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Policy Lab

Costs and Financing of Nuclear Power Plant Decommissioning

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Table of Contents

Chapter **Page**

(1) **Executive Summary………………………………………..……………….………….. 3**

(2) **Introduction..……………………………..……………………………………….... 4**

(3) **Categories of Decommissioning Costs……….…………………………………..…….. 6**

(4) **Regulations…………………………………………………………………….….... 17**

(5) **Case Studies and Current Status……………………………………………….…… 21**

(6) **Examples from Europe…………………………………………………………….... 28**

(7) **Conclusion and Recommendations for Future Research…………………………..…. 31**

Appendices……………………………………………………………………………….….. 35

(1) Executive Summary

In the process of drafting its study on the decommissioning of nuclear power plants, the International Joint Commission has requested additional information on the financing of the decommissioning process to shape its policy recommendations. This report details the research completed by the Harris School of Public Policy at the University of Chicago's Policy Lab on current regulatory structures and financing strategies within the United States and Canada - as well as case studies from Europe - to illustrate current sources of instabilities within the financing process of nuclear facilities in the Great Lakes Basin and to provide recommendations for future research.

Regulations for financing decommissioning in Canada and the United States are established by the Canadian Nuclear Safety Commission and the Nuclear Regulatory Commission, respectively. Broadly, these regulations establish how licensees must calculate costs of decommissioning activities and what types of financing mechanisms are acceptable to guarantee sufficient funds. Regulations also stipulate reporting requirements for updating the relevant agency on the status of a licensee's decommissioning resources.

In Canada, Ontario Power Generation Inc., owner of nuclear facilities in Ontario, is in the process of preparing to shut down and decommission both units of the Pickering Nuclear Generating Station (PNGS) in 2024. In the United States, the decommissioning of the Zion Nuclear Power Station (ZNPS) provides an example of the considerations that go into decommissioning from the United States perspective. This report also describes how countries in Europe approach decommissioning.

The report concludes with recommendations for future research. The decommissioning process and its associated financing concerns are complex and varied by location and governing body. This report finds that the regulatory system in the United States is generally weaker than its counterpart in Canada and, consequently, provides recommendations to research institutional instabilities specific to the United States as well as those present in both countries in the Great Lakes basin.

(2) Introduction

The decommissioning process for nuclear power facilities is a long and costly process including the removal of nuclear waste, decontamination of equipment and facilities, and the eventual return of the site to greenfield status - safe for residential, agricultural, and industrial use. The extensive set of steps needed to safely decommission a nuclear power facility makes the retirement of these plants significantly more expensive than those of plants utilized for alternate forms of power generation. As a result, the financial planning process for the decommissioning of a nuclear power facility begins prior to its first day of operation, submitted with a decommissioning plan when applying for an operating license. The respective national regulatory boards, the United States Nuclear Regulatory Commission (NRC) and the Canadian Nuclear Safety Commission (CNSC), establish the processes for this financial planning.

The Great Lakes Basin is home to 30 nuclear reactors at 12 nuclear power stations. The region has already experienced the closure and decommissioning of five nuclear power plants - Enrico Fermi Atomic Power Plant (Newport, MI), Douglas Point Nuclear Generating Station (Kincardine, ON), Big Rock Point (Charlevoix, MI), Zion Nuclear Power Station (Zion, IL), and Kewaunee Power Station (Carlton, WI). Four more closures have been announced: Pickering Nuclear Generating Station (Pickering, ON), Davis-Besse Nuclear Power Station (Oak Harbor, OH), Perry Nuclear Power Plant (Perry, OH), and Palisades Nuclear Power Plant (Covert, MI).[1] The financing question has been prominent in each of these cases. With certain plants, for example, Zion Nuclear Power Station and Pickering Nuclear Generating Stations, the question of proper course of action in the case that planned financing comes short becomes particularly important. As energy prices decline with the availability of cheaper natural gas, market forces cause some plants to shut down sooner.[2] Those that are able to operate until their planned closure - often through the use of zero emissions credits or competitive pricing[3] - face a rising

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[1] Great Lakes Water Quality Board - Legacy Issues Working Group. *Decommissioning Practices of Nuclear Power Facilities in the Great Lakes Basin*. Report. Revision 2 ed. Background Report Prepared for the International Joint Commission. March 2019.

[2] "Nuclear Energy in the U.S.: Expensive Source Competing with Cheap Gas and Renewables." Climate Nexus. April 02, 2019. Accessed June 2019. www.climatenexus.org.

[3] Nuclear Energy Institute. *Zero-Emission Credits.* Report. April 2018. https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/zero-emission-credits-201804.pdf.

cost of decommissioning and, at the same time, declining annual contributions to decommissioning funds.[4]

These challenges surrounding decommissioning financing demonstrate the need to develop regulations and strategies that guarantee adequate funding. To further explore these challenges, this report provides background on the topic and addresses the following questions:

- How is the decommissioning of nuclear power plants financed in Canada, the United States, and elsewhere?
- What are the existing financial rules and responsibilities for decommissioning of nuclear plants?
- What are the best practices for financing the decommissioning of Great Lakes nuclear power plants?
- What are other potential funding sources when in a plant's decommissioning fund is insufficient?

From these questions, the report discusses the costs associated with decommissioning, describes the regulations applicable to decommissioning financing in the United States, Canada, and Europe, and identifies current institutional weaknesses within the current regulatory structure. These institutional instabilities – identified as areas for future research on the part of the IJC – represent opportunities for improvement for both Canada and the United States. As this report describes a generally stronger regulatory system in Canada, the weakness in the United States regulatory system are a particular focus of the recommendations pertaining to the entire Great Lakes Basin.

[4] *2017 Nuclear Decommissioning Funding Study: NDT Fund Balances, Annual Contributions, and Decommissioning Cost Estimates as of Dec. 31, 2016.* Report. 2017. https://www.callan.com/wp-content/uploads/2017/09/Callan-2017-NDT-Survey.pdf.

(3) Categories of Decommissioning Costs

The cost to decommission a nuclear power plant depends on many factors, including what decommissioning strategy is chosen for the plant. In Canada, these strategies include Prompt Decommissioning, Deferred Decommissioning, *In-situ* Confinement, and Phased Decommissioning. In the United States, strategies include DECON (immediate dismantling), SAFSTOR (deferred dismantling), and ENTOMB. Depending on what strategy is selected, each phase of decommissioning will include specified activities that drive the overall cost of decommissioning. For example, a facility that undergoes SAFSTOR will incur larger costs associated with the long-term storage of spent fuel, such as monitoring and management costs. Conversely, the longer SAFSTOR horizon allows financing mechanisms, like trust funds, to accumulate interest so there's more funds when decommissioning occurs.

3.1 Phases of Decommissioning in Canada[5]

Phase 1: Planning for Decommissioning

This phase generally begins at the design phase (or as early as possible) and continues throughout the operating life of a nuclear power generation station. A decommissioning strategy and a Preliminary Decommissioning Plan (PDP) are developed during this phase. A PDP is required for all licensed activities encompassing a facility's life cycle and provides the basis for cost estimate for decommissioning. For major facilities, the PDP is required to be updated and reviewed every five years or when requested by the CNSC.

Phase 2: Preparation for Decommissioning

This phase begins with the decision to cease operations and begin decommissioning. A detailed decommissioning plan (DDP), developed during this phase, is required to be filed with the

[5] Graydon RC, Meyer PA, and Burrows MJ. 1 March 2019. *Decommissioning Practices of Nuclear Power Facilities in the Great Lakes Basin: Background Report* (Revision 2). Submitted to the International Joint Commission's Great Lakes Water Quality Board: Legacy Issues Work Group.

CNSC prior to decommissioning. The DDP is required for appropriate licensing action and refines and adds procedural and organizational detail to the PDP.

Phase 3: Execution of Decommissioning

This phase begins with the implementation of the DDP after regulatory approval has been obtained from the CNSC. It includes the physical works (i.e., decontamination, Dismantling & Demolition of the facility) and any periods of storage-with-surveillance between interim end states.

Phase 4: Completion of Decommissioning

This phase involves verifying that all decommissioning activities have been completed satisfactorily, the final end-state has been reached, and all documentation has been completed. Licensee will submit an application for a License to Abandon[6] to the CNSC.

3.2 Phases of Decommissioning in the United States [7]

Phase 1: Transition from Operation to Decommissioning

When a nuclear reactor licensee shuts down the reactor permanently, it must submit a written certification of permanent cessation of operations to the NRC within 30 days. When radioactive nuclear fuel is permanently removed from the reactor vessel, the owner must submit another written certification to the NRC, surrendering its authority to operate the reactor or load fuel into the reactor vessel.

Within two years after submitting the certification of permanent closure, the licensee must submit a Post-Shutdown Activities Reports (PSDAR) to the NRC. PSDAR should have a description of the planned decommissioning activities, a schedule for accomplishing them, and an estimate of the expected costs. After receiving the report, the NRC publishes a notice of

[6] If approved by the CNSC, the license to abandon will end the licensee's responsibility for the site and then transfer responsibility for regulatory oversight or institutional control from the CNSC to the province or territory, if applicable.

[7] Graydon RC, Meyer PA, and Burrows MJ. 1 March 2019. *Decommissioning Practices of Nuclear Power Facilities in the Great Lakes Basin: Background Report* (Revision 2). Submitted to the International Joint Commission's Great Lakes Water Quality Board: Legacy Issues Work Group.

receipt in the Federal Register, makes the report available for public review and comment, and holds a public meeting near the plant to discuss the licensee's intentions.

Phase 2: Major Decommissioning Activities

Ninety days after the NRC receives the planning report, the owner[8] can begin major decommissioning activities without specific NRC approval. These include permanent removal of such major components as the reactor vessel, steam generators, large piping systems, pumps, and valves.

Phase 3: License Termination Activities

The owner or operator is required to submit a license termination plan within two years of the expected license termination. The plan addresses each of the following: site characterization, remaining site dismantlement activities, plans for site remediation, detailed plans for final radiation surveys for release of the site, updated estimates of remaining decommissioning costs, and a supplement to the environmental report describing any new information or significant environmental changes associated with the final cleanup. The license termination report requires NRC approval of a license amendment. Before approval can be given, a hearing notice is published and a public hearing is held near the plant site.

If the remaining dismantlement has been performed in accordance with the approved license termination plan, and the NRC's final survey demonstrates that the facility and site are suitable for release, the NRC issues a letter terminating the operating license.

3.3 Cost Estimates

The estimate of costs of decommissioning in US and Canada varies by a range of factors, such as location of nuclear facility, type of reactor, and applicable regulations. Costs estimates in Canada cover a more comprehensive set of processes - including removal of structures and fuel storage - than cost estimates within the United States.

[8] If the proposed owner is an "electric utility" as defined in the NRC's regulations, no further review of financial qualifications for operations is generally required. If the proposed owner is not an "electric utility," the NRC evaluates revenue sources and the plant's projected 5-year operating costs. This helps the NRC determine whether the proposed owner can obtain the funds to operate the plant safely. (link: https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-transfer.html)

3.3.1. Cost Estimates in the United States

In the United States, the NRC allows for funding decisions to be made with the expectation that an operator may wait for up to fifty years after the closure before fully reclaiming the site. This period is known as "SAFSTOR".[9] The use of SAFSTOR in financing decisions allows for nuclear facilities to defer their saving and operate under the assumption that their available funds in the form of trusts will grow as the plants sit, often to the detriment of the community where they reside.

The NRC allows nuclear facilities to assume that their funds will grow at a rate of two percent above the rate of inflation regardless of the current market. This assumption can be dangerous in situations such as the 2009 economic crisis, where many facilities experienced a massive decline in their available funds with the market downturn.[10] Currently, market growth has shielded these trust funds, but the possibility of a market downturn is a constant concern within the financial assurance system.

Additional market related instability is the range of estimates allowed under the current NRC formula. Massively different estimates for decommissioning costs can be calculated dependent upon a facility's estimated cost of decommissioning per kilowatt hour. For example, Chicago-based Exelon estimates that its nuclear decommissioning will cost around $13.2 billion at a rate of $589 per kilowatt. This estimate falls far below many of its competitors, such as Entergy of New Orleans at $1,053 per kilowatt, New Jersey's Public Service Enterprise Group at $924 per kilowatt, and Ohio's First Energy at $1,054. Exelon explains its lower estimates by the location and decommissioning needs of its plants. But if Exelon's cost of decommissioning were to fall closer to the midpoint of the other companies estimates - approximately $989 per kilowatt - then decommissioning costs would fall much closer to $22.2 billion, putting the company far short of

[9] Graydon RC, Meyer PA, and Burrows MJ. 1 March 2019. *Decommissioning Practices of Nuclear Power Facilities in the Great Lakes Basin: Background Report* (Revision 2). Submitted to the International Joint Commission's Great Lakes Water Quality Board: Legacy Issues Work Group.

[10] Callan Institute. *2018 Nuclear Decommissioning Funding Study: Comprehensive Data on Funding, Contributions, and Costs as of Dec. 31, 2017.* Report. October 2018. www.callan.com.

the needed funds.[11] The differing cost estimates allowed under the NRC formula in combination with the assumptions made regarding market growth and limited areas of cost covered present a significant area of concern.

Pacific Northwest National Laboratory (PNNL) is a national lab based out of Richland, WA. The Nuclear Energy Assembly (NEA) analyzed decommissioning cost estimation data presented in the 2011 PNNL report and created cost structures grouped in high level processes to understand the meaning of cost elements as shown in Table 1.

Table 1: Cost Structure Used in the PNNL Study[12]

<table>
<tr><td rowspan="8">Direct Costs</td><td rowspan="4">Decontamination/removal</td><td>Decontamination</td></tr>
<tr><td>Removal</td></tr>
<tr><td>Packing</td></tr>
<tr><td>Transportation</td></tr>
<tr><td rowspan="2">Waste disposition</td><td>Waste disposal</td></tr>
<tr><td>Waste processing</td></tr>
<tr><td rowspan="2">Other direct</td><td>Spent fuel pool isolation</td></tr>
<tr><td>Miscellaneous equipment</td></tr>
<tr><td colspan="2" rowspan="2">Management Costs</td><td>Program management</td></tr>
<tr><td>Site operation and management</td></tr>
</table>

[11] Daniels, Steve. "Will Exelon Nuke-site Cleanup Cash Be There When Needed?" Crain's Chicago Business. January 26, 2018. Accessed May 2019. https://www.chicagobusiness.com/article/20180126/ISSUE01/180129909/nuclear-site-cleanup-shortfall-deepens-at-exelon.

[12] Source: PNNL (2011), *Assessment of the Adequacy of the 10 CFR 50.75(c) Minimum Decommissioning Fund Formula*, Pacific Northwest National Laboratory, Richland, WA.

Other Costs	Insurance and regulatory
	Energy
	Characterization and licensing
	Property taxes

3.3.2 Cost Estimates in Canada

For nuclear plant decommissioning, a PDP developed during Phase 1 of decommissioning needs to include a conservative cost estimate (based on work packages) for labor, materials, equipment, waste management, environmental assessment, monitoring, and administration (e.g., training, safety, licensing, project management, government and public liaison).

In the cost estimate, the work packages are logical grouping of relatively contiguous decommissioning tasks aimed at achieving a particular step in the overall decommissioning project. For example, the removal of a specific facility component could constitute a single work package – including its decontamination, disassembly and delivery to a waste segregation area. The number and scope of individual work packages will depend on the physical complexity of a facility, the nature of the hazards present, and whether the planning is at the preliminary or detailed stage. See Appendix 1.

Ontario Power Generation Inc. (OPG), owner of nuclear facilities in Ontario, is 100% owned by the Province of Ontario and currently operates Darlington, Pickering A and Pickering B nuclear generating stations. In 2001, OPG entered into an agreement with Bruce Power, a private sector consortium, to lease its Bruce A and Bruce B nuclear generation station. OPG maintains the decommissioning plan and an associated consolidated financial guarantee for all of its Ontario nuclear facilities – including Bruce A and Bruce B stations. OPG is required to have in place financial guarantee acceptable to the CNSC. Table 2 provides a detail of nuclear stations in Canada.

Table 2: Canada's Nuclear Power Plant Stations[13]

Nuclear Station	Province	Mwe	In service date	Operator
Pickering A	Ontario	4 x 515	1971-73	OPG
Pickering B	Ontario	4 x 516	1983-86	OPG
Darlington	Ontario	4 x 881	1990-93	OPG
Bruce A	Ontario	4 x 750	1977-79	Bruce Power
Bruce B	Ontario	4 x 860	1984-87	Bruce Power
Gentilly 2*	Québec	1 x 635	1983	Hydro Québec
Point Lepreau	New Brunswick	1 x 635	1983	NB Power

*Gentilly 2 station was permanently shut down in December 2012. In August 2017, CNSC accepted the total financial guarantee of C$835 million proposed by Hydro-Quebec as a financial guarantee for the future decommissioning of the Gentilly-2 nuclear reactor and the nuclear waste facilities located in Becancour, Quebec. [14]

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[13] https://www.nrcan.gc.ca/energy/uranium-nuclear/7715

[14] Financial guarantee for the future decommissioning of Gentilly-2, located in Becancour, Quebec (Link: http://nuclearsafety.gc.ca/eng/the-commission/pdf/Record%20of%20Decision-Hydro-Quebec-Gentilly-2-FinancialGuarantee-CMD17-H107-ENGLISH.pdf)

OPG is required to have in place a financial guarantee acceptable to the CNSC and needs to update the guarantee every five years. OPG's consolidated CNSC financial guarantee expired in December 31, 2017, and OPG's proposed consolidated financial guarantee for the next five years, 2018 to 2022 (2018 – 2022 CNSC Consolidated Financial Guarantee), has been approved by CNSC.

Table 3: OPG 2013 – 2017 CNSC Financial Guarantee Submission to 2018 – 2022 CNSC Financial Guarantee Submission[15]

Program	2013 – 2017 CNSC Financial Guarantee Year 2017	2018 – 2022 CNSC Financial Guarantee Year 2018	Variance
	Jan. 1, 2018 M$ PV	Jan. 1, 2018 M$ PV	Jan. 1, 2018 M$ PV
Nuclear Generating Station Decommissioning	4,643	5,301	657
Used Fuel Management	10,246	8,870	(1,376)
L&ILW Management	1,524	2,232	708
Decommissioning PWMF	16	15	(1)
Decommissioning WWMF	48	32	(15)
Decommissioning DWMF	11	5	(5)
Decommissioning RWOS1 and CMF	10	12	2
Total	**16,498**	**16,468**	**(30)**
Variance Breakdown			
Changes in Economic Assumptions			**(1,116)**
Changes in Cost Estimates and Planning Assumptions			**1,086**

*Details may not add to total due to rounding.

In Table 3, the variance in cost estimates from 2013-2017 to 2018-2022 period are primarily attributable to the following:

i) Nuclear Generating Station Decommissioning: The increased cost estimates from 2013-2017 to 2018-2022 period are primarily related to a better definition of work required during preparation for safe storage after station shutdown. This also includes de-watering and de-fueling of reactors, and a higher forecasted volume of waste arising from decommissioning.

[15] CD# N-CORR-00531-18741, "Ontario Power Generation Inc.'s Acceptance of OPG's Financial Guarantee," August 4, 2017.

ii) Used Fuel Management: The decreased used fuel management cost estimates from 2013-2017 to 2018-2022 period primarily reflect a proposed new, more cost-effective container design and engineered barrier concept to house used nuclear fuel for disposal. Further, the increased costs are also attributed to a later planned in-service date for Canada's proposed used fuel Deep Geologic Repository (DGR).

iii) L&ILW Management (Low and Intermediate Level Waste Management): The increased L&ILW management cost estimate from 2013-2017 to 2018-2022 period is mainly due to a later planned in-service date for the L&ILW DGR and application of a higher confidence level of DGR construction cost estimate.

3.2.3 Establishing Nuclear Fund Trust

The Nuclear Fuel Waste Act (NFWA) came into existence on November 15, 2002 and is a key component of the Government of Canada's 1996 Policy Framework for Radioactive Waste. Under NFWA, the owners of nuclear fuel waste were required to establish trust funds and to make annual payments into those trust funds to finance the long-term management of nuclear fuel waste. Accordingly, OPG established the Ontario NFWA Trust[16] and made an initial deposit into the Trust fund on November 25, 2002. Under the NFWA, OPG is required to make a contribution to the Trust each year within 30 days of the submission of the Nuclear Waste Management Organization (NWMO)[17] Annual Report to the federal Minister of Natural Resources. Please see Appendix 2 for details on deposit and annual contributions.

The funds in the Trust are to meet the payment obligations associated with the long-term management of highly radioactive nuclear used fuel, as permitted by the NFWA. A Statement of Investment Policies and Procedures (SIPP) is established for the Trust, which sets out the investment framework of the Trust, including the investment assumptions, permitted investments

[16] The Ontario NFWA trust audited financial statements December 31, 2017 by E&Y (Link: https://www.nwmo.ca/~/media/Site/Files/PDFs/2018/07/19/11/09/NFWA_2017_FINAL.ashx?la=en)
[17] Under the NFWA, the owners of nuclear fuel waste established, by incorporation, NWMO, which proposes to the Government of Canada approaches for the management of nuclear fuel waste and to implement the approach selected by the Federal Government.

and various investment constraints. The SIPP is reviewed and approved annually by the Deputy Minister of Finance, on behalf of the Province.[18]

OPG is the owner of the Trust, and the Province owns all of the shares of OPG. Hence, OPG and the Ontario Financing Authority (OFA), an agency of the Province, jointly make decisions on the Trust's asset mix and investment manager selection and retention. The Trustee of the Trust is CIBC Mellon Trust Company.[19]

The Ontario Nuclear Funds Agreement (ONFA Access Agreement) between OPG and the Province of Ontario governs two segregated funds, the Decommissioning Segregated Fund (DSF) and the Used Fuel Segregated Fund (UFSF).[20] Under ONFA Access Agreement the total CNSC Requirement would continue to be satisfied, in part, by the federally-mandated Ontario NFWA Trust. The remainder of the requirement would be satisfied by providing the CNSC with access to DSF and UFSF.

Table 4: Proposed 2018-2022 Total CNSC Requirement[21]

YEAR	TOTAL CNSC REQUIREMENT M$
2018	16,468
2019	17,094
2020	17,722
2021	18,300
2022	18,836

Table 5: 2018 – 2022 Forecast Fair Market Value of the Nuclear Funds (The forecast is based on assumed 5.15% growth in the assets of the Nuclear Funds.)

[18] Her Majesty the Queen in Right of Ontario as represented by the Minister of Finance, hereinafter the "Province."
[19] CIBC Mellon Global Securities Services Company is an independent custodian of the Trust's assets under the custody agreement dated September 20, 2010.
[20] UFSF covers the costs associated with the management of highly radioactive used nuclear fuel bundles.
[21] D# N-CORR-00531-18741, "Ontario Power Generation Inc.'s Acceptance of OPG's Financial Guarantee," August 4, 2017.

YEAR	NUCLEAR FUNDS M$
2018	18,198
2019	18,975
2020	19,732
2021	20,470
2022	21,175

As illustrated in Table 4 and 5, the Total CNSC Requirement for the 2018 to 2022 period is expected to be satisfied by the forecasted fair market value of the Nuclear Funds.

3.2.4 Public Commission Hearings and Participant Funding Program

The public commission hearings are governed by CNSC Rules of Procedure under the Nuclear Safety and Control Act (NSCA). CNSC makes decisions on the licensing of major nuclear facilities through a public hearing process. CNSC holds commission hearings in the communities that will be most affected by the decision at hand, when possible.

Funding for Participant Funding Program (PFP): The CNSC made a total of $100,000 available through PFP to assist members of the public, Indigenous groups, and other stakeholders in providing value-added information to the Commission through informed and topic-specific interventions. This funding will be used by stakeholders to review OPG's license renewal application and other relevant documentation specifically related to the application, and to prepare for and participate in the Commission public hearing.

(4) Regulations

Both Canada and the United States impose general regulatory requirements for financing decommissioning activities.

4.1 Statutory and Regulatory Requirements in Canada

Under Canada's system, responsibility for decommissioning costs generally falls to licensees. Pursuant to the Nuclear Safety and Control Act (NSCA), the CNSC adopts regulations relating to the safe operation and decommissioning of Canadian nuclear power facilities. Section 24 of the NSCA prohibits a person from operating or decommissioning a nuclear facility without a license issued by the CNSC. The Act also authorizes the CNSC to establish requirements for holding a license, including a financial guarantee that the licensee is able to carry out all licensed activities, provided in a form that is acceptable to the Commission. The CNSC requires licensees to submit a preliminary decommissioning plan, which includes a description of this financial guarantee, as part of a license application for the operation of a nuclear facility. To meet the requirement of the financial guarantee, decommissioning plans must provide information relating to both the cost of decommissioning and funding measures for those costs.

In Regulatory Guide G-206, *Financial Guarantees for the Decommissioning of Licensed Activities*, the CNSC details the financial conditions that the CNSC imposes on licensees as part of the decommissioning plan process. As articulated in the Regulatory Guide, licensees are not limited to specific types of cost estimates or financing measures. Instead, "Applicants and licensees that are required to submit decommissioning plans maintain the flexibility to propose those decommissioning plans and financial guarantees that they consider appropriate to their individual situations." Decommissioning plans filed with the CNSC must estimate costs for all decommissioning activities taking place before and after a facility is closed, including disposition of spent fuel and other waste and ongoing monitoring and maintenance of the facility site. Plans must demonstrate that the decommissioning activities described by the licensee "will remediate all significant impacts and hazards to persons and the environment." Thus, costs for decommissioning must support activities that achieve that standard.

Regulatory Guide G-206 specifies standards for cost estimates provided by licensees to the CNSC. Depending on the accuracy and precision in the estimates, licensees are required to include an extra contingency level of funding; for example, a "Grade A" estimate only requires an additional 10 percent contingency amount, "Grade B" requires an additional 15 to 20 percent, and "Grade C" requires an additional 25 to 30 percent. Cost estimates are required to contain a significant level of detail and reflect conditions like local labor and material construction rates. If determining estimates to that level of detail is infeasible, estimates may instead cover worst-case scenarios.

The funding measures for these cost estimates are subject to evaluation by the CNSC as to the adequacy of each funding measure in covering the decommissioning activities identified by the licensee. Licensees must assure the CNSC that the Commission can, upon demand, access or direct adequate funds if a licensee is not available to fulfil its obligations for decommissioning. Other criteria established by the CNSC for the acceptability of identified funding measures include liquidity, certainty of value, adequacy of value, and continuity. Regulatory Guide G-206 provides the following examples of acceptable financial guarantees: cash (including trusts), letters of credit, surety bonds, insurance, and expressed commitments from the federal or provincial governments to cover unfunded decommissioning costs. Parent company guarantees and pledges are not considered satisfactory financial guarantees.

4.2 Statutory and Regulatory Requirements in the United States

In the United States, the NRC regulates the decommissioning of nuclear power facilities. Pursuant to 10 CFR 50.75, licensees must submit a decommissioning plan to the NRC that includes a certification that the licensee holds financial assurances for funding to cover the estimated cost of decommissioning the licensed facility. Notably, while estimated costs as defined by the CNSC are required to cover all decommissioning activities, decommissioning activities in the United States do not include the cost of removal and disposal of spent fuel or of nonradioactive structures and materials present at the decommissioned facility. Instead, the minimum amount to demonstrate reasonable assurance of funds is determined by a formula established by regulation that depends on the type of reactor (pressurized water reactor (PWR) or boiling water reactor (BWR)) and the facility's power level. Below is the funding formula in January 1986 dollars:

		Millions
For a PWR:	greater than or equal to 3400 MWt	\$105
	between 1200 MWt and 3400 MWt	\$(75+0.0088P)
For a BWR:	greater than or equal to 3400 MWt	\$135
	between 1200 MWt and 3400 MWt	\$(104+0.009P)

The formula is subject to an adjustment factor that reflects escalation factors for labor and energy drawn from the United States Department of Labor Bureau of Labor Statistics and an escalation factor for waste burial from the NRC. The adjustment factor is calculated as $0.65 L + 0.13 E + 0.22 B$, where L is labor, E is energy, and B is waste burial, as specified. In general, the NRC estimates a total of \$280 million - \$612 million to be typical for a complete decommissioning project.

Financial assurances for minimum funding can include prepayment of the full amount needed for decommissioning into a trust, periodic payments into an external sinking fund, a surety bond, a letter of credit, insurance, or a guarantee from a state or federal government agency. In contrast to the Canadian system, the licensee's parent company, or contractual obligations on the part of the licensee's customers (ratepayers) are also acceptable assurances.

Detailed descriptions of funding mechanisms, as defined by the NRC in 10 CFR 50.75 are contained below:

1) Prepayment: Prepayment is the deposit made before a power plant starts to operate or before the transfer of a license into an account segregated from licensee assets and outside the administrative control of the licensee and its subsidiaries or affiliates of cash or liquid assets. Prepayment may be in the form of a trust, escrow account, or government fund with payment by, certificate of deposit, deposit of government or other securities or other method acceptable to the NRC. These prepayment methods need to establish agreement with a U.S. state or federal agency at all times. Expected earnings on prepaid trust funds during periods of safe storage, final dismantlement and license termination can be credited using a real rate of return up to 2 percent.

2) Surety, insurance or other guarantee method: A surety or insurance agreement guarantees decommissioning costs will be covered. A surety method can take the forms of a bond or a letter of credit. A surety or insurance will be automatically renewed (if a specific term applies, such as "2 years") unless the issuer notifies the NRC, beneficiary and licensee 90 days before the renewal day. Furthermore, the surety or insurance must be payable to a trust that is acceptable to the NRC. Such trustees can include a state or federal agency, or another entity whose operations are regulated by a state or federal agency.

3) External sinking fund: An external sinking fund refers to a fund established and maintained by setting funds aside periodically in an account segregated from licensee assets and outside the administrative control of the licensee and its subsidiaries or affiliates. Different from a prepayment, an external sinking fund allows a real rate of return greater than 2 percent when calculating earnings, if a rate-setting authority has specifically authorized a higher rate for its licensee.

Licensees must provide updates on the state of each decommissioning fund to the NRC every two years. If the plant is within five years of the end of its operation, the licensee must report annually.

Under 10 CFR 50.82, prior to filing a notice with the NRC that the licensee intends to cease operations of its facility, the amount of the licensee's decommissioning fund that can be used for planning purposes is limited to three percent. After a site-specific funding estimate has been filed following the cessation of operations, additional funding may be spent. Once spending on decommissioning activities has begun, the licensee is required to submit updates on the status of the decommissioning fund to the NRC annually, including information such as the amount spent in the previous year, estimates for the remaining costs, and the amount remaining in the fund. The licensee must also report on the status for its funding for managing spent fuel.

(5) Case Studies and Current Status

5.1 Canada Case Study: Pickering Generating Stations A & B

5.1.1 Condition

OPG's licenses require that OPG have in place acceptable decommissioning plans and an acceptable financial guarantee which shall remain valid and in effect and sufficient to meet decommissioning needs.

5.1.2 Current Status

On November 2017, following the public hearing (on Oct. 11, 2017), the CNSC accepted OPG's proposed consolidated Financial Guarantee for the future decommissioning of its Class I facilities in Ontario. The proposed guarantee covers the period between 2018-2022.

5.1.3 Decommissioning Phases: Pickering Generating Stations A & B[22]

1. Phase 1, Planning for Decommissioning: PDP shared with CNSC.
2. Phase 2, Preparation for Decommissioning: Pickering has entered into this phase in February 2010 when OPG announced its decision not to refurbish the nuclear facility, but to extend its operations up to 2024 for PNGS. After the units in PNGS are permanently shut down, OPG will defuel and dewater the reactors and make all the necessary modifications to the Structures, Systems and Components (SSCs) to prepare for the subsequent Safe Storage Stage; this phase will end when the units enter into Safe Storage stage.
3. Phase 3, Execution of Decommissioning: During this phase, the station will have been placed in Safe Storage and will be monitored and maintained as necessary while the radiation levels in the reactor systems decay. For planning purposes, it is assumed that the dismantling of the station will begin after a nominal 30 years of Safe Storage.
4. Phase 4, Completion of Decommissioning: This work will require nominal 4 years to complete.

[22] Refer to Appendix 5 for OPG Decommissioning Process.

5.1.4 Methodology to Estimate Financial Cost

OPG's decommissioning cost estimate methodology follows the basic approach developed by the Atomic Industrial Forum (now the Nuclear Energy Institute). This reference describes a unit cost factor method for estimating decommissioning activity costs. The unit cost factors used in this study reflect site-specific costs and the latest available information about worker productivity in decommissioning. This estimate reflects the experience gained in the Shipping Port Station Decommissioning Project[23] located on the Ohio River in Shippingport Borough, Pennsylvania, completed in 1989, as well as TLG's involvement in the decommissioning planning and engineering for the Vermont Yankee, Chrystal River, Gentilly-2, Shoreham, Yankee Rowe, Trojan, Rancho Seco, Pathfinder and Cintichem reactor facilities.

5.1.5 Areas Covered in Financial Guarantee

The Preliminary Decommissioning Plan - Pickering Generating Stations A & B (PNGS). OPG contracted TLG Services, Inc. (TLG) for the update of the decommissioning cost estimates. The cost associated with decommissioning PNGS is estimated at $5.19 billion (2015 Dollars). The major contributors to the overall decommissioning cost are labor and radioactive waste management. The cost is based on several key assumptions, regarding regulatory requirements, estimating methodology, allowance requirements, low and intermediate-level radioactive waste, disposal site availability for radioactive waste management and site restoration requirements.

Table 4: Summary of Decommissioning Estimate for PNGS[24]

Work Category	Cost Estimate 2015$ CAD (thousands)
Decontamination	42,991
Removal	669,859
Packaging	260,954

[23] One of the most important elements of the project was to provide a needed demonstration of dismantlement of a large size nuclear power reactor.
[24] OPG, Documentary Information Summary 2018 - 2022 CNSC Financial Guarantee W-REP-00531-00010-R000.

LLW and ILW Transportation and Disposal	236,782
Project Management	1,253,918
Deep Geologic Repository	247,358
Management of Heavy Water	16,140
Other	1,580,958
Sub-Total Direct Cost	**4,308,959**
Allowance	677,868
Sub-Total Direct Cost with Allowance	4,986,827
Risk Contingency	199,473
TOTAL	**5,186,300**

The categories as used in the summary Table 4 include:

- Decontamination – The cost of decontaminating systems and structures.
- Removal – The cost of removing systems and structures.
- Packaging – The cost of packaging contaminated material for disposal.
- LLW and ILW Transportation and Disposal – The cost of transporting and disposing of contaminated material.
- Project Management – The cost associated with managing and supporting the decommissioning work activities.
- Deep Geologic Repository – Incremental decommissioning-related costs associated with the L&ILW DGR excavation and decommissioning (allocated among NGSs). New item added in 2016.
- Management of Heavy Water – The costs associated with the long-term management of heavy water.

- Other – Those costs not directly associated with the cost categories described above, including defueling, de-watering, Environmental Assessments, energy, taxes, fees, insurance, overhead.
- Allowance – The cost allocated to project allowance. This cost is applied to each Work Breakdown Structure (WBS) element and varies by element.
- Risk Contingency – The costs associated with decommissioning circumstances not included within specific WBS elements of the estimate. The risk contingency addresses problems likely to occur beyond the project scope (i.e. unknown unknowns).

5.1.6 Community Engagement

OPG provides transparent disclosure of its operations and potential impacts, both positive and negative that may occur as a result of their operations. In 2014, OPG conducted a three-day emergency drill near Pickering Nuclear site to test the emergency response plans and demonstrate how the participating agencies and government work together. OPG also conducts smaller-scale safety drills continuously and meet with citizens and community groups.

5.2 United States Case Study: Zion Nuclear Power Station (ZNPS)

5.2.1 History of license ownership and current Status

Located in Lake County, Illinois, the Zion Nuclear Power Station consists of two 1040 MW electric PWRs that together produced a total of 249 TWh of electricity before permanent shutdown in 1998. Originally operated by Commonwealth Edison (ComEd), the license was transferred to Exelon Nuclear Generation LLC in 2000.

PSDAR, site-specific cost estimate, and fuel management plan were submitted in 2000. Decommissioning started in 2010 when the license was transferred to Zion*Solutions*, LLC, a subsidiary of EnergySolutions LLC. Possession license, management authority and decommissioning trust fund were passed on to Zion*Solutions*, except real estate, spent fuel and Greater Than Class C Waste (GTCC), which would remain under ownership of Exelon. The primary reason for the license transfer was to take advantage of EnergySolution's expertise in accelerating "the decommissioning of the ZNPS and eliminate the risk associated with the cost and capacity for low level waste disposal in future years."[25]

Decontamination and dismantlement began in 2011. Submittal of the license termination plan (LTP) occurred in December 2014, and an NRC LTP public meeting was held in April 2015. Completion of fuel transfer to the independent spent fuel storage installation (ISFSI) was completed in January 2015. As of May 2018, the only structures remaining were containment buildings. Final site survey and license reduction to the ISFSI is currently planned for 2019 - 2020. EnergySolutions plans to apply to transfer the license back to Exelon for final spent fuel management in 2020. Appendix 6 provides a graphical representation of selected milestones of the Zion decommissioning project.

5.2.2 Cost Estimates

Cost estimates can vary across time and thus must be periodically updated. The table below summarizes and compares cost estimates for ZNPS Unit 1 and Unit 2, prepared by TLG Services, Inc. in 2000 and by Zion*Solutions* (in collaboration with TLG) in 2008 respectively. Adjusting to the schedule of remaining work and drawing previous industry experiences from similar decommissioning projects, Zion*Solutions* suggested a new estimate that showed an approximately 30% decrease in cost from the 2000 figures. Contingencies were included in the updated estimate to cover costs on unforeseeable events. All values are converted to 2008 dollars in thousand.

In 2018, Zion*Solutions* submitted its most recent funding report, with a cumulative decommissioning cost of $631.9 million in 2017 dollars. As Figure 1 shows, the estimate included costs on decommissioning, decontamination, dismantlement, and spent fuel management of both ZNPS units as an integrated project. Decommissioning costs specifically considered costs of removing the fuel to a dry storage facility, as well as the decontamination and dismantlement of the radiologically-involved systems, structures, and components. Although costs of dealing with spent fuel are not typically included in decommissioning estimates, Zion*Solutions* was granted the authority by the NRC to use trust funds to cover the costs of spent fuel management as an exemption. On the other hand, the funding report does not include

[25] Application for License Transfers and Conforming Administrative License Amendments.

dismantling non-radiological systems and structures and other non-radiological site restoration. A rate of return of 2% was used in cost estimation.

Table 5. Cost Estimates Comparison Between 2000 and 2008

	Estimates in 2000 ($)	Estimates in 2008 ($)	% Change
Decommission Costs in the Previous Year	134,730	33,700	-75%
Staffing	140,040	206,400	47%
Low-Level Waste Burial	395,383	134,600	-66%
Equipment Removal	196,226	142,800	-27%
Low-Level Waste Packaging and Shipping	26,052	36,800	41%
Decontamination Activities	19,727	4,500	-77%
Other Costs[26]	223,615	155,100	-31%
Subtotal- License Termination	**1,135,773**	**713,900**	**-37%**
Spent Fuel Management	238,259	210,900	-11%
Total	**1,374,031**	**924,800**	**-33%**
Site Restoration		53,200	
Total	**1,374,031**	**978,000**	**-29%**

[26] Other Costs: Materials and Equipment, Insurance and Regulatory Fees, Other Decommissioning Costs, Exelon Fund Petainage, Exelon Tax Liability Petainage.

Figure 1. Funding status report prepared by Zion*Solutions* submitted to NRC in early 2018

Annual Radiological Decommissioning and Irradiated Fuel Management Funding Assurance Report for Zion Nuclear Power Station, Aggregate Costs

December 31, 2017
(2017 dollars, millions)

Trust Fund Amount at December 31, 2017 (A)	$29.3[1]
NRC Required Minimum Funding Assurance Amount at December 31, 2017 (B)	$24.0
Difference in Trust Fund Amount versus Required Minimum Funding at December 31, 2017 – Surplus/(Shortfall) (C) = (A) - (B)	$5.3
Projected End of Project Surplus at December 31, 2017 (D)	$5.7[2]
Estimated Costs to Complete Decommissioning at December 31, 2017 (E)	$24.0
Projected Costs to Manage Irradiated Fuel at December 31, 2017 (F)	$9.8[3]
Amount Spent on Decommissioning[4] (G):	
Cumulative (September 2010 – December 31, 2016)	$574.7
Calendar Year 2017	$57.2
Cumulative (September 2010 – December 31, 2017)	$631.9

5.2.3 Method used to prove financial assurance

Prepayment as well as an external trust fund were the funding sources for this decommission project.

5.2.4 Impact on Local Economy

The city of Zion experienced a 145% increase in property tax immediately after the shutdown of Zion.[27] Fewer businesses were willing to invest and fewer residents were willing to purchase properties. This created a feedback loop that worsened city's finances. In addition, spent fuel needs to be stored in the ISFSI on-site before the Department of Energy (DOE) picks it up. Before Zion*Solutions* receives information from DOE notifying the transfer, the ISFSI would keep occupying the land that could be otherwise used for lakefront real estate development and recreational spaces. Local residents and government have expressed increasing concerns

[27] Zion Still Struggling 19 Years After Nuke Plant Shut Down, Kelly McGowan, July 12, 2017. Retrieved from LoHud.com https://www.lohud.com/story/news/investigations/2017/07/12/zion-nuke-plant-shut-down/439915001/.

regarding whether and how the city could be compensated for the loss of economic activities after the shutdown of Zion.

(6) Examples from Europe

To overcome the lack of universally accepted standard for decommissioning cost estimates, in 2012 International Structure for Decommissioning Costing (ISDC) was established. ISDC is jointly developed by the NEA, the International Atomic Energy Agency (IAEA) and the European Commission (EC), and it provides a standard itemization of nuclear decommissioning costs within a common reporting structure for purposes of comparison across EU countries.

Table 5: Items included (and not included) in the scope of decommissioning cost estimates[28]

Items included in the scope of the decommissioning estimates	Finland	France	Slovak Republic	Spain	Sweden	Switzerland	UK
De-fuelling	Y	N	Y	N[1]	N	Y[2]	N
On-site storage of fuel	N	N	Y	N	N	N[3]	N
On-site storage of radwaste from decommissioning	Y	N	Y	N[4]	N	N	N
On-site storage of operational radioactive waste	N	N	Y	N	N	N[5]	Y
Retrieval and packaging of accumulated operational waste	N	N	Y	N[4]	N	Y[2]	Y
Removal of reactor building	Y	Y	Y	Y	Y	Y	Y
Removal of conventional plant/buildings, e.g. turbine halls	N	Y	Y	Y	Y	Y	Y
Removal of non-radioactive structures above ground level	N	Y	Y	Y	Y	Y	Y
Removal of non-radioactive structures below ground level	N	N	Y	Y[6]	N	Y[7]	Y
Transport and disposal of radioactive waste	Y	N	Y	N	N	Y	Y
Disposal or recycling of non-radioactive waste	N	N	Y	Y	Y	Y	Y
Contaminated ground remediation	N	N	Y	Y	Y	N[8]	Y
Landscaping and site de-licensing	N	Y	Y	Y	Y	Y	Y
Final site surveys	Y	Y	Y	Y	Y	Y	Y
De-licensing of the site	Y	Y	Y	Y	Y	Y	Y

[28] Source: Costs of decommissioning nuclear power plants, NEA No. 7201, © OECD 2016.

1. *Costs related with SNF temporary storage on-site are not included in the scope of the estimate. The underlying assumption is to transfer SNF to the future centralized temporary storage before starting the execution of decommissioning project*
2. *The costs for defueling and packaging of radwaste are allocated to the post-operational phase that is added to the decommissioning costs. Costs for fuel casks and their storage are allocated to the waste management costs*
3. *On-site and central storage of fuel are allocated to the waste management costs, separate from decommissioning costs.*
4. *Waste processing, storage and disposal cost item only takes in account tasks related with waste processing and temporary storage on-site during the execution of the dismantling activities. Decommissioning cost estimate does not consider any category of radioactive waste (high-, intermediate- and low-level) disposal cost*
5. *Central storage of operational radioactive waste costs is allocated to the waste management costs, separate from decommissioning costs.*
6. *The removal of non-radioactive structures below ground level may be included or not depending on the intended end point of individual decommissioning plans. In principle, non-radioactive structures could remain on-site if they do not constitute an obstacle for achieving the expected goal.*
7. *Removal of non-radioactive structures below ground level to be executed up to a depth of 2 meters*
8. *No ground contamination is assumed.*

ISDC report considers the difference in the cost estimation across countries which may be due to factors such as different allocations of expense due to the adoption of different methodologies, specific context and background of individual nations (Please see Appendix 3 for more details.) Therefore, the ISDN groups together the cost estimates in three broad categories[29]:

1. Dismantling activities, including dismantling activities within the controlled area and conventional dismantling, demolition and site restoration – corresponding to ISDC items 04 and 07.
2. Project management, including project management, engineering and site support and site infrastructure and operation – corresponding to ISDC items 08 and 06.
3. Waste management, including waste processing, storage and disposal – corresponding to ISDC item 05.

[29] ISDC 01 – Pre-decommissioning, ISDC 02 – Shutdown, ISDC 03 – Safe enclosure – not relevant for immediate dismantling, ISDC 04 – RC dismantle, ISDC 05 Waste management, ISDC 06 Site infrastructure and operation, ISDC 07 Conventional dismantling, demolition and site restoration, ISDC 08 – Project management, engineering and site support; ISDC 09 – R&D, ISDC 10 – Fuel and nuclear material, ISDC 11 – Miscellaneous

Table 6: Agencies responsible for financing nuclear decommissioning in Europe

	Responsible Agency	Status
France	Électricité de France (EDF)	In 2016, EDF gave cost estimate of 22.2 billion euros ($24 billion) for dismantling nuclear power stations.
Spain	Empresa Nacional de Residuos Radiactivos (Enresa)	In early 2018, Enresa's funds were reported as about €5 billion.
Slovak Republic	(i) Javys (state-owned) (ii) Slovenské Elektrárne (Slovak Electric- 66% stake of Italian utility ENEL)	The Bohunice International Decommissioning Support Fund (BIDSF), administered by the European Bank of Reconstruction and Development (EBRD), was set up in 2001 to support the decommissioning of the Bohunice V1 plan. By the end of 2013, BIDSF contributed €225 million.
Sweden	The Utilities: The state utility is Vattenfall AB, and private utilities include E.ON Sweden AB and Fortum Oy (majority-owned by the Finnish government)	The Swedish Nuclear Fuel and Waste Management Co (SKB) jointly owned by the NPP utilities, creates decommissioning financial plans. The regulatory authority, Swedish Radiation Safety Authority (SSM), appointed by the Government reviews the SKB cost calculations and submits a proposal for the size of the fees to the Government. The Government decides the final fee which is individual to each utility

(7) Conclusion and Recommendations for Future Research

As demonstrated by Europe, there is no one way to finance nuclear power plant decommissioning. However, the Canadian and United States systems have a number of features that make them unique. This report identifies several institutional instabilities related to the nuclear power plant decommissioning process in those two countries. While the impact of these instabilities may vary, additional research is likely needed to determine whether or not specific action is needed to avoid any potential negative consequences. While this report stops short of making specific policy recommendations, it does recommend that these instabilities be researched further by the IJC to determine what, if any, policy changes are needed.

7.1. Recommendations for the United States and Canada:

- **Assess impact of lack of permanent storage plans on financing**
  With the ongoing controversy surrounding the construction of a nuclear waste repository at Yucca Mountain, the United States lacks a permanent storage facility for the nuclear waste generated by decommissioned nuclear facilities.[30] Canada faces a similar situation with a series of delays postponing the construction of its deep underground repository.[31] As a result, waste is stored on site in secure storage or in interim storage facilities over a longer period of time that in turn generates additional costs. Further research is needed to fully understand the costs associated with this on-site storage and the financing benefits associated with the successful construction of a nuclear waste repository.

- **Reduce reliance of financing on market growth**

[30] "Backgrounder on Licensing Yucca Mountain." United States Nuclear Regulatory Commission - Protecting People and the Environment. Accessed May 2019. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/yucca-license-review.html.

[31] "How Is Used Nuclear Fuel Stored Today?" The Nuclear Waste Management Organization (NWMO). Accessed May 2019. https://www.nwmo.ca/en/Canadas-Plan/Canadas-Used-Nuclear-Fuel/How-Is-It-Stored-Today. Sorensen, Eric. "Canada's Nuclear Waste to Be Buried in Deep Underground Repository." Global News Canada. May 30, 2019. Accessed June 2019. https://globalnews.ca/news/5329835/canadas-nuclear-waste-to-be-buried-in-deep-underground-repository/.

In the case of the United States, the NRC allows for funding decisions to be made with the expectation that nuclear facility operators may wait up to fifty years following the closure of the facility before beginning the process of fully reclaiming the site (SAFSTOR).[32] The use of SAFSTOR in financing decisions allows for nuclear facilities to defer their saving and operate under the assumption that their available funds in the form of trusts will grow as the plants sit, often to the detriment of the community where they reside. The NRC, further, allows nuclear facilities to assume that their funds will grow at a rate of two percent above the rate of inflation regardless of the current market.[33] This assumption can be dangerous in situations such as the 2008 economic collapse where many facilities experienced a massive decline in their available finances as the market took a downturn.[34] Currently market growth has shielded these trust funds but the possibility of a market downturn serves as a constant concern within the financial assurance system. We recommend further research to be conducted on the risks associated with this reliance on market growth and its implications for the nuclear decommissioning process.

- **Quantify the costs of delayed decommissioning on local economies**

Although quantifying losses in employment can be challenging, governments should take considerations in compensating mechanisms to maintain or improve local residents' economic welfare.[35] The time nuclear facilities spend in SAFSTOR further works to the detriment of the local economy as the site no longer contributes to the community through employment or tax generation, but still remains unusable for alternate purposes. Further research is necessary to understand how these local costs contribute to the overall cost of decommissioning.

[32] Graydon RC, Meyer PA, and Burrows MJ. 1 March 2019. Decommissioning Practices of Nuclear Power Facilities in the Great Lakes Basin: Background Report (Revision 2). Submitted to the International Joint Commission's Great Lakes Water Quality Board: Legacy Issues Work Group.
[33] Daniels, Steve. "Exelon's Nuke Cleanup Funds Fall Short." Crain's Chicago Business. June 18, 2016. Accessed May 2019. https://www.chicagobusiness.com/article/20160618/ISSUE01/306189996/exelon-s-nuclear-cleanup-funds-fall-nearly-a-billion-dollars-short.
[34] Callan Institute. 2018 Nuclear Decommissioning Funding Study: Comprehensive Data on Funding, Contributions, and Costs as of Dec. 31, 2017. Report. October 2018. www.callan.com.
[35] Moore, Martha T. "Nuclear Plant Closures Bring Economic Pain to Cities and Towns." The Fiscal Times. September 5, 2018. Accessed June 2019. https://www.thefiscaltimes.com/2018/09/05/Nuclear-Plant-Closures-Bring-Economic-Pain-Cities-and-Towns.

7.2. Recommendations for the United States:

- **Evaluate the adequacy of NRC funding formula**

The estimate of costs associated with decommissioning varies by a range of factors including location of nuclear facility, type of reactor present, and the regulations in place regarding the decommissioning process. For example, calculations of costs within Canada cover a more comprehensive set of process - including removal of structures and fuel storage - than calculations of cost within the United States. A report prepared by Government Accountability Office further identified concern associated with the use of the undefined term "bulk" within the NRC formula.[36] The NRC requires that nuclear facilities provide a "bulk" of the finances necessary for decommissioning without a firm definition of the value contained within the term "bulk". We recommend further research regarding the need for a more comprehensive coverage of costs within the NRC formula and possible changes to the formula to create a more stable financing system.

- **Standardize cost estimate per kilowatt hour**

Massively different estimates for decommissioning costs can be calculated dependent upon a facility's estimated cost of decommissioning per kilowatt hour. For example, Chicago-based Exelon estimates that its nuclear decommissioning will cost around $13.2 billion at a rate of $589 per kilowatt. This estimate falls far below many of its competitors such as Entergy of New Orleans at $1,053 per kilowatt, New Jersey's Public Service Enterprise Group at $924 per kilowatt, and Ohio's First Energy at $1,054. Exelon explains its lower estimates as due to the location and decommissioning needs of its plants but if Exelon's cost of decommissioning were to fall closer to the midpoint of the other companies estimates - approximately $989 per kilowatt - then decommissioning costs would be much closer to $22.2 billion putting the company far short of the needed funds.[37] We have identified this as an area of concern and recommend future research.

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[36] United States Government Accountability Office. *Nuclear Regulation: NRC's Oversight of Nuclear Power Reactors' Decommissioning Funds Could Be Further Strengthened.* Report. April 2012. https://www.gao.gov/assets/590/589923.pdf.

[37] Daniels, Steve. "Will Exelon Nuke-site Cleanup Cash Be There When Needed?" Crain's Chicago Business. January 26, 2018. Accessed May 2019.

- **Examine role of third-party decommissioning companies**

It is become increasingly common for nuclear facilities to be sold to a third party - separate from the private corporation or public utility that managed the plant during its operation. An example is the sale of Zion Nuclear Power Facility during its decommissioning process. There has been little research conducted regarding the risk and benefits associated with the presence of these third party sales. The final disposition of surplus funds in the site's decommissioning funds is unclear. Depending on the jurisdiction in which the plant is located and the terms of agreement between the licensee and the third party company, remaining funds may be claimed as profits by the third party, returned to the utility, or reimbursed to ratepayers. This system has raised concerns regarding possible decision-making driven by cost-cutting and lack of responsibility by all parties in the case the funds are insufficient. We recommend that research be conducted to better understand the implications of this relationship on the decommissioning process.

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https://www.chicagobusiness.com/article/20180126/ISSUE01/180129909/nuclear-site-cleanup-shortfall-deepens-at-exelon.

APPENDIX 1: AN EXAMPLE OF THE LIST OF WORK PACKAGES FOR COST ESTIMATION IN CANADA

Title	Remarks
Public relations	Co-ordination for finding a new vocation/use for the reactor building
Owner's representative	Manager of projects and QA
Site operations	Operations and maintenance on-site and site labour
Decontamination	Work associated with the modifications in the service building and turbine buildings for transfer to Hydro Québec
Resident engineering	Engineering for spent fuel storage, building isolation and service building enhancement
Project management	On-site. Includes project manager, technical consultant and secretary
Site services	Planning and scheduling, administration, finance and procurement
Radiation protection	On-site
Fuel handling	Spent fuel storage support to project from AECL engineering laboratory
Licensing supervision	
Engineering design review	
Health physics	On-site
Health and safety	Health physics support to project from AECL
Finance, accounting and procurement	Support services to project from AECL

APPENDIX 2: NUCLEAR FUEL WASTE ACT (NFWA) TRUST FUNDS[38]

	Initial Deposit (Nov 2002)	Annual Contributions
Ontario Power Generation	$500,000,000	$100,000,000
Hydro- Quebec	$20,000,000	$4,000,000
NBP Power	$20,000,000	$4,000,000
Atomic Energy of Canada Ltd.	$10,000,000	$2,000,000

Source: Nuclear Fuel Waste Act 2002

APPENDIX 3: COST RELATED TO AGGREGATED CATEGORIES PER UNIT (in USD 2013 million)[39]

Name	ID	Dismantling activities ISDC 04 + 07	Waste management ISDC 05	Project management ISDC 08 + 06
PWR José Cabrera – 160 MWe	ES-P1	75.1	12.8	156.7
PWR Generic P (ES) – 1 066 MWe	ES-P2	178.9	22.6	185.0
PWR Generic (CH) – 1 000 MWe	CH-P1	143.2	116.9	393.9
PWR Generic (FR) – 3 600 MWe	FR-P1	181.1	69.0	51.4
BWR SM Garona – 466 MWe	ES-B1	92.4	18.6	176.4
BWR Generic B (ES) – 1 092 Mwe	ES-B2	184.2	34.0	176.0
BWR Oskarshamn – 2 576 MWe				
VVER Loviisa – 976 MWe	FI-V1	105.2	20.0	12.6
VVER Bohunice – 880 MWe	SK-V1	219.5	215.5	217.5

ES: Spain; CH: Switzerland; Fr: France; FI: Finland; SK: Slovak Republic
BWR- Boiling water reactor
PWR- Pressurized water reactors

[38] https://www.nwmo.ca/~/media/Site/Files/PDFs/2015/11/04/17/31/490_52_NWMO_background_paper.ashx?la=en
[39] https://www.opg.com/powering-ontario/our-generation/nuclear/nuclear-waste-waste-management/waste-facility-decommissioning/

APPENDIX 4: CANADA NUCLEAR STORAGE FACILITY

Current Nuclear Storage Facility: Western Waste Management Facility (WWMF)

Since 1974, the facility has stored low- and intermediate-level nuclear waste from the operation of OPG's 18 owned nuclear reactors, including eight leased to Bruce Power. In addition, the facility provides dry fuel storage for the Bruce reactors.

Designed to store 2,000 Dry Storage Containers, the Used Fuel Dry Storage Facility at the WWMF went into operation in 2002.

Low- and intermediate-level waste generated is safely transported and stored on an interim basis at the WWMF.

- Low-level waste is sorted and, when possible, compacted or incinerated to reduce the volume. After processing, low-level waste is stored in above-ground concrete warehouses.
- Intermediate-level waste from station operations is stored in steel-lined concrete containers and set in the ground. While low- and intermediate-level waste is safely stored on an interim basis, it will eventually be transferred to the proposed Deep Geologic Repository site for permanent disposal — the lasting solution.

Future Nuclear Storage Facility: Deep Geologic Repository (DGR)

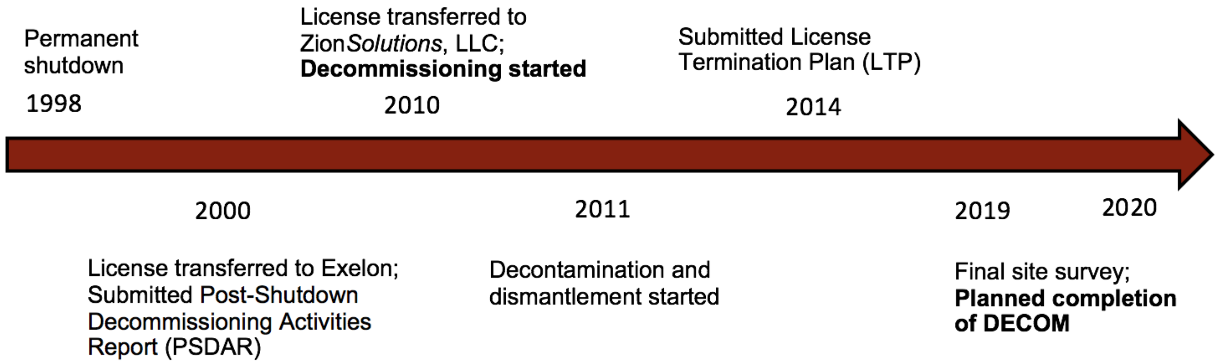
Ontario Power Generation has proposed creating a DGR for the long-term management of low and intermediate level nuclear waste, on lands adjacent to the Western Waste Management Facility, and that the DGR will have 680 meters storage depth to isolate waste; 200,000 cubic meters of waste will be stored and 90% of stored waste will be low level.

APPENDIX 5: DECOMMISSIONING PROCESS FOR OPG CANADA

Following international best-practices, OPG places decommissioned facilities into 30 years of safe storage. The dismantling and decommissioning process involves:

- Removing fuel and heavy water from reactors and placing equipment in a safe, caretaking state.
- Monitoring the facility for approximately 30 years as radiation levels decline.
- Moving used fuel from the wet storage bays to Dry Storage Containers (DSCs).
- Monitoring of used fuel in temporary storage, by OPG and the International Atomic Energy Agency (IAEA), until it's safely transferred to a long-term repository.
- After the safe storage period, specialists remove all radioactive material and dismantle the facility.
- Remaining structures are then demolished, and the site is made available for OPG's reuse.

APPENDIX 6: MILESTONES OF ZION DECOMMISSIONING



APPENDIX 7: PLANNED AND ACTUAL TIME OF OCCURRENCE OF KEY EVENTS

	PERIOD DATES	Proposed Dates	Actual Dates
SAFSTOR	SAFSTOR Dormancy		
	Unit 1	2000-2007	(2000-2010)
	Unit 2	2000-2007	
	Preparations for Decontamination and Dismantlement		
	Unit 1	2007-2008	
	Unit 2	2007-2008	
DECON	Decommissioning Operations (except ISFSI)		
	Unit 1	2007-2015	(2011-2019)
	Unit 2	2007-2015	
	License Termination Plan Submitted	2012	(2014)
	Major Equipment Removal Completed	2012	
	ISFSI Established	2010	
	Fuel and GTCC waste Transferred to ISFSI	2013	(2015)
	Final Site Survey/(all but ISFSI)	2017	(2019-2020)
	ZS applies to NRC for partial site release and transfer of ISFSI back to Exelon	2018	(2020)
	ISFSI Decommissioning by Exelon (unless transferred earlier to an approved storage site)	~2025	
	Full Site Restoration by Exelon (unless spent fuel and GTCC waste transferred earlier to an approved storage site)	~2026-2028	

Credit: Zion Nuclear Power Station Units 1 and 2 Amended Post-Shutdown Decommissioning Activities Report, March 17, 2008

APPENDIX 8: LIST OF ABBREVIATED TERMS

CNSC: Canadian Nuclear Safety Commission

DDP: Detailed Decommissioning Plan

DGR: Deep Geologic Repository

DSF: Decommissioning Segregated Fund

EC: European Commission

IAEA: International Atomic Energy Agency

ISDC: International Structure for Decommissioning Costing

L&ILW Management: Low and Intermediate Level Waste Management

NEA: Nuclear Energy Assembly

NFWA: Nuclear Fuel Waste Act

NRC: Nuclear Regulatory Commission

NSCA: Nuclear Safety and Control Act

NWMO: Nuclear Waste Management Organization

OPG: Ontario Power Generation Inc.

OFA: Ontario Financing Authority

ONFA: Ontario Nuclear Funds Agreement

PDP: Preliminary Decommissioning Plan

PFP: Participant Funding Program

PNGS: Pickering Nuclear Generating Stations

PNNL: Pacific Northwest National Laboratory

PSDAR: Post-Shutdown Activities Reports

SIPP: Statement of Investment Policies and Procedures

TLG: TLG Services, Inc.

UFSF: Used Fuel Segregated Fund

WBS: Work Breakdown Structure

Appendix 9: Comparison of US and Canadian Decommissioning | Key Regulatory Differences

Canada	**United States**
Funds must cover all decommissioning activities	Decommissioning funds must meet minimum formula amount
Decommissioning activities include waste management	Activities do not include waste management/removal of non-radioactive structures
Guarantees from parent companies are not acceptable	Guarantees from parent companies or customers are acceptable