986			2026		2026		2068	
Point Lepreau		1983	175,422	4,800	2040	259,000	2040	259,000	2040	259,000
Whiteshell		1965	2,301	0	1985	2,301	1985	2,301	1985	2,301
Chalk River/ NPD/other	-	-	8,286	0	-	8,286	-	8,286	-	8,286
TOTALS (bundles)			**3,341,842**	**93,350**		**5,696,000**		**5,882,000**		**6,362,000**
(t-HM)			***64,260***	***1,800***		***109,190***		***112,750***		***122,280***

APPENDIX B: SUMMARY OF EXISTING CANADIAN REACTORS & FUEL STORAGE

Appendix B presents a summary of commercial, demonstration and research reactors in Canada. Table B1 presents a summary of commercial power reactors in Canada and their status. Table B2 presents a summary of prototype and demonstration reactors in Canada and their status. Table B3 presents a summary of research reactors in Canada and their status.

Commercial, prototype and some research reactors have storage facilities for used nuclear fuel. Table B4 presents a summary of dry storage facilities for used nuclear fuel and Figure B1 shows the location of the major storage locations in Canada.

Table B1: Nuclear Power Reactors

Location	Rating (MW(e) net)	Year In-service	Fuel Type*	Current Status (2024)
Bruce Nuclear Power Development, Ontario				
Bruce A – 1	750	1977	37 element bundle	Refurbished and operating
Bruce A – 2	750	1977		Refurbished and operating
Bruce A – 3	750	1978		Undergoing refurbishment
Bruce A – 4	750	1979		Operating
Bruce B – 5	795	1985	37 element bundle; 37 element "long" bundle	Operating
Bruce B – 6	822	1984		Refurbished and operating
Bruce B – 7	822	1986		Operating
Bruce B – 8	795	1987		Operating
Darlington, Ontario				
Darlington 1	881	1992	37 element bundle; 37 element "long" bundle	Undergoing refurbishment
Darlington 2	881	1990		Refurbished and operating
Darlington 3	881	1993		Refurbished and operating
Darlington 4	881	1993		Undergoing refurbishment
Gentilly, Quebec				
Gentilly 2	635	1983	37 element bundle	Permanently shut down in 2012
Pickering, Ontario				
Pickering A – 1	515	1971	28 element bundle	Refurbished and operating
Pickering A – 2	515	1971		Non-operational since 1997; Permanently shut down in 2005
Pickering A – 3	515	1972		Non-operational since 1997; Permanently shut down in 2005
Pickering A – 4	515	1973		Refurbished and 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 bundle	Refurbished and operating

*Note: refer to Appendix B for description of fuel types, and their current storage status.

Table B2: Prototype and Demonstration Power Reactors

Location	Rating (MW(e) net)	Year In-service	Fuel Type	Current Status (2024)
Bruce Nuclear Power Development, Ontario				
Douglas Point (CANDU PHWR prototype)	206	1968	19 element bundle	Permanently shut down in 1984; All fuel is 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 1977; All fuel is in dry storage on site
Rolphton, Ontario				
NPD (CANDU PHWR prototype)	22	1962	7 and 19 element bundles	Permanently shut down in 1987; All fuel is in dry storage at Chalk River

Table B3: Research Reactors

Location	Rating (MW(th))	Year In-service	Fuel Type	Comments
Chalk River, Ontario				
NRU	135	1957	various driver fuel and target designs (U-metal, U-Al, U_3Si-Al)	Permanently shut down in 2018. The majority of NRU fuel has been transferred to dry storage.
ZED-2	0.00025	1960	various uranium fuels	Operating
NRX	42	1947	various driver fuel and target designs (U-metal, U-Al, UO_2)	Permanently shut down in 1992
MAPLE 1	10	-	U_3Si-Al driver fuel; UO_2-targets	Never fully commissioned
MAPLE 2	10	-		
Whiteshell, Manitoba				
WR-1 (organic cooled reactor prototype)	60	1965	various research and prototype fuel bundle designs (similar size and shape to standard CANDU bundles; UO_2, UC)	Permanently shut down in 1985; Fuel is in dry storage on site.
Hamilton, Ontario				
McMaster University	5	1959	U_3Si-Al fuel pins	MTR Pool type reactor; Operating.
Kingston, Ontario				
Royal Military College	0.02	1985	UO_2 fuel pins	SLOWPOKE-2 reactor; Operating.
Montreal, Quebec				
Ecole Polytechnique	0.02	1976	UO_2 fuel pins	SLOWPOKE-2 reactor; Operating.

Note: the SLOWPOKE reactors can operate on one fuel charge for 20 to 40 years. Other former research reactors include the 2 MW(th) SLOWPOKE Demonstration Reactor at Whiteshell, the low power PTR and ZEEP reactors at Chalk River, and shut down / decommissioned SLOWPOKE reactors at University of Toronto, Dalhousie University, Nordion Kanata, University of Alberta and University of Saskatoon. Used fuel from these shut down research reactors is stored at the Chalk River site, Whiteshell site or has been returned to the country of origin.

Table B4: Summary of Dry Storage Facilities for Used Nuclear Fuel

Facility	Owner	Technology	Fuel Type	Year In-service
Chalk River	AECL	AECL Concrete Canister/Silo	CANDU & prototype CANDU (mainly 19 element)	1992
Darlington Waste Management Facility (DWMF)	OPG	OPG Dry Storage Container (DSC)	CANDU (37 element)	2008
Douglas Point Waste Management Facility	AECL	AECL Concrete Canister/Silo	CANDU (19 element)	1987
Gentilly 1	AECL	AECL Concrete Canister/Silo	CANDU-BLW (18 element)	1984
Gentilly 2	HQ	AECL CANSTOR/MACSTOR modular concrete vault	CANDU (37 element)	1995
Pickering Waste Management Facility (PWMF)	OPG	OPG Dry Storage Container (DSC)	CANDU (28 element)	1996
Point Lepreau	NBPN	AECL Concrete Canister/Silo	CANDU (37 element)	1990
Western (Bruce) Waste Management Facility (WWMF)	OPG	OPG Dry Storage Container (DSC)	CANDU (37 element)	2003
Whiteshell	AECL	AECL Concrete Canister/Silo	CANDU & prototype CANDU (various sizes)	1977

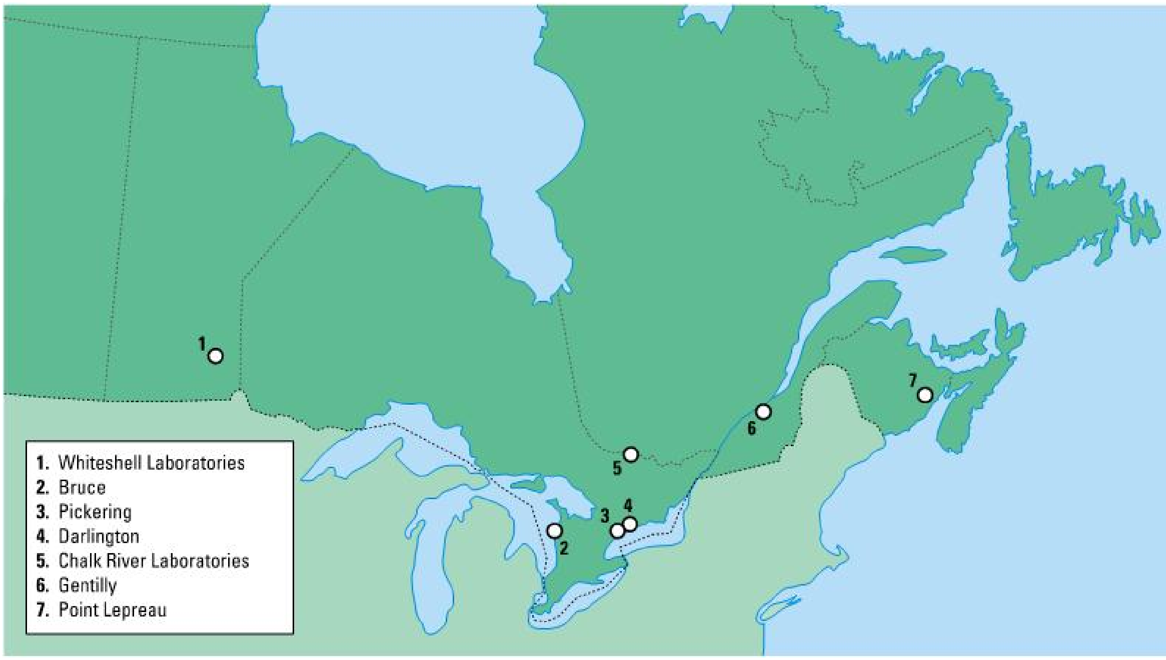


Figure B1: Current Nuclear Fuel Waste Major Storage Location in Canada

APPENDIX C: DESCRIPTION OF FUEL TYPES

Table C1 summarizes the inventory of the various fuel types in Canada as of June 2024.

Section C.1 details the physical characteristics and usage of the fuels in operating reactors. Section C.2 details the physical characteristics and usage of the fuels in demonstration and prototype reactors. Section C.3 details the physical characteristics and usage of the fuels in projects undergoing regulatory review. Note that these are fuel characteristics, the fuel wastes accepted for disposal may be different.

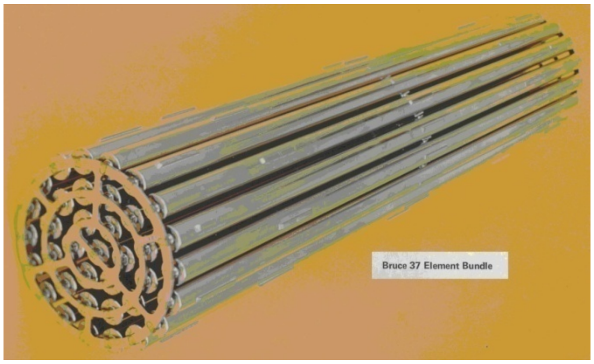
Note that the physical characteristics of the fuels described in this appendix are intended to be nominal and other sources may quote different numbers.

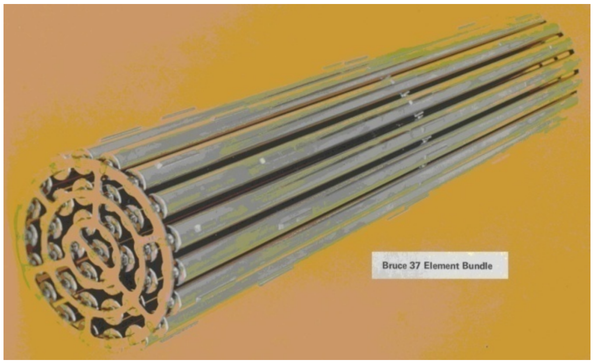
Table C1: Summary of Inventory by Bundle Type (June 2024)

CANDU Bundle Type	Where Used	Wet Storage (# bundles)	Dry Storage (# bundles)	Total (# bundles)
18 Element	Gentilly 1	-	3,213	3,213
7 Element / 19 Element	NPD, Douglas Point	-	27,446	27,446
28 Element	Pickering	367,552	469,615	864,167
37R	Bruce, Darlington, Gentilly 2, Pt Lepreau	368,700	1,267,346	1,636,046
37R Long	Bruce, Darlington	73,811	169,059	242,870
37M	Bruce, Darlington	441,965	-	441,965
37M Long	Bruce, Darlington	120,714	-	120,714
43 Element LVRF	Bruce	24	-	24
Other	AECL (various)	-	5,397	5,397
	Total	**1,372,766**	**1,969,076**	**3,341,842**

C.1 FUELS FROM OPERATING REACTORS

<table>
<tr><th colspan="2">28 element CANDU bundle</th></tr>
<tr><td rowspan="5"></td><td>Physical dimensions:
102.5 mm OD x 497.1 mm OL</td></tr>
<tr><td>Mass:
20.1 kg U (22.8 kg as UO_2)
2.0 kg Zircaloy (e.g., cladding, spacers)
24.8 kg total bundle weight</td></tr>
<tr><td>Fissionable material:
Sintered pellets of natural UO_2</td></tr>
<tr><td>Typical 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 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.</td></tr>
<tr><td colspan="2">Comments:
- Used in Pickering A and B reactors</td></tr>
</table>

<table>
<tr><th colspan="2">37 element CANDU standard length 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 (e.g., cladding, spacers)
24.0 kg total bundle weight</td></tr>
<tr><td>Fissionable material:
Sintered pellets of natural UO_2</td></tr>
<tr><td>Typical 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, Point Lepreau and EC-6 reactors (Gentilly-2 and Point Lepreau have minor construction differences on the end plates and spacers compared to the Bruce and Darlington designs).
- Two variants, designated 37R (regular) and 37M (modified), have slightly different center pin configurations and uranium masses (19.2 kg U for 37R vs 19.1 kg U for 37M). 37M is presently in use in Bruce and Darlington stations replacing prior 37R.</td></tr>
</table>

<table>
<tr><th colspan="2">37 element CANDU long bundle</th></tr>
<tr><td rowspan="5">
</td><td>Physical dimensions:
102.5 mm OD x 508 mm OL</td></tr>
<tr><td>Mass:
19.7 kg U (22.3 kg as UO_2)
2.24 kg Zircaloy (e.g., cladding, spacers)
24.6 kg total bundle weight</td></tr>
<tr><td>Fissionable material:
Sintered pellets of natural UO_2</td></tr>
<tr><td>Typical 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:
- Similar to 37 element “standard” bundle, but is 13 mm longer.
- Used in Bruce B, and Darlington reactors.
- Two variants, designated 37R-long and 37M-long, have slightly different center pin configurations and uranium masses (19.7 kg U for 37R-long vs 19.6 kg U for 37M-long). 37M-long is presently in use in Bruce stations, replacing prior 37R-long.</td></tr>
</table>

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 (e.g., cladding, spacers)
23.1 kg total bundle weight

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

Typical 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 (an element that absorbs neutrons and reduces the bundle power maintaining a flat neutronic field profile across the bundle during operation).
- Diameter and composition of fuel pins vary by ring.
- Construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity.

Comments:

- Has been used in Bruce B reactors in limited quantities, option for use in EC-6 reactors

C.2 FUELS FROM DEMONSTRATION AND PROTOTYPE REACTORS

7 element CANDU bundle

Physical dimensions:
82.0 mm OD x 495.3 mm OL

Mass:
13.4 – 13.5 kg U (15.2 – 15.3 kg as UO_2)
1.4 – 1.5 kg Zircaloy (e.g., cladding)
16.7 kg total bundle weight

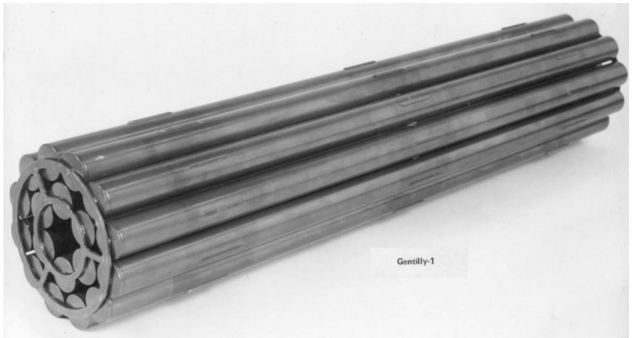
Fissionable material:
Sintered pellets of natural UO_2
A small quantity of up to 2.5 wt% U-235 bundles were used in NPD for experimental purposes.

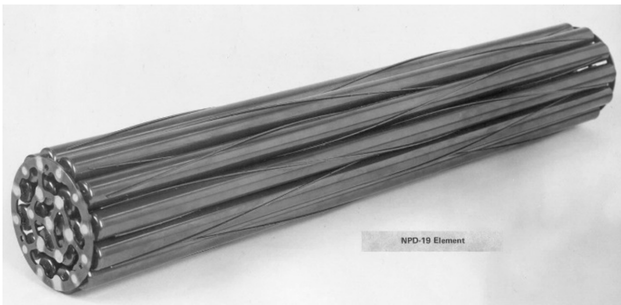
Typical burnup:
6474 MW day / tonne U
(156 MWh/kg U)

Cladding material:
Zircaloy-2
Nickel-free Zircaloy-2
Zircaloy-4

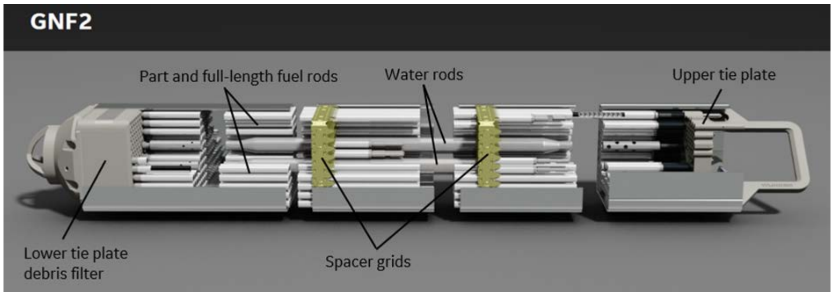
Construction:
- Bundle is composed of 7 elements (fuel pins), arranged as 1 element surrounded by a ring of 6 elements.
- Construction included wire-wrap and split-spacer fuel elements; riveted or welded end plates (only one bundle model had riveted end plates, all others had welded end plates) and thin, medium and thick walled cladding

Comments:
- Used in NPD

18 element CANDU bundle	
 	**Physical dimensions:** 102.4 mm OD x 500 mm OL **Mass:** 20.7 kg U (23.5 kg as UO_2) 3.2 kg Zircaloy (e.g., cladding, spacers) 26.7 kg total bundle weight **Fissionable material:** Sintered pellets of natural UO_2 **Typical burnup:** 6972 MW day / tonne U (168 MWh/kg U) **Cladding material:** Zircaloy-4
Construction: - Bundle is composed of 18 elements (fuel pins), arranged in 2 concentric rings with 6 elements in the inner most ring and 12 elements in the second ring. - Construction includes end plates, spacers and bearing pads to improve flow characteristics and maintain structural integrity.	
Comments: - Used in Gentilly 1	

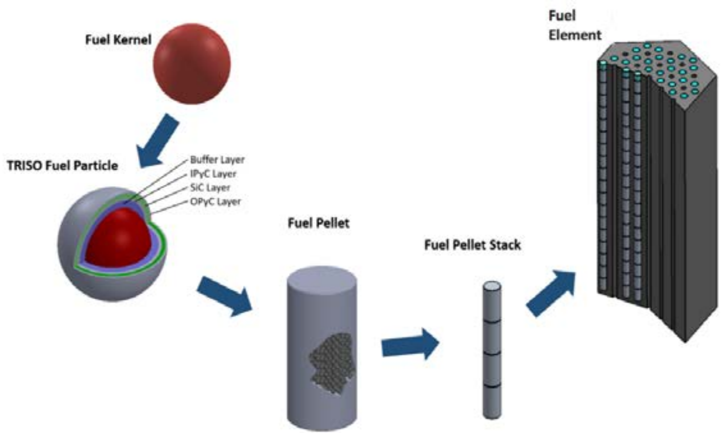
19 element CANDU bundle	
	**Physical dimensions:** 82.0 mm OD x 495.3 mm OL **Mass:** 12.1 – 13.4 kg U (13.7 – 15.2 kg as UO_2) 1.4 – 2.2 kg Zircaloy (e.g., cladding) 15.8 – 16.7 kg total bundle weight **Fissionable material:** Sintered pellets of natural UO_2 Some low-enriched 19 element bundles exists at up to 1.4% wt ^{235}U enrichment **Typical burnup:** 6474 MW day / tonne U at NPD 7885 MW day / tonne U at Douglas Point (156 MWh/kg U at NPD) (190 MWh/kg U at Douglas Point) **Cladding material:** Zircaloy-4
Construction: - Bundle is composed of 19 elements (fuel pins), 1 element is surrounded by 2 concentric rings of fuel pins, 6 elements in the first ring and 12 elements in the outer ring. - Originally produced as a wire-wrapped bundle this design was eventually replaced with split-spacer variation.	
Comments: - Used in NPD and Douglas Point	

C.3 FUEL FROM PROJECTS UNDERGOING REGULATORY REVIEW

<table>
<tr><th colspan="2">GEH BWRX-300 fuel assembly [2]</th></tr>
<tr><td rowspan="5">
</td><td>Physical dimensions:
Up to 150 mm square x 4500 mm long</td></tr>
<tr><td>Mass:
186.5 kg U (211.6 kg as UO_2)
Up to 93.4 kg metals in cladding, tie plates, channels
Up to 305 kg total mass</td></tr>
<tr><td>Fissionable material:
Sintered pellets of UO_2
Average enrichment 3.81, max 4.95% U-235</td></tr>
<tr><td>Typical burnup:
~50,000
MW day/tonne U</td></tr>
<tr><td>Cladding material:
Zircaloy-2</td></tr>
<tr><td colspan="2">Construction:
- Global Nuclear Fuel GNF2 fuel design; same as in some operating BWRs.
- The GNF2 design contains a 10x10 array of 78 full-length fuel rods, 14 part-length rods, and two central water rods.</td></tr>
<tr><td colspan="2">Comments:
- To be used in new OPG Darlington site small modular reactor</td></tr>
</table>

[2] GE Hitachi Nuclear Energy, 2023. BWRX-300 General Description, 005N9751, Revision F, December 2023.

GFP USNC MMR fuel [3,4,5]



Original fuel concept diagram shown (2019). 2023 update to fuel pellet design shown in the photograph.

Physical dimensions:
TRISO fuel particles have a diameter of ~750-830 µm.
The dimensions of the fuel pellets or elements are not yet available.

Fissionable material:
TRISO fuel kernels can contain Uranium Carbide (UC_2) or Uranium oxide (UO_2)
Enrichment range 9.9-19.75% U-235

Cladding material:
TRISO fuel kernel particles are coated in several layers, including:
- Buffer layer of porous PyC
- IPyC layer
- SiC layer
- OPyC layer

Construction:
- TRISO fuel particles are encased into a SiC matrix forming an FCM Fuel Pellet.
- FCM Fuel pellets are stacked vertically in channels within hexagonal graphite blocks, forming a fuel element.

Comments:
Details on the irradiation characteristics and physical form of the fuel elements are not yet available.

---

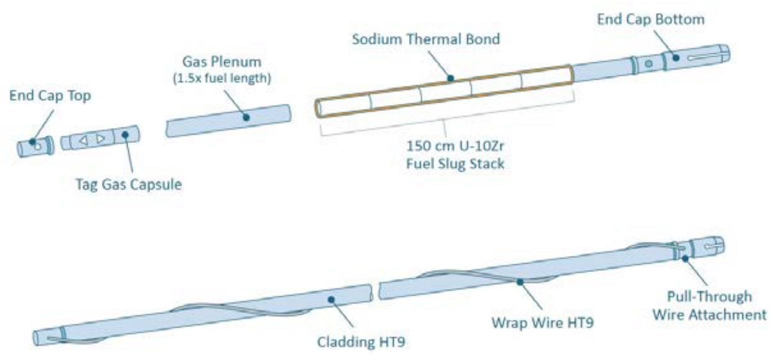
[3] Global First Power, 2019. Project Description for the Micro Modular Reactor™ Project at Chalk River, CRP-LIC-01-001, Revision 2, 2019.

[4] Pacific Northwest National Laboratory, 2021. TRISO Fuel: Properties and Failure Modes, PNNL-31427, June 2021.

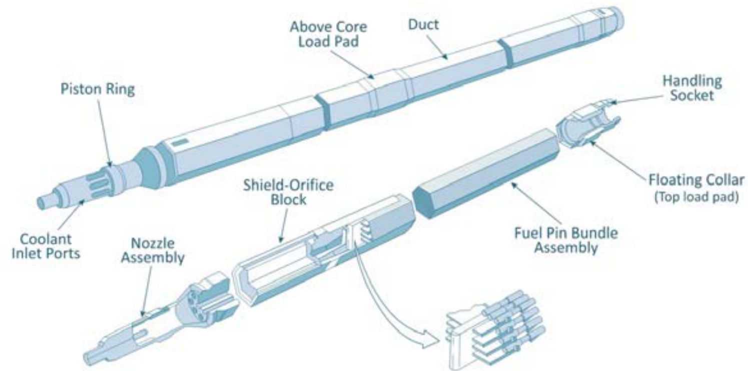
[5] Global First Power, 2024. Global First Power Newsletter February 2024.

ARC-100 fuel [6]

Fuel pin:



Fuel assembly:



Physical dimensions:
Fuel pins are ~1 cm in diameter,
Total active fuel length is 150 cm (fuel slug stack)

The dimensions of the fuel assembly are not yet available

Mass:
~250 kg U per assembly

Fissionable material:
Metal fuel (Uranium with 10 wt% Zirconium alloy).
Enrichment of 10.9-15.5% U-235.
Average 13.1% U-235

Typical burnup:
77,000 MW day/tonne U

Cladding material:
Fuel pins are clad in HT-9 (heat-treated martensitic steel)

Construction:
- Details on the loading of the fuel pins into the fuel assembly are not currently available.

Comments:
- ARC-100 metallic fuel is based on the prototypical operations at EBR-II at Argonne National Laboratory.

[6] M. Manley, P. Thompson, B. Pilkington, 2023. Fuel Cycle for ARC-100 Commercial Demonstration at the Point Lepreau Nuclear Site in New Brunswick. Available from: https://www.arc-cleantech.com/technology (accessed November 2023)